Solid Earth Discuss., 6, 1127–1153, 2014
www.solid-earth-discuss.net/6/1127/2014/
doi:10.5194/sed-6-1127-2014

Solid Earth Discussions
Open Access

Coffee husk mulch on soil erosion and runoff: experiences under rainfall simulation experiment

H. Moreno-Ramón[1], **S. J. Quizembe**[2], **and S. Ibáñez-Asensio**[1]

[1]Department of Plant Production, Universitat Politècnica de València, Spain
[2]Instituto de Investigações Agrárias de Angola (IIA), Chiamba, Huambo, Angola

Received: 28 March 2014 – Accepted: 2 April 2014 – Published: 6 May 2014

Correspondence to: S. Ibáñez-Asensio (sibanez@prv.upv.es)

Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

The high erosion rates found in the agriculture land make valuable the use of mulches to control the soil and water losses. Coffee husk (*Coffee canephora* var. *robusta*) can be one of those mulches. This paper evaluates how to apply the mulch in order to obtain, with the same doses, the best effectiveness. An experimental factorial design 4 × 3 × 2 with two replicates was designed in a greenhouse with a total amount of 48 treatments. All the samples were deposited in trays of 0.51 m^2 and applied a simulated rain of 122 $mm\,h^{-1}$ during 21 min. The factors examined were: four soil classes; three treatments: buried (B), surface (S) and non-residue (C), and the presence (WC) or absence (WOC) of the soil surface crusting. The coffee husk residue (S and B treatments) reduced runoff by 10.2 % and 46 % respectively, soil losses by 78.3 % and 88.7 % and sediment concentration by 77 % and 84.4 %. The infiltration rate increased on average by 104 % and 167 %, and time to runoff by 1.58 and 2.07 min respectively. The coffee husk mulch (S and B) avoided the influence of crust. Coffee husk is an efficient mulch to reduce the soil and water losses.

1 Introduction

It is estimated that 20 million km^2 of agricultural lands are affected by soil erosion in the world, and 1.3 million km^2 are affected by water soil erosion in Europe. The developing countries are having very high erosion rates due to the deforestation, the agriculture expansion and the use of fire for the shifting agriculture, (Montgomery, 2012; Hockbridge, 2012; Zhao et al., 2013). Soil losses by water erosion occur by the detachment and transport of soil particles during the rainfall and runoff processes (Ellison, 1944; Laws, 1940; Fernández et al., 2012; Ziadat and Taimeh, 2013). Soil cover reduces the amount of runoff generated, decreases runoff velocity and increases infiltration because it protects the soil surface against kinetic energy of drops (Bielders et al., 1996; Cerdà, 2001; Grismer and Hogan, 2004; Groen and Wood, 2008), which is very useful for agriculture land (Novara et al., 2013) and recently fire affected land (León et al., 2013).

Researchers have tested several covers which act as a mulch: rice straw, wood and olive residues, pine-needle, and other vegetable residues to protect soil (García-Orenes et al., 2009; Cerdà and Doerr, 2008; Prats et al., 2012; Jiménez et al., 2013) and improve the soil quality (Stavi et al., 2012). The review of the scientific literature published about mulch in soil conservation show us that the use of coffee husks as mulch has not been investigated yet. The coffee husk is a residue generated in the coffee production process and constitutes around 50 % of dry residue in coffee fruit business. It is usually removed by combustion with the consequent environmental problems: heat, CO_2 emissions and fly ash (Saenger et al., 2001). Its various industrial uses as bioethanol, aroma production, wood particleboard manufacture, clay and food industry or livestock feed (Prata and Oliveira, 2007; Choi et al., 2012; Bekalo and Reinhart, 2010; Murthy and Naidu, 2012) or as compost or substrate in gardening and agriculture (Kasongo et al., 2011; Santos et al., 2001). However, this does not solve the problem of the coffee husk waste. To find a strategy to use the coffee husk in large quantities will be a solution, and as mulch in agriculture, forestry and gardening to reduce the soil and water losses is a viable application.

The research on the mulch applications reveals that the mulch efficiency depends on both, the residue quality and its management (Gangwar et al., 2006). It is also clear that the right incorporation rate and the best way to apply it on the soil is the key to get success (Bakr et al., 2012; El Kateb et al., 2013; Gangwar et al., 2006; Huang et al., 2012; Ma and Li, 2011; Mashingaidze et al., 2012; Singh et al., 1994; Lee et al., 2013; Jiménez et al., 2013). If the residue is applied on the surface as mulch the improvement of the soil physical properties and the increase of soil organic carbon (SOC) occur over time. In contrast when the residue is buried there is a fast improvement on soil quality and the soil erosion control seems less efficient.

It is important to know the advantages or disadvantages associated with each management practices before proceeding with the mulch application. Bakr et al. (2012)

found that the effectiveness in relation to soil losses is lower in tilled soils than in soils with superficial application, whereas Abdelkadir and Yimer (2011) revealed the suitability of breaking the compacted superficial layer to increase the infiltration rate in loamy soils. There is a close relationship between erosion and the protective layer of mulch, but there are several authors like Jin et al. (2008), Ma and Li (2011) and Thierfelder and Wall (2009) who indicated that the degree of effectiveness depends largely on soil permeability, percentage of soil surface cover, SOC, and also the interactions among the variables. Findeling et al. (2003) and Le Bissonnais et al. (2005) highlighted that the soil behavior under the rainfall thunderstorms is strongly influenced by compaction and surface crusting and it is regardless of the specific quality of soil. Bielders et al. (1996) said that mulch is the main responsible for thickness and crust type in soils.

The use of simulated rainfall technique is common in studies about water and erosion soil variables. In that kind of research the aim is to determine the influence of one individual factor over the soil characteristics (Cerdà, 1998; Brodie and Misra, 2009; Calvo-Cases et al., 2003; Grismer and Hogan, 2004; Huang et al., 2012; Jin et al., 2008). In addition, it is also very useful in orthogonal designs where conditions are identical except for one factor that undergoes a change.

Although in the last decade researchers have begun to explore the possibilities of recycling coffee husk, there is not research that has thought to use it as soil protector. The hypothesis is that the coffee husk used as mulch reduces soil water erosion. To control hydrological and erosive variables, a laboratory rainfall simulation experiment on soil erosion trays was developed.

2 Materials and methods

2.1 Experimental design

An experimental factorial design (4 × 3 × 2) with three independent variables was developed. The factors were (i) soil class (I, II, III and IV), (ii) treatment: soil bare or control

(C), superficial deposition of coffee husk (S) incorporated or buried coffee husk (B); and (iii) soil crusting: presence (WC) or absence (WOC) of surface crust. The combination of these factors resulted in 24 treatments, which were replicated twice. The total amount of simulated rainfall experiments were 48 (4 soils types × 3 treatments of the coffee husk × 2 crust conditions × 2 replicates). The measured dependent variables were: time to runoff, infiltration rate, runoff, sediment concentration and soil loss.

2.2 Erosion trays and soil preparation

The rainfall simulations were carried out on four air-dried soils samples collected in the soils of the river Turia alluvial plain, and they were formed over quaternary materials rich in carbonates, slightly stony and with loam texture. Despite soils were fairly homogeneous, they showed differences in the content of organic matter and salts.

The soils were sampled in agriculture fields, and deposited in galvanized aluminum trays (74.9 cm length × 67.9 cm width × 10 cm height). They were analyzed in disturbed samples (texture and chemical properties) and core samples (physical and hydrological properties) according to the Soil Survey Staff (2004). The parameters analyzed were: the carbonate content ($CaCO_3$) by Bernard calcimeter method, electrical conductivity of saturated extract (EC_e), pH, organic matter (OM) by Walkley-Black method, field capacity (FC) and wilting point (WP) by pressure plate method, texture by Bouyoucos method and Sodium Absorption Ratio (SAR) by main cations and anions. Hydraulic conductivity was obtained by a constant charge permeameter method, whereas porosity was obtained by mercury porosimeter and aggregate stability by wet sieving.

Table 1 illustrates some of the main characteristics of used soils. $CaCO_3$ values were between 24.9 and 34 %, pH values were basic (8.08–8.53), electrical conductivity was relatively high ($EC_e > 3.95\,dS\,m^{-1}$) and they did not present risk of sodification (SAR < 4.64). Three soils were sandy clay loam, and soil I was clay loam. Soil III was the most saline ($EC_e = 7.89\,dS\,m^{-1}$) whereas soil I had the highest content of organic matter (OM = 6.27 %). Soil II had the largest water storage capacity, in contrast with soil IV that showed the lowest (9.42–6.88 % respectively).

SED
6, 1127–1153, 2014

Coffee husk is a byproduct from the coffee bean dry processing and it is composed of carbohydrates, pectins, proteins, tannins, fat and caffeine (Pandey et al., 2000). The husk used in this experience was from the Angolan coffee region with maximum storage capacity 6.9 % of moisture. The organic content was 2.5 %, bulk density values were between 0.32–0.35 $g\,cm^{-3}$ and the diameter of husk between 0.5–2 cm.

Once the trays were prepared, we periodically dampened one of the two trays in each treatment for a period of 6 months to generate surface crusts (Fig. 1). We applied, at least, 5 cycles of wetting-drying monthly. Distillated water was sprayed on the soil surface by runoff was always avoided.

The soil coverage used in S and B trays were 80–85 % according to previous studies (Prats et al., 2012; Montenegro et al., 2013). To obtain the same percentage of coverage, we had to depose 0.73 $kg\,m^{-2}$ of coffee residue on S trays and mix 1.6 $kg\,m^{-2}$ in B trays (0.05 m of depth). Leys et al. (2010) agreed with us that to achieve the same percentage of soil cover, it is necessary about 2 or 3 times more material in buried treatments. This larger doses of coffee husk in the buried treatment resulted in an increase in the organic matter, and therefore it affects the aggregate stability and other physical properties that control the behavior of the water in the soil. However, the organic matter content in the coffee husk is low because it has a higher content of inorganic compounds. In this case our priority was to obtain the same soil surface protection by the residue. Findeling et al. (2003) showed that the increase of runoff showed a linear relation with mulch, and Vandervaere et al. (1998) demonstrated that in crusted soils, the top layer is the key factor as control the infiltration process.

When the damping cycles were finished, the trays were placed at 12 % of slope under the rainfall simulator. Erosion trays were prepared without stone or vegetation cover that protects soil from the direct impact of rainfall drops. Slope and vegetation conditions (12 % and 0 % respectively) reproduced an unfavorable soil condition, which is common in agricultural areas. The laboratory layout was provided with a collector system at the end of tray to collect and measure the runoff yield (Fig. 1).

2.3 Simulated rainfall

The rainfall simulator is composed of a metallic structure of 3.08 m of height and 1.99 m wide by 1.59 m length (Fig. 1). At the top of the metallic structure, a water tank with a capacity of 25 L and a device with 51 rows and 255 droppers a 2 m in height was placed. To obtain uniformity in the rainfall, we attached a mechanical stirrer to the device. Ibáñez (2001) measured the rainfall characteristics of the simulated rainfall. The rainfall intensity was 122 mm h^{-1} with an average droplet diameter of 5.76 mm. The falling drop speed was between 4.7 and 5.5 m s^{-1}. The kinetic energy generated was 12.6 J L m^{-2} and the Christiansen uniformity coefficient of 98 %. Each erosion tray was subjected to a total rainfall of 21 min with water CE < 2 dS m^{-1}.

2.4 Data collection and calculated variables

Runoff was measured at the outlet of runoff, sediments were measured after filtering the runoff and soil losses, sediment concentration and infiltration rate were calculated. Overland flow was collected in plastic containers at intervals of 3 min. The protocol consisted in collecting the runoff every 3 min during the rainfall simulations, and filtering the runoff with a calibrated paper that was previously gauged. Subsequently, we measured soil losses by the gravimetric method. Water volume collected and weight data were used to calculate soil losses (g m^{-2}) and sediment concentration (g L^{-1}).

The Horton (1940) equation was used to estimate the infiltration rate, and the parameter (K1h, steady state infiltration rate after one hour) was calculated. Previous studies have demonstrated the efficiency of Horton's regression for the determination of the rate of infiltration at saturation conditions (Ibáñez, 2001; Telis, 2001; Hsu et al., 2002).

2.5 Statistical analyses

Data were statistically analyzed by one-way and two-way ANOVA and least significant difference (LSD) test at the 95 % probability level ($p < 0.05$) to obtain the relationships

SED
6, 1127–1153, 2014

among the factors (categorical independent variables) and determined parameters (dependent variables). The normality of samples was demonstrated with the Shapiro–Wilk test. All statistical analyses were completed using the computer software package Statgraphics Centurion XVI.I.

3 Results and discussion

3.1 Time to runoff

Control treatments reached ponding and runoff after 0.62 min followed by S (2.20 min) and finally B (2.69 min on average). Therefore coffee husk incorporation retards runoff generation by 4.3 and 1.2 times respectively (Table 2). C treatments showed $p < 0.01$ between coffee husk incorporation (S or B), while there were not statistically differences between coffee husk position (B and S treatments). Therefore, the coffee husk mulch was able to delay the time to runoff generation.

Soil crusting was a significant factor (Table 3), and the absence of soil crust supposed an increase of time to runoff about 1.58 times. Also there were statistically significant double interactions between treatments and soil crusting (Table 3). Thus, in decreasing order: B-WOC took 3.11 min to generate runoff followed by S-WOC (2.45 min), B-WC (2.02 min), S-WC (1.67 min), and the most unfavorable situations, C-WOC (0.65 min) and C-WC (0.59 min). Soil class was not significant in ANOVA analyses ($p > 0.05$). Despite the fact, time to runoff in soil III was the lowest in all the treatments (there was a time reduction between 1.33 and 1.28 times). To sum up the coffee husk presence and the absence of crust produced a delay in the runoff generation.

There is no data about the runoff behavior derived by the application of coffee mulch in crops, but Thierfelder et al. (2013) studied plots of 0.13 m^2 and several management techniques at on-farm sites with maize crop. They registered an increase in time to runoff between 1.12–1.13 times after mulch application. In forest areas, Groen and Woods (2008) used rice straw in plots of 0.5 m^2 and average slope of 15 %, and the time to runoff increased by 1.75 times. Finally, Grismer and Hogan (2004) registered a quite large variability in micro-forest plots with simulated rain under different types of soils. However, we found good correlations and this is probably due to the fact that agriculture land is less variable than the forest land.

3.2 Infiltration rate

The infiltration rate was higher in B treatments compared with S and C situations. Average values were respectively 77.09 mm h^{-1}, 47.98 mm h^{-1} and 46.1 mm h^{-1} (Table 2). The treatment was statistically significant ($p < 0.01$). S and C showed similar outcomes (husk on the surface caused an improvement of 4.1 % in infiltration rate) and differed of B treatments (buried husk had 60.7 % and 67.2 % improvement compared with S and C respectively).

The influence of the soil condition on soil infiltration rate also showed statistically significant differences. The crust reduced on average infiltration rate of 17.75 mm h^{-1} in comparison to the non-crusted treatments. This outcome highlights that crust on bare soil served as a barrier to the water infiltration (Table 4; and Fig. 2a and b). In the same trend, it can be seen in Fig. 3a that the buried incorporation improves the infiltration rate, although the crust was present in the top layer. The superficial residue is able to protect the soil from the raindrop impact. The buried residue also improves the soil properties and probably can develop preferential or matrix flows that contribute to a deeper and faster infiltration. Soil classes did not present double interactions and neither significant differences (Tables 2 and 3). Anyway, soil III had an outstanding behavior with the residue incorporation (Fig. 2). In the previous characterization of soils (Table 1), it showed a moderate value of Ks in relation to its porosity. This value was attributable to its low aggregate stability. After coffee husk burying, infiltration rate over control treatment had an increase of 101.7 % on average.

Morgan (1995), Cerdà, (1996), Franzluebbers (2002) and Adekalu et al. (2006) demonstrated that there is an increase in the infiltration rate with the amount of organic matter content. In our study the high cover of the soil (80–85 %) and the presence of

SED
6, 1127–1153, 2014

residue to a depth of up to 5 cm facilitated the physical-chemical and biological processes, which favored the improvement of the soil infiltration rate. Thierfelder and Wall (2009) determined the importance of texture on agricultural conservation practices for improving the hydraulic conductivity. In their experiences founded that fined-medium-textured soils had 57 % and 87 % improvement in infiltration rate, whereas sandy soils had between 47–49 %. Soils studied were sandy clay loam and clay loam (medium textures), hence the reduced data obtained in our experience were in the same range. In any cases, soil crust reduced on average infiltration rate 15.15 $mm\,h^{-1}$, whereas non-crusted treatments decreased 17.7 $mm\,h^{-1}$. This behavior is in concordance with Thierfelder et al. (2005) results.

Crusts reduce porous space and contribute to low infiltration rates. This fact was more evident in soil I situation because its textural condition (high silt content) produced thicker crusts (Fig. 1).

3.3 Runoff

Runoff decreases with the incorporation of coffee husk. The comparative data between control and S and B treatments revealed that runoff was reduced on average by 10.2 % and 46 % respectively (Table 2). Superficial treatments exhibited the same trend as Buried. S and C treatments showed similar runoff values, and both were higher than B values (Fig. 2c and 2d). The ANOVA analysis showed that the treatment factor was statistically significant ($p < 0.01$), and there were important differences between control and buried trays (Tables 2 and 3). This fact revealed the effect of spread the coffee husk on surface, which was not able to reduce runoff as effectively as burying it into the soil.

Soils without crust recorded average runoff values lower than soil with crust for any treatment or soil class (Fig. 2c and d). In fact, WC treatments were 6.59 mm higher than WOC (Table 2). However it is highlighted that buried coffee husk induce a reduction in the runoff (16.31 mm in B-WC soils) as the average value for S-WOC and C-WOC (18.51 mm and 20.54 mm respectively). This behavior shows the large capacity of buried residue to avoid the negative effect of the crust on the infiltration. There were also statistically significant differences ($p < 0.01$) in this factor but there were not it in soil class factor (Table 3). On one hand, soils I, II and IV registered runoff average values between 18–20 mm (including any treatments and all surface situations), whereas soil III showed the lowest data (16.52 mm) (Table 2). In that sense, if we analyzed the behavior of soils with buried residue in relation to the absence or presence of crust, the III WOC and IV WOC were similar to III WC and IV WC. On the other hand, soils I and II WOC were lower than I and II WC. In each case, there were not double interactions among the studied factors. This behavior showed in relief that: (i) the crust and the residue position have a greater influence on the runoff generation compared with soil classes; and (ii) burying the residue improved the behavior of soil I, and in lower value on soil II. In soils III and IV that action was not effective.

Other studies with simulated rainfall in field plots have shown similar results. Thierfelder and Wall (2009) compared conventional tillage with conservation techniques and found a reduction between 50 % and 90 % in function of texture. Brodie and Misra (2009) and Montenegro et al. (2013) obtained outcomes about 50 % in runoff reduction with diverse residue incorporation: 16 $kg\,m^{-2}$ for fresh material and 50 $kg\,m^{-2}$ for aged product; and 0.4 $kg\,m^{-2}$ for rice straw cover. Findeling et al. (2003) found that runoff coefficient was reduced by 50 % on average due to the addition of 1.5 $Mg\,ha^{-1}$ of corn residue. These authors found that the small amount of residue could dramatically cut down the runoff even in bare soil unplanted.

3.4 Sediment concentration

From the Fig. 4 and Table 2 we can see that B and S treatments of coffee husk did not record significant differences between them (11.47 and 10.63 $g\,L^{-1}$ respectively), although both values were lower than C treatments (46.19 $g\,L^{-1}$). With the residue application sediment concentration was reduced at least 75.7 %.

Figures 3b and 4 shown than WOC and WC treatments generated similar values and the results assessed by soil condition revealed that the presence or absence of the crust did not significantly affect the sediment concentration (Tables 2 and 3). The average value of WC was 23 $g L^{-1}$ and WOC was 22.18 $g L^{-1}$. There were not interactions between factors, and C-WC generated a flow with higher sediment load while, the B-WOC generated fewer concentration.

The unique statistically significant difference in soil classes was registered between soil I and III. They were distinguished by their values of texture and salinity, very different to normal trend of the soil set. Both characteristics define the aggregate stability and control the sediment content mobilized by overland flow. Moreover, although the soils showed higher sediment concentration in C treatments than in S or B, they exhibited a very different behavior value in WOC in front WC treatments. This situation can be understood if we consider that there was a little source of error in the measurement method. Sometimes small pieces of coffee husk were weighed together sediments, because they were intimately tied with soil particles and it was impossible to separate them. These cases can be seen in Fig. 4 where the treatments with coffee husk and crust displayed lower concentrations of sediment than treatments without crust, except in the control treatment. The thickness of the crust also affected sediment concentration because at the beginning the thick crust avoided the removal of sediment, and we measured runoff with no sediments. When the erosive process broke the soil crust, began to lose soil by channels. We must pay attention in the future to the water repellency of the crust as this can be the reason of this behavior such it has been found in other soils of the region (Bodí et al., 2013).

Other measurements on forest and agricultural land shown similar results. Groen and Woods (2008) determined a reduction coefficient between control and mulch application of 85 % in soils with less erodibility. Several researches registered high variability in the results; Bakr et al. (2012) showed a decrease around 72 %, Jin et al. (2008) registered values higher than 92 % and Grismer and Hogan (2004) obtained a concentration values between 0.2 and 15 $g L^{-1}$. These outcomes depend on the coverage (bare, needle mulches-pines or pines, bare or straw wheat, and compost/mulch thickness respectively), and the slope class (48–72 %). Le Bissonnais et al. (2005) found that the mulch presence in crusted tilled fields decreases the sediment concentration

Discussion Paper | Discussion Paper | Discussion Paper | Discussion Paper |

SED
6, 1127–1153, 2014

Coffee husk as mulch to reduce erosion and runoff

H. Moreno-Ramón et al.

between 20–65 %. Its efficiency depended on the precipitation intensity and the soil moisture status.

3.5 Soil loss

The soil loss pattern showed in Fig. 4 and Table 2 reveals a reduction in soil losses due to the coffee husk mulch. The average value of soil losses was lower in B treatments (121.92 $g\,m^{-2}$) than in S (235.04 $g\,m^{-2}$) and C (1084.07 $g\,m^{-2}$). The C treatment was statistically significantly higher than B or S, and coffee husk incorporation reduce soil losses by 8.9 and 4.6 times respectively. The soil losses of trays whit coffee husk did not have different significantly between them (B and S treatments).

There was a decrease of 31 % between C-WC treatments and C-WOC (Fig. 4), and in addition the simple effect to incorporate the coffee husk (B or S) decreased on average soil losses 83 % respect to control treatment. Donjadee and Chinnarasri (2012) showed in field experiments with a portable rainfall simulator that grass mulch cover reduced soil loss by 33.7–82 % (for rainfall intensities about 55 and 140 $mm\,h^{-1}$). The use of other soils covers like straw and aerial seeding (Groen and Woods, 2008), mulch cover and seeds (Grismer and Hogan, 2005), forest residues (Prats et al., 2012) or compost (Bakr et al., 2012) showed a reduction of 74–87 % in soil erosion in relation to the bare soils.

The presence of soil crust produced a differentiation between B and S treatments only in some soils. Although we can observe the differences (Fig. 4c and d), there were no significant differences in soil crusting and also in soil type factors (Tables 2 and 3). In control trays, soil I registered a maximum value of 2068.24 $g\,m^{-2}$ in one replica, whereas other soils showed maximum values between 963.7 and 1155.8 $g\,m^{-2}$ (Table 4).

These results justify that the residue is most effective in soils of lower quality, because it protects the soil against erosion by reducing raindrop impacts (FAO, 1967; Jin et al., 2008; Brodie and Misra, 2009). In addition, Grosbellet et al. (2011) revealed that the improvement of a soil physical property increases over time with the incorporation

SED
6, 1127–1153, 2014

of organic matter. Buried treatment reached both functions in a loamy soil with high erodibility (soil I). Lal (1988) suggested that soils with a high content of lime present the highest ratios of erosion. The textural fraction of silt presents distinct disadvantages related to other textural classes: it induces the formation of smaller pores and therefore hydraulic conductivity is lower than the sand fraction. In addition, it provides weaker aggregates than those formed by clays. Finally, Leys et al. (2007) showed in experiences similar to ours that crusting and total soil covers were more important in controlling runoff/soil losses than organic matter content and texture.

4 Conclusions

Coffee husk reduces soil losses, sediment concentration and runoff; and increases the time to runoff and steady-state infiltration rates. All of these outcomes with low mulch rate of application ($< 1.6\,\mathrm{kg\,m^{-2}}$) and under loamy textured soils submitted to high intensity rainfall events ($122\,\mathrm{mm\,h^{-1}}$ rainfall intensity) and an average drop diameter of 5.76 mm, demonstrate that the Mediterranean soils under high magnitude-low frequency rainfall events can avoid or reduce the soil and water losses with mulches or amendments of coffee husk.

References

Abdelkadir, A. and Yimer, F.: Soil water property variations in three adjacent land use types in the Rift Valley area of Ethiopia, J. Arid Environ., 75, 1067–1071, 2011.

Adekalu, K. O., Okunade, D. A., and Osunbitan, J. A.: Compaction and mulching effects on soil loss and runoff from two southwestern Nigeria agriculture soils, Geoderma, 137, 226–230, 2006.

Bakr, N., Weindorf, D. C., Zhu, Y., Arceneaux, A. E., and Selim, H. M.: Evaluation of compost/mulch as highway embankment erosion control in Louisiana at the plot-scale, J. Hydrol., 468–469, 257–267, 2012.

Bekalo, S. A. and Reinhart, H- W.: Fibers of coffee husk and hulls for the production of particleboard, Mater. Struct., 43, 1049–1060, 2010.
Bielders, C. L., Baveye, P., Wilding, L. P., Drees, L. R., and Valentin, C.: Tillage-induced spatial distribution of surface crusts on a sandy Paleustult from Togo, Soil Sci. Soc. Am. J., 60, 843–855, 1996.
Bodí, M. B., Muñoz-Santa, I., Armero, C., Doerr, S. H., Mataix-Solera, J., and Cerdà, A.: Spatial and temporal variations of water repellency and probability of its occurrence in calcareous Mediterranean rangeland soils affected by fire, Catena, 108, 14–25, 2013.
Brodie, I. M. and Misra, R. K.: Evaluation of greenwaste mulch to control runoff quality from landfill sites during frequent storms, Water Air Soil Poll., 201, 75–85, 2009.
Calvo-Cases, A., Boix-Fayos, C., and Imeson, A. C.: Runoff generation, sediment movement and soil water behaviour on calcareous (limestone) slopes of some Mediterranean environments in southeast Spain, Geomorphology, 50, 269–291, 2003.
Cerdà, A.: Seasonal variability of infiltration rates under contrasting slope conditions in southeast Spain, Geoderma, 69, 217–232, 1996.
Cerdà, A.: The influence of aspect and vegetation on seasonal changes in erosion under rainfall simulation on a clay soil in Spain, Can. J. Soil Sci., 78, 321–330, 1998.
Cerdà, A.: Effects of rock fragment cover on soil infiltration, interrill runoff and erosion, Eur. J. Soil Sci., 52, 59–68, 2001.
Cerdà, A. and Doerr, S. H.: The effect of ash and needle cover on surface runoff and erosion in the immediate post-fire period, Catena, 74, 256–263, 2008.
Choi, I. S., Wi, S. G., Kim, S.-B., and Bae, H. J.: Conversion of coffee residue waste into bioethanol with using popping pretreatment, Bioresource Technol., 125, 132–137, 2012.
El Kateb, H., Zhang, H., Zhang, P., and Mosland, R.: Soil erosion and surface runoff on different vegetation covers and slope gradients: a field experiment in sourthern Shaanxi Province, China, Catena, 105, 1–10, 2013.
Ellison, W. D.: Studies of raindrop erosion, Agr. Eng., 25, 131–136 and 181–182, 1944.
FAO: Soil erosion by water – some measures for its control on cultivated lands, Land and Water Development Division – FAO Agricultural Development, Paper No 81, Rome, 300 pp., 1967.
Fernández, C., Vega, J. A., Jiménez, E., Vieira, D. C. S., Merino, A., Ferreiro, A., and Fonturbel, T.: Seeding and mulching + seeding effects on post-fire runoff, soil erosion and species diversity in Galicia (NW Spain), Land Degrad. Dev., 23, 150–156, 2012.

SED
6, 1127–1153, 2014

Coffee husk as mulch to reduce erosion and runoff

H. Moreno-Ramón et al.

Findeling, A., Ruy, S., and Scopel, E.: Modeling the effects of a 9-partial residue mulch on runoff using a physically based approach, J. Hydrol., 275, 49–66, 2003.
Franzluebbers, A. J.: Water infiltration and structure related to organic matter and its stratification with depth, Soil Till. Res., 66, 197–205, 2002.
Gangwar, K. S., Singh, K. K., Sharma, S. K., and Tomar, O. K.: Alternative tillage and crop residue management in wheat after rice in sandy loam soils of Indo-Gangetic plains, Soil Till. Res., 88, 242–252, 2006.
García-Orenes, F., Roldán, A., Mataix-Solera, J., Cerdà, A., Campoy, M., Arcenegui, V., and Caravaca, F.: Soil structural stability and erosion rates influenced by agricultural management practices in a semi-arid Mediterranean agro-ecosystem, Soil Use Manage., 28, 571–579, 2012
Grismer, M. E. and Hogan, M. P.: Simulated rainfall evaluation of revegetation/mulch erosion control in the lake Tahoe basin – 1: Method assessment, Land Degrad. Dev., 15, 573–588, 2004.
Grismer, M. E. and Hogan, M. P.: Simulated rainfall evaluation of revegetation/mulch erosion control in the lake Tahoe basin-3: Soil treatment effects, Land Degrad. Dev., 16, 489–501, 2005.
Groen, A. H. and Woods, S. W.: Effectiveness of aerial seeding and straw mulch for reducing post-wildfire erosion, north-western Montana, USA, Int. J. Wildland Fire, 17, 559–571, 2008.
Grosbellet, C., Vidal-Beaudet, L., Caubel, V., and Charpentier, S.: Improvement of soil structure formation by degradation of coarse organic matter, Geoderma, 162, 27–38, 2011.
Hockbridge, E.: Healthy soil: healthy people, healthy planet, Soil Health, 7, 9–11, 2012.
Horton, R. E.: An approach towards a physical interpretation of infiltration capacity, Soil Sci. Soc. Am. Pro., 5, 399–417, 1940.
Hsu, S. M., Masce, P. E., Ni, C. F., and Hung, P. H.: Assessment of three infiltration formulas based on model fitting on Richards Equation, J. Hydrol. Eng., 7, 373–379, 2002.
Huang, J., Wu, P., and Zhao, X.: Effects of rainfall intensity, underlying surface and slope gradient on soil infiltration under simulated rainfall experiments, Catena, 104, 93–102, 2012.
Ibáñez, S.: Estudio de la erosión hídrica en suelos desarrollados sobre margas: métodos de estima en bancales abandonados. (Doctoral Tesis), Universidad Politécnica de Valencia, Departamento de Producción Vegetal, 396 pp., 2001.
Jiménez, M. A., Fernández-Ondoño, E., Ripoll, M. A., Castro-Rodriguez, J., Huntsinger, L., and Navarro, F. B.: Stones and organic mulches improve the Quercus Ilex L. Afforestation

success under Mediterranean climatic conditions, Land Degrad. Dev., Land Degrad. Dev., doi:10.1002/ldr.2250, 2013.

Jin, K., Cornelis, W. M., Gabriels, D., Schiettecatte, W., De Neve, S., Lu, J., Buysse, T., Wu, H., Cai, D., Jin, J., and Harmann, R.: Soil management effects on runoff and soil loss from field rainfall simulation, Catena, 75, 191–199, 2008.

Kasongo, R. K., Verdoodt, A., Kanyankagotem, P., Baert, G., and Van Ranst, E.: Coffee waste as an alternative fertilizer with soil improving properties for sandy soils in humid tropical environments, Soil Use Manage., 27, 94–102, 2011.

Lal, R.: Erodibility an erosivity, in: Soil Erosion Research Methods, edited by: Lal, R., Soil and Water Conservation Society, Iowa, USA, 141–160, 1988.

Laws, J. O.: Recent studies in raindrops and erosion, Agr. Eng., 21, 431–433, 1940.

Le Bissonnais, Y., Cerdana, C., Lecomtea, V., Benkhadraa, H., Souchèreb, V., and Martin, P.: Variability of soil surface characteristics influencing runoff and interrill erosion, Catena, 62, 111–124, 2005.

Lee, J.-W., Park, C.-M., and Rhee, H.: Revegetation of decomposed granite roadcuts in Korea: developing Digger, evaluating cost effectiveness, and determining dimension of drilling holes, revegetation species, and mulching treatment., Land Degrad. Dev., 24, 591–604, 2013.

León, J., Bodí, M. B., Cerdà, A., and Badía, D.: The contrasted response of ash to wetting, the effects of ash type, thickness and rainfall events, Geoderma, 209–210, 143–152, 2013.

Leys, A., Govers, G., Gillijns, K., and Poesen, J.: Conservation tillage on loamy soils: explaining the variability in interrill runoff and erosion reduction, Eu. J. Soil Sci., 558, 1425–1436, 2007.

Leys, A., Govers, G., Gillijns, K., Berkmoes, E., and Takken, I.: Scale effects on runoff and erosion losses from arable land under conservation and conventional tillage: the role of residue cover, European J. Hydrol., 390, 143–154, 2010.

Ma, I. J. and Li, X.-Y.: Water accumulation in soil by gravel and sand mulches: influence of textural composition and thickness of mulch layers, J. Arid Environ., 75, 432–437, 2011.

Mashingaidze, N., Madakadze, C., Twomlow, S., Nyamangara, J., and Hove, L.: Crop yield and weed growth under conservation agriculture in semi-arid Zimbabwe Soil Till. Res., 124, 102–110, 2012.

Montenegro, A. A., Abrantes, J. R. C. B., de Lima, J. L. M. P., Singh, V. P., and Santos, T. E. M.: Impact of mulching on soil and water dynamics under intermittent simulated rainfall, Catena, 109, 139–149, 2013.

Montgomery, D. R.: Soil and civilization: time for a Greener revolution, Food Ethics, 7, 4–6, 2012.
Morgan, R. P. C.: Soil Erosion and Conservation, 2nd edn., Longman, 198 pp., 1995.
Murthy, P. S. and Naidu, M. M.: Sustainable management of coffee industry by-products and value addition – a review, Resour. Conserv. Recy., 66, 45–58, 2012.
Novara, A., Gristina, L., Guaitoli, F., Santoro, A., and Cerdà, A.: Managing soil nitrate with cover crops and buffer strips in Sicilian vineyards, Solid Earth, 4, 255–262, doi:10.5194/se-4-255-2013, 2013.
Pandey, C., Soccol, C. R., Nigam, P., Brand, B., Mohan, R., and Roussos, S.: Biotecnological potential of coffee pulp and coffee husk for bioprocesses, Biochem. Eng. J., 6, 153–162, 2000.
Prata, E. R. B. A. P. and Oliveira, L. S.: Fresh coffee husks as potential sources of anthocyanins, LWT-Food Sci. Technol., 40, 1555–1560, 2007.
Prats, S. A., MacDonald, L. H., Monteiro, M., Ferreira, A. J. D., Coelho, C. O. A., and Keizer, J. J.: Effectiveness of forest residue mulching in reducing post-fire runoff and erosion in a pine and eucalypt plantation in north-central Portugal, Geoderma, 191, 115–124, 2012.
Saenger, M., Hartge, E.-U., Werthe, J., Ogada, T., and Siagi, Z.: Combustion of coffee husk, Renew. Energ., 23, 103–121, 2001.
Santos, J. C. F. I., Souza, I. F., Mendes, A. N. G., Morais, A. R., Conceição, H. E.O, and Marinho, J. T. S.: Allelophatic effect of coffee and rice husks arranged in soil layers on the germination and initial growth of Amaranthus viridis, Planta Daninha, 19, 197–207, 2001.
Singh, B., Chanasyk, D. S., McGill, W. B., and Nyborg, M. P. K.: Residue and tillage management effects on soil properties of a typic cryoboroll under continuous barley, Soil Till. Res., 72, 117–133, 1994.
Soil Survey Staff: Soil Survey Laboratory Methods Manual – Soil Survey Investigations Report No. 42. Version 4.0. Burt. R. US Department of Agriculture, Natural Resources Conservation Service, 2004.
Stavi, I., Lal, R., Jones, S., and Reeder, R. C.: Implications of cover crops for soil quality and geodiversity in a humid-temperate region in midwestern USA), Land Degrad. Dev., 23, 322–330, 2012.
Telis, P. A.: Estimation of infiltration rates of saturated soils at selected sites in the Caloosahatchee river basin, Southwestern Florida US Geological Survey, Open-File Report 01–65, 2001.

Thierfelder, C. and Wall, P. C.: Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe, Soil Till. Res., 105, 217–227, 2009.
Thierfelder, C., Amézquita, E., and Stahr, K.: Effects of intensifying organic manuring and tillage practices on penetration resistance and infiltration rate, Soil Till. Res., 82, 211–226, 2005.
Thierfelder, C., Mwila, M., and Rusinamhodzi, L.; Conservation agriculture in eastern and southern provinces of Zambia: long-term effects on soil quality and maize productivity, Soil Till. Res., 126, 246–258, 2013.
Vandervaere, J. P., Vauclin, M., Haverkamp, R., Peugeot, C., Thony, J. L., and Gilfedder, M.: Prediction of crust-induced surface runoff with disc infiltrometer data, Soil Sci., 163, 9–21, 1998.
Zhao, G., Mu, X., Wen, Z., Wang, F., Gao, P.: Soil erosion, conservation, and Eco-environment changes in the Loess Plateau of China, Land Degrad. Dev., 24, 499–510, 2013.
Ziadat, F. M. and Taimeh, A. Y.: Effect of rainfall intensity, slope and land use and antecedent soil moisture on soil erosion in an arid environment, Land Degrad. Dev., 24, 582–590, 2013.

SED
6, 1127–1153, 2014

Table 1. Analytical characteristics of soils.

Soil parameters	I	II	III	IV
pH	8.5	8.44	8.08	8.53
CE_e ($dS\,m^{-1}$)	3.95	5.49	7.89	5.51
$CaCO_3$ (%)	34	30.8	24.9	34.1
RAS	1.71	3.35	4.64	4.46
Organic matter (%)	6.27	1.6	2.51	1.57
Field capacity (%)	8.83	9.42	9.16	6.88
Wilting point (%)	4.04	5.13	5.49	3.57
Clay (%)	27	29	27	24
Silt (%)	42	22	14	22
Sand (%)	31	49	59	54
Textural class (USDA)	Clay loam	Sandy clay loam	Sandy clay loam	Sandy clay loam
Hydraulic conductivity ($cm\,h^{-1}$)	1.85	1.43	1.75	2.14
Porosity (%)	40.5	41.5	51.5	42
Aggregate stability (%)	2.3	2.4	1.9	2.7

SED
6, 1127–1153, 2014

Table 2. Influence of factor levels over the studied parameters (average values).

Factors	Levels	Runoff (mm)	Time to runoff (min)	Infiltration rate ($mm\,h^{-1}$)	Soil loss ($g\,m^{-2}$)	Sediment Concentration ($g\,L^{-1}$)
Treatment	Superficial	20.87 a	2.20 b	47.98a	235.04 a*	11.47 a
	Buried	12.48 b	2.69 b	77.09 b	121.92 a	10.63 a
	Control	23.24 a	0.62 a	46.10 a	1084.07 b	46.19 b
Soil condition	Without crust	15.57 a	2.25 a	65.94 a	389.50 a	22.43 a
	With crust	22.16 b	1.42 b	48.19 b	571.18 a	23.09 a
Soil class	I	18.19 bc	1.99 b	55.89 a	644.07 c	30.66 c
	II	20.62 c	1.92 b	52.89 a	431.61 bc	19.66 bc
	III	16.52 b	1.5 b	65.52 a	334.26 b	16.26 b
	IV	20.14 c	1.97 b	53.94 a	511.44 bc	24.48 bc

* Values with different letter (in each column) are significantly different ($p \leq 0.05$).

SED
6, 1127–1153, 2014

Table 3. ANOVA data and double interactions significance.

Effects and interactions	F values Runoff (mm)	Time to runoff (min)	Infiltration rate ($mm\,h^{-1}$)	Soil loss ($g\,m^{-2}$)	Sediment concentration ($g\,L^{-1}$)
Treatment (A)	39.68^{**}	54.78^{**}	12.67^{**}	34.43^{**}	24.93^{**}
Soil condition (B)	40.50^{**}	23.92^{**}	9.92^{**}	3.08^{NS}	0.02^{NS}
Soil class (C)	3.30^{NS}	1.91^{NS}	1.05	1.60^{NS}	1.77^{NS}
AC	1.37^{NS}	0.49^{NS}	0.44^{NS}	0.53^{NS}	0.27^{NS}
BC	2.37^{NS}	0.09^{NS}	0.71^{NS}	0.82^{NS}	0.30^{NS}
AB	0.45^{NS}	5.35^{**}	1.52^{NS}	1.24^{NS}	0.30^{NS}

^{NS} indicate no differences, * $p \le 0.05$; ** $p \le 0.01$.

SED
6, 1127–1153, 2014

Table 4. Statistical summary of results divided in soil classes.

Statistical variables	Soil class	Runoff (mm)	Soil loss ($g\,m^{-2}$)	Sediment concentration ($g\,L^{-1}$)	Time to runoff (min)	Infiltration rate ($mm\,h^{-1}$)
Mean	I	18.2	644.1	30.7	1.99	55.89
Median		19.7	371.7	23.5	1.79	43.96
Std. Dev.		9.3	743.8	23.34	1.35	29.94
Var.		86.7	553 300.9	544.90	1.82	896.66
Max.		28.1 (C WC)	2068.2 (C WC)	73.6 (C WC)	4.0 (B WOC)	115.0 (B WOC)
Min.		1.5 (B WOC)	29.1 (B WOC)	11.8 (B WC)	0.4 (C WOC)	32.8 (C WC)
Mean	II	20.6	431.6	19.7	1.9	52.9
Median		21.4	227.8	11.7	2.1	49.1
Std. Dev.		6.1	396.4	15.6	0.9	18.1
Var.		36.9	157 100.2	241.9	0.9	325.9
Max.		27.7 (S WC)	992.1 (C WC)	40.2 (C WC)	3.3 (B WOC)	85.9 (B WOC)
Min.		10.2 (B WOC)	131.1 (B WOC)	6.5 (S WOC)	0.54(C WC)	35.0 (S WC)
Mean	III	16.5	334.3	16.3	1.5	65.5
Median		17.4	139.6	8.5	1.4	61.7
Std. Dev.		6.4	390.6	15.4	1.1	21.0
Var.		41.5	152 544.5	236.2	1.2	441.8
Max.		24.9 (C WC)	963.7 (C WC)	38.6 (C WC)	3.0 (B WOC)	93.0 (B WOC)
Min.		7.7 (B WOC)	40.1 (S WOC)	2.7 (S WOC)	0.3 (C WC)	37.6 (C WC)
Mean	IV	20.1	511.4	23.8	1.9	53.9
Median		19.1	234.5	10.1	2.1	52.4
Std. Dev.		4.2	493.4	22.3	1.1	14.4
Var.		17.9	243 429.1	497.3	1.3	205.9
Max.		26.0 (C WC)	1155.8 (C WOC)	59.9 (C WOC)	3.2 (B WOC)	75.6 (B WOC)
Min.		14.9 (B WOC)	143.5 (B WOC)	9.4 (B WOC)	0.54 (C WC)	40.9 (C WC)

Where, S = superficial, B = buried, C = control, WOC = without crust and WC = with crust.

SED
6, 1127–1153, 2014

Fig. 1. Experimental equipment and crust formation.

SED
6, 1127–1153, 2014

Coffee husk as mulch to reduce erosion and runoff

H. Moreno-Ramón et al.

SED
6, 1127–1153, 2014

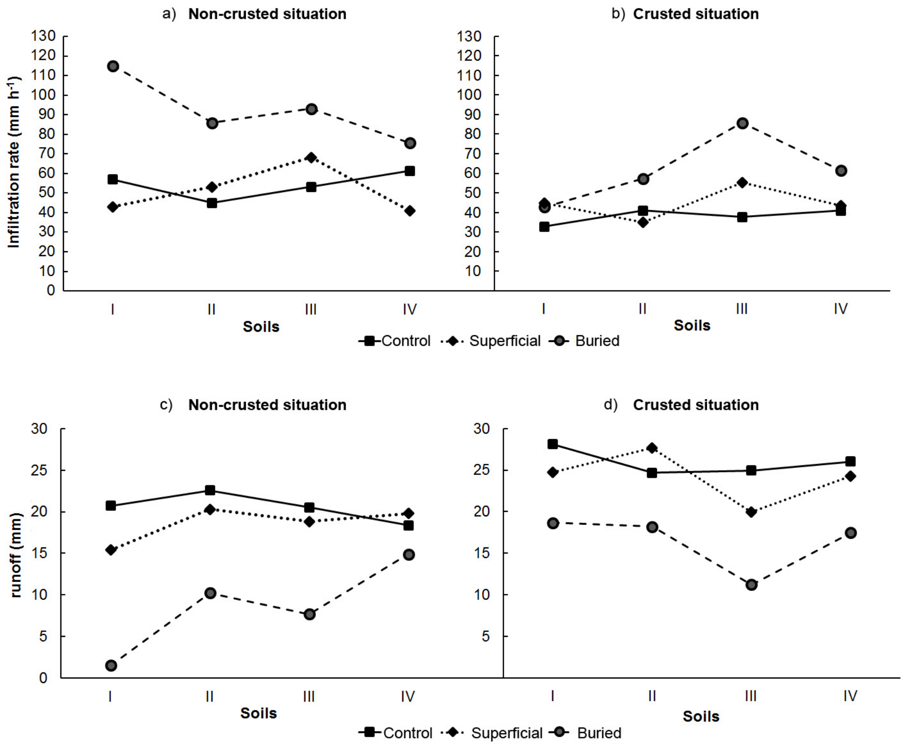

Fig. 2. Behavior of hydrological variables in function of the studied factors: infiltration rate **(a)**: without crust, **(b)**: with crust; and runoff **(c)**: without crust, **(d)**: with crust.

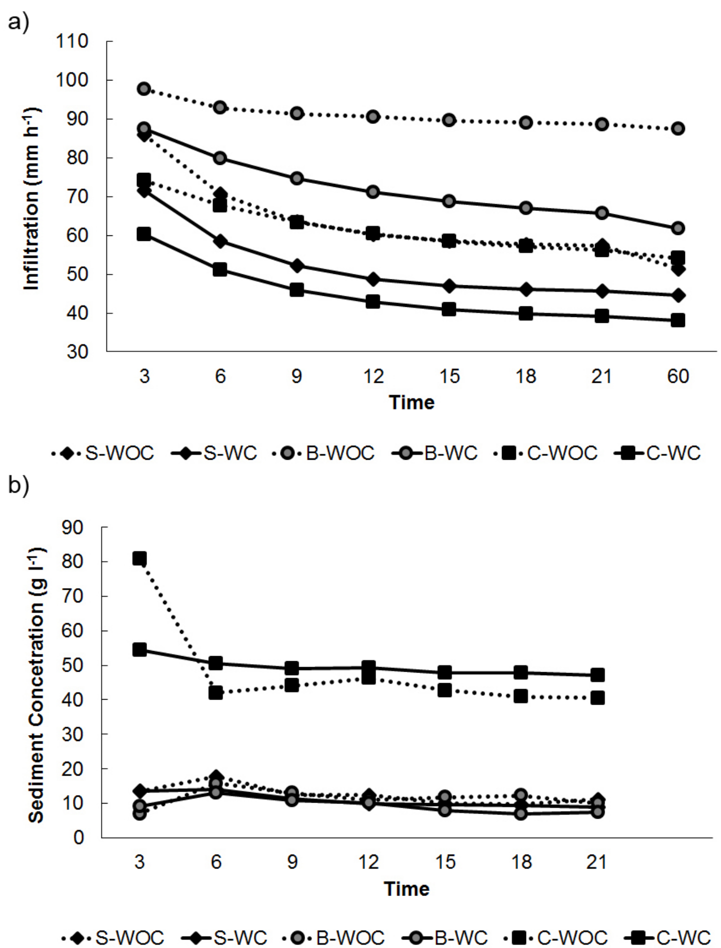

Fig. 3. Temporal evolution of infiltration rate (by Horton) **(a)** and sediment concentration **(b)**.

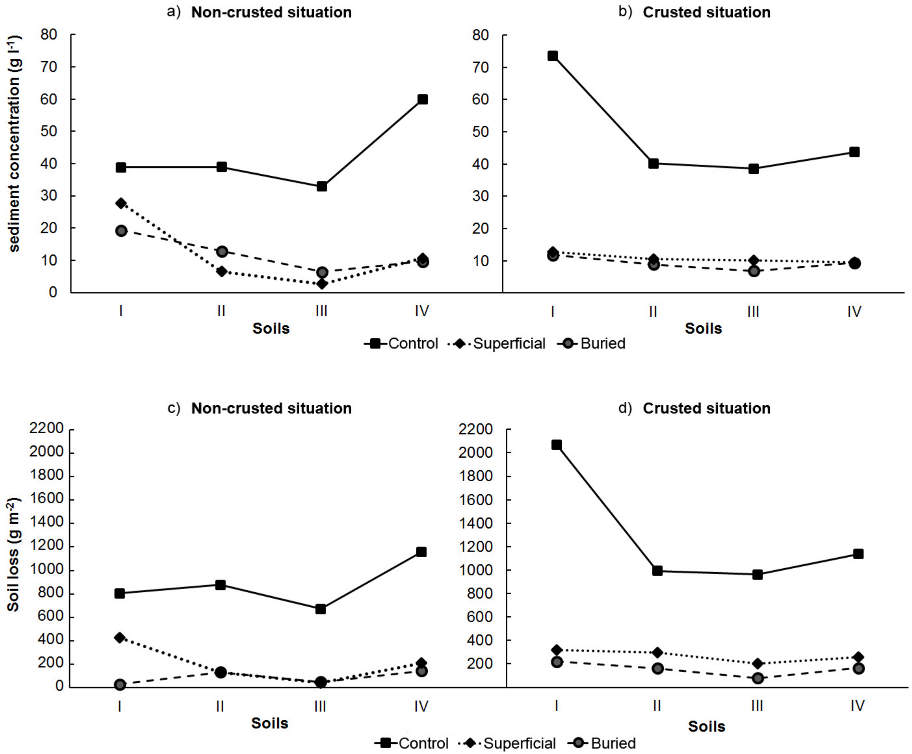

Fig. 4. Behavior of erosive variables in function of the studied factors: sediment concentration **(a)**: without crust, **(b)**: with crust; and soil loss **(c)**: without crust, **(d)**: with crust.

SED
6, 1127–1153, 2014