J. Hydrol. Hydromech., 67, 2019, 4, 297–304
DOI: 10.2478/johh-2019-0018

The dominant runoff processes on grassland versus bare soil hillslopes in a temperate environment - An experimental study

Gabriel Minea[1, 2*], Gabriela Ioana-Toroimac[3], Gabriela Moroşanu[3, 4, 5]

[1] Research Institute of the University of Bucharest, University of Bucharest, 36-46 Bd. M. Kogălniceanu, Sector 5, 050107, Bucharest, Romania.
[2] National Institute of Hydrology and Water Management, 97 E Bucureşti - Ploieşti Road, Sector 1, 013686, Bucharest, Romania.
[3] Faculty of Geography, University of Bucharest, 1 Nicolae Bălcescu Avenue, Sector 1, 010041, Bucharest, Romania.
[4] Institute of Environmental Sciences, University of Grenoble Alpes, CS 40700, 38058 Grenoble Cedex 9, France.
[5] Institute of Geography, Romanian Academy, 12 Dimitrie Racoviță, Sector 2, 023994, Bucharest, Romania.
[*] Corresponding author. Tel.: +40213181115. Fax: +40213181116. E-mail: gabriel.minea@hidro.ro

Abstract: This paper aimed to investigate the dominant runoff processes (DRP's) at plot-scale in the Curvature Subcarpathians under natural rainfall conditions characteristic for Romania's temperate environment.

The study was based on 32 selected rainfall-runoff events produced during the interval April–September (2014–2017). By comparing water balance on the analyzed Luvisol plots for two types of land use (grassland vs. bare soil), we showed that DRP's are mostly formed by Hortonian Overland Flow (HOF), 47% vs. 59% respectively. On grassland, HOF is followed by Deep Percolation (DP, 31%) and Fast Subsurface Flow (SSF, 22%), whereas, on bare soil, DP shows a higher percentage (38%) and SSF a lower one (3%), which suggests that the soil-root interface controls the runoff generation.

Concerning the relationship between antecedent precipitation and runoff, the study indicated the nonlinearity of the two processes, more obvious on grassland and in drought conditions than on bare soil and in wet conditions (as demonstrated by the higher runoff coefficients). Moreover, the HOF appeared to respond differently to rainfall events on the two plots - slightly longer lag-time, lower discharge and lower volume on grassland - which suggests the hydrologic key role of vegetation in runoff generation processes.

Keywords: Dominant runoff processes; Grassland; Soil water balance plot; Rainfall-runoff event.

INTRODUCTION

The conversion of precipitation into runoff on hillslopes represents dynamic processes, highly variable in space and time (Weyman, 1973; Bachmair and Weiler, 2012; Rodrigo-Comino et al. 2019). The hydrological relevance of understanding hillslope runoff processes lies in the practical necessity to predict river discharge in ungauged basins.

The determination of dominant runoff processes (DRP's) is an important approach in investigating and analyzing soil-hydrological parameters in detail, with respect to hydrological predictions in ungauged basins, water conservation management, flood and erosion hazards prevention (Müller et al., 2009; Hümann and Müller, 2013; Rodrigo-Comino et al. 2017; Ferreira et al., 2018).

Several methods have been developed to determine the DRP's and characterize the spatial extent and distribution of areas where a specific runoff process occurs. Naef et al. (2002) have defined DRP on a site as being the process that mostly contributes to the runoff for a given rainfall event. In recent decades, a large number of intensive plot-scale experiments have been conducted in the field to identify DRP's (e.g., Scherrer et al., 2007; Müller et al., 2009; Jost et al., 2012).

The DRP's literature includes two approaches: (i) manual field investigation; (ii) automatic GIS-based, also called GIS-DRP. Hümann and Müller (2013) considered that the *field investigations* approach is the best way to analyze dominant runoff processes and Antonetti et al. (2016) added that it is reliable but time-consuming. To foster investigations on runoff formation, Schmocker-Fackel et al. (2007) conducted sprinkling experiments at plot scale in Switzerland, while Antonetti et al. (2016) performed measurements of soil profile properties in Germany, on grassland hillslopes with varying slopes, geology, and soils. On the basis of the above-mentioned approaches, a number of studies have been carried out to obtain a decision scheme and a spatial distribution (mapping) of DRP's on grassland sites. Significant results from Scherrer and Naef (2003) have shown that, by studying the four main processes in a catchment, they were able to separate their different effects on floods in terms of location and spatial extent of the DRP's. Also, the authors proposed a decision tree to define the dominant hydrological flow processes on a variety of grassland sites in Switzerland. Likewise, Scherrer et al. (2007) concluded from the sprinkling experiments on several grassland plots in Switzerland that overland flow was dominant in most of the studied runoff events followed by subsurface flow at a few sites. Schmocker-Fackel et al. (2007) designed an experiment to determine the potential of each grassland plot to produce a given runoff process. However, the experiment failed to establish the hydrological connectivity occurring between them. Antonetti et al. (2016) tested the suitability of different automatic DRP's mapping approaches for mapping ungauged catchments and quantified the uncertainties of hydrological simulations due to different spatial representations of DRP.

In Romania, regarding the hydrological influence of vegetation on runoff generation, few field investigations at microscale were initiated within the Curvature Subcarpathians (e.g., Stanciu and Zlate-Podani, 1987; Minea et al., 2018), and different results on runoff processes such as runoff coefficients, overland flow volume, and discharge or infiltration rates were found. These hydrologic experimental studies on hillslopes were marked by the pioneering work of Blidaru (1965).

While the Romanian literature has shown valuable information on the role of land use on the overland flow occurrence (e.g., Stanciu and Zlate-Podani, 1987; Miţă and Mătreaţă, 2016), other runoff pathways (e.g., subsurface flow and deep percolation) have remained little explored. The data on DRP's on hillslopes are nearly unknown in the Romanian literature.

Therefore, this work is based on the following hypothesis: (i) dominant runoff processes on Romanian hillslopes reflect the complex relationship between rainfall and runoff; (ii) a relationship between rainfall and runoff exists for the grassland and can be used to predict water flow pathways. In the present study, we used field data to identify DRP's at plot-scale. The objectives of this paper are to: (i) identify the dominant runoff processes at plot and event scales, and (ii) examine how grassland influences the peak discharge and lag-time of water flow pathways, in the typical case of the Voineşti Experimental Basin, Romania.

MATERIAL AND METHODS

Site description

The study area is located in the Curvature Subcarpathians (hilly region), dominated by Dacian sedimentary rocks (e.g., sands and clays and sandstones with marnes), about 110 km northwest of Bucharest, on the left side of Dâmboviţa River (Figure 1). The experimental site (45°05'07.27" N and 25°15'15.43" E) of Voineşti Experimental Basin – VEB is operated and maintained by the National Institute of Hydrology and Water Management. The experimental basin is situated in grassland at an elevation of 500 m a.s.l., in an area highly exposed to erosion (Zaharia and Ioana-Toroimac, 2009). The underneath soil is classified as Luvisol (Florea et al., 1971; Florea and Munteanu, 2012), and it is composed of 51% sand, 21% silt, and 28% clay. Luvisols have a well-developed Ao-Ea-Bt-C profile with a sandy clay loam texture (USDA-NRCS, 1999). The parental material is represented by clays (Maftei et al., 2002). According to the Köppen System for climate classification, the Curvature Subcarpathians are described by "Dfb" subtype or temperate humid continental climate (Peel et al., 2007).

Average annual precipitation and air temperature are 822 mm and 9.8°C (1980–2017), with the highest monthly average temperature of 20.2°C in July, and the lowest average of –0.6°C in January (Figure 2). Most rainfall events (64%) occur during the vegetation season (April–September 1967–2017: average precipitation depth = 510 mm, standard deviation SD 142 mm), and the highest number of rainfalls was recorded in June (13.1%) and July (12.6%). June is the wettest month receiving an average of 103.7 mm (SD ±46 mm), while February is the driest month, recording only 40 mm (SD ±28.5 mm) of precipitation.

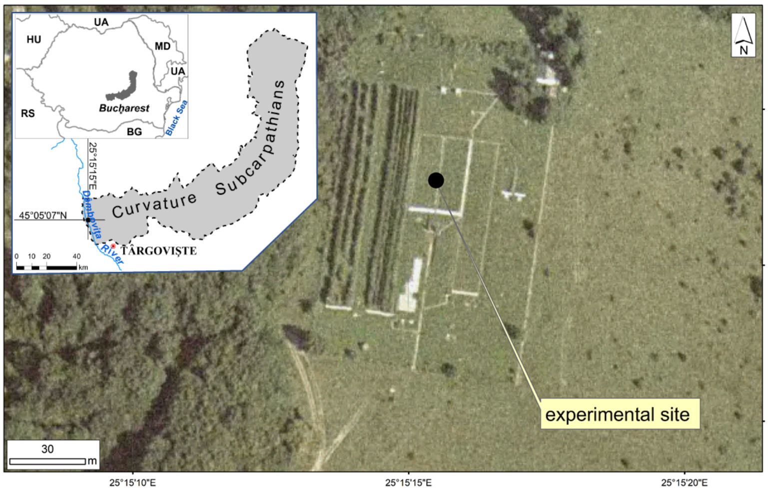

Fig. 1. Location of the study site in the Romania and Curvature Subcarpathians with the point of the experimental site - Voineşti Experimental Basin.

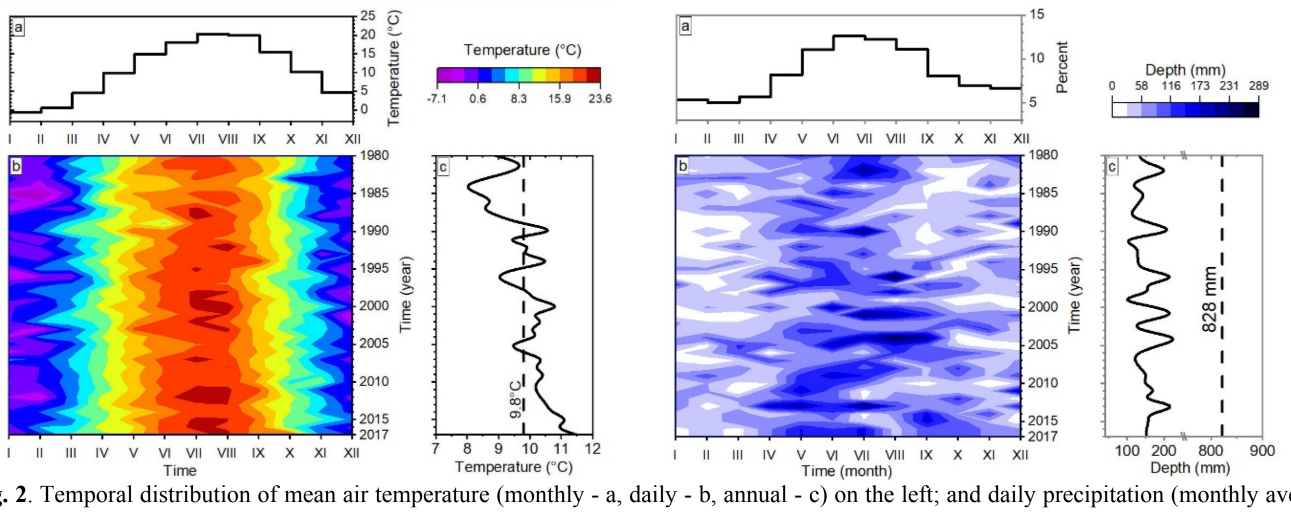

Fig. 2. Temporal distribution of mean air temperature (monthly - a, daily - b, annual - c) on the left; and daily precipitation (monthly average - a, daily amounts - b, and the highest monthly amounts - c) on the right; dashed line represents the multiannual average value. Period: 1980–2017, location: Voineşti Experimental Basin.

Methods

In order to answer our research questions, measurements of rainfall, overland flow, subsurface flow, and base flow were made during the period April to September 2014–2017. The measurements had a temporal resolution of 1 minute (2016–2017) or 10 minutes (2014–2015).

Runoff - soil water balance plots cover an area of 300 sq m (length = 30 m and width = 10 m), N-S aspect with a 13% planar slope and 500 m a.s.l. The land use of the soil water balance plots falls in the following categories:

(i) grasslands – corresponding to secondary perennial grass (Figure 1); this plot was never grazed, but herbage was cut in June, according to traditional practices in the region; the average height of grass species surrounding the plot was about 40 cm and an abundant superficial network of grass roots dominated in the top ~ 20 cm of the soil (see Minea et al., 2018);

(ii) bare soil or *"working soil"* – the plot was spaded annually in March; the spading created microdepressions (depth of less than 20 cm) and enabled infiltration of rainfall and water retention in the eroded soil; regular application of the herbicide treatments may sometimes lead to the formation of a soil crust covering the plot.

The soil water balance plots were bordered by an impervious (concrete) wall. A number of ditches, drainage and conveyance underground pipes (subsurface and base flow/deep percolation), and, at their lower part, shelters containing calibration water tanks with drainage installation for evacuated water were used. The concrete walls were dug in at a depth of 1.50 m and raised above ground by 0.20 m. The concrete ditches were covered by metal caps to avoid the rain falling directly into these. The overland flow (*HOF*) across the soil water balance plots was collected by one concrete cutslope ditch, situated at the outlet of the plot, a few centimeters below the surface. Subsurface flow (*SSF*) was represented by water collected at the depth of 0.4 m (below the effective root zone and at sandy clay Bt horizon) and deep percolation/base flow (*DP*) was collected at the depth of 1.3 m in the soil (Blidaru, 1965).

Six calibration metal measuring tanks were installed in a shelter below the plots: (i) 2 big tanks (0.380 m^3) with 45° V-notch sharp-crested weir after volumetric retention level (Q_{max} = 10 l/sec with a head of 20 cm) for the overland flow measurement; (ii) smaller tanks with the capacity of 0.120 m^3 capacity for measurement of the *SSF* and *DP*. Each tank contained a device (OTT float-cable counterweight followed by 2016 Nivotrack probes) for the continuous detection of the water level with a resolution of 0.001 m.

The rain gauge devices were located at the height of 1.5 m above the ground, between the two plots, and included a pluviometer (stage non-recording) and a pluviograph used to continuously record rainfall.

Supplementary data about the setup and handling of the runoff devices and rain gauges were given by Minea and Moroşanu (2016) and Minea et al. (2016; 2018).

Data calculation and analysis

The first step in the analysis was to convert continuous water level measurements (overland flow, subsurface flow, and base flow/deep percolation) into flow rate by a volumetric method $V = f(H)$ and rating curve $Q = f(H)$. Then, the flow data obtained (e.g., volumes, discharges) were compared.

Considering the rainfall-runoff analysis, we only used rainfall events defined by precipitation ≥ 0.2 mm. The rainfall events were considered finished when there was no precipitation during the following 1 hour. Event duration, rainfall depth and intensity (average and maximum) were determined for each event. We analyzed data from period 2014–2017. In 2014, only the data from April were used due to technical difficulties in the rest of the year.

In order to assess the influence of antecedent conditions (e.g., soil moisture) within a plot before a runoff event, the Antecedent Precipitation Index (API) (Kohler and Linsley, 1951; Rodríguez-Caballero et al., 2014) was calculated as a weighted sum of the total rainfall during three days preceding an event (API_3):

$$API_3 = \sum_{t=-1}^{-i} P_t\, k^{-t}$$

where API_3 is the antecedent precipitation index on day t, k is an empirical decay parameter (0.9 in this study), P_t is the total rainfall for the day t, and i = 3; k was fixed to 0.9, based on previous studies (Miţă and Mătreaţă, 2016).

For the specific runoff response, different flow processes and DRP's were determined for the rainfall-runoff events following the approach and terminology used by Scherrer et al. (2007). Water flow pathways during an event were denoted as the "Hortonian Overland Flow" (*HOF*), "Fast Subsurface Flow" (*SSF*) or interflow, and "Deep Percolation" (*DP*) or base flow. The process that mostly contributed to total runoff was assumed to be the "dominant" one (Schmocker-Fackel et al., 2007). Several additional runoff characteristics were determined for each event (rainfall and runoff durations, depths and volumes, and runoff coefficients – *RC's*).

The land use influence during the rainfall-runoff events was analyzed using the peak discharge and volume response to the rainfall, and the lag-time between the maximum rainfall and the peak flow (*HOF, SSF*, and *DP*).

Descriptive statistics (frequency distribution; relationships between rainfall and runoff characteristics) have also been employed. The relations between the rainfall and runoff characteristics were studied by using the coefficient of determination/regression (r^2).

RESULTS

Characteristics of rainfall events

Runoff process mainly depends on the rainfall event characteristics, in particular on rainfall intensity (Woolhiser and Goodrich, 1988; Bronstert and Bárdossy, 2003). The characteristics of natural rainfall events (duration, average, and maximum rainfall intensity) from April–September 2015–2017, are given in Table 1. More precisely, 297 rainfall events were measured (e.g., 94 events in 2015; 101 in 2016, and 102 in 2017). In April 2014, 37 rainfall events were recorded. Those of 18/4/2014 (32.2 mm; I_{max} = 6 mm/h) and 19/4/2014 (22.8 mm; I_{max} = 6 mm/h) produced runoff. As a rule, in April, the rainfall events were characterized by small depths and low intensities. Following periods with no precipitation, most of the rainfall events from this month did not produce runoff or significant runoff events, but have contributed to restoring the soil moisture storage.

The most important pluviometric feature of the rainfall events was represented by the small rainfall depth (see Table 1). Thus, in warm/growing period of April–September 2015 around 8 cases of rainfall events with rainfall depth over *P90* (90^{th} percentile) were registered, 4 of which being even over

P95; in 2016 a greater number of small rainfalls was registered (*P90* = 9.70 mm, 11 events; *P95* = 16.1 mm, 2 events); whereas in 2017, the number of the rainfalls with total rainfall depth exceeding *P90* (14.96 mm) was bigger (*P90* = 14.96 mm, 11 events in total, 6 of which exceeded *P95*).

The intensity of rainfall events, especially those with the highest peak values, was generally characterized by low values in the warm/growing period of April–September 2015 and somewhat higher in 2016 and 2017. In the warm/growing period of April–September 2016, 10 rainfalls with a maximum intensity ≥ *P90* were registered (24.6 mm/h), 5 of which were higher than *P95* (28.2 mm/h), and in 2017 there were 11 rainfalls with maximum intensity ≥ *P90* (33.2 mm/h), 7 of which from June – July being superior to *P95* (45.6 mm/h).

Several rainfall events were remarkable in terms of quantity (depth and maximum intensities). The events with hydrological impact corresponded to those characterized by a high rainfall intensity (see Figure 3a).

Dominant runoff processes at plot scale

Figure 3 gives an overview of the runoff response observed during the experiments performed under natural rainfall. The 32 rainfall-runoff events were produced by very different rainfall amounts (4.40 – 51.9 mm; SD = ± 12.2 mm) at wetness state characterized by API_3 (0 – 65.5 mm amounts). Very variable rainfall amounts and wetness states led to high differences in runoff characteristics (e.g., volume and runoff coefficients). As expected, infiltration processes on the hillslope, given the two land use categories, played an important role, especially in dry conditions ($API_3 \leq 10$ mm).

Moreover, the runoff rates and response times were affected by API_3 values. The results show that *RC's* of 32 selected events were low, despite the occurrence of heavy rainfall events and potentially erosive rains (Figure 3). The major part of the total runoff is produced by *HOF*. Cumulative runoff depth values on grassland plot are low, which indicates the role of the grass retention and the water consumption affected by the plants, associated with drier soil moisture conditions compared to the bare soil. However, cumulative runoff depths from grassland plot in a few cases showed high values of up to 25.4 mm (3/7/2017), if topsoil saturation occurred. Vertical flow dynamics indicated *HOF* as the fastest runoff generation mechanism delivering the greatest volumes of water (maximum value observed on 3/7/2017, 15.9 mm or 4791 l), followed by *DP* (3108 l or 10.3 mm on 19/4/2014).

The bare soil cumulative runoff depth plot depicted considerable runoff value, mainly based on *HOF* (24.3 mm on 20/9/2016), followed by *DP* (e.g., 3/7/2017 event) and significantly by *SSF* (e.g., 1.14 mm on 20/9/2016 event). *HOF* was the dominant runoff generation process on the bare soil plot, especially in dry conditions. The greatest volumes correspond to the *DP* and were generated by the rainfall events that occurred at high soil moisture conditions (e.g., 19/4/2014; 20/9/2016, 3/7/2017 rainfall events).

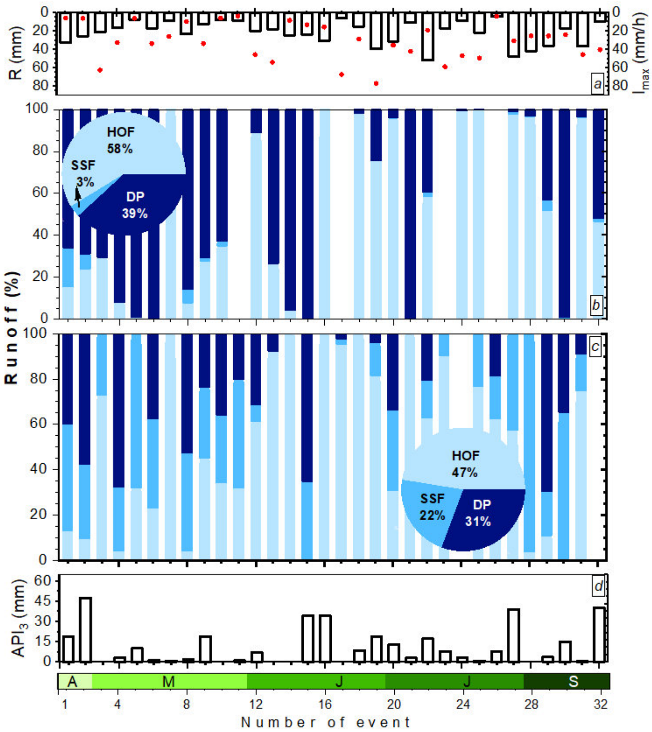

Fig. 3. Rainfall and runoff plot characteristics for 32 events sorted by months (April to September); a) - rainfall depth (*R*) and red dots represent maximum intensities of rainfall events, I_{max} (mm/h); runoff and its components (*HOF, SSF, DP*) from the runoff plots with the bare soil b) and grass c); the blank stacked column means that no flow occurred; d) - API_3.

The minor contribution of *SSF* – particularly on the bare soil plot – was observed, and 55% of the rainfall events did not generate any runoff (total). *SSF* was quantitatively dominant for the grassland plot.

On the bare soil plot, *SSF* is a relatively absent and less important process in terms of peak discharges. This situation is probably due to soil matrix, macropore system and pipe flow, water from infiltration passing to the deeper storage.

We assume that the important volume of water was transported from the topsoil into the matrix macropores to *DP*. *HOF, DP,* and *SSF* contributed to total water volume during the analyzed 32 rainfall-runoff events by 47%, 31%, and 22%, respectively at the grass plot. The *HOF, DP* and *SSF* contributions on the bare soil plot were 59%, 38%, and 3%, respectively.

Table 1. The rainfall events parameters from April–September, 2015/17 at Voineşti Experimental Basin.

Year (IV-IX)	2015				2016				2017			
Percentile	Parameters											
	D (min)	De (mm)	Intensity Avg (mm/h)	Intensity Max (mm/h	D (min)	De (mm)	Intensity Avg (mm/h)	Intensity Max (mm/h)	D (min)	De (mm)	Intensity Avg. (mm/h)	Intensity Max (mm/h)
Min	10	0.30	1.80	0.30	10	0.30	1.80	0.42	10	0.30	1.80	0.30
25th	30	0.70	1.40	1.20	20	0.60	1.80	1.20	40	0.80	1.20	1.20
50th	60	2.20	2.20	2.22	60	1.60	1.60	1.98	70	2.35	2.01	2.94
75th	170	5.75	2.03	5.40	110	4.00	2.18	7.80	130	7.58	3.50	9.60
90th	401	19.1	2.86	15.7	210	9.70	2.77	24.6	307	14.9	2.91	33.2
95th	667	24.3	2.19	25.7	300	16.1	3.22	28.2	499	21.6	2.60	45.6
Max	1310	35.9	1.64	62.4	910	81.8	5.39	62.4	920	51.9	3.38	76.8

D = Duration; De = Depth; Avg = average; Max = maximum.

The relationship between rainfall and runoff coefficients

The boxplots of *RC's* of 32 rainfall-runoff events experiments grouped by land use are shown in Figure 4. We found a greater variability of *RC's* on bare soil than on grassland. The maximum and median were higher on the bare soil plot, while the minimum was slightly smaller on the grassland plot.

The 75th percentile of *RC's* at the bare soil plot was more than two times higher than at the grassland plot. The high *RC's* on bare soil could be explained by the soil water repellency on *HOF*. The 90th percentile values of cumulative runoff coefficient of events were 0.37 for the grassland and 0.60 for the bare soil (Figure 4). This indicates an increase in water retention capacity at the grassland plot under extreme conditions.

It was found that in very dry conditions (API_3 < 4 mm) grassland plot runoff coefficients (*HOF, SSF, DP*) are greatly reduced to 0, and in extreme wetness conditions, the *RC's* went up to 0.50 (e.g., 0.49 on 3/7/2017; 0.42 on 27/5/2017). Runoff coefficients on the bare soil plot have generally higher values than on the grassland plot. The bare soil plot release more than half of the rainfall volume in extreme conditions (e.g., *RC* = 0.65 on 9/5/2017 and *RC* = 0.63 on 3/7/2017). On the grassland, when API_3 was up to 4 mm, more than 8 mm of rainfall was needed to produce a minor *RC's*, while on the bare soil, minor RC's was produced by the rainfall event of 8 mm already at API_3 of 1 mm (Figure 4).

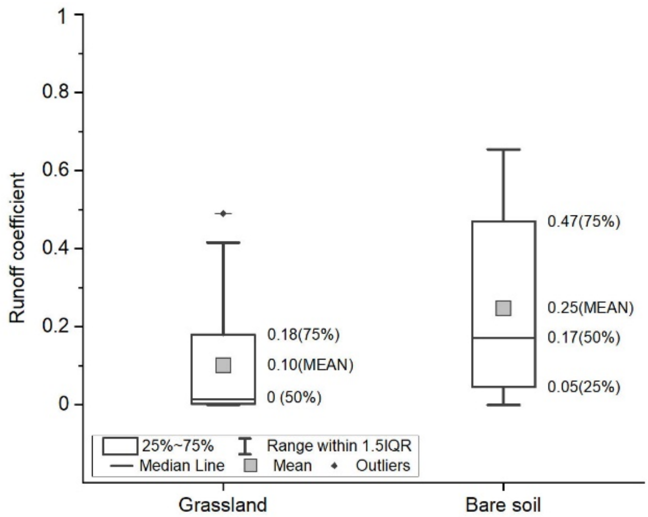

Fig. 4. Boxplots of the runoff coefficients of 32 rainfall-runoff events grouped by the land-use.

The relationship between rainfall and water flow pathways

The relationship between rainfall and water flow pathways (*HOF, SSF, DP* and cumulative) based on the 32 events is shown in Figure 5. These results reflect the nonlinearity of the rainfall-runoff processes, particularly on grassland (r^2 = 0.09) when compared to the bare soil (r^2 = 0.45).

Lag-time and peak discharge

The results concerning the lag-time to peak discharge at the two runoff plots for the same events are presented in Table 2.

The lag-times differed from one case to another. The *HOF* hydrographs of a few events showed a rapid response to rainfall at the bare soil plot. However, in some cases, the *HOF* hydrographs had approximately the same lag-time on both plots (e.g., the 30/5/16 15:00 and 5/5/17 20:07 events).

The peak flow after the long rainless periods with high transpiration at the bare soil plot occurred earlier than at the grassland plot, e.g., after 12 and 18 min, respectively on 26 June 2017. Concerning the response time in the case of *SSF*, a lower drainage capacity was recorded on grassland than on the bare soil. This finding could be explained by the influence of the root system (Ghestem et al., 2011). *DP* occurring only after substantial rainfall events shows in most cases intermittent flow (dripping) which was quantitatively significant, but had no clear peak.

One of the most notable runoff elements is *HOF* peak discharge. In our pedoclimatic conditions, we observed that *HOF* peak discharges at grassland and bare soil plots do not respond

Table 2. Lag-time (min) of water flow pathways for grasslands and bare soil.

Events time	Grassland				Bare soil		
	HOF	SSF	DP	Growth stage	HOF	SSF	DP
13/5/16 4:00	NR	NR	NR	Initial	66	NR	IR
16/5/16 8:00	70	383	IR		59	NR	IR
30/5/16 15:00	50	NR	IR	Mid	50	NR	IR
2/6/16 4:00	104	NR	NR		81	NR	NR
17/7/16 3:30	69	NR	NR		NR	NR	NR
19/9/16 10:50	48	64	IR	Late	38	62	IR
20/9/16 0:40	151	154	IR		120	120	IR
20/9/16 7:00	39	72	IR		40	300	IR
25/9/16 15:00	NR	159	368		NR	IR	IR
5/5/17 20:07	187	206	232	Initial	187	653	653
7/5/17 17:30	91	111	162		5	160	810
9/5/17 8:00	141	164	219		121	340	905
27/5/17 15:17	163	173	188	Mid	154	IR	177
26/6/17 20:10	18	34	115		12	IR	2090
3/7/17 6:00	5	295	1500		0	60	858
25/7/17 13:50	87	160	289	Late	NR	NR	NR
19/9/17 10:40	758	792	803		771	826	1220
22/9/17 10:20	NR	NR	NR		186	299	304

HOF = Hortonian Overland Flow; SSF = Fast Subsurface Flow; DP = Deep Percolation; NR = no runoff; IR = intermittent runoff.

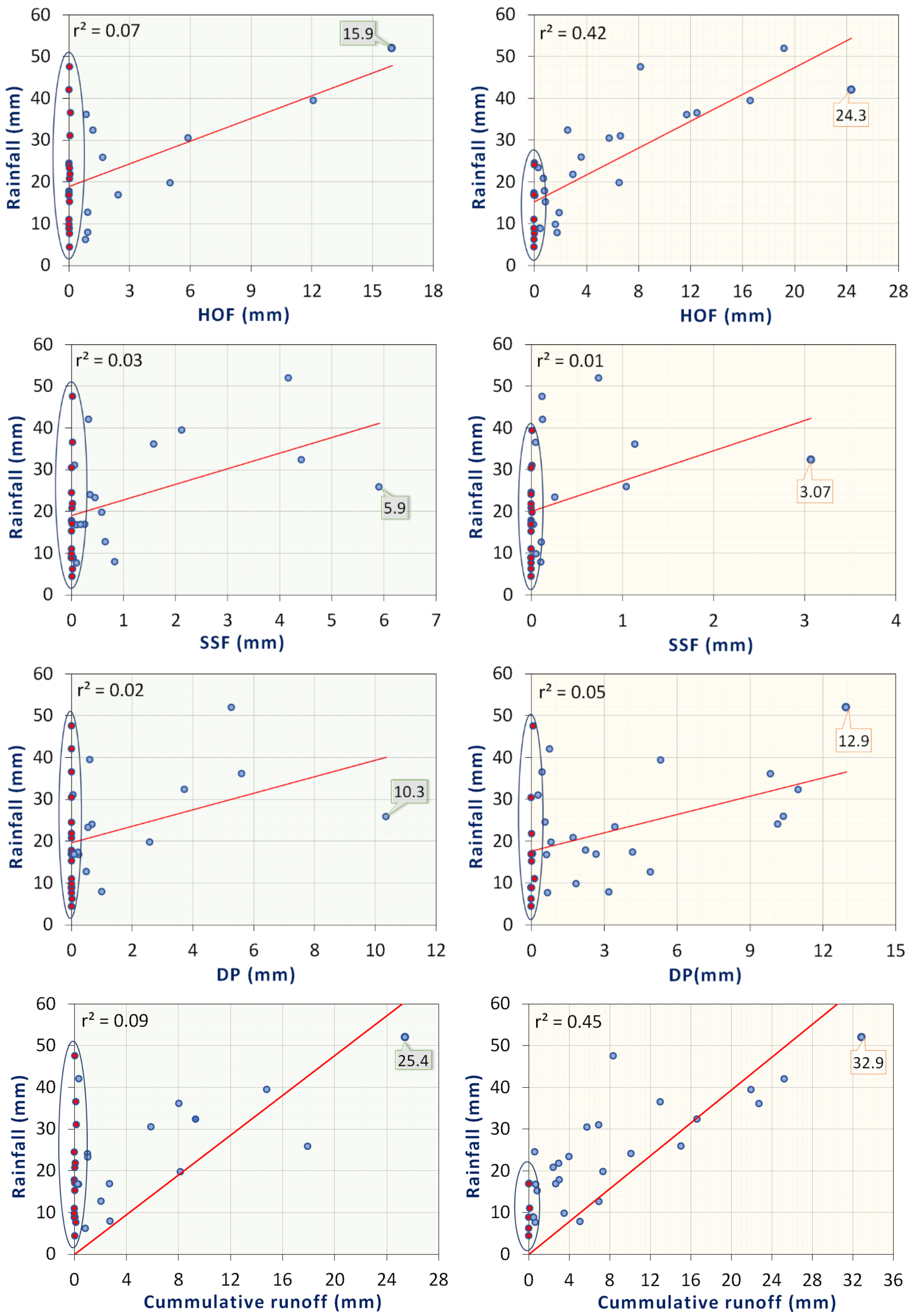

Fig. 5. The relationship at the event scale between rainfall and runoff (*HOF, SSF, DP*, and cummulative) for grassland (left row) and bare soil (right row); red dots show dry conditions (API_3 < 4 mm).

to rainfall events in a similar way (e.g. hydrograph shapes, peak discharges). In some cases, the *HOF* runoff peak was relatively synchronous on both plots (e.g., 30/5/2016; 5/5/2017). The decrease of *HOF* is more intense under dry conditions and it shows the hydrological key role of grassland for the water regulatory function.

Under extreme rainfall conditions in an unsaturated soil, a few major runoff events were produced. The *HOF* peak discharges at the grassland plots were smaller than at the bare soil plots. The *HOF* hydrograph shapes were very similar to those of hyetographs (see the double peaks in Fig. 6. The peak discharge of the *SSF* on grassland and bare soil plots was also (Figure 6).

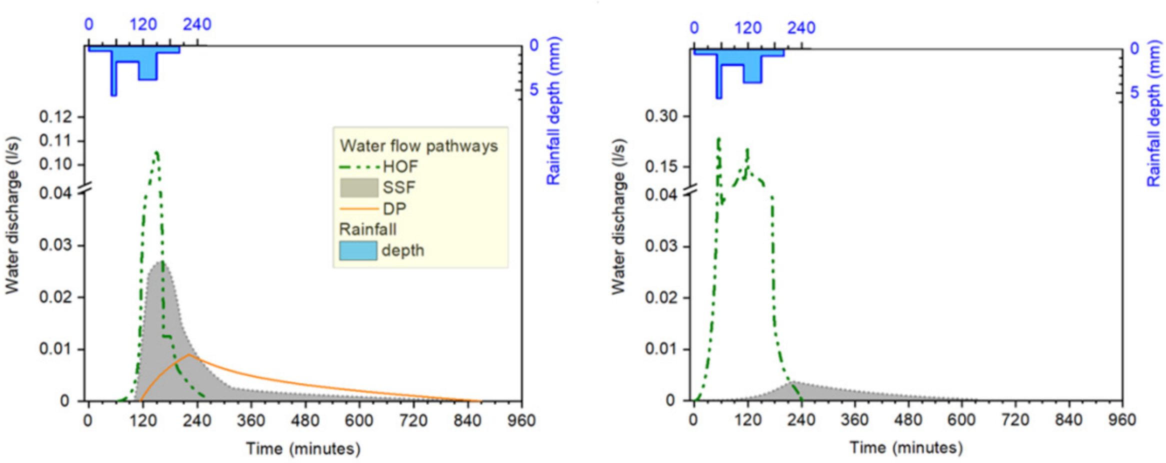

Fig. 6. Hydrographs during the rainfall-runoff event on July 5, 2017, on the grassland (left) and bare soil (right) plots.

The grassland plot had a fast *SSF* response. On the bare soil plot, reduction and flattening of the *SSF* peak discharge was a characteristic process, sometimes followed by bypass flow to *DP*. *SSF* does not occur under light rainfall intensities. On the bare soil plot, the *DP* peak discharge was insignificant and the *DP* hydrograph had flat rising and falling limbs.

DISCUSSION

Role of antecedent wetness on DRP's

Our study contributes to the improvement of knowledge on water flow pathways, namely DRP's, in relation to land use in a hilly temperate environment.

On the grassland plot, a strong control of antecedent wetness conditions for drainage paths was observed, by reducing the volumes of drained water (5% of the rain). The most visible hydrologic influences in dry conditions are on *SSF* (often absent) and *HOF,* which has often been severely diminished. However, the initial conditions did not control the flow response. Also, Scherrer et al. (2007), analyzing the RC's, observed that the DRP was not affected by antecedent wetness and that runoff volume increased only slightly at higher soil moisture. However, in their study of cambisol plots (10 sq m), Leitinger et al. (2010) found a mean surface runoff coefficient of 0.18 on pastures. Likewise, our results show similarly low values, with the P75 runoff coefficient of 0.18 for *HOF* (see Figure 4).

Rainfall characteristics such as depth (e.g., 26/6/2017 events), maximum intensities (e.g., 27/6/2015; 26/6/2017 events) had an important role in the occurrence and dynamics of DRP, particularly *HOF*. Compared to bare soil plot during drying period conditions, the DRP changed from *DP* in grassland plot to *HOF*. Dominant *HOF* (64%) on bare soil plot occurs when water repellent soils restrict (soil crust) infiltration and increase runoff. A subordinate process was *DP* (35%), whereas *SSF* were negligible (~ 1%).

In a case study of grassland DRP's, Scherrer et al. (2012) found that on grassland plots the dominant process changed from very delayed infiltration excess overland flow under dry conditions to delayed saturation excess overland flow under wet conditions. Also, several authors found that temporary *HOF* occurred only at the beginning under dry conditions (Scherrer et al., 2007; Leitinger et al., 2010; Ries et al., 2017). Therefore, results at plot-scale confirm the expectations that grassland on hillslopes influenced runoff and can modify the peak discharge and lag-time.

How does vegetation growth stage influence the DRP's?

From a hydrological point of view, an uncertain relationship between vegetation growth stage (initial, mid and late) and lag-time of runoff was observed.

In June–July period (months characterized by a pluviometric maximum), after the grass cutting on the grassland plot, a relatively variable lag time was observed. Statistical analysis of the vegetation stage and runoff coefficients did not show significant differences between the two periods (pre-cut and growth, respectively cut off).

The growth stage did not seem to have a great influence on runoff (e.g., thrugh water uptake by transpiration and percolation). One possible explanation is that the grass root system does not change by grass cutting. As for the runoff peak time, the grassland plot has a higher effect on the runoff peak attenuation, suggesting a stronger regulatory effect of grassland on the runoff process. We observed that most of the *HOF* grassland hydrographs had steep rising and falling limbs and narrow peak discharges. It was also noticed that the *HOF* lag-time on grassland was greater than on the bare soil. A possible explanation could be related to the dynamics and interactive behavior of soil characteristics, e.g., water repellency, vertical movement of water etc. (Lichner et al., 2011).

CONCLUSIONS

Our results suggest that runoff process on the grassland plot was dominated by *HOF* (47%) followed by *DP* (31%) and *SSF* (22%). Runoff on the bare soil plot was dominated by *HOF* (59%) followed by *DP* (38%) and *SSF* (3%).

These results indicate that *HOF* is actually the dominant runoff generation mechanism for both land uses. The vertical distribution of water in the soil gradually decreases in the case of grassland, whereas on bare soil, gravitational drainage of water changes *HOF* into *DP*.

Antecedent wetness conditions do not affect the DRP, but reduce the peak runoff rate during dry conditions. On the grassland plot, most of the rainfall percolated through the root zones into Luvisols and formed *SSF*. The soil-root interface has a strong hydrologic control there. On bare soil plot, where the grass root system was absent, the *SSF* was minor.

Runoff coefficients (for *HOF, SSF* and *DP*) indicated the influence of the antecedent conditions which were more important on the grassland plot. On the contrary, on the bare soil plot, higher runoff coefficients were observed (up to 0.65).

Lag-time of peak flow was not strongly influenced by the land use. Grasslands had the biggest effect on the peak discharge and volume reduction, particularly on *HOF*. Clear influence of the vegetation growth stage on the runoff generation mechanism was not identified.

To conclude, grasslands have both positive (e.g., lag-time and attenuation of discharge volumes) and negative (e.g., retention and consumption of water in the soil-root zone during dry conditions) aspects (Lobet et al., 2014; Ries et al., 2017).

Acknowledgements. The authors would like to express their gratitude to Research Institute of the University of Bucharest for financial support of Gabriel Minea's postdoctoral research, and to the National Institute of Hydrology and Water Management for the continuous support in carrying out the research at microscale. We thank the Associate Editor and two anonymous reviewers for their thoughtful comments and time devoted to the improvement of our manuscript.

REFERENCES

Antonetti, M., Buss, R., Scherrer, S., Margreth, M., Zappa, M., 2016. Mapping dominant runoff processes: an evaluation of different approaches using similarity measures and synthetic runoff simulations. Hydrology and Earth System Sciences, 20, 7, 2929–2945.

Bachmair, S., Weiler, M., 2012. Hillslope characteristics as controls of subsurface flow variability. Hydrology and Earth System Sciences, 16, 10, 3699–3715.

Blidaru, S., 1965. Emploi des bassins représentatifs et des stations expérimentales a l'étude des phénomènes hydrologiques. Studies and reports in hydrology, IAHS, 66, 2, 107–115.

Bronstert, A., Bárdossy, A., 2003. Uncertainty of runoff modelling at the hillslope scale due to temporal variations of rainfall intensity. Physics and Chemistry of the Earth, Parts A/B/C, 28, 6–7, 283–288.

Ferreira, C.S.S., Keizer, J.J., Santos, L.M.B., Serpa, D., Silva, V., Cerqueira, M., Ferreira, A.J.D., Abrantes, N., 2018. Runoff, sediment and nutrient exports from a Mediterranean vineyard under integrated production: An experiment at plot scale. Agriculture, Ecosystems & Environment, 256, 184–193.

Florea, N., Conea, A., Munteanu, I. (coord.), 1971. Soil Map Romania, sc. 1: 500,000. Inst. Geol. Bucureşti, Bucharest.

Florea, N., Munteanu, I., (Eds.), 2012. Romanian System of Soil Taxonomy/Sistemul Român de Taxonomie a Solurilor (SRTS-2012). Publish House Sitech, Craiova.

Ghestem, M., Sidle, R. C., Stokes, A., 2011. The influence of plant root systems on subsurface flow: implications for slope stability. BioScience, 61, 11, 869–879.

Hümann, M., Müller, C., 2013. Improving the GIS-DRP Approach by Means of Delineating Runoff Characteristics with New Discharge Relevant Parameters. ISPRS International Journal of Geo-Information, 2, 1, 27–49.

Jost, G., Schume, H., Hager, H., Markart, G., Kohl, B., 2012. A hillslope scale comparison of tree species influence on soil moisture dynamics and runoff processes during intense rainfall. Journal of Hydrology, 420, 112–124.

Kohler, M.A., Linsley, R.K., 1951. Predicting the runoff from storm rainfall (Vol. 30). US Department of Commerce, Weather Bureau. Washington, DC, 9 p.

Leitinger, G., Tasser, E., Newesely, C., Obojes, N., Tappeiner, U., 2010. Seasonal dynamics of surface runoff in mountain grassland ecosystems differing in land use. Journal of Hydrology, 385, 1–4, 95–104.

Lichner, L., Eldridge, D.J., Schacht, K., Zhukova, N., Holko, L., Sir, M., Pecho, J., 2011. Grass cover influences hydrophysical parameters and heterogeneity of water flow in a sandy soil. Pedosphere, 21, 6, 719–729.

Lobet, G., Couvreur, V., Meunier, F., Javaux, M., Draye, X., 2014. Plant water uptake in drying soils. Plant Physiology, 164, 1619–1627.

Maftei, C., Chevalier, P., Ciurea, C., Roşu, L., 2002. Considerations Concerning the Characteristics of Permeability of the Podzolic soil in Voineşti Catchment. Analele Universitatii "OVIDIUS" Constanta, Seria Constructii, I, 3–4, 525–530.

Minea, G., Iliescu, M., Dedu, F., 2016. Temporal rainfall properties at events scale in the Curvature Subcarpathians (Romania). Forum Geografic, XV, Suppl. 2, 115–123. DOI:10.5775/fg.2016.

Minea, G., Moroşanu, G.A., 2016. Micro-scale hydrological field experiments in Romania. Open Geosciences, 8, 1, 154–160.

Minea, G., Tudor, G., Stan F-I., Ioana-Toroimac, G., Zamfir, R., 2018. How can the grasslands under rainfall events modify water balance in drought conditions. Journal of Water and Land Development, 38, 53–65.

Miţă, P., Mătreaţă, S., 2016. Representative Basins in Romania: Synthesis of Research Result. Didactica Publishing House, Bucharest, 36 p.

Müller, C., Hellebrand, H., Seeger, M., Schobel, S., 2009. Identification and regionalization of dominant runoff processes-a GIS-based and a statistical approach. Hydrology and Earth System Sciences, 13, 6, 779–792.

Naef, F., Scherrer, S., Weiler, M., 2002. A process based assessment of the potential to reduce flood runoff by land use change. Journal of Hydrology, 267, 1, 74–79.

Peel, M.C., Finlayson, B.L., McMahon, T.A., 2007. Updated world map of the Köppen-Geiger climate classification. Hydrol. Earth Syst. Sci., 11, 5, 1633–1644. https://doi.org/10.5194/hess-11-1633-2007

Ries, F., Schmidt, S., Sauter, M., Lange, J., 2017. Controls on runoff generation along a steep climatic gradient in the Eastern Mediterranean. Journal of Hydrology: Regional Studies, 9, 18–33.

Rodrigo-Comino, J., Senciales, J. M., Sillero-Medina, J. A., Gyasi-Agyei, Y., Ruiz-Sinoga, J. D., & Ries, J. B. 2019. Analysis of Weather-Type-Induced Soil Erosion in Cultivated and Poorly Managed Abandoned Sloping Vineyards in the Axarquía Region (Málaga, Spain). Air, Soil and Water Research, 12, 1–-11.

Rodrigo-Comino, J., Wirtz, S., Brevik, E.C., Ruiz-Sinoga, J., Ries, J.B. 2017. Assessment of agri-spillways as a soil erosion protection measure in Mediterranean sloping vineyards. J. Mt. Sci. 14, 6,1009–1022.

Rodríguez-Caballero, E., Cantón, Y., Lazaro, R., Solé-Benet, A., 2014. Cross-scale interactions between surface components and rainfall properties. Non-linearities in the hydrological and erosive behavior of semiarid catchments. Journal of Hydrology, 517, 815–825.

Scherrer, S., Naef, F., 2003. A decision scheme to indicate dominant hydrological flow processes on temperate grassland. Hydrological processes, 17, 2, 391–401.

Scherrer, S., Naef, F., Faeh, A.O., Cordery, I., 2007. Formation of runoff at the hillslope scale during intense precipitation. Hydrology and Earth System Sciences Discussions, 11, 2, 907–922.

Schmocker-Fackel, P., Naef, F., Scherrer, S., 2007. Identifying runoff processes on the plot and catchment scale. Hydrology and Earth System Sciences, 11, 2, 891–906.

Stanciu, P., Zlate-Podani, I., 1987. A study of hydrological regimes in experimental basins in relation to cultivation practices. Water for the Future: Hydrology in Perspective (Proceedings of the Rome Symposium, April 1987). IAHS, 164,193–203.

USDA-NRCS, 1999. Guide to Texture by Feel. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/?cid=nrcs142p2_054311, Accessed on November 27, 2018.

Weyman, D.R., 1973. Measurements of the downslope flow of water in a soil. Journal of Hydrology, 20, 3, 267–288.

Woolhiser, D.A., Goodrich, D.C., 1988. Effect of storm rainfall intensity patterns on surface runoff. Journal of Hydrology, 102, 1–4, 335–354.

Zaharia, L., Ioana-Toroimac, G., 2009. Erosion dynamics – precipitation relationship in the Carpathian's Curvature Region (Romania). Geografia Fisica e Dinamica Quaternaria, 32, 95–10.

Received 23 May 2018
Accepted 19 December 2018