© IWA Publishing 2020
773

Water Practice & Technology Vol 15 No 3
doi: 10.2166/wpt.2020.061

The effect of different crops and slopes on runoff and soil erosion

Jinhua Gao[a,*], Yu Bai[b], Haifeng Cui[c] and Yu Zhang[d]

[a] Changchun Institute of Technology, Changchun 130012, China

[b] Zhejiang University of Water Resources and Electric Power, Zhejiang 310000, China

[c] Changchun Heli Soil and Water Conservation Technology Co., Ltd, Changchun 130000, China

[d] Jilin Scientific Research Academy of Soil and Water Conservation, Changchun 130000, China

*Corresponding author. E-mail: zgsherry@sina.com

Abstract

Runoff and soil erosion are serious environmental issues in farmland management. In a field experiment in Xingmu, China, data from nine plots with different slopes and crops were collected, and the crops' leaf area index (LAI) used to represent the impact of vegetation on runoff and soil erosion. The results show that slope and crop both have significant effects on runoff and soil erosion, and that the LAI can indicate the effects of different crops.

Key words: crop-type, LAI, rainfall, rainfall intensity, slope

Highlights

- The lack of research on soil and water loss of slope farmland affected by different crops will greatly affect the food security in Northeast China.
- This paper studies the difference of soil and water loss under the action of rainfall in different crops with different slopes in the experimental plots.
- The result can provide a theoretical reference for the use of soil and water conservation measures in slope farmland.

INTRODUCTION

Accelerated soil erosion rate is a major cause of land degradation and unsustainable agriculture. It can lead to loss of soil fertility and reduce agricultural yield and, hence, farmers' incomes (Novara *et al.* 2013; Colazo & Buschiazzo 2015; Yan & Cai 2015). Soil erosion is also a serious and challenging environmental issue related to land management worldwide. It is a complex natural process altered by anthropogenic activities including land clearance, agricultural practices, surface mining, construction and urbanization (Krasa *et al.* 2005; Illangasinghe & Hewawasam 2013; Hewawasam & Illangasinghe 2015). Studies have shown that the key factors controlling soil erosion on hillslopes are erodibility, slope, and land use cover, and that changing these factors can reduce soil erosion (Diyabalanage *et al.* 2017).

High erosion rates from agriculture land are usually due to lack of vegetation cover, which is a key factor to understand in soil erosion (Ola *et al.* 2015; Zhao *et al.* 2016). The structure of soil without vegetation is easily broken by the impact of raindrops, increasing runoff and soil erosion rates (Cerdà 2000). Much research on runoff and soil erosion has been based on simulated natural rainfall in

Water Practice & Technology Vol 15 No 3
doi: 10.2166/wpt.2020.061

laboratories as the conditions are easier to control (Cerdà *et al.* 2016; Prosdocimi *et al.* 2017; Vaezi *et al.* 2017). There has also been research at field stations where conditions may be closer to natural (Tanner *et al.* 2016; Anache *et al.* 2017). Although there has been much work on runoff and soil erosion from agricultural land, comprehensive studies of the impacts of slope, rainfall intensity, rainfall and leaf area index (LAI) are uncommon.

Cultivation of sloping farmland is common in western and central Jilin Province, China. Excessive deforestation for farming, and serious disconnection between crop types and soil and water conservation measures, have caused severe soil erosion. It is very important, therefore, to study different crop types there. In this paper, the effects of rainfall, rainfall intensity, slope and LAI, on runoff and soil loss from sloping farmland are considered. Field experiments were carried out at Xingmu experimental station, Jilin, and the effects of different crops assessed on water and soil loss from farmland.

MATERIALS AND METHODS

Study area

The study was carried out at the National Soil and Water Conservation Science and Technology Demonstration Park, Xingmu, south-central Jilin Province, China. Its coordinates are 42°17′40″ to 43° 13′40″ N latitude and 124°51′22″ to 125°49′52″ E longitude. The soil is a clay loam, with 35.9% clay, 35.4% silt, and 28.7% sand, and bulk density 1.13 gm/ml. Annual sunshine typically exceeds 2,500 hours, the average temperature is 5.2 °C, and annual precipitation 658 mm. The experimental station is in a small watershed typical of the low mountain and hilly landform type, and is representative of the central part of Jilin Province.

Experimental plot design

The study area contains nine plots, each 5 m × 20 m and with slopes of 3°, 5°, and 8°, variously. At the bottom of each plot a measuring device (Figure 1) gathers runoff and soil from it. Equations (1) and (2) were used to calculate the runoff and soil loss. The experimental set up is shown in Table 1, each crop type being combined with three slopes. The rainfall and rainfall intensity data were measured using a field weather station on the experimental plot. Maize and soybean grow from May to September. Maize was planted on May 7, 2012 with ridge spacing 65 cm, plant spacing 30 cm and planting density 50,000/hm^2. Soybean was planted on May 10, 2012 with ridge spacing 60 cm, plant spacing 7.5 cm and planting density 200,000/hm^2.

$$\begin{cases} H_1 + H_2 = H \\ \rho_1 H_1 A + \rho_2 H_2 A = W \end{cases} \tag{1}$$

where H_1 is the water depth (m); H_2 the soil depth (m); H the total depth (m); ρ_1 the density of water (gm/ml); ρ_2 the saturated soil density (gm/ml); A the device's base area (m^2); and W the total weight (kg).

From this the runoff and soil mass can be calculated:

$$\begin{cases} W_1 = \rho_1 H_1 A + S_s\, \rho_1 H_2 A \\ W_2 = \rho_2 H_2 A - S_s\, \rho_1 H_2 A \end{cases} \tag{2}$$

where W_1 is the runoff mass; S_s the saturated soil moisture content and W_2 the soil mass,.

Water Practice & Technology Vol 15 No 3
doi: 10.2166/wpt.2020.061

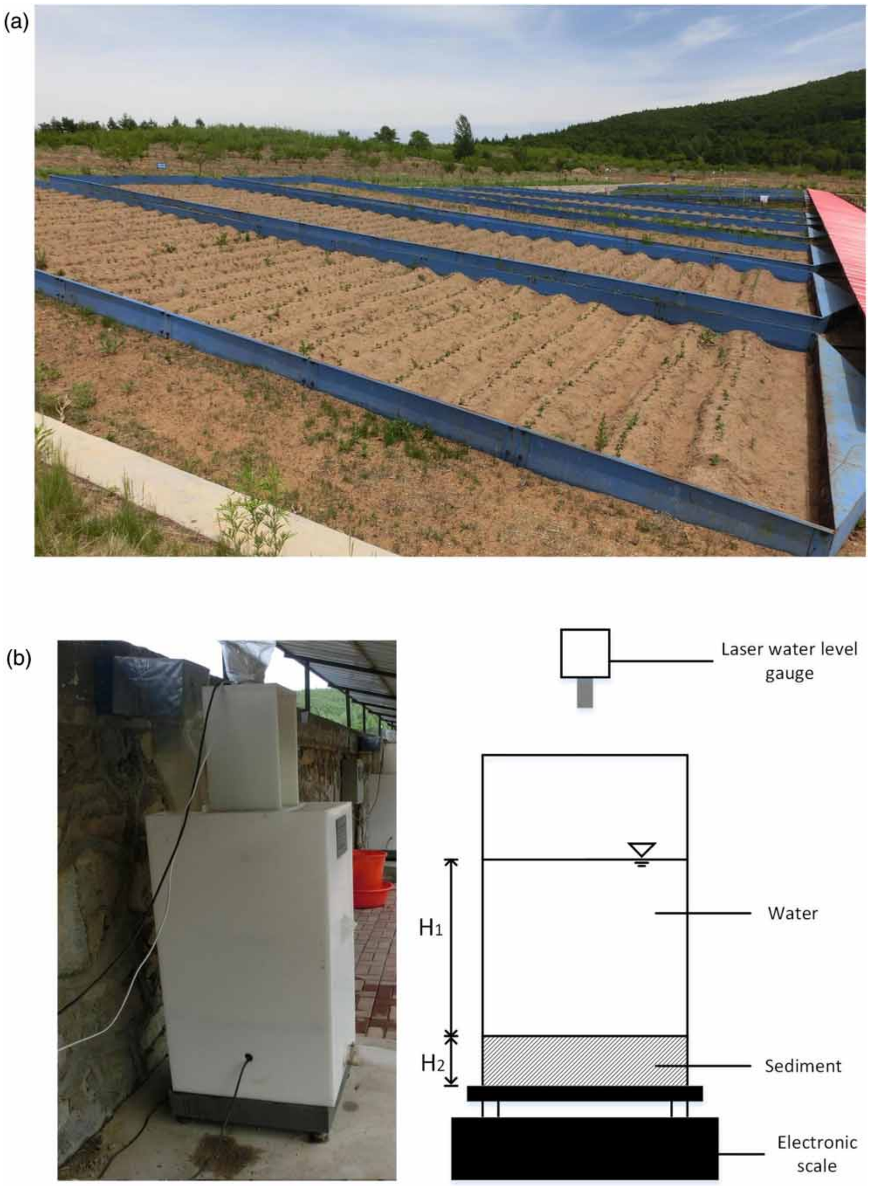

Figure 1 | (a) Experimental plots and (b) soil loss and runoff measuring device.

Table 1 | Experimental set up

Plot	Slope(°)	Crop
1	3	Maize
2	3	Soybeans
3	3	Uncultivated
4	5	Maize
5	5	Soybeans
6	5	Uncultivated
7	8	Maize
8	8	Soybeans
9	8	Uncultivated

Water Practice & Technology Vol 15 No 3
doi: 10.2166/wpt.2020.061

Data analysis

The contribution of rainfall, rainfall intensity, slope, LAI, runoff, and soil loss for each plot was determined using the difference between the variables during the experimental runs. Comparison of the variables between the three crop types was done using the independent-samples t-test, and the effects of each on runoff and soil loss were determined using Pearson's correlation matrix (r).

RESULTS AND DISCUSSION

The average annual rainfall from 1978 to 2008 and the rainfall in 2012, the year of the study, are shown in Figure 2(a), which shows that rainfall in 2012 basically conformed to the 30-year (1978–2008) annual average. The heaviest rainfall occurs in July and August, with rainfall intensity up to 78.31 mm/h (Figure 2(b)). The LAIs of maize and soybean were up to 3.73 and 5.69, respectively,

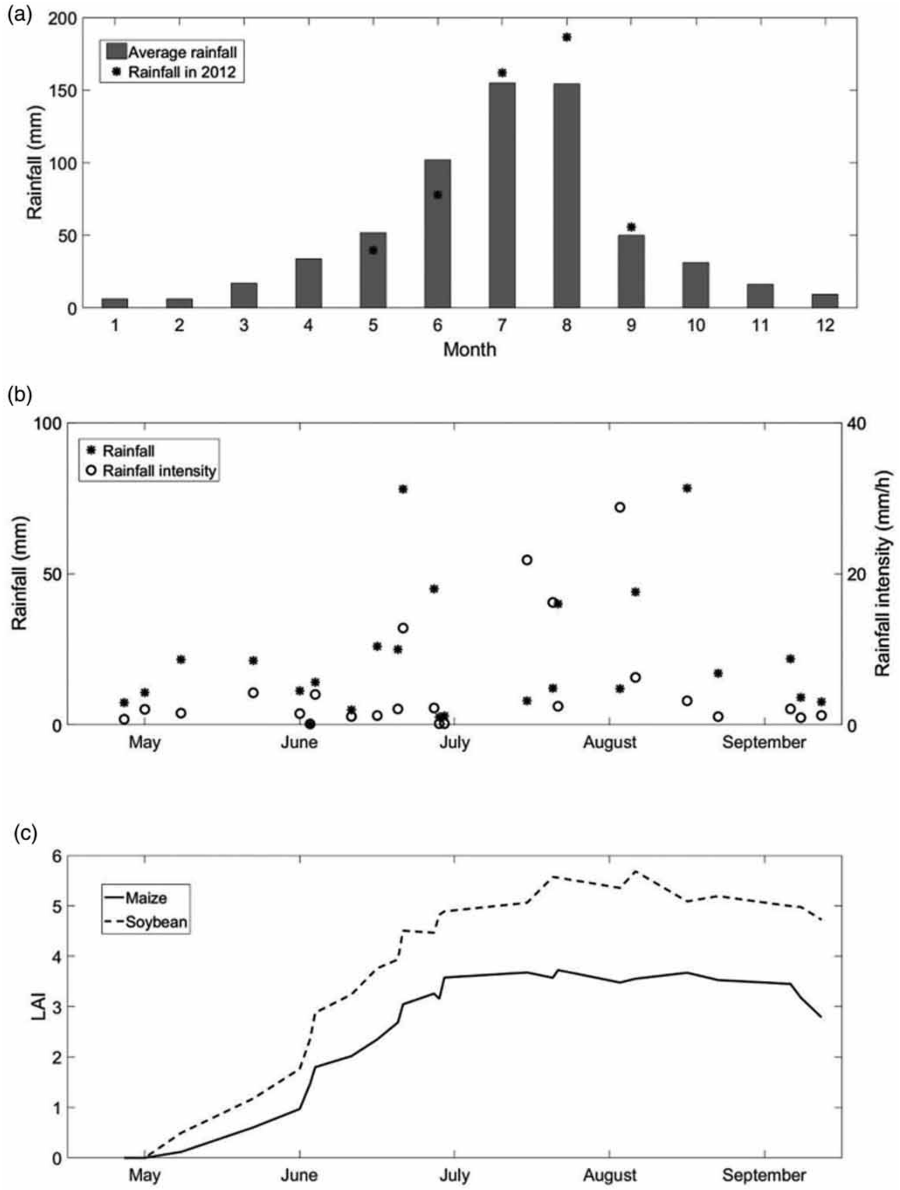

Figure 2 | (a) Average annual rainfall from 1978 to 2008, with rainfall in 2012 superimposed; (b) rainfall and rainfall intensity from May to September 2012; and (c) experimental crop LAIs from May to September 2012.

Water Practice & Technology Vol 15 No 3
doi: 10.2166/wpt.2020.061

and that of soybean always exceeds that of maize. The LAIs increased in the early period but began to decline later in the study (Figure 2(c)).

The soil loss and runoff from the plots are shown in Figures 3–5. With increased slope, the amount of soil loss and runoff increased from the maize plots. When the slope of the soybean plots increases from 3 to 5°, the amount of soil loss and runoff does not change greatly, but it changes significantly when the slope increases to 8°. Compared with the same slopes on maize and soybean plots, the soil loss and runoff from uncultivated plots can be higher by two orders of magnitude or more.

Table 2 shows significant positive correlation between soil loss, and rainfall intensity and slope, but there is no significant relationship between soil loss and rainfall. Only intense rainfall splashes much, destroying the soil structure and making it easier to move the soil away. Vaezi *et al.* (2017) showed that at 20 to 30 mm/h rainfall intensity, raindrop impact was the dominant factor controlling soil loss, while rainfall intensity below 20 mm/h has no significant soil erosion effect. Plant leaves can cushion the raindrops' fall, reducing splashing and thus soil loss (Römkens *et al.* 2002; Novara *et al.* 2011; Balota *et al.* 2016), and the correlation between soil loss and LAI is significantly negative (Table 2), so that the runoff from cultivated and uncultivated land is different. The steeper the slope, the more likely soil erosion is to occur, so the slope is positively correlated with soil erosion (Table 2) and this study's results are consistent with those of others (Defersha & Melesse 2012; Sajjadi & Mahmoodabadi 2015; Mahmoodabadi & Sajjadi 2016).

The relationship between different crops, and runoff and soil loss on different slopes, is shown in Table 3. During the experiments, the runoff and soil loss from uncultivated land were much higher

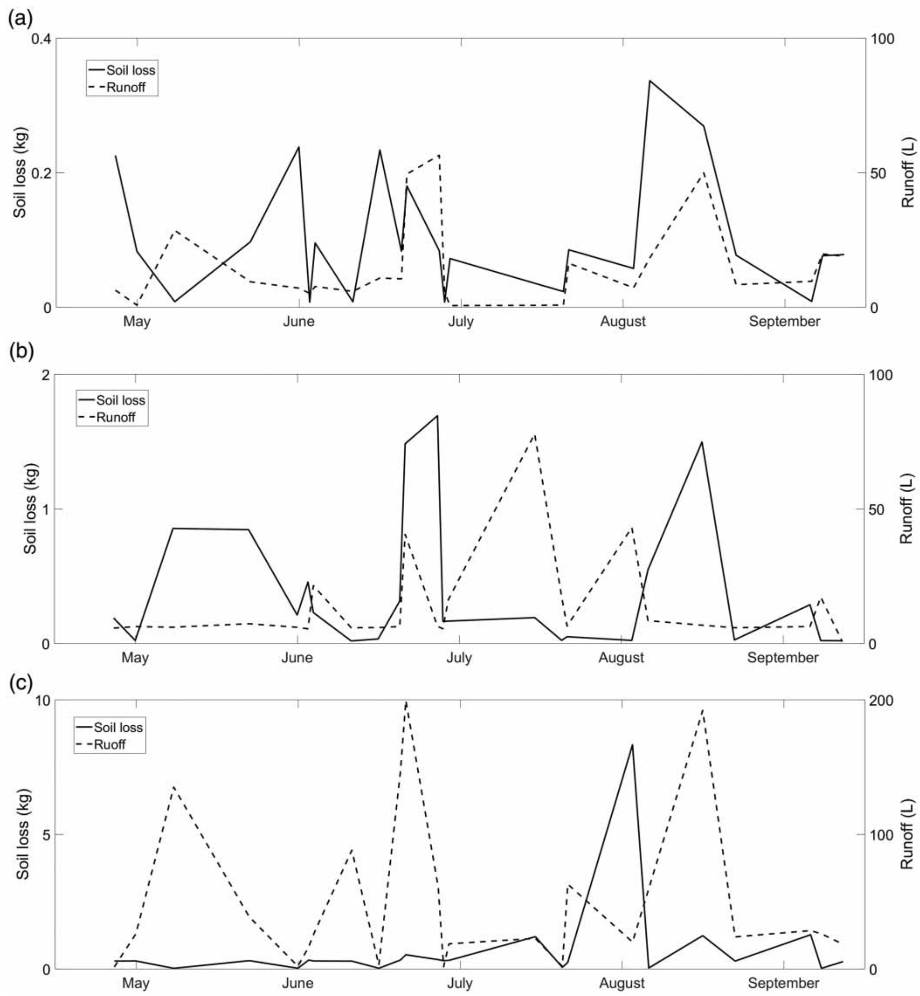

Figure 3 | Soil loss and runoff from maize plots with different slopes: (a) 3°, (b) 5°, (c) 8°.

Water Practice & Technology Vol 15 No 3
doi: 10.2166/wpt.2020.061

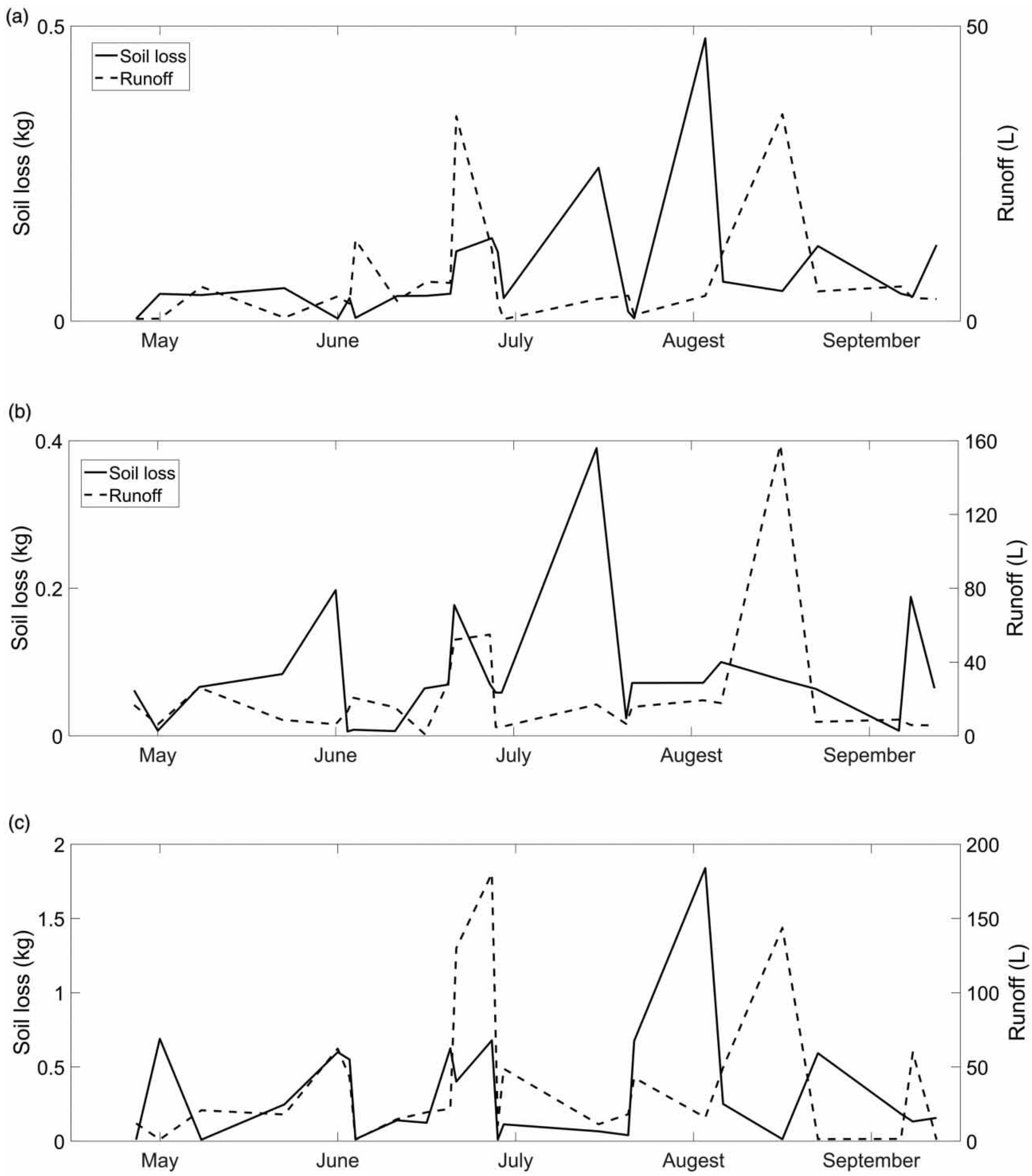

Figure 4 | Soil loss and runoff from soybean plot with different slopes: (a) 3°, (b) 5°, (c) 8°.

than from cultivated plots, and soybeans gave better protection from runoff and soil loss than maize on the same slopes.

CONCLUSIONS

The study revealed the variation in runoff and soil erosion on different slopes under different crops in a small watershed in Xingmu. Both the slope and crop have significant effects, and the effect of the crop can be indicated by its LAI. Soybeans have a better effect on soil erosion than maize, as soybean's LAI is greater. The crop type should be considered when solving runoff and soil erosion problems.

Water Practice & Technology Vol 15 No 3
doi: 10.2166/wpt.2020.061

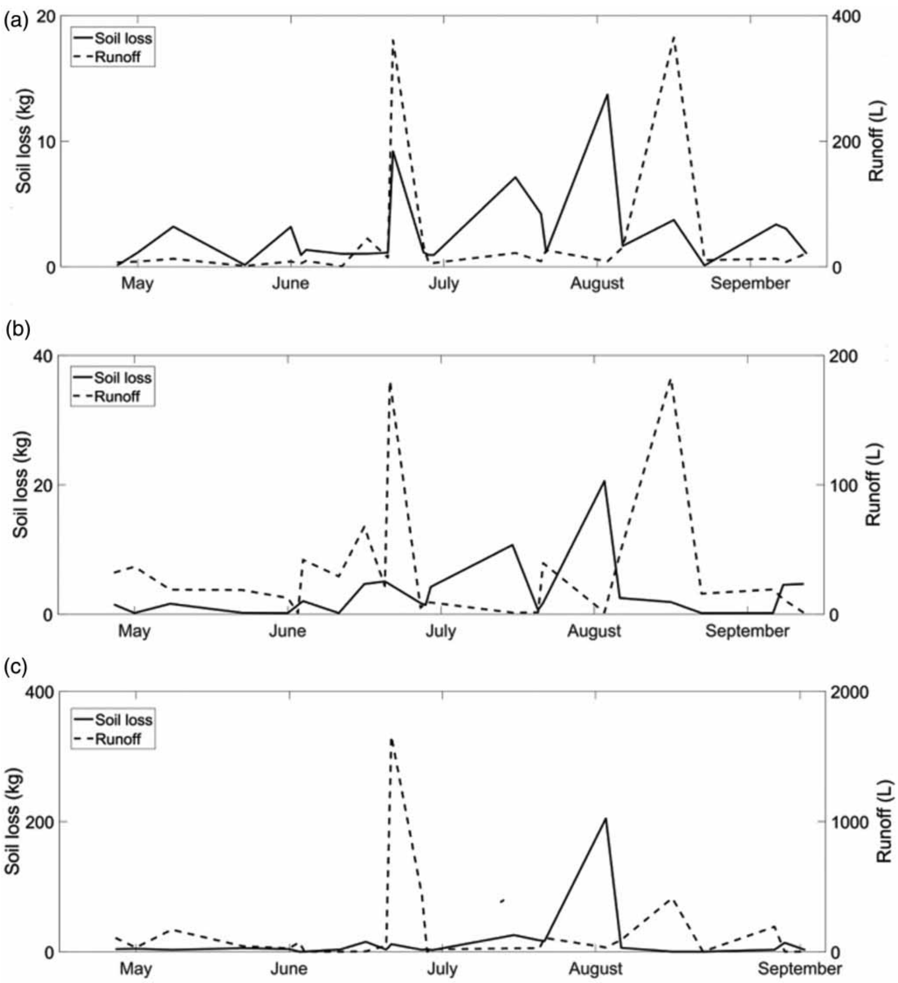

Figure 5 | Soil loss and runoff from uncultivated plots with different slopes: (a) 3°, (b) 5°, (c) 8°.

Table 2 | Correlations between runoff, soil loss, amount of rainfall, rainfall intensity, slope and LAI

	Soil loss	Runoff	Rainfall	Rainfall intensity	Slope	LAI
Soil loss	1.0000	0.0522	−0.0244	0.6993[a]	0.5007[a]	−0.4577[a]
Runoff		1.0000	0.7517[a]	0.0616	0.4592[a]	−0.3165[b]
Rainfall			1.0000	0.0745	0.0000	0.0091
Rainfall intensity				1.0000	0.0000	0.0156
Slope					1.0000	0.0065
LAI						1.0000

[a] – $P < 0.05$; [b] – $P < 0.1$.

Table 3 | Total soil loss and runoff from trial plots during the experimental period

	Slope	3°	5°	8°
Soil loss (kg)	Maize	2.465	6.667	16.533
	Bean	1.967	1.991	8.154
	Uncultivated	64.540	76.338	359.030
Runoff (L)	Maize	352.592	467.076	1,217.678
	Bean	173.852	521.494	928.509
	Uncultivated	1,030.706	802.381	3,523.614

Water Practice & Technology Vol 15 No 3
doi: 10.2166/wpt.2020.061

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

REFERENCES

Anache, J. A., Wendland, E. C., Oliveira, P. T., Flanagan, D. C. & Nearing, M. A. 2017 Runoff and soil erosion plot-scale studies under natural rainfall: a meta-analysis of the Brazilian experience. *Catena* **152**, 29–39.

Balota, E. L., Machineski, O., Honda, C., Yada, I. F., Barbosa, G. M., Nakatani, A. S. & Coyne, M. S. 2016 Response of arbuscular mycorrhizal fungi in different soil tillage systems to long-term swine slurry application. *Land Degradation & Development* **27**(4), 1141–1150.

Cerdà, A. 2000 Aggregate stability against water forces under different climates on agriculture land and scrubland in southern Bolivia. *Soil and Tillage Research* **57**(3), 159–166.

Cerdà, A., González-Pelayo, Ó., Giménez-Morera, A., Jordán, A., Pereira, P., Novara, A. & Orenes, F. G. 2016 Use of barley straw residues to avoid high erosion and runoff rates on persimmon plantations in Eastern Spain under low frequency–high magnitude simulated rainfall events. *Soil Research* **54**(2), 154–165.

Colazo, J. C. & Buschiazzo, D. 2015 The impact of agriculture on soil texture due to wind erosion. *Land Degradation & Development* **26**(1), 62–70.

Defersha, M. B. & Melesse, A. M. 2012 Effect of rainfall intensity, slope and antecedent moisture content on sediment concentration and sediment enrichment ratio. *Catena* **90**, 47–52.

Diyabalanage, S., Samarakoon, K. K., Adikari, S. B. & Hewawasam, T. 2017 Impact of soil and water conservation measures on soil erosion rate and sediment yields in a tropical watershed in the Central Highlands of Sri Lanka. *Applied Geography* **79**, 103–114.

Hewawasam, T. & Illangasinghe, S. 2015 Quantifying sheet erosion in agricultural highlands of Sri Lanka by tracking grain-size distributions. *Anthropocene* **11**, 25–34.

Illangasinghe, S. & Hewawasam, T. 2013 Introducing surface sampling threshold factor for suspended sediment transport: model development using Sri Lankan tropical highland river basins. *Hydrology Research* **46**(1), 136–155.

Krasa, J., Dostal, T., Van Rompaey, A., Vaska, J. & Vrana, K. 2005 Reservoirs' siltation measurements and sediment transport assessment in the Czech Republic, the Vrchlice catchment study. *Catena* **64**(2–3), 348–362.

Mahmoodabadi, M. & Sajjadi, S. A. 2016 Effects of rain intensity, slope gradient and particle size distribution on the relative contributions of splash and wash loads to rain-induced erosion. *Geomorphology* **253**, 159–167.

Novara, A., Gristina, L., Saladino, S. S., Santoro, A. & Cerdà, A. 2011 Soil erosion assessment on tillage and alternative soil managements in a Sicilian vineyard. *Soil and Tillage Research* **117**, 140–147.

Novara, A., Gristina, L., Guaitoli, F., Santoro, A. & Cerdà, A. 2013 Managing soil nitrate with cover crops and buffer strips in Sicilian vineyards. *Solid Earth* **4**(2), 255–262.

Ola, A., Dodd, I. C. & Quinton, J. N. 2015 Can we manipulate root system architecture to control soil erosion? *Soil* **1**(2), 603–612.

Prosdocimi, M., Burguet, M., Di Prima, S., Sofia, G., Terol, E., Comino, J. R., Cerdà, A. & Tarolli, P. 2017 Rainfall simulation and Structure-from-Motion photogrammetry for the analysis of soil water erosion in Mediterranean vineyards. *Science of the Total Environment* **574**, 204–215.

Römkens, M. J., Helming, K. & Prasad, S. N. 2002 Soil erosion under different rainfall intensities, surface roughness, and soil water regimes. *Catena* **46**(2–3), 103–123.

Sajjadi, S. A. & Mahmoodabadi, M. 2015 Sediment concentration and hydraulic characteristics of rain-induced overland flows in arid land soils. *Journal of Soils and Sediments* **15**(3), 710–721.

Tanner, S., Katra, I., Haim, A. & Zaady, E. 2016 Short-term soil loss by eolian erosion in response to different rain-fed agricultural practices. *Soil and Tillage Research* **155**, 149–156.

Vaezi, A. R., Ahmadi, M. & Cerdà, A. 2017 Contribution of raindrop impact to the change of soil physical properties and water erosion under semi-arid rainfalls. *Science of the Total Environment* **583**, 382–392.

Yan, X. & Cai, Y. L. 2015 Multi-scale anthropogenic driving forces of karst rocky desertification in Southwest China. *Land Degradation & Development* **26**(2), 193–200.

Zhao, C., Gao, J. E., Huang, Y., Wang, G. & Zhang, M. 2016 Effects of vegetation stems on hydraulics of overland flow under varying water discharges. *Land Degradation & Development* **27**(3), 748–757.