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Different land-use intensities and their susceptibility to soil erosion

[1*]Boglárka KELLER, [2]Judit SZABÓ, [3]Csaba CENTERI, [2]Gergely JAKAB, [2]Zoltán SZALAI

[1] NARIC Institute of Agricultural Engineering, Gödöllő
[2] MTA Research Centre for Astronomy and Earth Sciences, Budapest
[3]Institute of Nature Conservation and Landscape Management, Szent István University, Gödöllő

Introduction

Soil water erosion is a worldwide environmental problem which can negatively affect soil fertility (MORGAN, 2009), reducing the amount of valuable soil organic matter and nutrient content (LAL, 2003), reducing soil water retention ability, etc. These all contribute to a decline in soil productivity (LAL, 1999), while the soil is a non-renewable resource (LAL, 1998). Soil degradation processes may generate many on-site and off-site environmental problems (VERSTRAETEN and POESEN, 2000; SHARPLEY et al., 1994).

Appropriate land use and land management have great importance for soil water erosion (FELIX-HEMINGSEN et al., 1997), greatly influencing soil quality. The most important factors in soil quality are the structural composition and fertility of the soil. These factors depend on the size and stability of soil aggregates, the organic carbon content of the soil and other agents. Conventional tillage itself greatly reduces the amount of soil organic carbon, increases soil compaction and destroys aggregates, so the use of conservation tillage methods is of increasing importance. On bare soil surfaces, the aggregates are broken down by raindrop impact during rainfall events and the smaller aggregates are washed away (RODRIGUEZ et al., 2002; SCHIETTECATTE et al., 2008). Soil erosion is a selective process, and soil organic matter (SZALAI et al., 2016) is usually the first to be removed by runoff, thus reducing soil resistance to degradation processes. Therefore, in erosion-prone areas, proper land use has a major role in managing soil functionality (RIMAL and LAL, 2009; JORDAN et al., 2005; PODMANICKY et al., 2011; CHEN et al., 2007; ERSKINE et al., 2002; MOHAMMAD et al., 2010; PETŐ et al., 2008; VACCA et al., 2000; PENGA ÉS WANG 2012; KERTÉSZ et al., 2010; KOULOURI et al., 2007; SZILASSI et al., 2006).

In Europe soil water erosion processes on agricultural areas have been widely studied (HILL and SCHÜTT, 2000; DEVENTE and POESEN, 2005; BOARDMANN and POESEN, 2006; CERDAN et al., 2010, etc.).

Climate change has raised the number, intensity and duration of rainfall events. According to the IPCC (2013) report, the frequency and intensity of extreme rainfall events are expected to increase in future decades. Climate change and the more intense, more erosive short duration rainfall events have a direct effect on soil

**Corresponding Author:* BOGLÁRKA KELLER, NARIC Institute of Agricultural Engineering, Gödöllő, 4. Tessedik S., HU-2100
E-mail: keller.boglarka@mgi.naik.hu

erosion (LI and FANG, 2016; JONES et al., 2014; ROUTSCLUK et al., 2014), as they increase the vulnerability of soils to erosion (NEARING et al., 2004). A large amount of precipitation over a short period may cause more runoff and soil loss, especially in summer heat waves. Heavy rainstorms rapidly reduce the infiltration capacity of the soil and increase soil sealing and crusting processes.

Rainfall simulation is a cost-effective, quick and well-known method to study and evaluate soil erosion processes. This method can be applied *in situ* under several land uses, such as arable land (CENTERI, 2006; FIENER et al., 2011; LE BISSONNAIS et al., 2005; LEYS et al., 2007; VOLF et al., 2007), grassland (JAKAB-SZALAI, 2005; KATO et al., 2009; KOLER et al., 2008), forest (SHERIDAN, 2008), vineyard (ARNAEZ et al 2007; COMINO et al., 2015) and under laboratory circumstances (ISERLOH et al., 2012; WON et al., 2012). In addition, rainfall simulators can be adjusted to different slope gradients and utilize variable rainfall intensities (SHEN et al., 2016; RIBOLZI et al., 2011)

In this study runoff and soil erosion data were collected for four high intensity rainfall simulation events on both arable land (AL) and grassland (GL). The main objectives were (1) to study the effects of different land use types on runoff and soil loss, (2) to compare the effects of different land uses on soil erosion.

Materials and methods

Experimental area

The study area can be found in Gerézdpuszta in Koppány Valley, situated in the north-eastern part of the South-Transdanubian Region of Hungary *(Figure 1)*, 30 km to the south of Lake Balaton. It is a hilly landscape formed by loess deposited on a layer of Pannonian clay and sand sediments. The terraces of the stream are covered by hydromorphic soils, whereas the hill slopes are covered by Ramann-type brown forest soils and chernozems formed on loess, as published in the oldest soil maps.

Figure 1
Location of Koppány Valley, Hungary

On steep hillsides with intensive crop production, tillage may reach the parent material, so there is significant erosion on the hills (SZABÓ et al, 2015), as can be seen on *Figure 1*. Almost half of the agricultural areas are situated on slopes steeper than 12% and the famers use no soil protection methods. In addition the main crops on slopes covered with soils formed on loess are sunflower and maize.

Soil parameters

The soil texture on the studied arable and grassland areas was silty loam (*Table 1*), the main differences being in chemical properties, with higher pH, $CaCO_3$ and phosphorus content on the arable land, while the humus was near to the original state on the grassland.

Table 1
Physical and chemical soil properties

	Physical soil properties				
	Clay %	Silt %	Fine sand %	Coarse sand %	Texture
Arable land	4.5	56.8	38.6	0.2	Silty loam
Grassland	3.1	57.3	39.1	0.5	
	Chemical soil properties				
	pH (KCl)	$CaCO_3$ %	Humus %	AL-P (mg kg^{-1})	AL-K (mg kg^{-1})
Arable land	7.6	13.3	1	9.6	6.29
Grassland	7.3	9.9	3.5	3.72	9.84

Rainfall simulation

The study was carried out with a Shower Power-02 rainfall simulator, constructed at the Geographical Institute, Research Centre for Astronomy and Earth Sciences, Hungarian Academy of Sciences. Four rainfall events were simulated on both arable land (AL) and grassland (GL), involving 90 mm h^{-1} rainfall intensity on the arable land, and intensities of 90, 110 and 130 mm h^{-1} on the grassland area. The intensities effectively reached were below those planned (*Table 2*).

The plots were on fenced ground with a plot size of 6 m^2 (3×2 m). The device is equipped with two 80100 Veejet alternating nozzles. The rainfall intensity can be adjusted by changing the number of nozzle-swings during a given time. The runoff was collected by two metal triangles with a drain-pipe at the bottom of the plot. The runoff volume was registered through these triangles, and both the time and the amount of runoff were read when one of the two measuring barrels reached the 2-litre limit.

Table 2
Rainfall intensities and slope sections during the rainfall events

Planned intensity *(mm h^{-1})*	**Measured intensity** *(mm h^{-1})*	**Slope** *(%)*
	Grassland	
130	96.73	8.33
130	93.22	8.33
110	96.48	8.33
90	78.4	8.33
	Arable land	
90	80.44	7.7
90	86.12	8
90	84.68	6.7
90	70.19	8

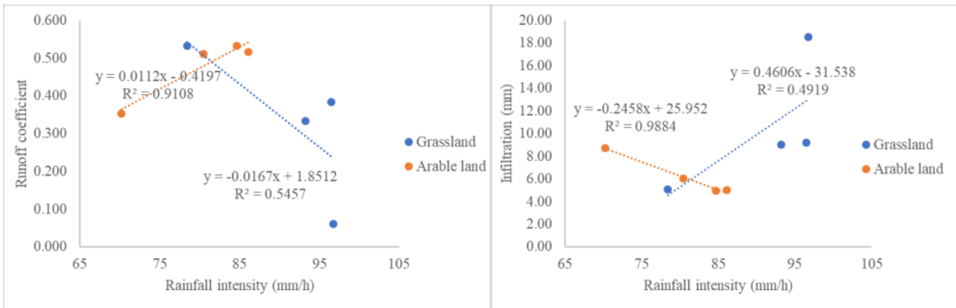
Results

When rainfall simulation was performed under similar circumstances but different land use types no great differences in runoff were observed (*Table 3*). On average 4.32 mm and 5.53 mm runoff was measured for GL and AL, respectively. The GL results showed higher standard deviation and error (*Figure 5*). A lower amount (ml) of runoff was recorded for GL than for AL (GL_{avg} 25922 ml; AL_{avg} 33207 ml).

Table 3
Summary of results obtained for different land uses

Land use	Basic statistic	Runoff (mm)	Runoff (ml)	Runoff coefficient	Infiltration (mm)	Soil loss (t ha^{-1})	Suspended sediment load (g l^{-1})
Grassland	AVG	4.32	25921.75	0.33	10.47	0.04	1.09
	SD	2.15	12870.55	0.20	5.70	0.01	0.62
	SE	1.07	6435.28	0.10	2.85	0.01	0.31
Arable land	AVG	5.53	33207.50	0.48	6.20	0.58	10.61
	SD	0.65	3909.89	0.08	1.78	0.14	1.60
	SE	0.33	1954.94	0.04	0.89	0.07	0.80

The runoff coefficient characterizes the relationship between rainfall and runoff during a rainfall event. The higher this value, the greater is the flow rate and the lower the infiltration rate. On average, higher values were obtained for AL than for GL (GL_{avg} 33 %; AL_{avg} 48 %). The measurements revealed a high correlation between rainfall intensity and runoff for AL (r^2=0.9108) and a moderate correlation for GL (r^2=0.5457), where the rainfall intensity negatively affected the runoff rate and increased the infiltration (r^2=0.4919) (*Figures 2-3*).



Figures 2-3
Effect of rainfall intensity on runoff coefficient and infiltration

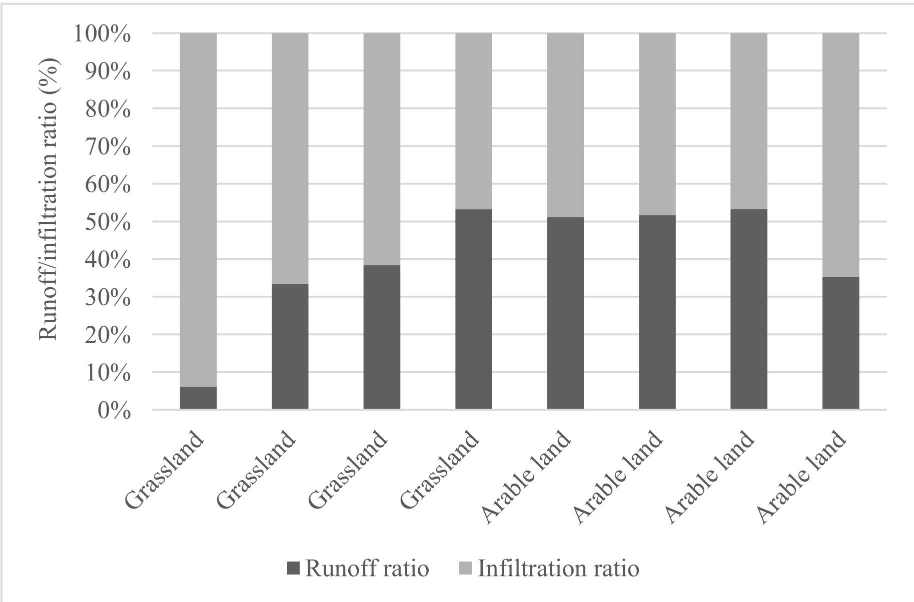
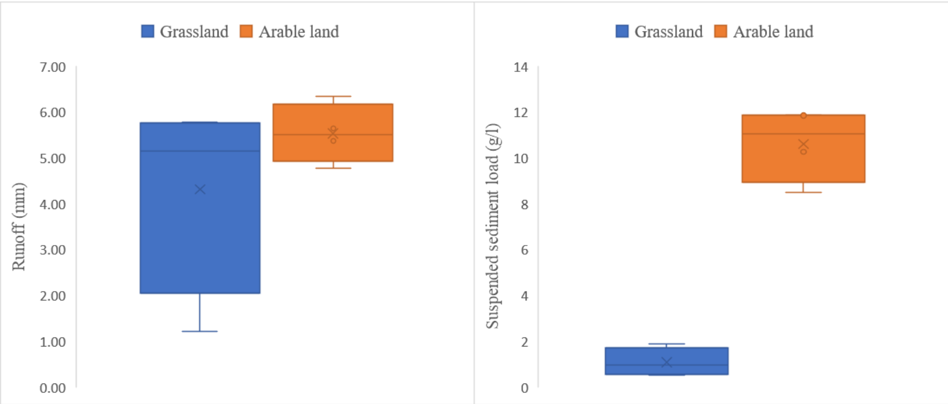


Figure 4
Runoff-infiltration ratios for different rainfall simulations

Besides the runoff coefficient, the runoff-infiltration ratio was also evaluated (*Figure 4*). Generally, a higher infiltration ratio was measured for GL, while for AL the runoff rate exceeded the infiltration rate in most cases, resulting in higher soil loss and suspended sediment load (*Figure 6*)

The most striking results were found for the suspended sediment load (*Figures 5-6*), where there was an almost 10-fold difference between GL and AL.



Figures 5-6
Runoff and suspended sediment load results between two land use intensities

Conclusions

It can be concluded from the results that the runoff and soil loss rate were higher on arable land (even at slightly lower rainfall intensities), leading to more concentrated suspended sediment loads. Similar rainfall intensities resulted in almost tenfold differences in suspended sediment load on AL, with greatly reduced infiltration.

In most cases infiltration was exceeded by runoff on AL. The results confirmed expectations that grassland would generate less runoff thanks to the better porosity, thick surface cover and greater surface roughness.

On AL rainfall intensity and runoff coefficient were in positive correlation, while in the case of GL increasing rainfall intensity decreased the runoff rate and moderately increased infiltration. Similar observations were made by NASSIF and WILSON (1975), BOWYER-BOWER (1993), JAKAB and SZALAI (2005) and SZABÓ et al. (2017), who found that soil permeability increases proportionally with higher rainfall intensity, partly due to the increasing pressure of the water. Based on the suspended sediment load the two land use intensities were unambiguously distinguishable.

It is obvious that while the runoff values of GL overlapped those of AL to some extent, the suspended sediment load differed greatly, with no overlap between the values of the two land use intensities. The suspended sediment load values clearly formed two distinctive groups. This is in agreement with the findings of RIMAL and LAL (2009), JORDAN et al. (2005), PODMANICKY et al. (2011), CHEN et al. (2007), ERSKINE et al. (2002), MOHAMMAD et al. (2010), PETŐ et al. (2008), VACCA et al. (2000), PENGA and WANG (2012), KERTÉSZ et al. (2010), KOULOURI et al. (2007) and SZILASSI et al. (2006),who stated that proper land use has a major role in managing soil functionality. As arable farming is of increasing importance for the expanding world population, it would be important to find a balance by producing crops that provide enough soil cover to reduce the suspended sediment load to a sustainable limit. Our prime interest is for less soil to be lost than is formed under the given circumstances.

The present results suggest that there must be other important factors, besides chemical soil properties, such as biological soil activity and the water stored in plants, which are rarely considered in field experiments. Earthworms and other soil-dwelling animals, the plant leaf area, and plant remnants (both roots and the holes they leave after decay) have a tremendous effect on the infiltration rate and permeability, thus greatly influencing both runoff and, more importantly, the suspended sediment load.

The results emphasise the importance of adequate land use, which has a major role in climate resilience, SOC conservation and retention, and a reduction in soil loss.

Summary

Adaptation is the most important strategy to reduce the effect of climate change and soil erosion. During this process adequate, rational land use is necessary to ensure climate resilience. Therefore, the main objective in this study was to evaluate the susceptibility of different land use intensities (arable land and grassland) to soil erosion. The rainfall simulation method is a good tool to measure and estimate soil erosion *in situ*. The comparative measurements were carried out in the field with a Shower Power-02 simulator on 6 m^2 plots in Gerézdpuszta, where the slope angles were ~8% and the simulated rainfall events had high intensities (~70-96 mm h^{-1}). The runoff and soil loss were significantly higher from arable land. The runoff-infiltration ratio and runoff coefficient showed lower infiltration capacity in the case of arable land. On average, the suspended sediment loads were tenfold higher under intensive land use. In the case of grassland a moderate increase in infiltration was observed due to higher rainfall intensity, as also reported in the literature. The rainfall simulation method provides good data for soil loss estimations.

Keywords: soil erosion, different land uses, soil loss, runoff

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