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RUNOFF GENERATION ON ABANDONED FIELDS IN THE CENTRAL EBRO BASIN – RESULTS FROM MODELLING

MANUELSEEGER [(1)]
JOHANNES B. RIES [(2)]

(1) Instituto Pirenaico de Ecología, CSIC, Apartado 202, 50080 Zaragoza, Spain.

(2) Institut für Physische Geographie, Johann Wolfgang Goethe Universität, Senckenberganlage 36, 60325 Frankfurt am Main, Germany.

ABSTRACT: The results from several rainfall simulations performed on two abandoned fields of different ages in the Central Ebro Depression have been analysed by application of the physically based hydraulic model HILLFLOW 1D. The data gained by the simulations was used to parameterise the model. Afterwards, the runoff generation characteristics were determined by simulation of different rainfall intensities and different macroporosities of the soil. The young fallow land shows a minimum intensity for runoff generation of 6 mm h-1. An increase of the rainfall intensity leads rapidly to a growing runoff coefficient, being the value modelled for 30 mm h-1 nearly the same as the simulated one (40 mm h-1). Another conclusion of the simulations and their modelling is the homogeneity of the soils on the young fallow land, with no macroporosity all over the profile. On the other hand, the rainfall simulations and the modelling on the old fallow land show a high variability of rainfall-runoff response patterns, strongly conditioned by the presence of macropores. They are distributed very irregularly throughout the soil of the old fallow land. In both cases, water infiltrates only little into the soil matrix, for that measures for enhancing soil hydraulic properties are needed.

RESUMEN: Se han analizado los resultados de numerosas simulaciones de lluvia en campos abandonados de diferente antugüedad en la Depresión central del Ebro aplicando el modelo hidrológico de base física HILLFLOW 1D. Los datos de las simulaciones se utilizaron para parametrizar el modelo. A continuación, las características de la generación de escorrentía se analizaron modelizando diferentes intensidades de lluvia y volúmenes de macroporos en el suelo. En el campo recientemente abandonado se pudo calcular una intensidad de llluvia mínima para la generación de escorrentía de 6 mm h-1. Una intensidad de precipitación creciente produce un incremento muy fuerte del coeficiente de escorrentía, de modo que precipitaciones de 30 mm h-1 se diferencian poco de las simuladas con 40 mm h-1. Otra conclusion es que los suelos del campo recientemente abandonado son muy homogéneos y están caracterizados por la ausencia de macroporos. La respuesta de la generación de escorrentía a la precipitación es en cambio muy variable en el campo abandonado anti-

guo. Aquí, toda respuesta depende de la macroporosidad del suelo, de distribución muy irregular. En ambos casos, la infiltración al materal matricial del suelo es muy escasa, de modo que son necesarias medidas para mejorar las características hidráulicas de estos suelos.

Key-words: Rainfall simulation, Abandoned fields, Hydrological modelling, Soil Hydrology, Runoff generation, Ebro Depression.

Palabras clave: Simulación de lluvia, Campo abandonado, Modelo hidrológico, Hidrología del suelo, Generación de Escorrentía, Depresión del Ebro.

1. Introduction

The use of rainfall simulations to understand processes of runoff-generation and erosion has found a widespread use during the last decades. Its applications, possibilities and limitations are resumed by Cerdà (1999). In areas where soil water is the limiting factor to plant growth and vegetation succession to recolonise abandoned farmland, there is a need to understand the infiltration processes and the water movement during rainfall events into the soil. The experimental design for this purpose is complicated and would reduce considerably the possible number of experiment repetitions, introducing systematic errors, especially at low rainfall intensities. In addition, saline and gypsiferous soils show some complications for accurate soil-water measurements with gravimetric methods or Time-Domain-Reflectometry (TDR) (NSSC, 1996; Soilmoisture Inc., 1990).

The present combination of a large number of rainfall simulations (presented by here Ries and Langer, 2001), detailed soil mapping and physical characterisation of the soils (Seeger, 2001) give the possibility to parameterise with a high accuracy the model input and, at the same time, quantify the processes in the soil at every moment of the simulation. Parting from this, an extrapolation of the processes to other events with different rainfall characteristics is possible.

The aim of this work is, at one hand, to parameterise a physically based model, to explain with this the processes of infiltration and runoff-generation and, on the other hand, to identify the factors influencing these processes. In addition, this study may elucidate the possibilities and limitations of this kind of models as well as indicate some strategies to mitigate the constraints of the soils to water recharge.

2. The study area

The dominating soils are a Hyperochric Gypsisol on the young fallow land, closely associated to Leptic Gypsisols and Gypsiric Leptosols, depending on the depth of the tertiary gypsum bank, and a Haplic Gypsisol on the old fallow land.

Characteristic for the soil surface of the young fallow land is a 0.5 to 2 cm thick soil crust, developing rapidly after only some rainfall events. The differentiation of the lower horizons is very weak and can only be done in the field by changes in soil structure (see Table 1); subangular in the topsoil and platy and/or without structure beneath 30 cm depth. The whole area is characterised by a very low content in organic carbon (< 0.4 %)

Table 1. Brief profile description of the Hyperochric Gypsisol on the "young fallow land". Texture class and structure according to Schoenenberger et al. (1998), pore density to AG Boden (1994)

Horizon	*depth*	*Texture class*	*structure*	*pores*	*pH*	*CaSO4(%)*	*Corg(%)*	*CaCO3 (%)*
Apm	2	SL	m	none	7.7	20.4	0.38	10.5
Ap1y	15	SL	gr/sbk	low	7.4	17.6	0.30	10.6
Ap2y	30	SL	sbk	very low	7.2	19.9	0.25	11.2
2Cd	60	SL	pl	none	7.2	8.4	0.10	8.4

and a slightly alkaline soil pH all over the soil depth. The gypsum-content decreases from about 20 % in the upper 30 cm to less than 5 % at about 60 cm depth. Phosphorous and Nitrogen content is low, whilst the amount of nutrients like Potassium and Magnesium reaches very high values, especially in the deeper soil horizons. The grain size of the fine material is dominated by silt (>70 % in the upper 30 cm, see Figure 1), with in increasing amount of clay with depth. Thus, the soil material is highly erodible.

The soils of the old fallow land have developed a crust, too, which is only 0.5 cm thin. The upper 28 cm show a good structure development (Table 2), with stable small subangular aggregates. Below the aggregates become very much bigger, but until a depth of 76 cm there is recognisable a structure development. Until this depth there could be observed roots in the profile, too. The soil organic carbon is only low in the crust, and extremely low below. The pH of the soil is about the same like in the young fallow land, but especially the gypsum content is here very much higher (>25 %). Or this, the soil solution is completely dominated by Calcium, whilst other nutrients show low to very low contents. The matrix is composed here by silt (Figure 2), too, which causes a high erodibility of the soil.

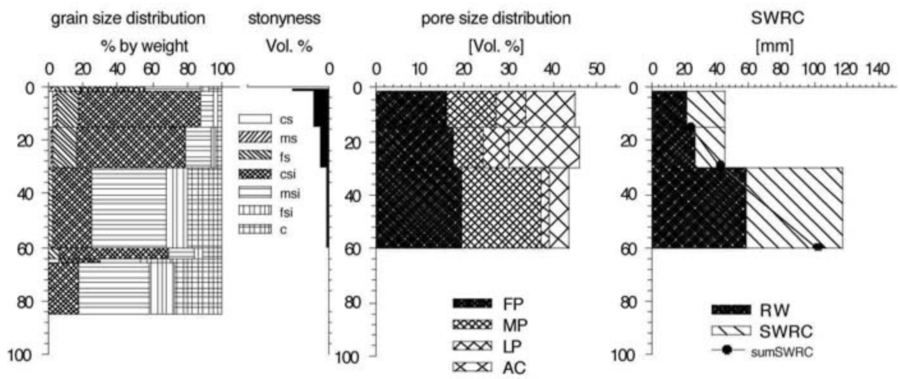


Figure 1. Physical soil characteristics of the Hyperochric Gypsisol on the young fallow land. On the right side the Soil Water Retention Capacity (RETC).

Table 2. Brief profile description of the Haplic Gypsisol on the "old fallow land". Texture class and structure according to Schoenenberger et al. (1998), pore density to AG Boden (1994)

Horizon	*depth*	*Texture class*	*structure*	*pores*	*pH*	*CaSO4(%)*	*Corg(%)*	*CaCO3 (%)*
Apm	0.5	SL	m	moderate	7.6	30.0	1.02	12.3
Apy	28	SL	gr/sbk	high	7.7	35.6	0.40	11.0
Cy1	52	SL	sbk	moderate	7.8	25.2	0.38	11.9
Cy2	76	SL	sbk	very low	7.6	26.0	0.29	12.1
2Cr	>76	SL	m	none	7.5	39.1	0.17	4.1

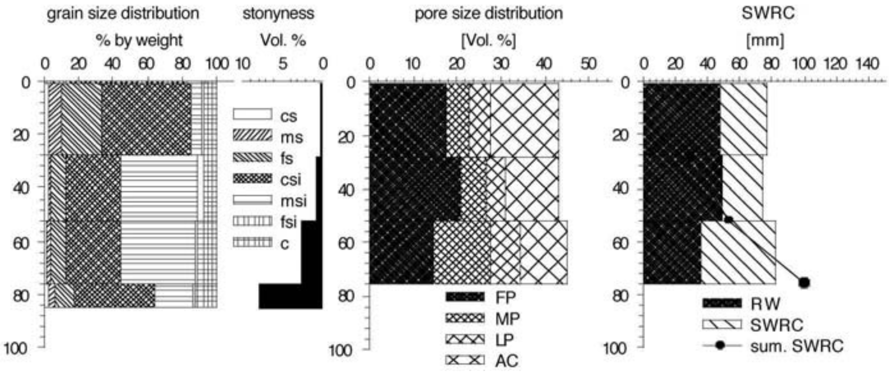


Figure 2. Physical soil characteristics of the Haplic Gypsisol on the old fallow land. On the right side the Soil Water Retention Capacity (RETC).

3. Material and methods

3.1. Methods of physical soil characterisation

Grain-size distribution was determined following the German Soil Survey Manual (AG Boden, 1994) by sedimentation, but without washing off the gypsum. Physical properties related to the pore distribution of the soils were measured in laboratory. For this, 100 cm^3 soil cores were taken at the rooted horizons. Water content was measured gravimetrically at pF-values of 1.8, 2.0, 3.0 and 4.2, the last one was measured with disturbed soil samples, after water extraction by suction (pF 1.8) and pressure (all other pF-values). In addition saturated hydraulic conductivity of all analysed horizons was measured with a falling head permeameter with water level gradients of 5, 10 or 20 cm, depending on the permeability of the soil. Water retention curves were adjusted according to van Genuchten (1980), with the RETC-program (van Genuchten et al., 1991).

In addition to the analyses in laboratory, infiltration measurements were done with a modified single-ring infiltrometer (Bork,, 1988; Link, 1999). The data used correspond to the ones obtained after 180 min of experiment and corrected after Tricker (1978). These experiments included measurements of infiltration after removing the soil crust for the quantification of the influence of the soil crust on infiltration capacity of the soils.

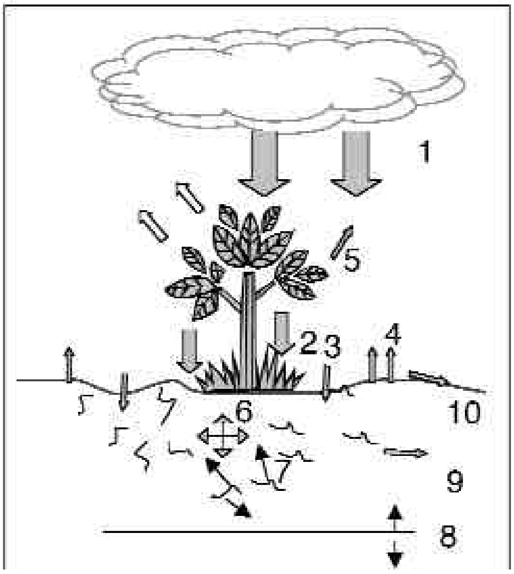
3.2. Rainfall simulations

Rainfall simulations were performed with an improved plot rainfall simulator like it is frequently used in Spain (Calvo et al. 1988; Ruiz-Flaño 1993; Cerdà 1999). Its function is described with more details by Ries et al. (2000) and Ries & Langer (2001, in this volume). The pressure-regulated jet-rainfall simulator generated a precipitation of an intensity of 40 mm h^{-1} (± 5 %) during 30 min on a round plot with 60 cm of diameter and an area of 0.28 m^2. The whole apparatus is covered by a plane so the influence of evaporation and especially of wind were turned off. Surface runoff was measured by capturing all runoff-water in bottles during 5 min intervals. The time when water appeared on the runoff funnel was recorded as runoff-begin. After the experiments the soil was digged to observe the infiltration depth and to install the TDR probes. Water content was measured with a Trase-TDR, for which the probes were placed horizontally into the soil at 3 and 9 cm depth.

In the years between 1995 and 1998 a total number of 13 simulations were done from which 6 simulations, performed between spring and autumn of 1998, were selected for this study. The plots of these experiments showed an inclination between 2º and 7º, and a vegetation cover was less than 5 %, so interception effects were negligible.

3.3. The HILLFLOW 1 D model

For the modelling of the runoff and infiltration on the fallow-land in Maria de Huerva there was used the physically based model HILLFLOW 1 D (Bronstert, 1994). The limitation to a one dimensional model was imposed by the plot experiments (see Figure 3), and for this lateral water movements are not modelled. The theoretical bases of the model have been discussed widely by Bronstert (1994) and Bronstert et al. (1998). One of the characteristics of the model is the separation of the processes in the micro and macropore system. Water movement inside the micro pore system (soil matrix) is modelled by approximation of the Richards-equation (Richards 1931) and assuming the lower boundary of the modelled soil column to be above ground water level. Macro-pore flow is supposed to be non-Darcian and modelled with application of the concept of the “kinematic wave”. Infiltration processes are modelled analogous: total infiltration is the sum of macropore- and matrix-infiltration, whilst the first is only active when the matricial infiltration capacity is exceeded by rainfall intensity. In the applied 1 D model surface runoff was considered to be the rainfall excess on infiltration, and at the same manner the subsurface stormflow was regarded: excess of throughflow was considered as interflow and/or percolation to the deeper, not modelled soil horizons.



1	**precipitation**
2	throughfall
3	**infiltration**
4	evaporation
5	ranspiration
6	**soil-waterflow**
7	**interaction micro-/macro-pore system**
8	percolation/capillary rise
9	**macropore flow (excess)**
10	**superficial flow (infiltration excess)**

Figure 3. Scheme of the model HILLFLOW 1D. Bold letters for the processes modelled in this case.

The model output includes total infiltration rate and amount as well as a differentiation of infiltration into matrix and macro-pore system and the infiltration excess (considered here to be the runoff) in time steps of one minute. The soil water content of the different horizons is included into the output with time steps of 5 min.

3.4. Parametrisation of the model

The model was parametrised by using the runoff and moisture measurements and observations of the rainfall simulations. Supported on their results some values of soil characteristics were adapted according to different observations in the field and laboratory measurements. An iterative approach was applied to approximate the runoff values calculated with the model to the ones measured during the rainfall simulations. The values of soil water content simulated and modelled were taken as control values to establish the validity of the model.

4. Results

4.1. Rainfall simulations

The rainfall simulations in Maria de Huerva are described in detail by Ries & Langer (2001) in this volume. For this, the descriptions here are centred on some patterns relevant for comparing the simulated and modelled data.

The water content of the upper 5 cm of the Hyperochric Gypsisol of the soil was determined always less than 7 %, reaching even values lower than 2 % before the simulation started. The beginning of the runoff was recorded in all simulations during the first

5 min interval, ranging between 1 min 20 s and 3 min after the beginning of the experiment. The runoff coefficient was very high, ranging after 30 min of experiment between 0.65 and 0.81. The observed infiltration depth never reached depths deeper than 7 cm, being mostly at about 4 cm. According to this the moisture values measured at 3 cm ranged at about 16 % after rainfall simulation, whilst at 8 cm depth the water content never exceeded 9 %.

The simulations on the old fallow land, started at soil water contents between 4.3 and 7.4 %, show a high variability: the total runoff coefficients range between 0.19 and 67.2, the runoff starts between 3 and 15 minutes after simulation begin, and the depth of the water inflow into the soil ranges between 2 and 40 cm.

4.2. Soil physical characteristics and model input parameters

The Hyperochric Gypsisol of the young fallow land is characterised by varying values of the hydraulic conductivity along the profile. Highest K_{sat}-values were measured between 15 and 30 cm depth, where no sealing and crusting can occur (like in the horizon above). The decrease in 30 cm depth can be related to the low content of fast draining pores due to the development of a platy structure by ploughing compaction. Infiltration measurements on the surface show a very low infiltration capacity (< 5 mm h^{-1}), which is considerably increased by removing the soil crust (~10 mm h^{-1}), about the same as the K_{sat}-value measured in laboratory. The total porosity varies little between the horizons, showing the 2Cd horizon the lowest one (43.7 %), the Ap2y-horizon shows the highest value (45.8 %). Contrasting with this, the fine-pore volume increases clearly with depth, from 16.2 to 19.4 % of the soil volume. The total water storage capacity reaches within the rooted depth a low value of 138 mm.

The measured water content of the soil is, according to the semi-arid climate, constantly very low, exceeding the PWP only exceptionally. This could be observed only once, in spring of 1997 after a unusual high climatic water excess during the preceding months. In spring and autumn of 1998, the upper 15 cm (excluding the crust) had a content about 8 Vol.-% of water, but in summer this decreased to values lower than 3 Vol.-%.

Additionally, field observations showed no or only a very low volume of macropores, for this the model stars with the assumption of no macro-pores. The parameters used for the modelling are shown in detail in Table 1. The data for the crust was determined according to Carsel & Parrish (1988) for silt loam material.

The Haplic Gypsisol of the old fallow land shows with depth decreasing hydraulic conductivities from high to medium values. Infiltration rates measured at surface are low-medium, too (~10 mm h^{-1}). The porosity is homogenous all over the profile depth. But with a clear decreasing air capacity with depth. The fine pore volume is high in the upper 52 cm, but decreases to ~15 % in the Cy2-horizon. The cumulated available water storage capacity is with 100 mm over nearly 80 cm depth low.

The water content of the soil was always below PWP, reaching values between 60 mm and 10 mm of stored water in the upper 50 cm, which supposes a water content between ~14 % and ~3 %.

4.3. Results from modelling

Modelling on the “young fallow land”

The application of the soil data gained in laboratory (Table 2), assuming no macropores in the soil, led to a total runoff coefficient substantially lower than the one measured in the field experiments. For this, infiltration rate of the soil surface was used instead of the Ksat-value of the A-horizon (see Table 3 for detailed information about the physical soil data in the model input). In this case, the begin of runoff is between 2 min 30 s and 3 min 30 s, little later than the median start of runoff of the simulations (Table 7). The final runoff coefficient was modelled with 0.8, within the range of measured runoff coefficients (RC) and about the same like the median of the measured RK of the simulations included in this paper (Figure 4). The RK increases rapidly, in a hyperbolic way, until it reaches after only a few minutes a value similar to the final runoff coefficient. It can be observed, that the predicted runoff and the median of the measured runoff are very close during the whole modelled experiment. This indicates that the infiltration-rate decreases, following a hyperbolic decay, very rapidly after runoff begin to very low values. They were calculated at about 4 mm h^{-1}. The total amount of water infiltrated is very low, about 4 mm, leading to an increase of soil moisture only in a very shallow superficial fringe of the soil. The final water content modelled was 15 % in 3 cm depth, 10 % in 9.5 cm and staying constant at about 7 cm below 15 cm (see Figure 5).

Table 3. Physical soil data of the Hyperochric Gypsisol (young fallow land) gained in laboratory.

Horizon	*bulk density*	*pore volume*	*pF 1.8*	*pF 2.5*	*pF3.0*	*pF 4.2*	*Ksat[mm/h]*
Ap1y	1.4	45.1	11.2	6.6	11.1	16.2	38.3
Ap2y	1.4	45.8	15.7	5.8	6.9	17.4	94.9
2Cd	1.7	43.7	4.5	1.7	18.1	19.4	7.2

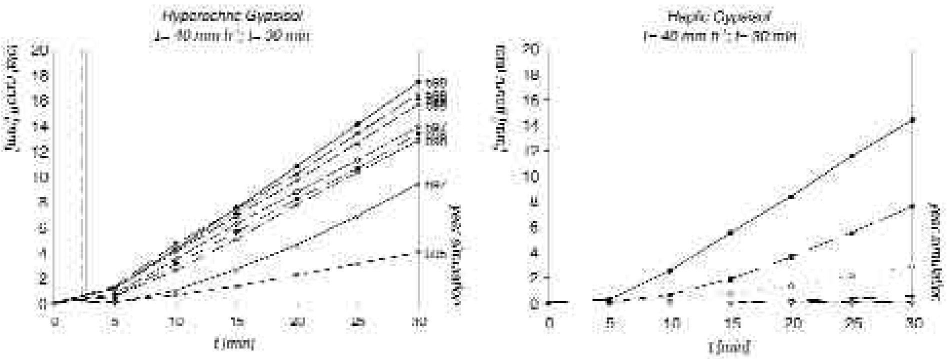


Figure 4. Runoff curves of the rainfall simulations in the María de Huerva test site. Left the simulations on the Hyperochric Gypsisol of the young fallow land; right the simulations on the Haplic Gypsisol on the old fallow land.

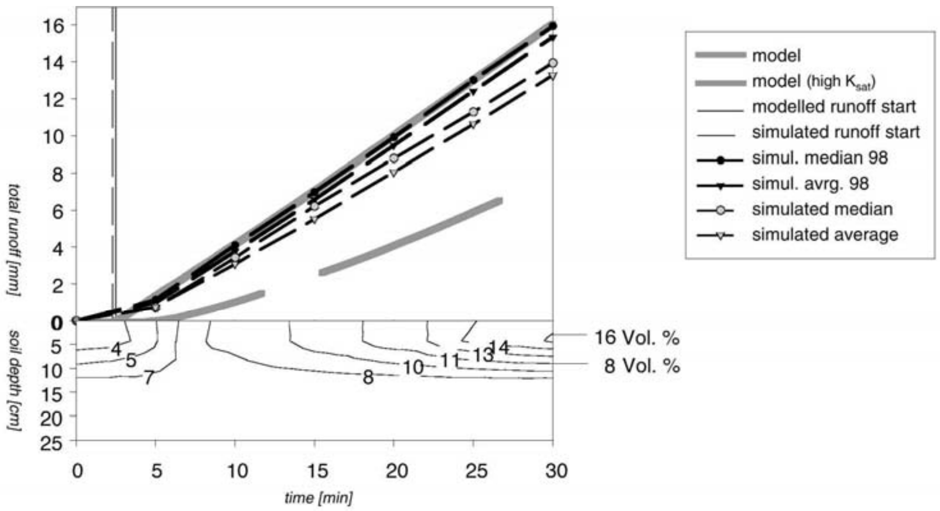


Figure 5. Simulated and modelled rainfall with an intensity of 40 mm h-1. There are shown the modelling results with different Ksat values. The soil moisture dynamic during the simulation is shown at the lower part of the figure.

Modelling infiltration and runoff with different rainfall intensities on the “young fallow land” (Figure 6)

With the calibrated parameters of the rainfall simulation the model was applied for different rainfall intensities. First, the lowest rainfall intensity was determined for which superficial runoff can be expected by iteration. This was at a rainfall intensity of 6 mm h^{-1}: after a very late begin of runoff at the 24^{th} min, at a soil moisture in the upper 3 cm of more than 10 %, the total runoff was very low (RK=0.02) showing a nearly linear increase from runoff begin. Nevertheless, infiltration rates decrease rapidly after runoff begin, reaching at the end of the model a very low value of 4.7 mm h^{-1}. The total amount of infiltrated water arises up to 2.9 mm.

With a rainfall intensity of 10 mm h^{-1} runoff begin is modelled in the 11^{th} minute, at a soil modelled soil moisture of less than 8 %. The runoff arises up to 30 % of the total

Table 4. Physical soil data of the Haplic Gypsisol (old fallow land) gained in laboratory.

Horizon	*bulk density*	*pore volume*	*pF 1.8*	*pF 2.5*	*pF3.0*	*pF 4.2*	*Ksat[mm/h]*
Ap	1.4	43.3	15.5	5.0	5.5	17.3	188.8
1By	1.5	43.2	12.3	4.3	5.9	20.7	38.7
2By	1.4	45.3	10.9	6.6	13.1	14.7	21.6

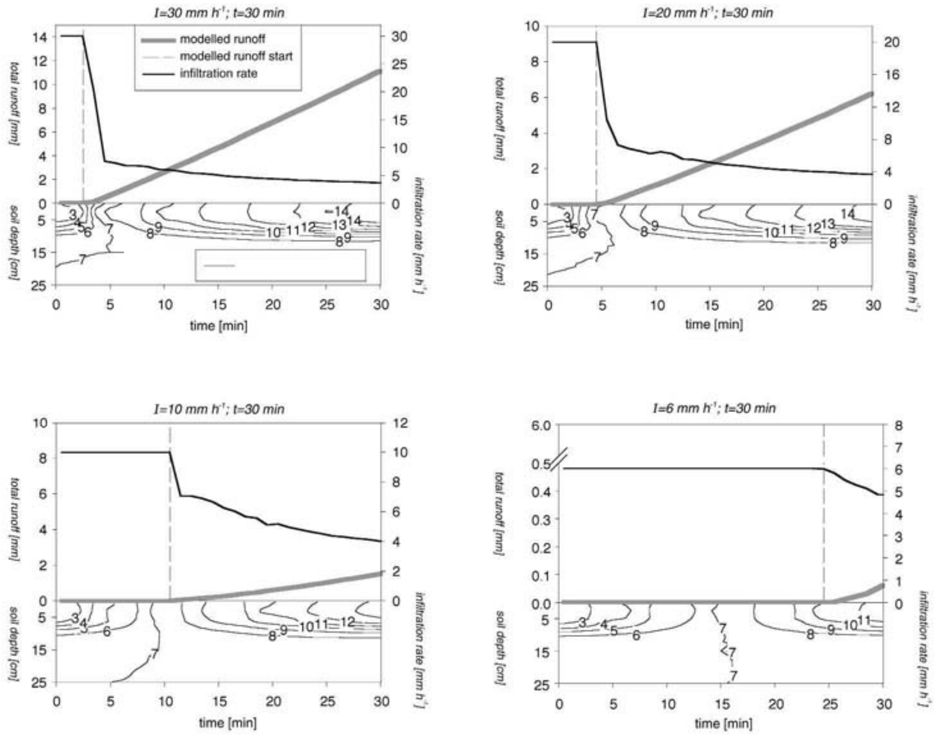


Figure 6. Results of the rainfall simulations at different rainfall intensities.

rainfall, whilst the infiltration rate decreases nearly in a linear way to 4.3 mm h^{-1}. So, water recharge into the soil is about 3.5 mm, leading to an increase of soil moisture in the upper 15 cm where a strong gradient was calculated.

Doubling the precipitation intensity to 20 mm h^{-1} conduces to a very high runoff with a RK of 0.62. Runoff starts within the first 5 min, and the end infiltration rate is with 4 mm h^{-1} very low. The reduction of the infiltration rate during the modelled rainfall event is, similar to the experimental results, following a hyperbolic decay curve. The infiltrated amount of water arises up only to 3.9 mm, showing that the moisture increase is limited to the upper 11 cm, reaching in the crust values of more than 14 %.

A very strong precipitation of 30 mm h^{-1} leads to an infiltration and runoff behaviour similar to the one simulated with a rainfall intensity of 40 mm h^{-1}. The RK reaches at the end of the modelled experiment 0.73. Between the 3rd and the 4th minute at a soil moisture of about 6 % at the soil surface the runoff begins, and the total water infiltrated is the same as in the model described above (3.9 mm). After 30 min of modelled rainfall the soil moisture arises up to more than 14 % at the topsoil, but beneath 13 cm depth there can't be no recharge of soil water calculated. The evolution of the infiltration rate shows, that this modelled event is very similar to the one simulated.

Common of all modelled rainfall intensities is the abrupt decrease of the infiltration rate with the begin of the runoff, and its decrease with time reaching a nearly asymptotic value. Only at low rainfall intensities there can be observed a – nearly – linear decrease of the infiltration rate.

Modelling on the “old fallow land”

Due to the heterogeneity of the rainfall simulations on the “old fallow land” (see Figure 4) there was not possible to parameterise the model with homogenous data for the Haplic Gypsisol. The response to precipitation reacted directly to the variation of the macroporosity of the soil.

A macroporosity of only 0.001 %, in combination with the data gained in laboratory (Table 5) and the hydraulic conductivity (Table 6) led to a RC of 0.07. The runoff started during the 6th minute of modelled simulation. The moisture increase is limited to the macroporous layer, being the it very high in the upper 5 cm of the soil. It can be observed, that the infiltration is dominated by the infiltration into the macropores. The infiltration into the matrix decreases very rapidly to a very low value and shows after this a slight increase.

With an only slightly lower macroporosity (0.0008 %) the runoff is nearly 3 times higher than in the modelisation before (RC=0.18), whilst the runoff begin is only one minute earlier. In this case, the increment of soil water shows a similar distribution like

Table 5. Input data of the Hyperochric Gypsisol (young fallow land) for the HILLFLOW 1 D-model. There are considered total porosity (Θ_{sat}). rest water content (Θ_r. here about pF 7) saturated hydraulic conductivity (K_{sat}). parameters α and n from parameterisation of the water retention curve and the initial soil water content (Θ_{ini})

Horizon	*depth (m)*	Θ_{sat} ($m^{3\circ} m^{-3}$)	Θ_r ($m^{3\circ} m^{-3}$)	K_{sat} ($mm^\circ h^{-1}$)	α (m^{-1})	*n*	Θ_{ini} ($m^{3\circ} m^{-3}$)
Apm	0.03	0.35	0.02	4.6	2.0	1.141	0.02
Ap1y	0.15	0.45	0.02	38.0	19.76	1.119	0.07
Ap2y	0.3	0.46	0.02	96.0	111.01	1.116	0.07
2Cd	0.6	0.43	0.02	7.0	0.05	1.341	0.08

Table 6. Input data of the Haplic Gypsisol (old fallow land) for the HILLFLOW 1 D-model. There are considered total porosity (Θ_{sat}). rest water content (Θ_r. here about pF 7) saturated hydraulic conductivity (K_{sat}). parameters α and n from parameterisation of the water retention curve and the initial soil water content (Θ_{ini}). In this case the soil macroporosity was set to 0.001 % and 0.0008 % to a depth of 0.25 m.

Horizon	*depth (m)*	Θ_{sat} ($m^{3\circ} m^{-3}$)	Θ_r ($m^{3\circ} m^{-3}$)	K_{sat} ($mm^\circ h^{-1}$)	α (m^{-1})	*n*	Θ_{ini} ($m^{3\circ} m^{-3}$)
Apm	0.005	0.41	0.02	10.2	2.0	1.141	0.04
Ap	0.28	0.43	0.02	189.0	43.7	1.235	0.07
1By	0.52	0.43	0.02	39.0	39.98	1.176	0.07
2By	0.76	0.45	0.02	22.0	8.73	1.432	0.08

the one described before, of course being lower. The infiltration dynamics is the same, too, being the macropore-infiltration predominant along nearly the whole modelisation.

Due to the uncertainty of the parameterisation of the soils for modelling the response to rainfalls the modelisation of rainfall of lower intensities was not performed. It can be observed, that the infiltration capacity of the macropore-layer is about 33.6 mm h^{-1} (0.001 % macropores) and 26.9 mm h^{-1} (0.0008 % macropores), so these have to be considered as lowest rainfall intensities able to generate superficial runoff.

5. Discussion and Conclusions

The results of the combination of field observations, simulation of rainfall and its modelisation give wide information about the response of the soils to precipitation. The sparsely vegetation-covered soils of a 6-year old abandoned cereal field are very homogenous in their physical characteristics. The crust created by the effect of the antecedent rainfall determinates the runoff generation. This crust reduces the infiltration capacity of the topsoil considerably, and its hydraulic conductivity tends to decrease with time. The modelisation results indicate that runoff is generated at least by rainfall intensities higher than 10 mm h^{-1} of a duration longer than 15 min. This values may decrease during the event as an effect of the sealing of the crust during precipitation and by the decrease of the hydraulic gradient in the upper centimetres of the soil. This effect was well calculated by the model. On the other hand, rainfall intensities of 30 mm h^{-1} and more lead to a very fast and high runoff generation (Figure 7).

The infiltration of water into this soils is always very low and shallow, leading to a significant limitation of soil water recharge during the rainfalls. If it is taken account that the atmospheric water deficit is always high, the constant drought of the soils all along the year can be explained.

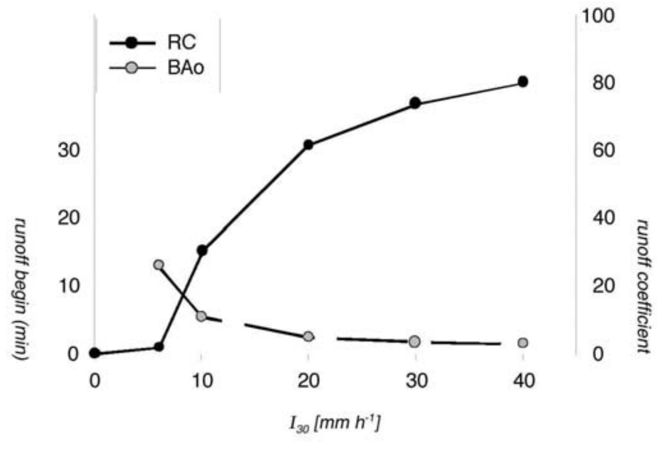


Figure 7. Comparison of the different rainfall intensities modelled. The final runoff coefficient and the runoff start is shown.

Table 7. Characteristic data of the rainfall simulations. Slope in degrees, moisture in Vol.-%, BegAo is beginning of runoff in minutes, Inf. Depth is infiltration depth, RC the runoff coefficient.

	date	*slope*	*moisture*	*BegAo*	*Inf. depth*	*RC*
"young fallow land"	06.10.95	2	4.5	3.40	3	20.0
	28.03.97	4	5.5	3.57	4	49.3
	23.07.97	5	3.5	3.40	10	74.8
	04.04.98	7	1.8	2.15	4	81.3
	04.04.98	7	1.7	2.32	4	73.9
	05.04.98	7	6.4	2.06	7	81.0
	05.04.98	7	4.8	2.10	3	65.6
	02.08.98	7	6.2	3.00	n.B.	68.5
	15.10.98	2	n.B.	1.43	n.B.	77.0
	Average	5.3	4.3	2.6	5.0	65.7
	Median	7	4.65	2.32	4	73.9
"old fallow land"	08.10.95	3	7.3	5.00	3	14.5
	31.03.97	2	5.8	6.08	23	0.2
	01.04.97	10	5.8	4.45	9	36.5
	25.07.97	5	7.4	15.04	40	2.5
	08.04.98	4	4.3	3.10	2	67.2
	Average	4.8	6.12	6.7	15.4	24.2
	Median	4	5.8	5.0	9	14.5

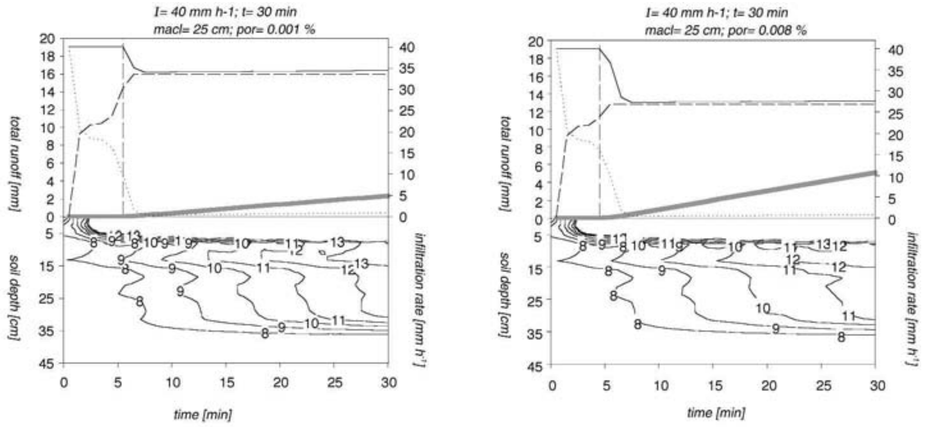


Figure 8. Results from the modelling of rainfall simulations on the old fallow land with different macropore volume. In addition, infiltration rates into the matrix and into the macropores are shown.

On the other hand, the soils of a 60-year old fallow land show some characteristics very different to the ones described above. The simulation results indicate a very high variability of physical characteristics in space. The shallow crust restrains the infiltration into the matrix, but at the same time, the macroporosity created by soil-animals makes possible an infiltration into the soil, even into deeper layers. For this, the high variability of the runoff measured by simulation can be explained by a high variability in macropore distribution. Deep and interconnected macropores may cause a rapid flow in the soil, without a significant water recharge into the matrix. As a consequence, piping processes may be enhanced, as it can be observed in the field: deep gullies erode the old abandoned fields.

The results of the modelisation of rainfall on the "old fallow land" shows, at the same time, the limitation of physical based hydraulic models. The accuracy required for the soil data is partly impossible to gain with conventional field methods. Infiltration processes into extreme dry soils, with air inclusions in the macropores, with hydrophobity effects of the matrix, may influence very strongly the infiltration processes and have to be taken account in models. The ongoing with a separated simulation of flows in matrix and macropores, with the consequent quantification of macropore volume, has to be considered. It seems to be more operable to quantify the variation of the hydraulic conductivity as a function of moisture and inclusion of macropores like proposed in CATFLOW. Nevertheless, the combination of the modelisation with simulation experiments enhances the understanding of infiltration and runoff-generation processes.

It is obvious now, that crust-formation has to be inhibited to enhance the infiltration of water into the soils of the abandoned farmlands of the semi-arid Inner Ebro Depression. At the same time a rapid recovery of vegetation and soil-animal population is necessary to enhance soil protection and physical characteristics. For this the, now usual, ploughing with set-aside programs has to be stopped as well as additional measures have to been undertaken, like artificial increment of soil organic matter, e.g. by application of sewage sludge or similar. The land management before abandonment is, on the other hand, very important for this purpose, too. The introduction of reduced tillage techniques or similar is a measure, which introduces rapidly high quantities of organic matter into the soils.

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