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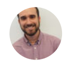
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An economic, perception and biophysical approach to the use of oat straw as mulch in Mediterranean rainfed agriculture land

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ABSTRACT

Soil erosion is a key cause of land degradation in agriculture lands; and it is a worldwide threat that must be solved by means of nature-based strategies to be able to achieve sustainability. The use of mulches can be a solution, but there is a lack of information on long-term effects of the use of straw. Furthermore, little is known about the perception of farmers and the economic cost on the implantation of straw as a conservation measure. Eight paired plots were selected in Sierra de Enguera on an agriculture field to determine the effect of straw cover on soil erosion. Four plots were tilled three times per year (Control) and four plots were not ploughed and 0.125 kg m^{-2} y^{-1} of oat straw cover was applied yearly (Straw). The plots were established in 2002, and runoff and sediment was continuously collected after each rainfall event from 2004 till 2014 when the two managements were applied. The results show an immediate effect of the straw mulches as in these plots the runoff (from 7.7 till 5.9%) and soil erosion (from 47 till 26 Mg ha^{-1} y^{-1}) was reduced already in the first year. The combined effect of the use of straw yearly and the no-tillage strategy resulted in a reduction of the sediment yield, and 11 years later soil erosion rates were two orders of magnitude lower than in the control plot. However, the perception of the farmers on the use of straw is very negative and they claim that subsidies need to be implemented, as the cost of straw mulch is 1.9 times more expensive than traditional tillage.

1. Introduction

Soil erosion is a worldwide concern in agriculture land due to the biophysical impact on soil functions, ecosystem services, water resources and landscape sustainability, but also due to the socioeconomic impacts that are the result of the degradation of the land (Keesstra et al., 2016a; Tilman et al., 2002; Yang et al., 2003). The impact of the millennia old tillage systems and the abuse of herbicides results in high non-sustainable soil erosion rates of the agriculture soils over the world (Logsdon, 2013; Nie et al., 2016). Agricultural land has the highest erosion rates because of the lack of vegetation cover, aggregate stability reduction, soil sealing and crusting, and soil compaction (Atucha et al., 2013; Gómez et al., 2014). To achieve sustainable agricultural management, soils should be protected and their functions should be restored; and for this, a key issue is to reduce soil erosion rates (Rodrigo-Comino et al., 2017a; Zhang et al., 2016).

Strategies to control non-sustainable soil erosion rates in agriculture land are diverse. Some of them such as land levelling, agri-spillways, terracing and soil bunds, results in landforms that contribute to collecting and storing surface runoff (Amare et al., 2014; Mekonnen et al., 2016; Rodrigo-Comino et al., 2017b). However, all these engineered strategies require a high economical investment; and some contribute to compacting and sealing the soil surface layer due to human trampling and passing of heavy machinery, that changes the soil horizons and properties (Becerra et al., 2010; Botta et al., 2012; Sarah et al., 2016).

Moreover, some of the above mentioned strategies were shown not to be efficient when high intensity rainfall events take place. Such

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events generate runoff discharges which are high enough to provoke the collapse of these infrastructures and create concentrate flows, which result in extraordinary soil erosion rates (Myronidis et al., 2010; Romero-Diaz et al., 2010).

Another soil erosion control strategy is to delay the runoff initiation and reduce the runoff discharge through improving the soil infiltration capacity, instead of collecting runoff once initiated to control the soil and water losses. A successful strategy to accomplish this is to cover the soil surface with vegetation and other raw materials. These strategies will avoid direct raindrop impact and soil sealing and will promote infiltration, that in turn will reduce the water and sediment delivery. Plants, geotextiles, and mulches all can accomplish this, and will reduce the runoff discharge due to the surface cover they offer (Giménez-Morera et al., 2010; Keesstra et al., 2016b). Plants, moreover, increase the soil organic matter, the soil fauna and the infiltration rates due to the preferential flow paths generated by the roots (Fischer et al., 2014). However, any type of mulching is not widely accepted by the farmers, as they prefer their soil to be bare to make the management of the crop easier (Marques et al., 2015). In addition to practical reasons, there is also a cultural issue, that farmers see plants (except the crop) as the enemy and they apply herbicides or tillage intensively to avoid them (Sastre et al., 2016).

However, straw mulches have been found to be very efficient to avoid runoff and erosion in different agricultural settings, either in persimmon plantations (Cerdà et al., 2016), vineyards (Prosdocimi et al., 2016) or forest fires affected land (Mataix-Solera et al., 2011). However, all this research assessed short-term measurements, and little is known how persistent the positive effect of straw will be, and if the trend of soil erosion reduction measured by other researchers will stabilize with time, and if this is the case, when the steady-state will take place. Long-term plot monitoring studies are rare due to the economic and labour expenses and the difficulties to maintain the measurement throught the research period. Additionally, under the light of recent reviews (García-Ruiz et al., 2015, 2017) it is clear that long-term experiments are needed to account for the natural variability of environmental factors and rates, and to asses the effectiveness of applied measures. In this paper, we present a study that shows the response of the plots (Straw and Control) that were monitored for 11 years under natural rainfall in Eastern Spain. In addition to the bio-physical effect of the straw mulching practice, it is essential to survey if farmers accept the use of straw mulch or not. The two main goals of this research were to determine the impact of the use of straw mulch in agricultural land to control soil losses at long term (11 years) and to survey the perception of the farmers about the use of straw as mulch. An economic survey of the cost of the tillage and straw mulch management was developed to better understand the perception of the farmers and the chances to be applied.

2. Material and methods

2.1. Study area and experimental setup

To determine the effect of straw mulch, we applied a paired plot strategy in the same way as was done by other researchers that investigated soil erosion and soil hydrology topics (Feng et al., 2016; Fraser and Stone, 2016). We selected the Sierra de Enguera range within the Massís del Caroig in Eastern Spain (750 m.a.s.l., 38° 55′ N, 00° 50′ W), to establish the El Teularet Soil Erosion and Degradation Research Station where high soil erosion rates in Marly soils affected by tillage have been observed (Fig. 1). This is a rainfed and rangeland region with a low population (29 inhabitants Km^2) in the Eastern part of the Iberian Peninsula. The total number of inhabitants in the Massís del Caroig is 25,695 in 900 Km^2 divided in 13 Municipalities (Suppl. Material 1). The climate is typical Mediterranean with a mean annual temperature of 12.7 °C as registered in the nearby meteorological station of Las Arenas Enguera (5 km from the study area). Mean annual rainfall is 540 mm and the soil texture is clay loam. The soil can be classified as a Typic Xerorthent (Soil Survey Staff, 2014).

The experimental set up comprised of a set of four plots under cultivation with moldboard as is the tradition at the study area (Control) and four plots (Straw) covered with oat straw mulch once a year with a dosis of 0.125 kg m^{-2} and with no-tillage and herb's sowing three

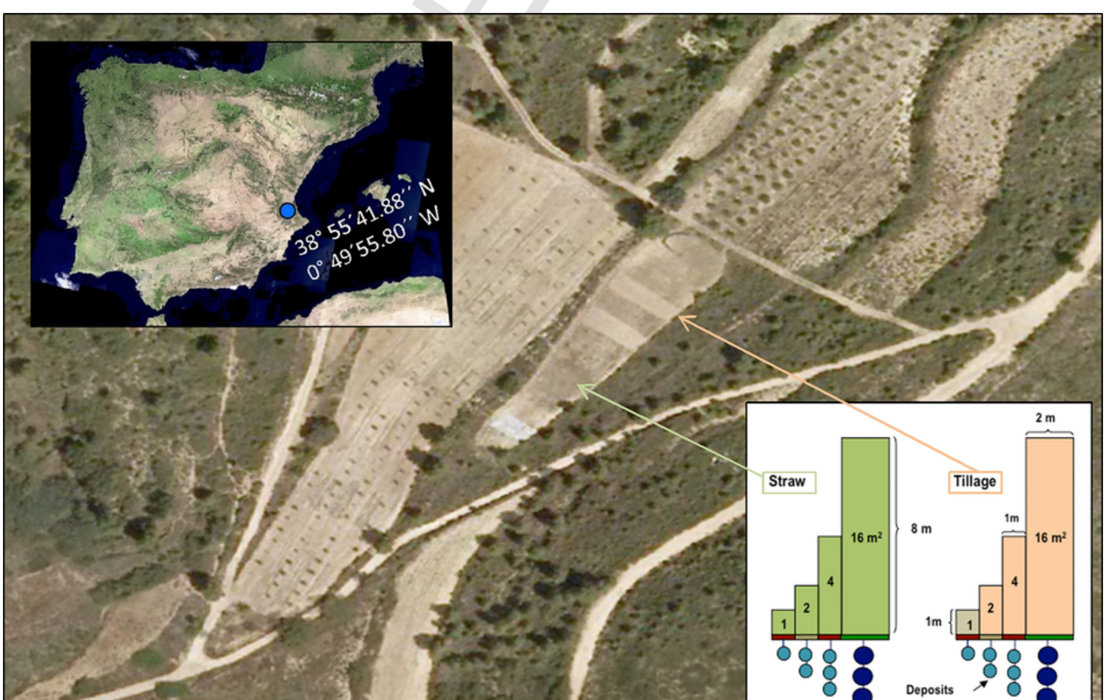

Fig. 1. Location of the study sites and layout of the soil erosion plots. The paired plots of Straw and Control show 4 subplots to have repetitions and to check the effect of the scale.

times per year. The tillage was 20 cm depth as it is a tradition at the study region. The main reason of the mouldboard tillage is to remove the weeds and deeper tillage does not take place at the study area. The tractor used was a John Deere 5050E.

The experiment was initiated in January 2004 and ended in December 2014. Plots were constructed with aluminum sheets that acted as borders, which were 1 mm thick × 50 mm in height × 1000 (2000) mm long to achieve plots of different sizes. Each plot consisted of five subplots of different sizes: (1 × 1; 1 × 2; 1 × 4; and 2 × 8) (Fig. 1). The Control plot was ploughed three per year (April, June and August) to remove the weeds. The field was bare the whole year around with the purpose to represent cultivated agricultural land that is subsidized by the European Union in the Mediterranean areas. Runoff (l) and sediment yield (g) were measured after each rainfall event. Events were separated when at least six hours without rainfall were recorded. Runoff was collected from the plots by a collector (gutter) of 0.15 m (width) × 1 m (2 m in the 16 m^2 plot) in length and 0.15 m in depth (see Fig. 2). The collected runoff was drained into deposits by a 3 cm diameter pipe that drains into containers of 125 and 250 l. The storage capacities were 125, 250, 375 and 600 l for the 1, 2, 4 and 16 m^2 plots, respectively. After each rainfall event, the runoff collected in the deposits was sampled at three depths (5–10 cm from the bottom of the deposit, 5–10 cm from the surface, and in an intermediate depth) to properly determine the average runoff sediment concentration. The samples (1 l) were dried to determine the sediment concentration. The sediments deposited at the collector were weighted and three samples per collector were used to determine the moisture. After that, the sediment yield (g), the soil erosion rates (Mg ha^{-11}) and the runoff coefficients (%) were calculated for each rainfall event. The rainfall was measured with a raingauge and compared with the meteorological station (AEMET, Agencia Estatal de Meteorología) located 5 km from the study site. Soil and vegetation description and sampling were elaborated during the experimental period. Descriptive statistics where applied and regression equations were fitted to the trends and show in graphs.

2.2. Farmer's perception and economic cost surveys

To evaluate the perception of the farmers in the region on soil management, a survey was carried out along the year 2013. To get insights into the perception of the use of straw mulch a set of questions (see Suppl. material 2) were addressed to 81 farmers in the Massis del Caroig study area. The questions were formulated to get a reply (yes or no) from the farmer, and it was recorded as 0 (no) and 1 (yes). The questions were addressed to understand the knowledge of the farmers about the use of straw mulch, their perception of it as a sustainable management, and how it could be promoted. The strategy used was based on personal interviews with the farmers. The first interview was use to select the farmers to be interviewed and to be confident with them. The second interview uses the questioners shown in Table 1. All the question were oral, and the interviewed replied to the researcher that typed the response into the computer to avoid the use of paper in front of the farmers, which use to reduce the confidentiality of the interviewed person. The gender and age of the farmer and the municipality where he/she was coming from was recorded (Suppl. material 2). The economical cost of the management of the plots was surveyed in 2014, the last year of the measurements. We surveyed the cost of the straw bales, the transport of the bales and the spread of the straw in the plots. Our objective is to determine the cost of the straw mulch to research the perception of the farmers about the use or not of soil conservation strategies. This is why we requested from the farmers their opinion about the subsidies they should receive for the use of straw mulch, and from their replies we calculated an average.

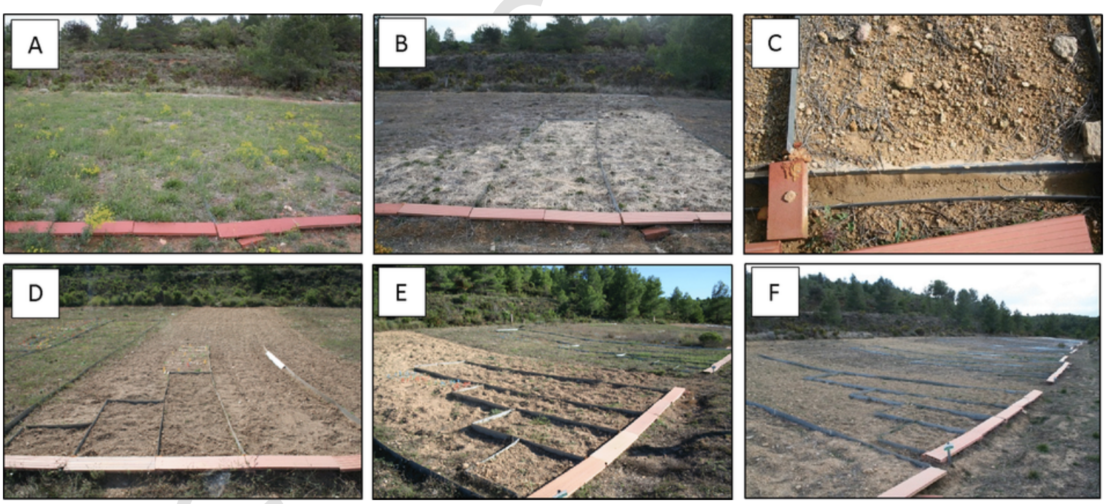

Fig. 2. View of the plots. A: Straw covered plot in spring; B: Straw covered plots in winter; C: view of the runoff collector; D: Control plot in summer after the ploughing; E: Control plot at the end of summer; F: View of the Control plot in winter.

Table 1
Statistical differences in soil erosion between plots sizes and land management (Control and Straw plots).

	Runoff		Runoff coefficient		Soil loss		Sediment concentration	
	p	Dif.	p	Dif.	p	Dif.	p	Dif.
1 m^2	0.046[a]	Yes	0.103	No	0.004[a]	Yes	< 0.001	Yes
2 m^2	0.062	No	0.133	No	0.006[a]	Yes	< 0.001	Yes
4 m^2	0.102	No	0.180	No	0.005[a]	Yes	< 0.001	Yes
16 m^2	0.069	No	0.121	No	0.010[a]	Yes	< 0.001	Yes

[a] When normality test (Saphiro-Wilks) failed, a Mann-Witney *U* test was performed instead of One-way ANOVA.

2.3. Statistical analysis

Runoff, runoff coefficient, soil loss and sediment concentration were showed as box plot graphics with median, averages (dashed lines) and percentiles (5th and 95th). To compare the results obtained in both paired plots (Control and Straw), a one-way ANOVA at $p > 0.05$ was performed with Sigma Plot 12.0 (Systat Software Inc.), after testing the data normality (Saphiro-Wilk test). However, soil loss and sediment concentration did not obtain a normal distribution. Therefore, a Tukey test was performed, where significant differences at $p < 0.001$ level were assessed.

3. Results

3.1. Rainfall

The mean annual rainfall after 11 years of measurements was 571 mm, with a very wet year, 2007 (749 mm) and a very dry one, 2005 (288 mm) (Fig. 3a). The inter-annual variability during the 11 years of measurements of the rainfall is similar to the ones registered since 1942 at the study area. The rainfall was measured daily. The largest rainfall event took place in September 28th 2009 with 140 mm. One rainfall event reached 111 mm in February 28th 2013, and four more rainfall events surpass 90 mm. Twenty out of 470 rainy days surpassed 50 mm day^{-1} (see Fig. 3b). On average, 1 out of 8.5 days was a rainy day: 470 out of 4018 days. The largest soil erosion events lasted more than one day, and they reached total rainfall that surpassed 10 times 100 mm (see Fig. 3c).

3.2. Runoff

The runoff discharges were twice at the control than at the straw covered plots. It ranged from 491 l in the 1 m^2 plots till 2079 l in the 16 m^2 plot, with a total value of 4098 l in the straw plot (Fig. 4a). The control plot contributed with 865 l in the 1 m^2 plot and reached 3678 l in the 16 m^2 plots during the 11 years of measurements. After eleven years, a total discharge of 7052 l was found for the four control plots (23 m^2 in total). There was a high inter-annual variability, with the wettest years (2004, 2007, 2009, with 699.8, 749 and 728.5 mm) with

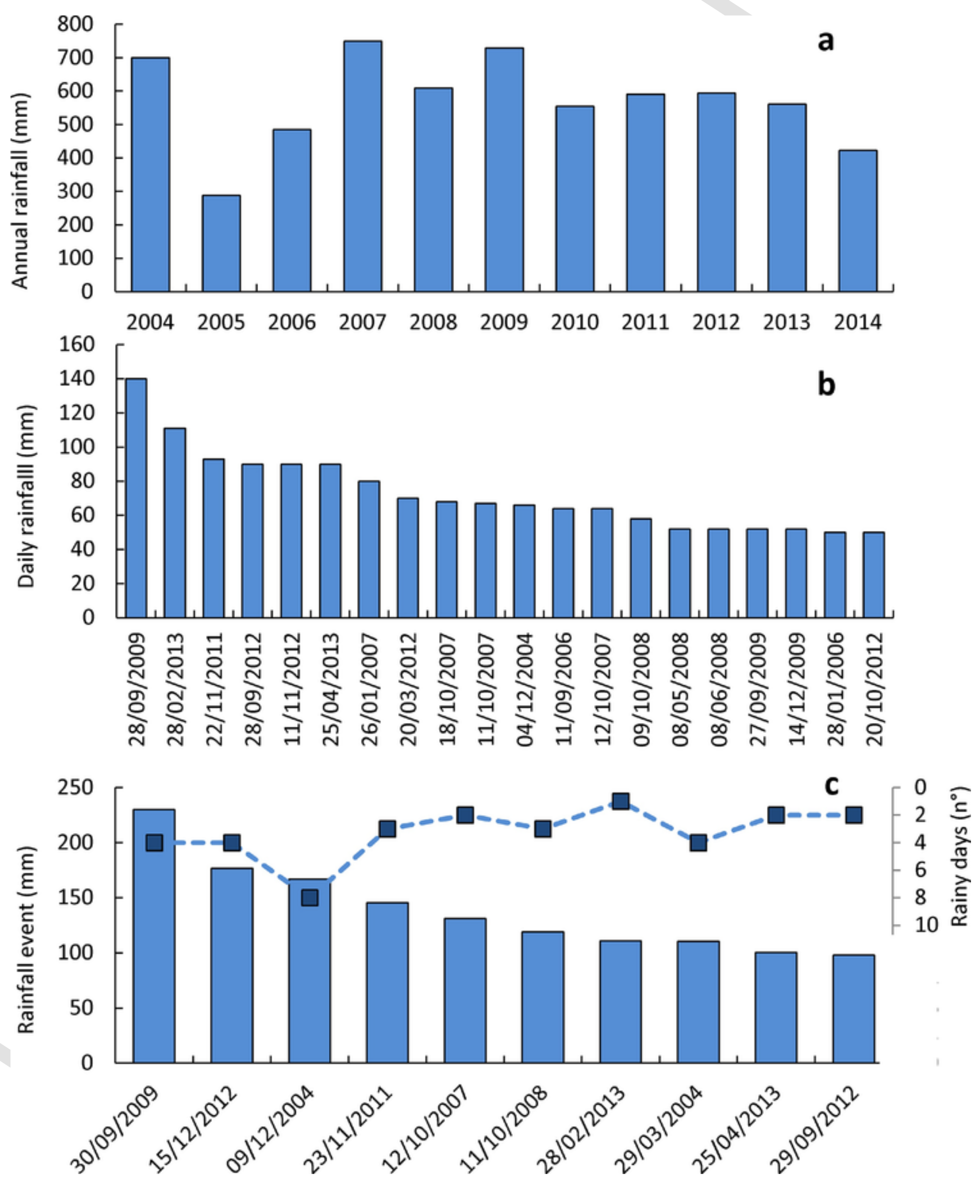

Fig. 3. Yearly rainfall (a), the twenty largest daily rainfall events in the study area (b) and the largest erosion events (c).

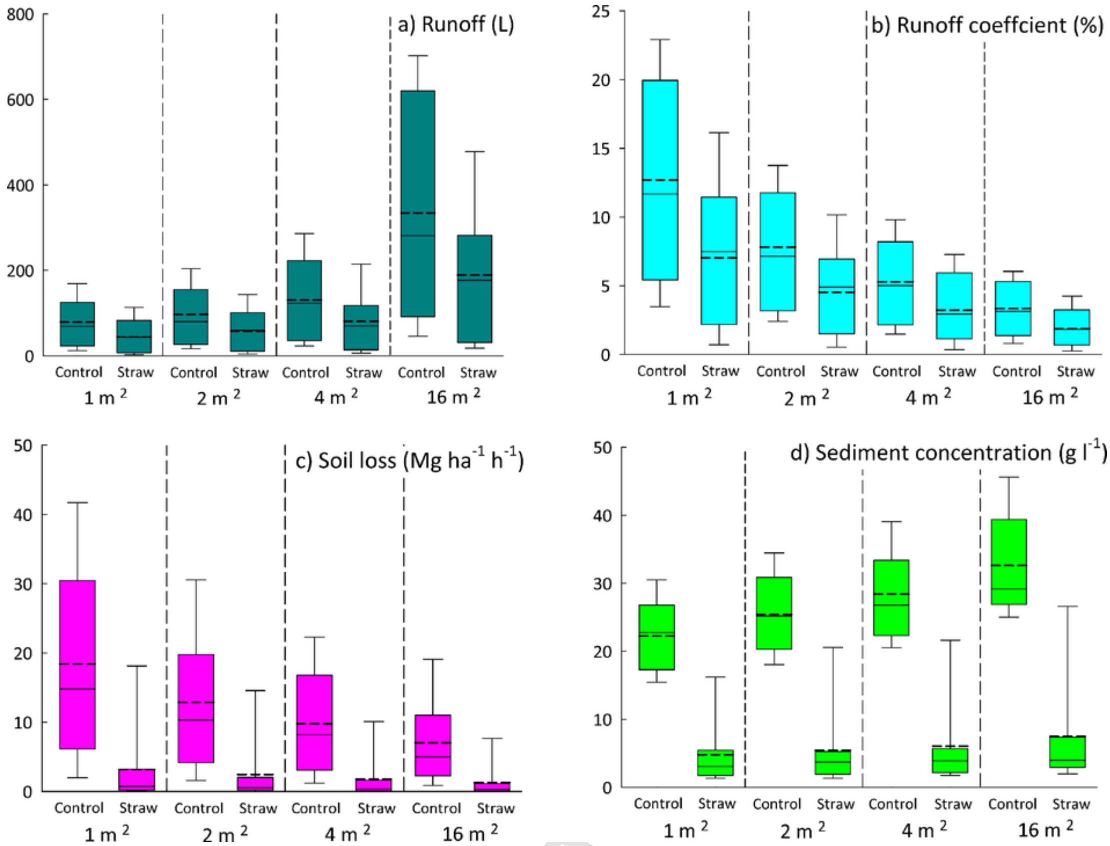

Fig. 4. Runoff, runoff coefficient, soil loss and sediment concentration dependent on the size of the plot.

high runoff discharges, 940, 893 and 516 l; and 1225, 1393, and 1123 l, respectively for the straw and control plot. The driest years (2005 and 2006 with 422.4, 288, 485 and 422.4 mm) yield much lower runoff discharges, 60, 479, 27; and 85, 691 and 179 l, respectively for the straw and control plots.

The runoff coefficient (Fig. 4b) showed that there was a clear impact of the size of the plots on the runoff delivery. For the straw plot, the runoff ranged from 7 to 1.9% of the rainfall with an average value of 4.2%. For the control plot, the trend was similar but the discharge was higher, ranging from 12.7 till 3.3% from the 1 till the 16 m^2 plots in the Control plot. The runoff coefficient at the Control plot was 7.3% on average. The one-way ANOVA test showed that only statistical differences was occurred in runoff on the 1 m^2 plot. On the other, no differences were found for the other plot sizes and runoff coefficient results (Table 1).

3.3. Soil loss and sediment concentration

Straw covered plots reduced soil loss rates efficiently after the application of the straw mulch (Fig. 4c). The control plot had an erosion rate of 12 Mg ha^{-1} y^{-1} on average, meanwhile the straw covered plot only had an erosion rate of 2.2 Mg ha^{-1} y^{-1}. In addition, there is a decreasing trend for the observed soil losses along the 11 years of study in the Straw covered plot, while the soil erosion rates in the Control plot does not show any trend. The smallest plots have the highest erosion rates, and they range from 3.18 Mg ha^{-1} y^{-1} in the 1 m^2 plot to 1.31 Mg ha^{-1} y^{-1} in the 16 m^2 plot for the control plot. The same situation was registered in the straw plot, ranging from 18.43 Mg ha^{-1} y^{-1} till 7.04 Mg ha^{-1} y^{-1} in the 16 m^2 plot. Statistics did not show normality of the data, therefore a Mann-Witney *U* test was conducted. For all of plot sizes statistical differences were found between Straw and Control plots (Table 1).

The sediment concentration showed a reduction from 2004 till 2014 for the straw plot, meanwhile in the control plot the sediment concentration did not show any temporal trend (Fig. 4d). The Control plot shows 4.6 times higher sediment concentration that the Straw one for the average values and is consistent for the whole set of plots. The sediment concentration gets is higher as the plots get larger. For sediment concentration, data showed normality and statistical difference between straw and control plots (Table 1).

3.4. Farmer's perception

The opinion of farmers about soil management strategies is shown in Fig. 5. Farmers are on average 54 years old, which is a consequence of the emigration and the low birth rate in the study area, which is a widespread issue in the North Mediterranean mountain areas. Another characteristic is that only 10 out of 81 farmers are women. The ageing of the population and the gender unbalance is a widespread phenomenon in the rural areas of Spain, Portugal, Italy, France and Greece, and more and more found in Europe and the developed countries.

The survey shows that the farmer does not known what is mulch (84%) although all of them know what is straw. The Massís del Caroig farmer community knows what is soil erosion (83%) but only 50% of them consider soil erosion as a real problem, and then usually only when it is related to gully formation, but not because of its effects on soil fertility. Farmers would prefer do not having straw in their farm (83%) and only 3 out of 81 farmers used straw in their fields. 50% of the farmers acknowledge that straw reduces soil losses, but they do not believe that straw will improve soil quality (33% said Yes) and biodiversity (44%).

Farmers prefer tillage (88%) and herbicide (89%) management than straw cover. They also see straw as a dirty type of management (89%)

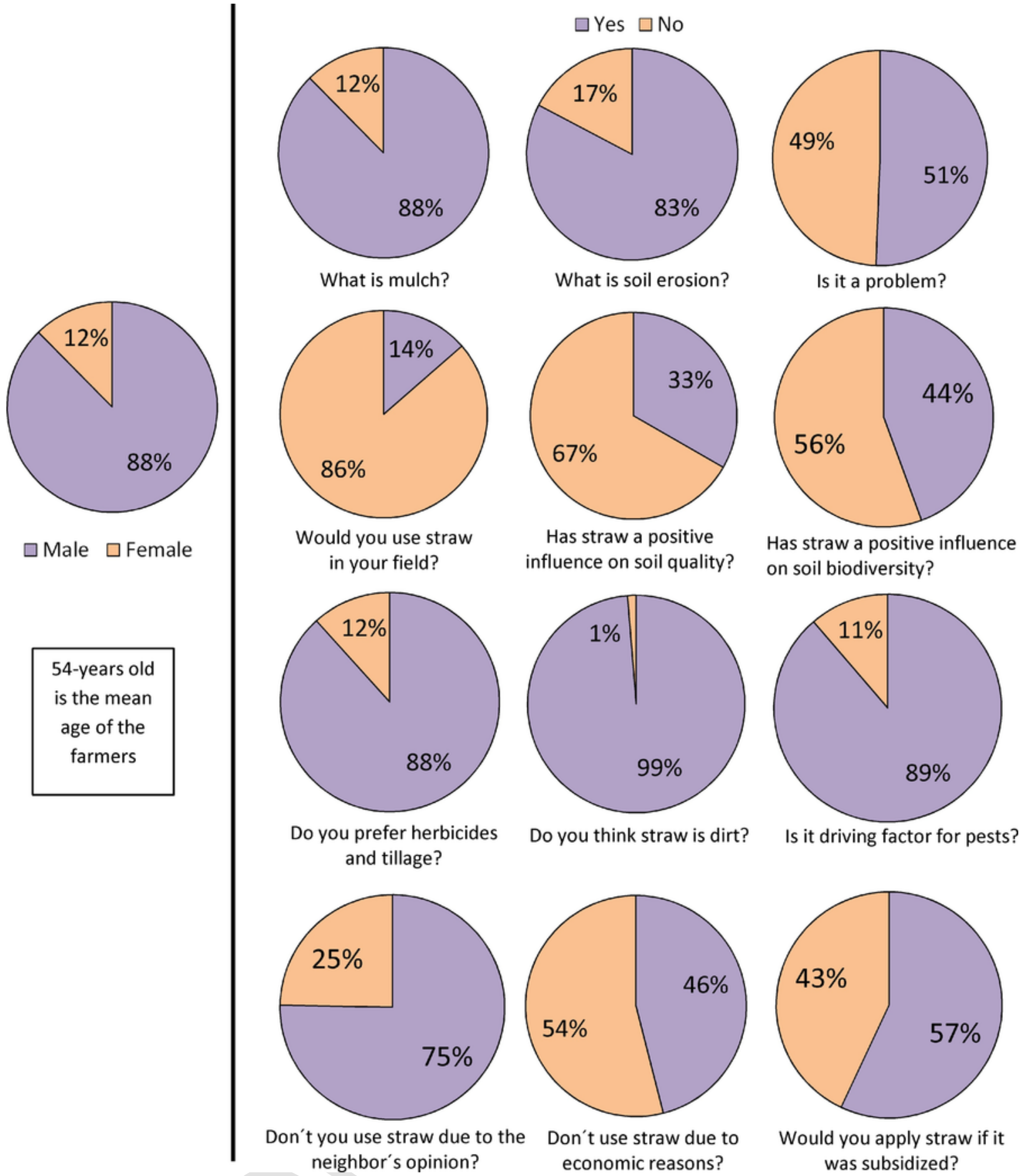

Fig. 5. Farmer's perception of soil erosion and the application of straw mulch.

and the main reason to avoid straw is that they consider that it is dirt in the farm (99%). The cost of the straw is not the main reason to avoid its use, as 46% of the farms consider this one of the reasons, but a more important reason for the farmers is that they see straw as the origin of pests (89%), and the negative opinion of the neighbours (75%) is relevant for them.

An option to encourage farmers to use straw is to subsidize this management strategy. In Table 2, we can observed that only 57% of the farmers would apply straw to their fields if subsides would be implemented and the farmers are requesting on average 44 € ha^{-1} to use straw, once the expenses are also paid. Farmers perceive the use of straw as a social problem for them as this will damage their reputation in the community (8% do not see straw mulch will increase their reputation) and they think straw will not increase the yield (only one out of 81 thinks that it will increase) of the farm. No one of the farmers thinks the straw will increase the final income of the farm, and this is related to the fact that straw mulch is seen as an organic farming technique and only 5 out of 81 farmers consider organic farming a potential solution. However, farmers do acknowledge that chemical farming is a health risk for them (78%) and organic farming is a healthier solution, which is demonstrated by a 58% support of the idea that organic farming is healthier. Farmers also accepted that they use dangerous chemicals that could affect their health (91%) and of the health of future generations (80%). Most of the social problems of the ageing rural population at this study area are shown in the interviews. Only 24 out of 81 farmers have a successor for the farm. The farmers also see that the Environmental issues of the region have not been solved after 20 years of EU Common Agriculture Policies (31%). However they consider that the subsidies promoted by the EU Common Agriculture Policies would be implemented, this would be a solution to compensate the loss of credibility by the farmers that use straw (54%) and will show

Table 2
Farmers' perception about productivity, organic farming and reputation. Positive answers in total and percentages.

Question (n = 81)	n	%
Is the use of straw improving your reputation as farmer?	6	7.4
Is the use of straw improving the yield of your farm?	1	1.2
Does the straw increase your income?	0	0
Is organic farming a solution for the farmer because economic issues?	5	6.2
Is organic farming a solution for the farmer because healthy issues?	47	58
Is chemical farming a problem due to the health risk?	63	77.8
Do you have a successor for your farm?	24	29.6
Will affect the use of chemicals future to next generations?	65	80.3
Have you being in contact with chemicals that are now recognized as no healthy?	74	91.4
Did the EU policies (subsidies) improve the environmental conditions of your region?	12	14.8
Did you see an improvement in the last 20 years in the environment health?	25	30.9
Is the payment to compensate the loss of credibility or reputation?	44	54.3
The payment will make the community will see you as a clever farmer because the extra income?	65	80.3

that a farmer implementing straw is not a sloppy farmer with dirty fields, but a clever entrepreneur (80%).

3.5. Economic cost

The local cost of straw is low due to a high production of cereals in the nearby regions of the Massís del Caroig. However, the transport is a constraint due to bad road quality and the rugged terrain. Straw bales of 20 kg cost 0.90 € in the field (0.045 € Kg^{-1}). The transport can range between 0.8 and 3.1 € $bale^{-1}$ in the study areas, as it is a remote and open rangeland with small roads. The transport's cost for the Soil Erosion and Degradation Research Station was 2.15 € $bale^{-1}$ (0.1074 € Kg^{-1}). The application in the field of the straw at a rate of 0.125 kg m^{-2} will be 1.25 € per bale (0.0625 € Kg^{-1}). The total cost of the application therefore was 4.3 € per bale (0.215 € Kg^{-1}) and 268.75 € ha^{-1}. Tillage management applied three times ploughing and the cost was in total 204 € ha^{-1}. In addition, in the Straw mulch plots weeds were sown three times per year, and will reach a cost of 125 € ha^{-1}. In total, the Straw mulch management costs 393.75 € ha^{-1} annually while the tillage management costs 204 € ha^{-1}.

4. Discussion

4.1. Short and long term benefits of straw mulching

Soil erosion control is necessary in agriculture land to achieve sustainable management because of the high erosion rates that occur under conventional agricultural practices. Our measurements over a period of 11 years in four plots under tillage management (Control) show these unsustainable high erosion rates with an average value of 12 Mg ha^{-1} y^{-1}. This is far beyond the acceptable erosion rate of 1 Mg ha^{-1} y^{-1}, which is the rate that the soil would have the capacity to recover the soil lost (Alewell et al., 2015). The long-term experiment in our research site gave insights into the dynamics of soil erosion over a longer period of time in an agricultural setting. The information we retrieved from the researched plots shows that soil erosion is very variable and depends on three factors: scale, rainfall amount and management.

The scale effect shows a reduction in the erosion rate with and increasing plot size. This was found also by other researchers with a similar plot approach (Bagarello et al., 2013), and by soil erosion reviews done by (García-Ruiz et al., 2015) and (de Vente et al., 2013). The second key factor is the rainfall amount; the higher the total annual rainfall the higher the soil erosion is (see Fig. 6). The importance of the amount of rainfall has been researched by other fellows such as Wang et al. (2014) and Beguería et al. (2015) as they found that the total kinetic energy is the key parameter that determines the soil erosion.

The third key factor is land management. Land management can change the fate of the soil erosion processes as we demonstrate here with the use of straw mulch, which reduces soil losses by two orders of magnitude after a decade of mulching and no-tillage, and bring the erosion rates close to sustainable values. The effect straw is immediate such as was found by (Prosdocimi et al., 2016) in vineyards as the application of the straw reduced the runoff discharge by 23% under extreme rainfall events under simulated rainfall. The key impact of the straw mulch is that is has an immediate effect on soil erosion control, as it reduces in the soil erodibility. This resulted in a decreased in sediment concentration from 38 till 26 g l^{-1} in the first year. The reason of this immediate effect is the reduction of the soil erosion rates is the effect of straw in the raindrop impact as the straw act as a mulch. Less runoff and very less sediment in the runoff resulted in a reduction from 29 till 15 Mg ha^{-1} y^{-1} in the soil erosion the year the mulch was applied. This is an immediate positive effect of the straw cover.

Apart from the immediate effect the straw has on the resilience of the soil to erosion, this research also shows the longer-term effect of mulching. Our results show that the impact of the straw continues for years and that the no-tillage and the vegetation cover and the straw applied yearly resulted in a progressive reduction in the runoff discharge (Fig. 7a). This is what explains that 10 years after the first application of the mulching, runoff discharge in the Straw plot was 5 times lower than in the Control plot (Fig. 7b). The sediment concentration showed a similar trend; although the reduction in the sediment concentration was sudden once the mulch was applied. Four years after the mulch application the sediment concentration was 7 times lower in the Straw than in the Control plot. This positive influence of the straw mulch reached its highest values after a decade, when the sediment concentration was 16 times higher in the control plot than in the straw mulch one.

Fig. 7c shows the trend in soil erosion along the 11 years of research by means of the ratio between the soil erosion in the Control and Straw mulch plot. During the first five years, there was one order of magnitude reduction and after 10 years it was two orders of magnitude, which seems a steady-state situation. Eleven years after the start of the use of straw, soil erosion rates were 128 times lower than in the control plot.

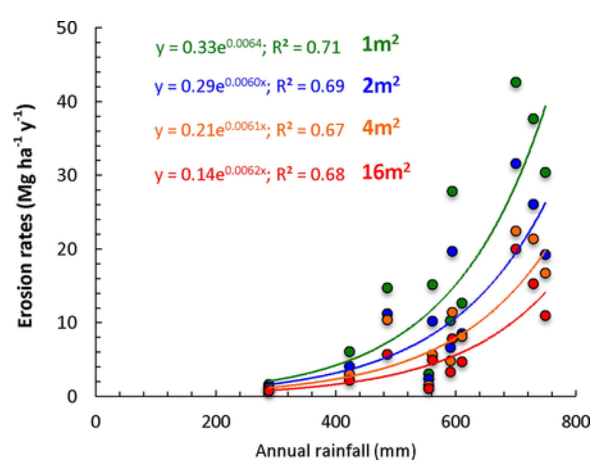

Fig. 6. Relationship between erosion rates and annual rainfall in each plot size.

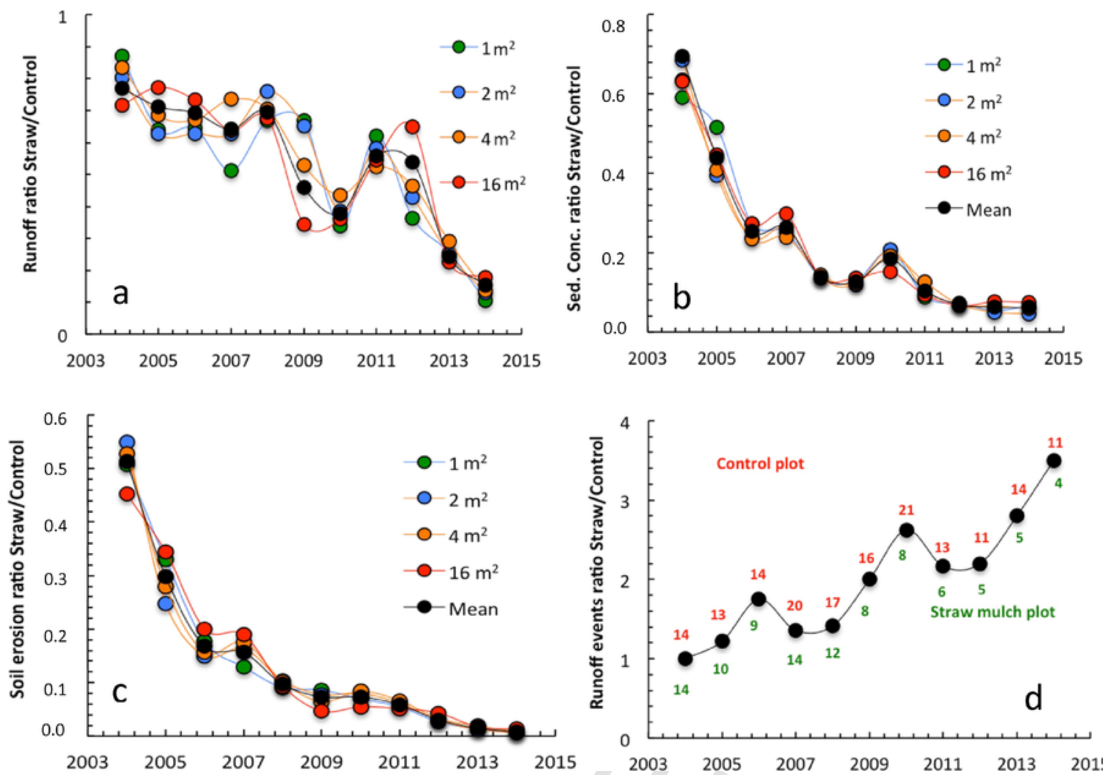

Fig. 7. Temporal changes from 2003 to 2015 in runoff (a), sediment concentration (b), soil erosion rates (c) and runoff event ratios between the Straw and Control plots.

The straw effect on the reduction in the water and sediment delivery can also be seen in the number of erosion events per year (Fig. 7d). The changes induced by the straw mulch reduced the runoff generation and year after year, the runoff events were less and less in the plot with straw cover. Fig. 7d shows the clear trend that end in 4 runoff events along the whole year 2014 for the straw covered plot and with 11 runoff events occurred in the control plot. In 2004, both plots had the same number of runoff events per year (14). The straw and the development of a plant cover on the straw covered plot results in a delay in the runoff initiation that was clearly found with rainfall simulation experiments when straw is applied (Prosdocimi et al., 2016). This is also due to the increase in the soil organic matter and biological activity that was assessed by (García-Orenes et al., 2012) in the same plots.

With these results we demonstrate a very efficient reduction in the soil losses that can help to improve other strategies such as cover crops, geotextiles, rotations, grass strips and other strategies that help to achieve sustainable development of the agricultural sector (Alliaume et al., 2014; Kirchhoff et al., 2017; Novara et al., 2013). The positive impact of the straw is very efficient at both short and long-term. There is an immediate effect of the mulch as it avoids raindrop impact causing splash erosion (Fernández and Vega, 2014; Gholami et al., 2013), but over a longer period the mulching practice is reinforced by the growth of weeds that will also reduce the overland flow velocity and will increase infiltration (Pan et al., 2017).

The results found at the El Teularet Soil Erosion and Degradation Research Station show that straw mulch can be the solution for the non-sustainable managements found in Mediterranean orchards and vineyards (Rodrigo-Comino et al., 2016; Hondebrink et al., 2017) as a consequence of the high erosion rates. Straw mulch can be very positive during the plantation of vines due to the high erosion rates registered during the plantation works and the year after (Cerdà et al., 2017). The benefit that the straw mulch produces must be taken as a service such as Parras-Alcántara et al. (2016) found with olive litter, and Galati et al. (2016) highlighted the need to assign the right payments for those services. Then, although straw is more expensive must be subsidised to maintain the services offers to the human societies.

4.2. Farmer's perception and economic constraints

This research aimed to go further than the pure biophysical approach to the soil erosion problem, and the solutions such as straw mulch. We also researched the cost of both management strategies and we found that straw mulch cost 394 € ha^{-1} meanwhile the traditional tillage cost 204 € ha^{-1}. This is 1.93 times lower. Even though, the straw mulch has demonstrated to reduce soil erosion by in 2.8 times after initial application and 128 times less erosion was found after a decade, the farmers mainly see the first information: straw mulch is more expensive. Only the society notes the second part: straw mulch is more sustainable as will reduce the soil degradation in the field and the impact outside the fields. Our research at the Massís del Caroig shows that there is a contrasted view between the scientists and policy makers on the one hand and the farmers on the other hand, about the use of straw mulch. This gap in perception needs to be acknowledged and bridged, as it forms the key constrain to reduce the soil and water losses in agriculture land.

In general, farmers dislike straw on their fields, however they claim that for some subsidies they would be willing to apply straw in their field. The European Common Policy induces the farmers to claim for subsides as they are relevant for the rural economy. The farmers are well informed about the subsidies but they do not receive information about the ecosystem services their crops can supply and also that they are the key to built a sustainable landscape. Here, at the Massís del Caroig, we found that the ecosystems services are highly valued by the society, but farmers do not see the value of soils and landscape elements. This contradiction in the perception of different societal groups is also found in other rural regions of the world such as the Wilsons River in NSW Australia (Smith and Sullivan, 2014). Similar findings were found related to the farmer's perception about biodiversity on organic and chemical management (Kelemen et al., 2013). Therefore, even tough poor agriculture practices such as intense tillage are a threat to ecosystem services of the land, and the use of straw mulch could solve this problem; farmers will not accept to use these strategies without the incentives of subsidies. This research clearly showed that subsides would be the best strategy for a fast implementation of sustainable agricultural practices such as straw mulching. The European farmers are led in their decision-making in terms of their land management by subsidies. And therefore, any change into the right direction of agriculture management strategies will need the incentive of funding by subsidies (Delmotte et al., 2016; Gutzler et al., 2015).

4.3. Straw and plot size reduce the connectivity of the flows

The research carried out at the El Teularet Soil Erosion and Degradation Station during 11 years demonstrate that the straw mulch reduce the soil and water losses as a consequence of the reduction in the connectivity of the flows. The straw avoids the impact of the raindrops on the soil surface and reduces the surface wash velocity, and as a consequence the connectivity of the flows is reduced. The connectivity is also affected by the size of the plots as a consequence of the effect of the scale in the soil erosion (Cerdà et al., 2013). Agriculture land is also affected by the impact of the scale of measurements such as Masselink et al. (2017) found using rare-earth oxide tracers in agriculture catchments and Cerdà et al. (2017) found by means of rainfall simulators at pedon scale. The concept of connectivity also is used in forest lands, and is of help for areas affected by disturbances such as forest fires (Williams et al., 2016) where the connectivity is enhanced by the effect of the fire. The use of straw mulches also contribute to disconnect the flows in fire affected land such as Vega et al. (2015) and Robichaud et al. (2013) demonstrated.

The connectivity issue explain why the soil erosion is higher on the smaller plots, as most of the sediments detached by the raindrop impact and the surface wash are exported out of the plots, and the transmission losses are lower. This was also found by Bagarello et al. (2015) when testing the assumptions and procedures to empirically predict bare plot soil losses under a Mediterranean Climatic conditions. Di Stefano and Ferro (2017) confirmed the effect of scale at basin scale in Sicily. Both approached are based on experiments to understand the geomorphological work (Seeger et al., 2017). Here we also added the perception and economic view of the problem of control the soil erosion rates.

The effect of the scale and the connectivity of the flows also bring a new topic: the increase of sediment concentration related to the increase of the plot size as we found in this research. This is due to the fact that the soil erosion in the small plots are a result of the sediment detachment by the raindrop impact, and surface wash, but not as a consequence of rill formation due to the short distances (1 m in the smallest plot). However, as the plot increase the length the rills will form and then the sediment concentration will be larger (Cao et al., 2014; Thomaz and Ramos-Scharrón, 2015). The data collected at the El Teularet Soil Erosion and Degradation Research Station shows that once the plots increase in size the runoff decrease, but the sediment concentration increase. The final results is a reduction of the soil losses as larger is the plot. This is very clear when straw mulch is applied as the mulch act as sinks of runoff and sediments.

5. Conclusions

The use of straw is a fast and efficient strategy to reduce soil losses in Mediterranean agriculture land. The positive effect is shown in two ways: i) an immediate reduction in the runoff discharge and sediment delivery; and ii) a progressive reduction during a decade that resulted in soil erosion rates two orders of magnitude lower in the Straw mulch than in the Control plot. However, the farmers of the region see the straw mulch as a non-acceptable management strategy due to cultural reasons, and because is 1.93 times more expensive than tillage. Farmers claim for subsidies to implement the use straw mulches, and this show a lack of information about the ecosystems services the farmers supply to the society.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecoleng.2017.08.028.

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