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The use of barley straw residues to avoid high erosion and 1 runoff rates on persimmon plantations in Eastern Spain under low frequency – high magnitude simulated rainfall events

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Abstract

Soil and water losses due to agricultural mismanagement are high and non-sustainable in many orchards. An experiment was setup using rainfall simulation experiments at 78 mm h^{-1} over one hour on 20 paired plots of 2 m^2 (bare and straw covered) in new persimmon plantations in Eastern Spain. The effects of a straw cover on the control of soil and water losses was assessed. An addition of 60% straw cover (75 g m-2) resulted in delayed ponding and runoff generation and as a consequence reduced water losses from 60 to 13% of the total rainfall. The straw cover reduced raindrop impact and as a consequence sediment detachment from 1,014 to 47 g per plot in one hour. The erosion rate was reduced from 5.1 to 0.2 Mg ha^{-1} h^{-1}. The straw mulch was found to be extremely efficient in reducing soil erosion rates.

Keywords: persimmon plantations, management, erosion, hydrology, rainfall simulation.

Introduction

Soil erosion is widely known to be one of the triggering factors of land degradation and desertification worldwide (Bai et al., 2013; Izzo et al., 2013; Wang et al., 2013; Jafari and Bakhshandehmehr, 2013; Zhao et al., 2013; Ola et al., 2015; Yan et al., 2015). High and non-sustainable erosion rates are due to human mismanagement of soils and their vegetation cover due to grazing (Cerdà and Lavee, 1999; Mekuria and Aynekulu, 2013; Angassa, 2014), forest fires (González-Pelayo et al., 2010), mining (Martín-Moreno et al., 2015) and agriculture (Brevik, 2009; Cerdà et al., 2009a; 2009c; Leh et al., 2013; Lieskovský and Kenderessy, 2014; Yuan et al., 2015).

Agriculture causes higher sediment yields from the continents than any other single source due to ploughing, removal of the original vegetation, soil disturbance and the use of pesticides and herbicides that reduce biological activity in soils, lower overall vegetation cover, the lack of terraces in sloping terrain, depletion of organic matter, and soil compaction and sealing (Cerdà et al., 2009c; Novara et al., 2011; Laudicina et al., 2012). This relationship is now well known. Civilizations have failed throughout human history due to erosion (Brevik and Hartemink, 2010), and erosion continues to negatively affect civilizations in all regions of the world (Costa, 1975; Pimentel et al., 1987; O'hara et al., 1993; Shi and Shao, 2000; Cerdà et al., 2007).

Orchards, more than cereal and vegetable production, are sources of sediments from agricultural land due to the lack of vegetation cover over large areas of the field (Dabasish-Saha et al., 2014). The compaction of soils as a consequence of heavy machinery passes, soil degradation due to the weakening of soil structure, and related organic matter depletion also affects sediment production (Fialho and Zinn, 2014; Parras-Alcántara et al., 2014). Soil erosion has been found to be high in olive (*Olea europaea*) orchards (Gómez et al., 2003; VanWalleghem et al., 2010), new citrus plantations (Cerdà et al., 2009b; Li et al., 2015), avocado (*Persea Americana*) orchards (Atucha et al., 2013) and vineyards (Novara et al., 2013; Costantini et al., 2015; Tarolli et al., 2015). Other types of orchards such as almonds (*Prunus dulcis*) (Faulkner et al., 1995) and apricots (*Prunus armeniaca*) (Abrisqueta et al., 2007) have also shown high erosion rates, but there is little information on soil erosion rates in orchards compared to other agricultural settings, and no research has been reported for pears (*Pyrus* sp.), apples (*Malus pumila*), cherries (*Prunus* sp.) or persimmons (*Dyospirus* sp.), even though fruit production is growing and the land area covered by various fruit and citrus orchards and vineyards is heavily managed with machinery and pesticides leading to soil damage and degradation.

Annual world persimmon production in 2013 was 4.6 million tonnes with China producing about 78% of the total world yield (FAO, 2015). Korea and Japan are the second and the third leading producers respectively with 0.35 and 0.21 million tonnes produced in 2013, and combined the three Asian countries represented more than 90% of 2013 world production (FAO, 2015). Spain produces 0.1 million tonnes annually but there has been a sudden increase in the production of and land used for persimmon production, making Spain an emerging producer and exporter of persimmons as a new product for the European markets. There has been a quick land use change from citrus orchards to persimmon orchards in Eastern Spain, which means much less vegetation cover as the latter is a deciduous tree that leaves the soil bare for 4 months of the year (Figure 1). The persimmon expansion in Eastern Spain is due to the high prices and the new markets that have developed in Europe, Brazil and the Arabic countries. The new chemically managed and highly mechanized plantations in Eastern Spain are using high doses of herbicides and the lack of vegetation is triggering high erosion rates due to the bare soils. Previous studies, in citrus orchards, have discussed how mulching reduced runoff and erosion by buffering the raindrop impact and improving soil physical conditions (Liu et al., 2014). Others such as Wakindiki and Danga (2011) described its effects on nutrient accumulation in soils, but few studies have addressed effects of extreme rainfall events on soil erosion on new persimmon plantations in semiarid conditions.

This paper aims to assess soil erosion rates on these new persimmon plantations and to test the efficiency of straw cover to reduce soil losses. Forty rainfall simulation experiments were carried out in

20 paired plots to determine the effect of a 60% straw cover on soil erosion and runoff generation on agricultural soils that were originally bare.

Materials and methods

The research was run in the western Mediterranean basin, within the Canyoles River watershed in the La Costera district of the Valencia region (Eastern Spain), where new persimmon plantations are widely replacing citrus production in drip-irrigation and flood-irrigated crop systems. Parent materials in the area belong to Cretaceous limestones and Tertiary deposits that develop Typic Xerothent (Soil Survey Staff, 2014) soils. Low levels of soil organic matter (SOM) are found (< 2%) in agricultural land in Eastern Spain and the Canyoles River watershed due to the millennia old agricultural use and soil disturbance by fire, grazing and ploughing, basic pH (8) and loamy soil textures that characterize the soils of the area. The climate is typically Mediterranean with 3-5 months of summer drought (June-September). Mean annual rainfall at the study site is 590 mm and there are 41 mean annual days of rain. Rainfall is distributed amongst autumn, winter and spring, with maximum peak rain intensities during the autumn season. The mean annual temperature is 14.2ºC while the hottest month (August) has average temperatures of 23ºC. Extreme storm events with return periods of 50 years are found in this area, which is 60 Km from the Mediterranean Sea. Examples of extreme events include more than 600 mm of rainfall in two days in 1982 in the Màssis del Caroig and 800 mm in slightly more than 24 hours in Gandia in 1987. Recurrent rainfall events of more than 100 mm day^{-1} make extreme rainfall events a key factor in local soil erosion.

A 15 year old plantation of persimmon (*Dyospirus lotus var. Rojo brillante*) was selected in Eastern Spain (Canals Municipality, La Costera District) to measure soil losses on no-till bare management (herbicide treatments, called Bare) and on barley straw covered plots (called Straw) (Figure 2). Persimmon trees were positioned in parallel rows with a slope angle and length of 2% and 40 meters, respectively. The straw cover was applied 3 days before the rainfall experiments at doses that covered on average 60% of the soil surface using 75 g of straw per m^2. Cover in the no-till bare treatments averaged 3%. Forty rainfall simulations (RS) conducted at 78 mm h^{-1} rainfall intensity for one hour were carried out on paired rectangular plots that were 2 m^2 (1 m wide x 2 m long); the paired plots were bare (20 RS) and covered with straw (20 RS). The measurements were carried out during July 2014 under very dry soil moisture contents ranging from 4.6 to 7.9% for the whole month. These measurements are representative of interill or pedon scale soil erosion processes since RS were placed in the row spaces between trees. Detailed information about the rainfall simulator set and on the distribution of rainfall parameters can be found in Cerdà and Doerr (2010) and Cerdà and Jurgensen (2011); the rainfall simulator is placed at 2 meters height. It uses three nozzles (Hardi-1553-12) with a constant rainfall intensity using deionized water. Overland flow from the plot area was measured at 1-min intervals at the plot outlet. Every tenth 1-min runoff sample was collected for laboratory analysis in order to determine sediment concentration. Runoff rates and sediment concentration were used to calculate the sediment yield, total runoff, runoff coefficient, and erosion rates. Parameters such as time to ponding (Tp, determines when the soil is saturated), time to runoff (Tr, is the time when runoff is initiated), time to runoff - time to ponding (Tp-Tr), time to runoff outlet (Tro, is the time of runoff initiation at the plot collector), and time to runoff outlet - time to runoff (Tro-Tr) were also analysed through statistical tests as described below. Vegetation cover was determined with 100 pins measurement in each 2 m^2 plot, and soil moisture was measured by means of the desiccation of soil samples collected before the simulated rainfall experiment drying at 105ºC for 24 hours. Sediment concentration in the runoff was calculated after the desiccation of the samples in the laboratory.

Normality of the data was tested through the Shapiro-Wilk test. The statistical differences between the mean values of some parameters for the Bare and Straw treatments was tested with the T-test (Tp, Tr, Tp-Tr, Tro, Tro-Tr, runoff coefficient, total runoff, sediment concentration, sediment yield, and soil erosion). Some other parameters did not meet the assumption for normality (Tp bare, Tr bare, sediment concentration bare, sediment yield bare and erosion bare), and data square-root and logarithmic transformations were carried out to achieve normality before carrying out the T-test. Linear correlation coefficients (R^2) with polynomial, exponential and linear fitting were also calculated to assess the relationship between RS (Tp, Tr, Tp-Tr) and erosion parameters (total runoff (l), sediment concentration ($g\ l^{-1}$), sediment yield (g) and soil erosion ($Mg\ ha^{-1}\ h^{-1}$). Statistical analyses were computed with the SPSS 22.0 software package (IBM Corporation, Armonk, NY, USA).

Results

The soil moisture in the 0-2 cm depth interval previous to RS experiments was very low (< 5% in all plots) and very homogeneous as the experiments were carried out in an area that is not irrigated and during the Mediterranean summer drought. There was no rain in the 45 days prior to the experiments. Measurements of the vegetation and litter (straw) cover (Table 1) showed that plants covered 2.5% of the bare plots, while the straw plots had 61.6% cover on average (Table 1; p-value<0.05). The bare (control) plots had a vegetation cover ranging from 0 to 6% and the straw plots ranged from 48 to 90% cover. The increase in cover reduced the raindrop impact and as a consequence the Tp increased from 64 (ranging from 33 to 96 s) to 309 seconds (from 201 to 495 s) in bare and straw plots, respectively (Table 1). Microtopography and soil roughness delayed runoff generation (Tr), which was reached after 262 seconds on the bare soils but took 815 seconds on the straw covered soils (Table 1; p-value<0.05). The minimum and maximum Tr values were 234 and 342 s for bare plots and 702 and 1,005 s for straw covered plots (Table 1; p value<0.05). The differences between Tp and Tr show the time that is needed for runoff to be initiated and is much more delayed in the straw covered soils (506 seconds) than on the bare soils (198 s) (Table 1; p-value<0.05). The time to runoff outlet (Tro) was 1,222 s in the straw mulch covered plots and 419 s in the bare ones (Table 1; p-value<0.05). Tro-Tr shows the velocity of the runoff, and this is delayed in the soil covered with straw (406 s) and much faster in the bare soils (156 s) (Table 1; p-value<0.05).

Table 2 shows the runoff rates, sediment yield and soil erosion. The runoff coefficient decreased from 60% in the bare control plots to 29% in the straw plots. Runoff in the bare plots ranged from 50 to 72%, meanwhile in the straw plots Rc ranged from 15 to 45% of the total rainfall. The bare plots also contributed runoff with much higher sediment concentration (10.9 g l^{-1}) in comparison to the straw covered plots (1 g l^{-1}). The amount of runoff generated in the bare plots had an average value of 93 litres (ranging from 79 to 113 l), while the amount of runoff was much less in the straw plots (46 l, ranging from 24 to 71 l).

Regression analyses between hydrological parameters (Figure 3) shows how Tr is dependent on the Tp, with the relationship being stronger in the straw plots than in the bare ones (R^2 of 0.34 vs 0.06, respectively). In fact, the relationship of the delay time between ponding and runoff (Tp-Tr) and Tr is stronger in the bare plots than in the straw ones (R^2 of 0.63 vs 0.20, respectively) and weaker between Tp-Tr and Tp (R^2 of 0.24 vs 0.36, respectively).

In the bare soil plots the total sediment yield was more than 1 Kg while it was only 47 g in the straw covered plots. The values ranged from 546 to 1,971 g in the bare plots and 21 to 80 g in the straw plots. This resulted in high erosion rates on the bare plots (5.1 Mg ha^{-1} h^{-1}) in comparison to the straw plots

(0.2 Mg ha^{-1} h^{-1}). The bare plots also showed a variability that ranged from 2.7 to 9.9 Mg ha^{-1} h^{-1} and the straw plots ranged from 0.1 to 0.4 Mg ha^{-1} h^{-1}.

The sediment yield was a consequence of the runoff generated and the sediment concentration. Differences in sediment concentration between straw and bare treatments increased with the runoff discharge of the bare plots at least one fold (1 to 11 g l^{-1}, respectively, Table 1) (Figure 4). In that sense, two trends were described in the sediment concentration-sediment yield relationships; in bare plots with an R^2 of 0.9 and a Pearson r coefficient of 0.962, while in the straw covered plots model fits with an R^2=0.5 and a Pearson r coefficient of 0.738 (Figure 4).

Discussion

The bare soils that persimmon production induces in Eastern Spain by means of the use of herbicides result in very high soil and water losses, such as the 5 Mg ha^{-1} h^{-1} measured in our experiments under single low frequency – high magnitude rainfall simulation experiments demonstrated. The 78 mm h^{-1} rainfall event over one hour is expected once every 50-100 years in the Cànyoles watershed study area. Those rainfall events produce damage to soils and infrastructure and create floods due to the high magnitude of the discharges. Research of low frequency – high magnitude rainfall events is rare because they have low recurrence and also due to the fact that most commonly used measurement equipment fails as a consequence of the high flow and sediment loads that collapse the gauging stations. This makes rainfall simulators useful to assess the impact of these intense thunderstorms as we can maintain accurate control of the measurements. Moreover, most of the soil erosion and water losses take place during these extreme rainfall events. Other researchers have reported that rainfall intensity (Ziadat and Taimeh, 2013; Nadal-Romero et al., 2015) and duration (González-Hidalgo et al., 2010a; 2010b; 2012) are key factors driving soil erosion and that research on extreme rainfall event effects on soil erosion is needed to advance our knowledge of soil erosion and to control non-sustainable erosion rates.

Soil losses on the persimmon plantations can be calculated as a lowering of the soil surface. After one hour of intense rainfall 0.51 mm of soil was removed from the surface with a range from 0.27 to 0.99 mm. This is a clear example of non-sustainable land management as these soil erosion rates are much higher than soil formation rates, which are typically tenths to hundredths of a mm per year (Brevik, 2013) and are very low under Mediterranean climatic conditions. Other researchers found extreme soil erosion rates under agricultural land in the Mediterranean, and they highlighted extreme storms events as the key events to understand Mediterranean ecosystems and landforms (Wainwright, 1996; Poesen et al., 1997; Martínez-Casasnovas et al., 2002; González-Hidalgo et al., 2007).

The results of the experiments on persimmon plantations in Eastern Spain show that the bare soils contributed to quick runoff and high runoff and sediment yield. The use of straw was an efficient strategy to reduce soil losses as these losses decreased from more than 1,000 g in the bare control plots to only 47 g in the straw covered plots. This resulted in a low erosion rate when the soil was covered with straw (0.24 Mg ha^{-1} h^{-1}), but a much higher erosion rate when the soil was not covered (5.07 Mg ha^{-1} h^{-1}) (Table 1). The positive effect of a vegetation or litter cover has also been documented in other ecosystems and agricultural lands around the world, as crop residues are used to restore soil quality or/and control soil losses (Moreno-Ramón et al., 2014; Weyers and Spokas, 2014; Sadeghi et al., 2015). Improved soil quality is often found on organic farms (van Leeuwen et al., 2015). The ability to use ecological techniques to improve soil quality and reduce erosion shows the interdisciplinary nature of soil science (Brevik et al., 2015). Geotextiles are another organic cover that can significantly reduce soil erosion (Giménez-Morera et al., 2010).

Runoff is widespread on persimmon plantations under high intensity thunderstorms such as were simulated in this experiment. On all the bare experimental plots runoff began within 4 min of rainfall inception, meanwhile in the straw plots the time to runoff was as much as 14 min. Ponding occurred on all the plots and Tp values were statistical higher (one order of magnitude) in the straw cover plots (Table 3). The average delay time between ponding and runoff (Tr-Tp) also indicated the reduced hydrological connectivity due to the straw mulch cover, increasing the Tro and reducing the runoff coefficient. It is very important to emphasize that the straw contributed to disconnecting the runoff flow pathways or at least to a delay in these connections and this reduced the soil erosion risk (Darbaux et al., 2002; Helming et al., 2005).

Tp and Tr have been considered as indicators of soil wettability (Cerdà and Doerr, 2007). Specifically, the higher the Tp value, the better the soil wettability conditions. The delay in Tp, Tr and the lower runoff coefficient on the straw plots (Table 1 and 2, Figure 3) are in agreement with the results of Jordán et al. (2010), which stated that the addition of plant residues to soil may increase porosity, roughness and interception of raindrop energy, delaying runoff generation and enhancing infiltration rates. In our research at the persimmon plantations the impact of the straw on runoff generation was due to the reduction of the raindrop impact as the straw was applied 3 days before the experiment and there were not changes in the soil properties as a consequence of the straw cover. Otherwise, plant residue additions could promote soil water repellence (SWR) from SOM incorporation. As Cerdà and Doerr (2005) and González-Peñaloza et al. (2012) reported, subcritical levels of SWR were measured in orchards (citrus) as a result of straw cover use. Also, in soils from fruit orchards, García-Moreno et al. (2013) highlighted the importance of the application rate and the period of time since application on the effects of the soil hydrological response. In this experiment, the short elapsed time between straw addition and RS experiments, three days, and the moderate straw application rate (Jordán et al., 2010) could hide the SWR effect due to the favourable effects on hydrology in two ways; i) physical, as raindrop interception and soil roughness were increased, in the short term, and ii) chemical, through organic matter inputs that improve soil hydrological properties (García-Orenes et al., 2009; Blanco-Canqui, 2011) in the middle term.

Sediment concentration in runoff provides information about soil susceptibility to erosion. Differences of one fold between treatments (1 to 11 g l^{-1}, respectively, Table 1), and a positive linear relationship in the bare plots (Figure 4) shows that the erosion process is transport-controlled, as the greater the discharge, the greater the amount of sediments transported in runoff (Cerdà et al., 2009). Opposite, on the straw covered plots, the runoff-sediment relationships are usually detachment-controlled due to the effect that straw exerts. Sediment concentration decreases when runoff discharge increases because the sediment available becomes exhausted or trapped and is diluted in the higher runoff discharge (Figure 4).

The straw application rate (75 g per m^2) created an average of 60% soil cover, which was enough to control erosion and agrees with the findings of Ruiz-Sinoga et al. (2010). In our case, soil cover reduced the collected sediment yield by 2-fold and thus the erosion rates (Table 1).

The importance of cover in Mediterranean persimmon orchards, through straw or litter, is explained by the fact that it reduces the kinetic energy of raindrops and traps soil particles. Thus, particle detachment by splash is negligible, as are soil losses. Several studies have found similar results: the lowest soil losses were found for straw mulch plots and fallow plot treatments (Schwing, 1978; Messer, 1980; Grill et al., 1989; Maigre and Murisier, 1992; Klik et al., 1998 in Garcia-Orenes et al., 2013). In some cases this is due to improved soil quality (Tejada and Benitez, 2014). However, this was not the case in our study as the straw cover was applied only three days before the experiment, which means that the straw effect was just the direct effect of its cover protecting the soil against raindrop impact, increasing the soil roughness and decreasing the runoff connectivity (Darboux et al., 2002). Additions of organic materials such as straw, mulches, or vegetative cover over longer time spans can also have other impacts on soil quality such as increasing the organic matter content (Cerdà et al., 2014; Debasish-Saha et al., 2014) and biological activity which leads to an increase in macropores and preferential flow along those macropores. This has been documented in ant nests (Cerdà and Jurgensen, 2008).

The management of agricultural soils in many parts of the planet is triggering land degradation (Borelli et al., 2013; Haregeweyn et al., 2013; Zhao et al., 2013; Zdruli, 2014). The most intense soil erosion rates negatively affect agriculture land (Cerdà et al., 2009), and in Eastern Spain it has been found that citrus orchards are one of the crops with the highest erosion rates due to management techniques that avoid cover crops and eliminate weeds and litter, (Cerdà and Jurgensen, 2008; Cerdà et al., 2009a; 2009b; 2009c; Cerdà et al., 2011; 2012). Similar findings have also been reported in China (Wu et al., 1997; Xu et al., 2010; Wang et al., 2011; Wu et al., 2011; Liu et al., 2012; Lü et al., 2011; Xu et al., 2012). The poor land management found in many of the citrus plantations resulted in soil degradation (Lu et al., 1997; Lü et al., 2012; Xu et al., 2012) and this study confirms that the new Spanish persimmon plantations are triggering the same effects and it is necessary to develop new strategies to reduce soil losses such as the straw cover evaluated here. The use of cover crops to reduce soil losses (Lavigne et al., 2012; Le Bellec et al., 2012) and the use of residues such as dried citrus peel has been found successful in reducing soil degradation (Bombino et al., 2010), but it is also well known that litter cover is a key way to avoid soil erosion. Meginnis (1935) was one of the pioneers in the research of litter cover to avoid high erosion losses. There is a need to find new plants (cover crops or living mulches) or residues to protect the soils in persimmon orchards and they should be developed now while farmers are increasing the land area where persimmons are being produced. Straw has been seen as a very efficient way to reduce water losses in other agriculture lands (García-Moreno et al., 2013), soil losses in fire affected lands (Prats et al., 2012; Robichaud et al., 2013a; 2013b; Fernández and Vega, 2014; Prats et al., 2015), and improve soil properties on agriculture land (García-Orenes et al., 2009; 2010; Jordán et al., 2010; García-Orenes et al., 2012). Those findings and the ones we show here support changing to a more sustainable agriculture. This advance in agronomy affects the control of soil erosion (Tejeda and Benitez, 2014) and the recovery of soil quality (Mahmoud and Abd El-Kader, 2015).

More research is needed to find the right straw application rates to be sustainable from both an agricultural and economical point of view, and it is necessary to convince farmers of the need to protect the soil. The cost of the straw (plus labour costs) at the doses we applied in this study was 500 € ha^{-1}, but this cost could be reduced with the use of machinery. One of the main constraints to commercial applications of straw is that farmers do not see the use of the mulches as a good strategy due to aesthetic reasons. Other soil erosion control strategies have also met with negative initial acceptance by farmers, so they need an introductory period (Huenchuleo et al., 2012; Nabahungu and Wisser, 2013) which is also related to the perception by farmers of the new strategies effectiveness at controlling soil and water loses (Recha et al., 2014; Mekonnen et al., 2015; Pereira et al., 2015). Most farmers can see that deforestation is causing high erosion rates (Borrelli et al., 2013), but they do not accept that farming is also causing the loss of soil resources.

Conclusions

The levels of soil and water losses in the new persimmon plantations in Eastern Spain are not sustainable, as they reached a lowering of the soil depth of 0.5 mm in one hour during extreme storm events as a consequence of raindrop impact and surface wash. These high erosion rates exceed soil formation rates and are due to the lack of vegetation cover as a consequence of the use of herbicides in the soils. Straw mulch cover reduced soil losses from 5.1 to 0.2 Mg ha^{-1} h^{-1} immediately after straw application. The use of straw mulches is very efficient at reducing soil and water losses in Mediterranean orchards as they suffer from a low vegetation cover and climatic conditions that induce very intense rainfall events, and as a consequence high erosion rates, which must be controlled in agricultural land to achieve sustainable production.

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Figure 1. Persimmon orchards in December (left) and February (right). Winter is when the soil is bare of vegetation and leaves and when the soil erosion risk is higher.

Figure 2. Plots. To the left the control (bare) plot, to the right the straw-covered plot.

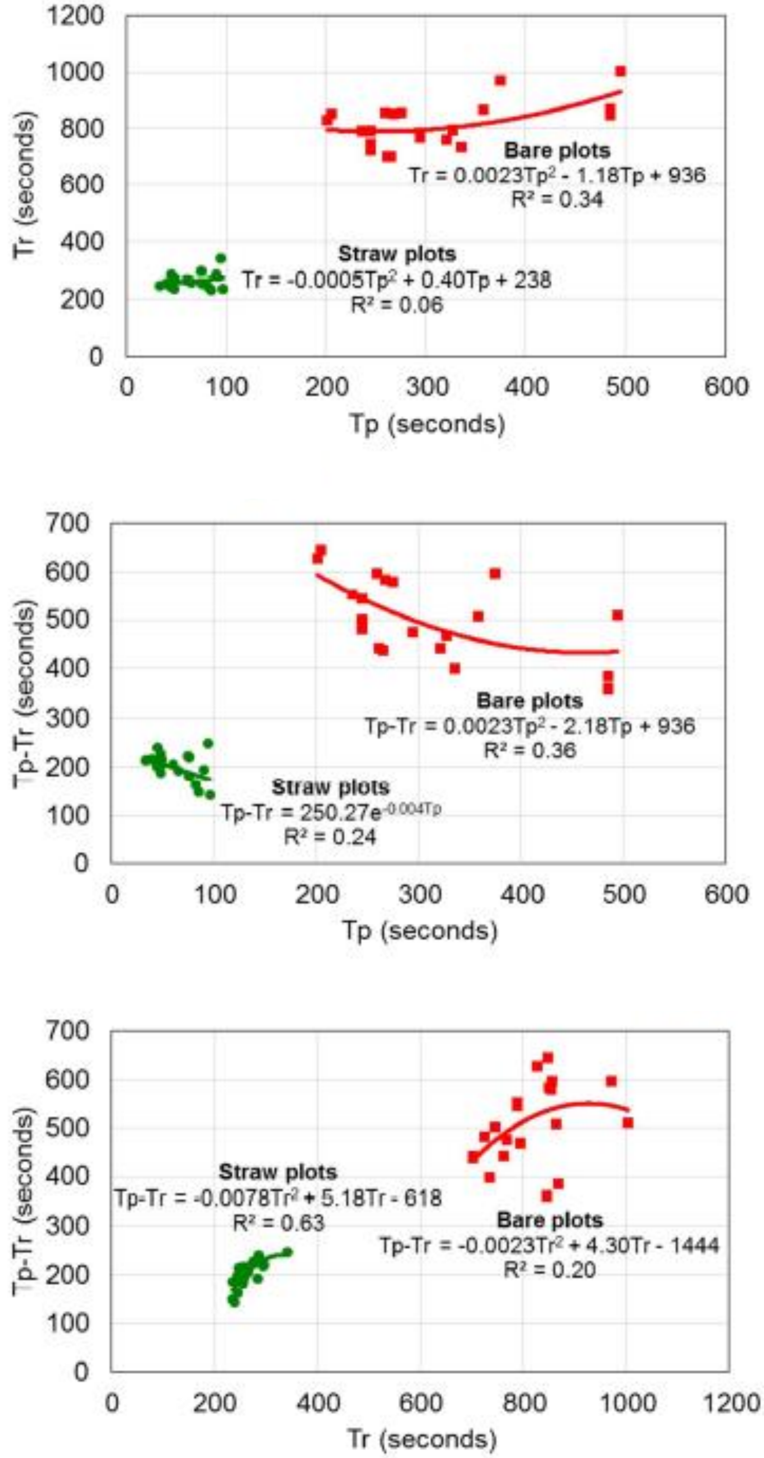

Figure 3. Relationship between time to runoff (Tr) and time to ponding (Tp), and delay time between ponding and runoff (Tr-Tp) and time to ponding (Tp), and with time to runoff (Tr), for all the datasets. N=40. Bare means no-till bare (herbicide treatments), and Straw means barley straw covered plots.

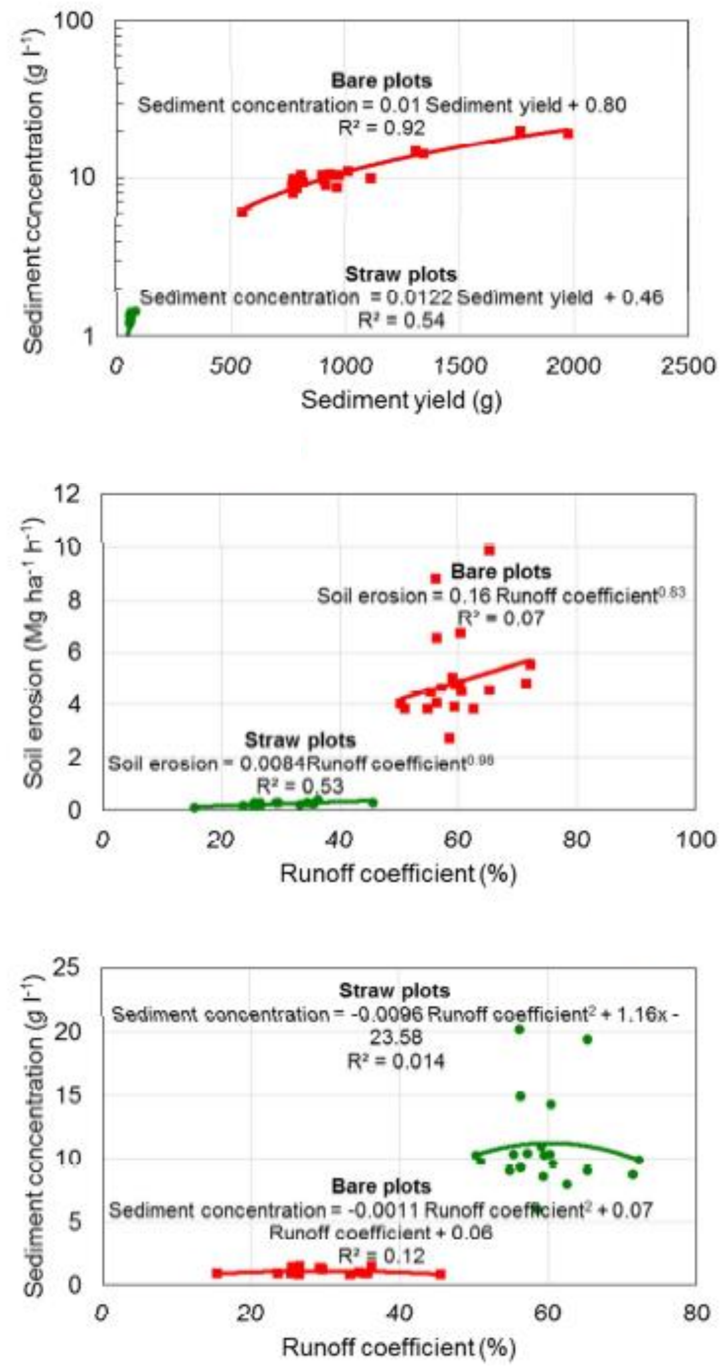

Figure 4. Relationship between sediment concentration (g l-1) and sediment yield (g), soil erosion (Mg ha-1 h-1) and runoff coefficient (%), and sediment concentration (g l-1) and runoff coefficient (%) for all the rainfall simulation datasets. N=40. Bare means no-till bare (herbicide treatments), and Straw means barley straw covered plots.

Plots	Cover (%)		Tp (s)		Tr (s)		Tp-Tr		Tro		Tro- Tr	
N=20	Bare	Straw	Bare	Straw	Bare	Straw	Bare	Straw	Bare	Straw	Bare	Straw
1	1	65	85	375	234	972	149	597	343	1235	109	263
2	2	58	94	485	342	869	248	384	502	1258	160	389
3	3	78	85	485	234	845	149	360	356	1269	122	424
4	0	56	96	495	238	1005	142	510	365	1325	127	320
5	2	54	75	358	256	865	181	507	365	1145	109	280
6	1	52	82	205	245	849	163	644	345	1203	100	354
7	5	53	74	236	296	789	222	553	409	1421	113	632
8	2	59	65	245	258	745	193	500	402	1025	144	280
9	2	57	45	259	245	856	200	597	436	1254	191	398
10	0	52	48	268	275	851	227	583	495	1325	220	474
11	2	59	49	245	265	725	216	480	456	1259	191	534
12	2	65	45	275	245	854	200	579	425	1268	180	414
13	4	75	60	245	265	789	205	544	401	1302	136	513
14	2	48	90	265	284	702	194	437	436	1020	152	318
15	1	66	75	294	295	768	220	474	441	1143	146	375
16	2	45	33	201	247	828	214	627	501	1074	254	246
17	5	59	39	261	256	702	217	441	410	1194	154	492
18	6	55	48	336	235	735	187	399	434	1239	199	504
19	2	85	45	327	285	795	240	468	434	1305	149	510
20	5	90	47	321	245	762	198	441	415	1167	170	405
Average	2.5	61.6	64.0	309.1	262.3	815.3	198.3	506.3	418.6	1221.6	156.3	406.3
Max	6	90	96	495	342	1005	248	644	502	1421	254	632
Min	0	45	33	201	234	702	142	360	343	1020	100	246
Std	1.7	12.0	20.3	90.1	27.3	81.0	29.7	82.5	48.2	102.7	40.3	104.8

Table 1. Values by plot, average, maximum and minimum values, and standard deviation of the cover (plants and straw, %), Time to ponding (Tp), Time to runoff (Tr), Tp-Tr, Time to runoff outlet (Tro) and Tr-Tro in seconds. Bare means no-till bare (herbicide treatments), and Straw means barley straw covered plots. Different letter for each parameter in paired rows (bare and straw) means statistical significant differences according to T-test. P. value <0.05 level.

Plots	Rc (%)		Sc (g l^{-1})		Total R (l)		Sy (g)		Se (g m^2 h^{-1})		Se (Mg ha^{-1} h^{-1})	
N=20	Bare	Straw	Bare	Straw	Bare	Straw	Bare	Straw	Bare	Straw	Bare	Straw
1	50.34	26.51	10.25	0.98	78.53	41.36	804.94	40.53	402.47	20.26	4.02	0.20
2	55.34	29.32	10.36	1.25	86.33	45.74	894.38	57.17	447.19	28.59	4.47	0.29
3	56.12	25.58	20.14	0.98	87.55	39.90	1763.20	39.11	881.60	19.55	8.82	0.20
4	56.32	15.32	14.87	0.89	87.86	23.90	1306.47	21.27	653.23	10.64	6.53	0.11
5	71.42	26.58	8.65	1.40	111.42	41.46	963.74	58.05	481.87	29.03	4.82	0.29
6	60.58	26.50	9.58	0.87	94.50	41.34	905.36	35.97	452.68	17.98	4.53	0.18
7	65.32	29.32	19.35	1.25	101.90	45.74	1971.75	57.17	985.87	28.59	9.86	0.29
8	72.15	26.35	9.88	0.98	112.55	41.11	1112.03	40.28	556.02	20.14	5.56	0.20
9	51.00	33.25	9.70	0.78	79.56	51.87	771.73	40.46	385.87	20.23	3.86	0.20
10	56.32	35.65	9.25	0.89	87.86	55.61	812.70	49.50	406.35	24.75	4.06	0.25
11	57.25	34.50	10.41	0.98	89.31	53.82	929.72	52.74	464.86	26.37	4.65	0.26
12	59.32	45.50	8.50	0.78	92.54	70.98	786.58	55.36	393.29	27.68	3.93	0.28
13	59.48	23.58	10.25	0.85	92.79	36.78	951.09	31.27	475.54	15.63	4.76	0.16
14	59.09	35.32	10.95	0.85	92.18	55.10	1009.38	46.83	504.69	23.42	5.05	0.23
15	60.38	36.25	14.25	1.42	94.19	56.55	1342.25	80.30	671.12	40.15	6.71	0.40
16	60.23	29.58	10.32	1.20	93.96	46.14	969.65	55.37	484.83	27.69	4.85	0.28
17	54.76	25.45	8.98	1.35	85.43	39.70	767.12	53.60	383.56	26.80	3.84	0.27
18	62.54	26.35	7.89	0.81	97.56	41.11	769.77	33.30	384.88	16.65	3.85	0.17
19	58.56	25.35	5.98	0.86	91.35	39.55	546.29	34.01	273.15	17.00	2.73	0.17
20	65.32	29.14	8.98	1.24	101.90	45.46	915.05	56.37	457.53	28.18	4.58	0.28
Average	59.6	29.3	10.9	1.0	93.0	45.7	1014.7	46.9	507.3	23.5	5.1	0.2
Max	72.2	45.5	20.1	1.4	112.6	71.0	1971.7	80.3	985.9	40.2	9.9	0.4
Min	50.3	15.3	6.0	0.8	78.5	23.9	546.3	21.3	273.1	10.6	2.7	0.1
Std	5.7	6.3	3.6	0.2	8.9	9.8	345.4	13.2	172.7	6.6	1.7	0.1

Table 2. Values by plot, average, maximum and minimum values, and standard deviation of the runoff coefficient (Rc, %), sediment concentration (Sc, g l-1), total runoff (Total R, l), sediment yield (Sy, g), soil erosion (Se, g m2 h-1) and soil erosion (Se, Mg ha-1). Bare means no-till bare (herbicide treatments), and Straw means barley straw covered plots. Different letter for each parameter in paired rows (bare and straw) means statistical significant differences according to Ttest. P. value <0.05 level.

	Treatment	N	Mean (SD)	Range	K-S	S-W	T-test
Tp (s)	Bare	20	64 (12)	63	0.012	0.063	**0.001**
	Straw	20	309 (20)	294	0.04	0.007	
Tr (s)	Bare	20	262 (27)	108	0.18	0.009	**0.001**
	Straw	20	815 (81)	303	0.2	0.168	
Tp-Tr (s)	Bare	20	198 (30)	106	0.2	0.387	**0.001**
	Straw	20	506 (82)	284	0.2	0.744	
Tro (s)	Bare	20	419 (48)	159	0.2	0.247	**0.001**
	Straw	20	1222 (103)	401	0.2	0.415	
Tr-Tro (s)	Bare	20	156 (40)	154	0.2	0.407	**0.001**
	Straw	20	406 (105)	386	0.2	0.629	
Runoff coef (%)	Bare	20	60 (6)	22	0.085	0.199	**0.001**
	Straw	20	29 (6)	30	0.088	0.105	
Total runoff (l)	Bare	20	93 (8)	34	0.084	0.198	**0.001**
	Straw	20	45 (10)	47	0.087	0.105	
Sed concentration (g l^{-1})	Bare	20	11 (4)	14	0	0.001	**0.001**
	Straw	20	1 (0,2)	0,6	0.003	0.011	
Sed yield (g)	Bare	20	1015 (345)	1425	0.001	0.001	**0.001**
	Straw	20	47 (13)	59	0.2	0.315	
Erosion (Mg ha^{-1} h^{-1})	Bare	20	5 (1.7)	7	0.001	0.001	**0.001**
	Straw	20	0.24 (0.06)	0.3	0.2	0.275	

Table 3. Statistical analyses. Mean (standard deviation) and range of datasets for the time to ponding (Tp), time to runoff (Tr), time to runoff - time to ponding (Tp-Tr), time to runoff outlet (Tro), and time to runoff - time to runoff outlet (Tr-Tro), total runoff (l), sediment concentration (g l-1), sediment yield (g), and erosion (Mg ha-1 h-1) for the rainfall simulation plots (n=40) over Bare (no-till bare) and Straw (straw mulch). Values for all water loss parameters are in seconds. For the normality assumption, the Shapiro-Wilk (S-W, *p*) tests were applied at the 0.05 significance level and non-normal parameters were transformed to meet normality. The parametric T-test was applied to check for differences between treatments (in bold).