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Policies can help to apply successful strategies to control soil and water losses. The case of chipped pruned branches (CPB) in Mediterranean citrus plantations

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ABSTRACT

There is a need to devise management strategies that control soil and water losses in agriculture land to allow the design of proper policies to achieve sustainability. It is the responsibility of scientists to work with other actors to co-construct strategies that will lead to sustainable land-use policies. Using chipped pruned branches (CPB) as mulch can be a viable option because they represent local (in situ) organic material that can restore soil nutrients and organic matter. This research assesses: i) the perception of farmers towards different types of management strategies and CPB's costs; ii) the biomass yield of citrus branches and the impact of CPB on soil properties; iii) how CPB affects soil erosion and runoff generation in citrus plantations; and, iv) a discussion about how to favour the use of CPB thought successful policies. To achieve those goals we carried out: i) one-hundred interviews to assess the perception of farmers and twelve interviews to assess the economic balance of twelve land owners; ii) soil was sampled at 0–2 and 4–6 cm depths; iii) pruned material was surveyed for 40 trees; and iv) forty rainfall simulation experiments ($55\,mm\,h^{-1}$) were carried out in two citrus plantations at paired sites (Control versus CPB), in La Costera District in Eastern Spain. Forty circular ($0.25\,m^2$) plots were installed in four rows ($4 \times 5 = 20$ plots) in control (CON) and CPB plots ($20 + 20 = 40$ plots) to perform the rainfall simulations over one hour. The cost of chipping ranged from 102 to $253\,€\,ha^{-1}$, and was related to the size of the farm. The soil quality, runoff and erosion assessment showed that CPB is a suitable strategy. CPB increased organic matter from 1.3% to 2.9% after 10 years in the 0–2 cm depth layer, while the 4–6 cm layer was largely not affected (OM moved from 1.1 to 1.3% after 10 years), and soil bulk density showed a similar trend: a decrease from 1.36 to $1.16\,g\,cm^{-3}$ in the surface layer with no change in the subsurface layer. The hydrological and erosional responses were different between CON and CPB. The CON plots initiated ponding (40 s) and runoff (107 s) earlier than the CPB plots (169 and 254 s, respectively); and runoff discharge was 60% in CON vs 43% in CPB plots. Sediment concentration was four times larger in the CON plots than in the CPB ($11.3\,g\,l^{-1}$ vs $3\,g\,l^{-1}$), and soil erosion was $3.8\,Mg\,ha^{-1}\,h^{-1}$ vs $0.7\,Mg\,ha^{-1}\,h^{-1}$. CPB mulches were effective at controlling soil and water losses in Mediterranean citrus plantations as they showed the relationship between vegetation/litter cover and soil erosion rates. However, the farmer's perception survey showed that the use of CPB was not welcomed nor accepted by the farmers. Policies that aim to promote CPB as soil conservation mulch need to be promoted by

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subsidies as the farmers requested, and by education to demonstrate the positive effects of CPB to of the farming community.

1. Introduction

Preserving soil is essential for sustainability, it provides vital functions. Soils produce food, biomass and raw materials, provide a habitat for flora and fauna, gene pools, sequester carbon, and manage water, minerals and biologic cycles. Climate change, desertification, and lack of water resources or food supply can be eventually successfully addressed only if soil sustainability issues are solved. The United Nations and European Union have highlighted soil protection as a key land-use policy issue (van Meijl et al., 2006; Keesstra et al., 2016a; Paleari, 2017). There is a need to design proper policies to achieve sustainability, and for this, the scientific community should produce information in collaboration with land managers and other actors, which will guide policy makers to implement the most efficient managements and strategies. Land degradation processes are a consequence of human misuse and mismanagement of natural resources due to economic activities that result in overgrazing (Gutiérrez et al., 2011; Schnabel et al., 2013), excessive tillage (Biddoccu et al., 2016; Novara et al., 2011), forest disturbances (Keesstra et al., 2016c; Navalho et al., 2017), high sediment yield due to mining (Brown et al., 2014) or as a consequence of the construction of road and road embankments (Jordán and Martínez-Zavala, 2008; Jordán et al., 2009) and abuse of herbicides (Taguas et al., 2015).

Soil erosion is a major threat to sustainability due to the immediate damage it causes to the soil system (Rodrigo-Comino and Cerdà, 2018). Many agricultural areas are highly prone to soil erosion due to the lack of vegetation cover, intense tillage, soil compaction due to heavy traffic and the use of biocides that reduce biologic activity such as plant growth; consequently soil forming processes can be impeded (Brevik et al., 2002; Brevik and Fenton, 2012). Non-suitable land management strategies and actions threaten the sustainable use of agricultural soils (Mhazo et al., 2016; Salomé et al., 2016) damaging soil quality (Bogunović et al., 2016; Khaledian et al., 2016). The impact of millennia old tillage on soils has reduced soil organic matter and aggregate stability in many regions worldwide (Rodrigo-Comino et al., 2018). Tillage has produced a long-term increase in soil bulk density, although each ploughing cycle reduces soil compaction temporally and removes the soil crust to induce higher infiltration rates (Rodrigo-Comino et al., 2016a; Rodrigo-Comino et al., 2017a). The use of herbicides and tillage result in a similar trend without any positive feedback and, as a result, soil degradation is faster with higher erosion rates (Cerdà et al., 2017a). Moreover, herbicides lead to the progressive compaction of soil due to the lack of tillage and organic matter, and therefore increase runoff rates and sediment yield (García-Díaz et al., 2017). Some researchers have already highlighted this impact of herbicide use, which makes agricultural land highly vulnerable to degradation (Keesstra et al., 2016b), and also it is relevant the impact of the plantation works (Rodrigo-Comino et al., 2017b).

The need to develop new sustainable management practices in agriculture is widely accepted (Araya et al., 2010; Marques et al., 2015; Mekonnen et al., 2015; Sastre et al., 2016; Cerdà et al., 2017b). However, there are three key points that need to be prioritized: i) the construction of new strategies in collaboration with farmers and policy-makers to achieve sustainability; ii) the acceptance of these new strategies by farmers; and, iii) development of policies that will make the new strategies suitable for farmers. The importance of well-designed and implemented policies for sustainable land management is well accepted in both agricultural and forest ecosystems (Muñoz-Rojas et al., 2015).

Citrus plantations in Spain were originally located in the bottoms of valleys, on fluvial terraces and deltas where flood irrigation is possible. During the last century there was an expansion of Mediterranean citrus plantations due to market growth in Northern Europe and technical and energy production improvements that allowed water to be pumped to higher altitudes, first by steam power (1860s) and later by electricity (1930s). Over the last 30 years, the expansion of citrus plantations reached ever-higher terrain as a result of the introduction of drip irrigation, which allows irrigation on sloping landscapes. This resulted in a new agricultural system where unsustainable soil erosion rates are taking place due to intensive ploughing and the excessive use of herbicides (Cerdà et al., 2009). This is not a unique or special situation; it has also been found with other crops such as persimmon (Cerdà et al., 2016), apricot (Keesstra et al., 2016c) olive (Gómez et al., 2014; Taguas et al., 2015), vineyards (Rodrigo-Comino et al., 2016b), and avocado (Bravo-Espinosa et al., 2014) plantations. This clearly shows that there is a need to develop sustainable management strategies to avoid high soil losses in several types of crops. The most effective option known to date is to use local materials such as rock fragments, living ground cover (Zhang and Chen, 2017), or pruned branches. Pruned branches need to be chipped to produce proper mulch that covers the soil and allows machinery and people in the orchards to move around. Chipping also accelerates decomposition of the branches which contributes to soil fertility and biomass turnover and helps to create a mulch (CPB) that protects the soil from the impact of raindrops, supplies organic matter, and increases biological activity (Walmsley and Cerdà, 2017). Our hypothesis is that CPB soil cover affects soil quality over the long-term following decomposition, therefore inducing an improvement of the soil through the addition of organic matter, which also improves soil hydraulic conductivity and reduces runoff and sediment delivery (Saxton and Rawls, 2006). Furthermore, it leads to an immediate reduction in soil erosion because the use of mulches (Prosdocimi et al., 2016a) also contributes to improved soil quality over a longer time span (Barreiro et al., 2016; Parras-Alcántara et al., 2016; Masvaya et al., 2017).

Therefore, the aim of this research was to assess the effects of chipped pruned branches on soil and water losses after a decade of CPB cover in citrus orchards. This paper evaluates the use of CPB as a mulch to control soil and water losses based on a paired-plot sampling strategy, and considers the perception of farmers in the area in order to find the right strategy to implement policies for agricultural land that are sustainable from a biophysical, social and economic point of view. Mediterranean type ecosystems are characterized by contrasting climate seasons, sloping terrain, and a millennia old human use and abuse that triggers soil erosion rates that must be reduced to achieve sustainability, and chipped pruned branches can be a suitable and sustainable strategy.

2. Material and methods

2.1. Study area

The Soil Erosion and Degradation Research Group (SEDER) at the Universidad de Valencia (Spain) established the Montesa Experimental Station in 2005. The Montesa Station is located in the southwest part of Valencia province in Eastern Spain (altitude 200 m.a.s.l), within La Costera district. This research station is devoted to studying the impact of citrus plantations on soil degradation and restoration, and is composed of six 300 m^2 soil erosion plots, a meteorological station and sampling fields to determine the impact of agricultural management on soil erosion, runoff generation, soil degradation, soil quality and crop production. Mean annual rainfall and temperature are 550 mm and 15.5 °C, respectively. The soils are classified as Xerorthents (Soil Survey Staff, 2014) with an average grain size distribution of 30% clay, 33% silt, and 34% sand with 4.3% gravel content. The field used in this study is located in the "Camí del Riu" within the municipality of Montesa, an area where parent material is colluvium coming from the nearby Limestones, and with an average slope of 2% as the land was levelled to allow flood irrigation in the 1940′s, although for the last twenty years the irrigation has been performed through dripping.

Two paired-neighbouring plots with a total area of 5000 m^2 were selected, both of them planted with citrus (Ortanique variety 25 year-old trees, see Fig. 1). The planting pattern is a 5 × 4 m grid. Herbicide treatments (Glyphosate (N-(phosphonomethyl glycine) are applied 4 times per year and the fields are chemically fertilized with 0.8 Mg ha^{-1} yr^{-1} of NPK 15% applied in parallel with the drip irrigation. Farmers maintain the field bare of plant cover the whole year to avoid any herbaceous competition for the crop, and also because the tradition in this area is to plough as a widespread strategy to control weeds. Keeping the soil free of weeds is important for the local reputation of the farmers, as rainfed crops were widespread until 1990.

2.2. Soil sampling points

In July 2013, twenty control (CON) plots and twenty chipped pruned branches (CPB) points were established along eight rows, each row with five sampling points (every 5 meters) for the CON and CPB plots (see Fig. 2). The CON plot used conventional (chemical) farming practices to manage the trees, with the pruned branches being transported out of the plot and burned. Since 2003, the pruned branches were chipped and spread in the rows between trees such that they covered the soil surface in the CPB plots. Pruning was done yearly in April. At each sampling plot, soil and water losses were measured with a rainfall simulator and a sample was collected to determine soil water content (SWC), bulk density (BK), organic matter and grain size with a 100 cm^3 cylinder. The soil samples were collected from 0 to 2 and 4 to 6 cm depths. Vegetation cover was determined as the percentage of soil covered by plants using a 1 cm^2 grid. Soil organic matter (SOM) was determined using the Walkley and Black (1934) methodology, and soil moisture was measured after drying the samples for 24 h at 105 °C.

2.3. Farmer perception survey and economic cost calculation

A survey was conducted to evaluate farmers' perception of soil management in the region. The survey was designed to gain insights into their perception of the use of herbicides, tillage, cash crops, weeds, geotextiles, grass strips, rock fragment mulch, modern terraces, straw and branch mulches. One-hundred farmers responded to six questions: i) is this strategy financially viable?; ii) is it an efficient way to reduce soil losses?; iii) is it easy to apply?; iv) should it be subsidised?; v) is it socially accepted?; and, vi) does it add value to the land? The data obtained are shown in Table 1, where the positive responses are given as a percentage of the total number of famers interviewed. The cost of the individual management practices was then calculated (Table 1) for both chipped branches and burned branches after asking twelve farmers for input cost information. The twelve farmers were selected to provide representation from the various sizes of farms that were surveyed, as this information is relevant to understand management costs per ha and if those costs are different for different sized farms. The twelve farmers represented the small (< 3 ha), medium (3–10) and large (> 10 ha) farms that were surveyed.

2.4. Rainfall simulation experiments

Plant, litter and rock fragment covers were determined prior to the rainfall simulation experiments by measuring their presence (1) or absence (0) at 100 regularly distributed points in each 0.25 m^2 plot. Forty rainfall simulation experiments (4 rows × 5 plots × 2 managements) were carried out at 55 mm h^{-1} rainfall intensity for one hour on circular paired plots (0.55 m in diameter, 0.25 m^2). Natural rainfall events with intensities of 55 mm h^{-1} have a return period of 5 years in this area (Elías Castillo and Ruiz Beltrán, 1979). In order to overcome the effects of inter-annual variability in soil moisture and allow

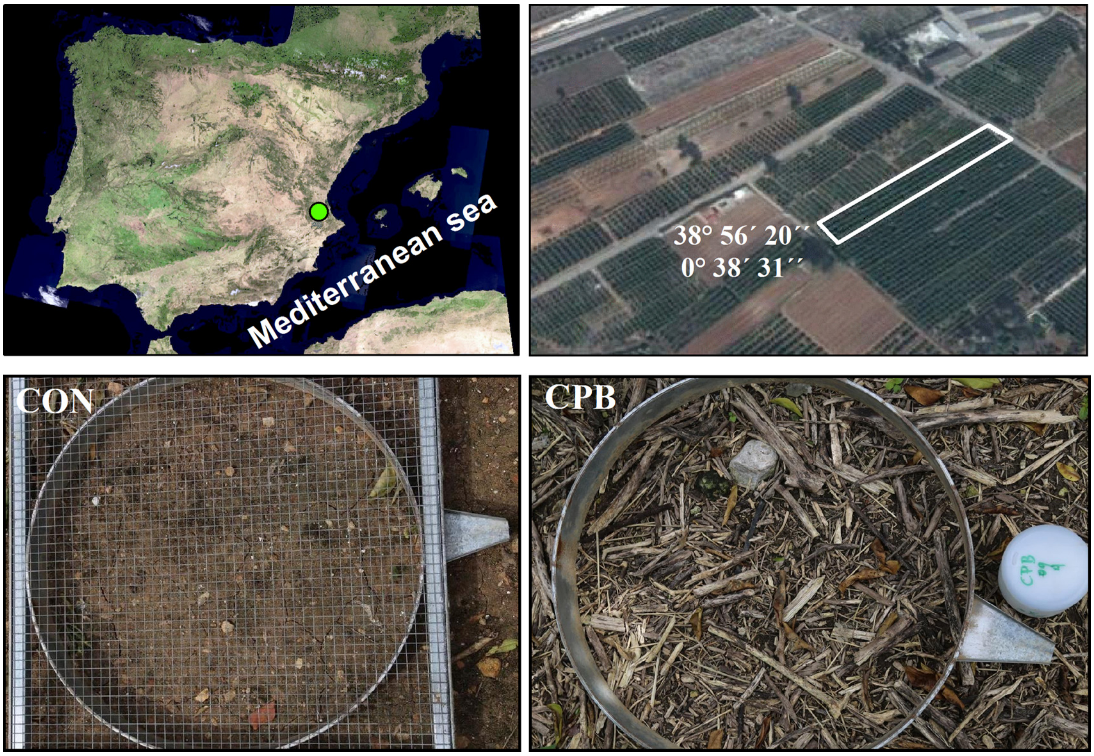

Fig. 1. Study area and example of the type of covers. CON: Control plots; CPB: Chipped pruned branches plots.

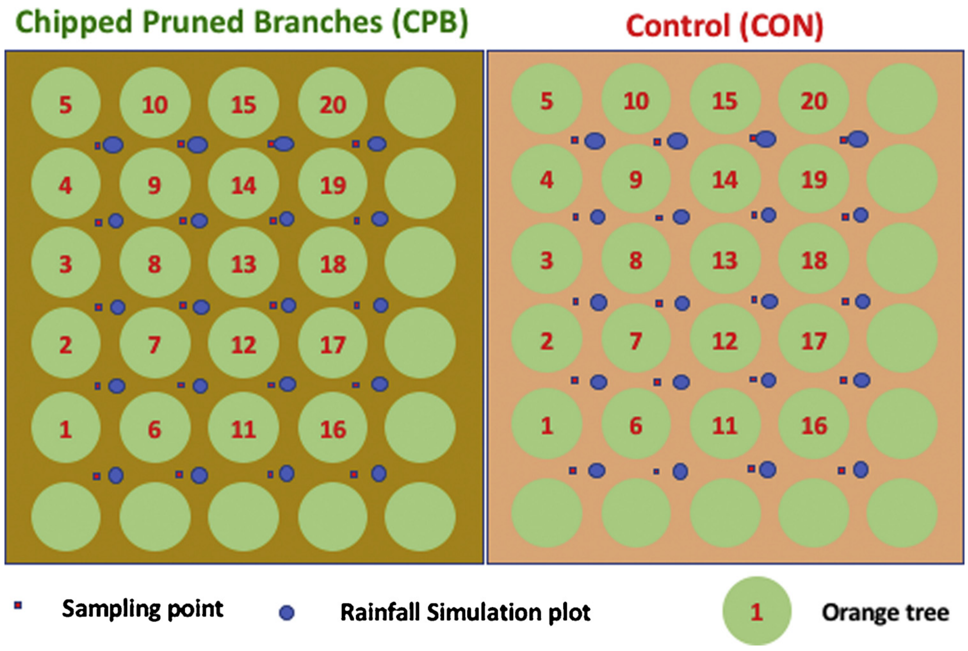

Fig. 2. Soil sampling and rainfall simulation experiments strategy. CON: Control plots; CPB: Chipped pruned branches plots. The rainfall simulation plot diameter is 55 cm.

Table 1
Farmer's opinion about the type of management (%).

Questions (n = 100[a])	Cost[b]	Efficiency[c]	Applied[d]	Subsidised[e]	Social[f]	Add value[g]	Average points
Herbicides	**67**	30	**93**	**94**	**95**	3	63.7
Tillage	54	**87**	59	**89**	**97**	6	65.3
Catch crops	12	65	1	67	68	12	37.5
Weeds	15	32	7	45	41	1	23.5
Geotextiles	3	35	1	62	34	14	24.8
Grass strips	3	4	0	23	35	5	11.7
Rock fragment mulch	56	2	0	5	6	2	11.8
Modern terraces	10	30	5	43	17	24	21.5
Traditional terraces	4	34	23	**78**	**98**	**89**	54.3
Straw mulch	14	68	2	59	53	21	36.2
Chipped branches mulch	12	2	18	57	23	14	21.0

Bold values signifies the highest % of positive replies.
[a] Only it was counted the positive answer.
[b] Is the cost affordable by the farmer?
[c] Is efficient this type of management?
[d] Is easy to apply?
[e] Should be subsidesed?
[f] Is social accepted?
[g] Does add value to the land?

comparisons between study sites, all experiments were carried out when the soil moisture levels were low, during the last week of July 2013, after no rainfall events had happened during the summer. Information on the characteristics of the rainfall in the region and the rainfall simulator are available in Cerdà (1997) and Prosdocimi et al. (2016b). At each plot, runoff flow was collected at 1-min intervals and the water volume was measured. The runoff coefficient was calculated as the percentage of rainfall water running out the circular plot. Runoff samples were desiccated (105 °C for 24 h) and sediment yield calculated on a weight basis in order to calculate soil loss per area and time ($\mathrm{Mg\,ha^{-1}\,h^{-1}}$). During the rainfall simulation experiments, time to ponding (time required for 40% of the surface to be ponded; Tp, s), time to runoff initiation (Tr, s) and time required for runoff to reach the outlet (Tro, s) were recorded. Tr-Tp and Tro-Tr were calculated as indicators of how the ponding is transformed into runoff, and how much time the runoff on the soil surface needs to reach the plot outlet, respectively. These data sets show runoff initiation and how rainfall is transformed into runoff.

2.5. Statistical analysis

Runoff, sediment yield and sediment concentration were represented in the form of box plot graphics including median, averages and outliers. Runoff characteristics related to the time of generation and time to ponding were expressed in tables with averages, standard deviation (±), and maximum and minimum values. To be able to compare the results obtained in both paired plots a one-way ANOVA test was performed with Sigma Plot 12.0 (Systat Software Inc.). However, the results did not show a normal distribution (only bulk density at 4–6 cm depth) after testing for normality with Saphiro-Wilk and equal variance tests. Therefore, a Tukey test was carried out, where significant differences at the $P < 0.001$ level were assessed. Lineal regressions analysis showed correlations between the soil erosion results and the vegetation and litter covers.

3. Results

3.1. *Farmer's perception and economic cost*

The results of the farmer surveys on opinions about different types of soil management from La Costera District are shown in Table 1 for the 100 interviewees set. Farmers indicated that the most affordable management was the use of herbicides (67%), rock fragments mulches (56%) and tillage (54%). In relation to efficiency, farmers agreed that tillage was the most efficient management option (87%), although cash crops (65%) and straw mulch (68%) also had a high number of positive answers. Undoubtedly, famers find the use of herbicides the easiest management strategy in citrus plantations (93%) and think that it should be subsidized (94%), with tillage (89%) and traditional terraces (78%) as their second and third best options, respectively. The most accepted management options were also the use of herbicides (95%), tillage (97%) and traditional terraces (98%). Most farmers agreed that traditional terraces (89%) add the most value to the land. Overall, we found that tillage, herbicides and traditional terraces had the highest acceptance rates with averages of 65.3%, 63.7% and 54.3%, respectively, for the 100 interviewed farmers. The farmers' perception of CPB was generally negative (Table 1). One of the reasons given by the farmers was that chipping branches requires new and expensive machinery, and that they feel comfortable with the tradition of burning branches after pruning. The average cost to chip pruned branches was 176 $€\,ha^{-1}$ while burning them cost 127 $€\,ha^{-1}$ (Table 2).

3.2. *Soil analysis and total pruned biomass*

Soil properties for all test plots are compared in Table 3. Stone fragment cover had values of about 5–6%. Differences between SOM in the surface levels were found, ranging from 1.2% in CON and 2.9% in CPB with maximum values of 4%. However, no differences in SOM were found in the subsurface layers (1.1% in CON and 1.3% in CPB). Soil bulk density had higher values in the CON plots in the surface (1.36 $g\,cm^{-3}$) and subsurface (1.47 $g\,cm^{-3}$) layers than the soil with pruned branches (1.16 $g\,cm^{-3}$ and 1.44 $g\,cm^{-3}$, respectively). Soil water content (SWC) was also higher in the plots with pruned branches (surface = 8.3%; subsurface = 10.7%) as compared to the control plot (surface = 5.9%; subsurface = 9%). Following a Tukey test after failing the normality test, almost all paired soil sampling results showed that the differences in the mean values among the treatment groups were greater than would be expected by chance, therefore giving statistically significant differences ($p < 0.001$). The only exception was for BD at the 4–6 cm depth, where no significant differences were found ($p < 0.356$). Finally, total pruned biomass in CON and CPB were quantified (Table 4), and similar branch biomass was found in both plots (CON: 171 $g\,m^{-2}$ and CPB: 159 $g\,m^{-2}$). No statistically significant differences were found.

3.3. *Water and soil losses*

The results of the rainfall simulations are shown in Fig. 3 and Tables 5 and 6. In the CON plots, the average runoff value was 8.3 ± 1 $l\,m^{-2}\,h^{-1}$ with a range of 6 $l\,m^{-2}\,h^{-1}$ to 10 $l\,m^{-2}\,h^{-1}$, an average runoff coefficient of 60.1 ± 7.5%, and an average Tp of 39.3 ± 6.9 s. Tr and Tro were 107.7 ± 16.6 and 227.3 ± 19.4 s, respectively. The CPB plots had a lower mean runoff of 6 ± 1.1 $l\,m^{-2}\,h^{-1}$ with a range of 4–8 $l\,m^{-2}\,h^{-1}$. The mean runoff coefficient was 16.8% lower than in the CON plots, which delayed runoff generation. Tp (169.2 ± 59.1 s), Tr (253.9 ± 69.3) and Tro (428.3 ± 87.2 s) values were also higher in CPB than in CON.

Soil losses were significantly different between the CPB and CON plots. Soil erosion in the CON plots averaged 376.5 ± 101.2 $g\,m^{-2}\,h^{-1}$ (3.8 ± 1 $Mg\,ha^{-1}\,h^{-1}$) with maximum values of 566 $g\,m^{-2}\,h^{-1}$. CON sediment concentrations averaged 11.3 ± 2.2 $g\,l^{-1}$ with a range of 8.56 $g\,l^{-1}$–15.59 $g\,l^{-1}$. In the CPB plots soil loss averaged 74 $g\,m^{-2}\,h^{-1}$ (0.7 ± 0.4 $Mg\,ha^{-1}\,h^{-1}$), which was 5 times lower than in the CON plots. Sediment concentrations were also lower, averaging only 3 ± 1 $g\,l^{-1}$ with a range from 1.57 $g\,l^{-1}$ to 5.28 $g\,l^{-1}$, which was 3.8 times lower than in the CON plots. The data failed the normality test in all paired rainfall simulations. Results from the Tukey test showed that the differences in the mean values between the treatment groups were greater than would be expected randomly, meaning the differences were statistically significant ($p < 0.001$).

4. Discussion

Some strategies that can be utilized to avoid herbicides and tillage are already well known and widely tested. The use of weeds as a cover is positive from an economic point of view as there is no cost to establish the vegetation cover and it is efficient at reducing soil and water losses and enhancing the development of a litter layer to protect the soil against raindrop impact, just as other mulches and vegetation covers do (Benvenuti and Bretzel, 2017; Keesstra et al., 2016b; Prosdocimi et al., 2016b; Mekonnen et al., 2017; Tanveer et al., 2017). However, farmers in eastern Spain do not accept weeds in their fields for social, cultural and moral reasons as tradition requires a tidy orchard, which is essential to maintain a farmer's reputation as a good land manager (Marques et al., 2015; Sastre et al., 2016; Cerdà et al., 2017b). Weeds can also deplete soil water resources and reduce crop yields, and this has become even more relevant for soil management due to climate change (Lovelli et al., 2012). The use of geotextiles has been shown to be profitable as they reduce soil losses, although they can increase

Table 2
Cost of the individual management practices for both chipped branches and burnt branches after asking twelve owners. The average does not count the surface of the plots. CON: Control plot; CPB: plot with pruned brunches.

Owners	ha	CON €	CPB €	CON € ha^{-1}	CPB € ha^{-1}	CPB-CON €	CPB-CON € ha^{-1}	CPB-CON (%)
1	3.2	387.2	532.12	121.00	166.29	45.29	14.15	37.4
2	4.6	438.9	678.3	95.41	147.46	52.04	11.31	54.6
3	17.5	1899.2	2342.3	108.53	133.85	25.32	1.45	23.3
4	3.1	432.3	632.1	139.45	203.90	64.45	20.79	46.2
5	2.8	325.3	435.2	116.18	155.43	39.25	14.02	33.8
6	13.2	1987.23	2543.34	150.55	192.68	42.13	3.19	28
7	1.4	200.2	354.65	143.00	253.32	110.32	78.80	77.2
8	2.6	432.32	623.2	166.28	239.69	73.42	28.24	44.2
9	22.5	3010.2	3654.3	133.79	162.41	28.63	1.27	21.4
10	250	23331.2	25542.4	93.32	102.17	8.84	0.04	9.5
11	176.2	17823.3	19823.1	101.15	112.50	11.35	0.06	11.2
12	78.2	8922.12	9987.3	114.09	127.71	13.62	0.17	11.9
Total/Mean	320.9	32444.05	37337.91	126.75	175.72	48.97	0.15	38.6

Table 3
Soil properties. CON: Control plot; CPB: Pruned branches plot; x̅±: Average and standard deviation; Max.: maximum values; Min.: minimum values; SOM: Soil organic matter; BD: Bulk density.

Variables	Stone cover (%)		SOM (%)				BD (g cm^{-3})				SWC (%)			
Depth	0-2 cm		0-2 cm		4-6 cm		0-2 cm		4-6 cm		0-2 cm		4-6 cm	
Management	CON	CPB	CON	CPB	CON	CPB	CON	CPB	CON	CPB	CON	CPB	CON	CPB
x̅±	5.9 ± -1.7	5.2 ± 1.8	1.2 ± 0.2	2.9 ± 0.6	1.1 ± 0.1	1.3 ± 0.2	1.36 ± 0.1	1.16 ± 0.1	1.47 ± 0.1	1.44 ± 0.1	5.9 ± 1	8.3 ± 1.1	9 ± 0.6	10.7 ± 1.2
Max.	9	9	1.8	3.9	1.5	1.8	1.6	1.3	1.7	1.7	8	10.2	10.9	12.9
Min.	3	1	0.9	1.9	0.9	1	1.2	1	1.3	1.2	3.9	6.3	8	8.9

Table 4
Total fresh and dry pruned biomass. CON: Control plots; CPB: Chipped pruned branches plots;x̅±: Average and standard deviation; Max.: maximum values; Min.: minimum values; FPB: fresh pruned biomass.

Plots	FPB (g)		Moisture (%)		Dry biomass (%)		Dry biomass (g)		FPB (g m^{-2})		Dry biomass (g m^{-2})	
n = 20	CON	CPB	CON	CPB	CON	CPB	CON	CPB	CON	CPB	CON	CPB
x̅±	14,138 ± 230-9.1	14033.9 ± 2692.4	72.6 ± 4	74.6 ± 4.4	27.4 ± 4	25.43 ± 4.4	3868.7 ± 863.3	3604.9 ± 1009.1	706.9 ± 115.5	701.7 ± 134.6	171.1 ± 74.9	159.4 ± 78.1
Max.	18976	19823	79	79	33	36	5842	6296	949	991	292	315
Min.	10976	10324	67	64	21	21	2537	2267	549	516	0	0

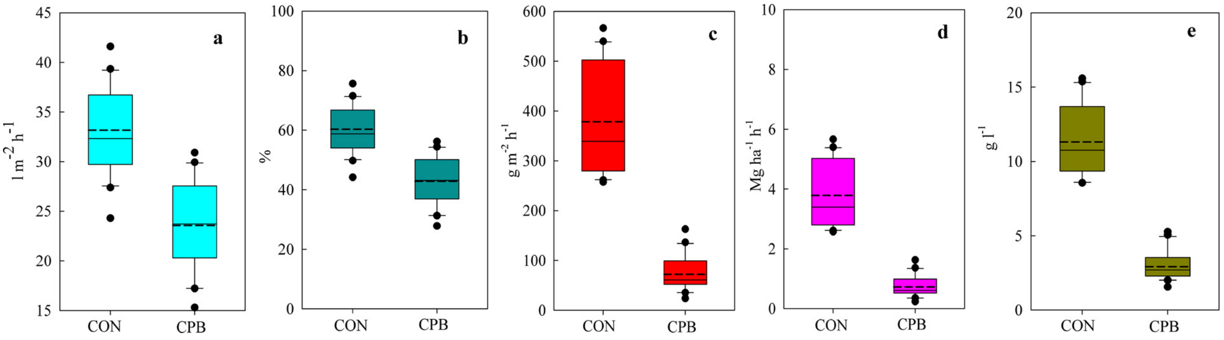

Fig. 3. Runoff, soil erosion and sediment concentration measured by mean of rainfall simulation experiments. CON: Control plots; CPB: Chipped pruned branches plots. a: Runoff; b: Runoff coefficient; c: sediment yield; d: soil erosion; and, e: sediment concentration. Trees are planted at 5 × 4 m, rainfall simulation plots are 0.24 m^2 in size and the sampling took place in a 10 × 10 cm square plot.

Table 5
Soil erosion results on the control plot and with branches. CON: Control plot; CPB: Pruned branches plot; $\overline{x}\pm$: Average and standard deviation; Max.: maximum values; Min.: minimum values; Rc: Runoff coefficient; Sc: Sediment concentration; Tr: Total runoff; Sy: Sediment yield; Se1: Soil erosion in g m^2 h^{-1}; Se2: Soil erosion: Soil erosion in Mg ha^{-1} h^{-1}.

Plots	Rc (%)		Sc (g l^{-1})		Tr (l)		Sy (g)		Se1 (g m^2 h^{-1})		Se2 (Mg ha^{-1} h^{-1})	
n = 20	CON	CPB	CON	CPB	CON	CPB	CON	CPB	CON	CPB	CON	CPB
$\overline{x}\pm$	60.1 ± - 7.5	43.3 ± 7.9	11.3 ± 2.2	3 ± 1	8.3 ± 1	6 ± 1.1	94.1 ± 25.3	18.5 ± 8.9	376.5 ± 101.2	74.0 ± 35.7	3.8 ± 1	0.7 ± 0.4
Max.	76	56	16	5	10	8	142	41	566	163	6	2
Min.	44	28	9	2	6	4	64	6	258	24	3	0

Table 6
Times to runoff characterization on the control plot and with branches. CON: Control plot; CPB: Pruned branches plot; $\overline{x}\pm$: Average and standard deviation; Max.: maximum values; Min.: minimum values; Tp: Time to ponding; Tr: time to runoff; Tro: time to runoff in outlet.

Plots	Tp (s)		Tr (s)		Tp-Tr (s)		Tro (s)		Tr-Tro (s)	
n = 20	CON	CPB	CON	CPB	CON	CPB	CON	CPB	CON	CPB
$\overline{x}\pm$	39.3 ± - 6.9	169.2 ± 59.1	107.7 ± 16.6	253.9 ± 69.3	68.5 ± 17.6	84.8 ± 25.2	227.3 ± 19.4	428 ± 87.2	119.6 ± 18.7	174.1 ± 26.4
Max.	58	312	135	410	103	160	251	605	156	235
Min.	27	95	69	178	32	44	185	325	80	138

runoff if the material has a hydrophobic response (Giménez-Morera et al., 2010). Moreover, geotextiles are expensive and not all farmers can access these types of materials. The use of straw mulch has also proved to be positive and efficient on agricultural land (Prosdocimi et al., 2016a; Cerdà et al., 2017b). But the acceptance by farmers is poor, as the straw and its application are costly and farmers see the straw mulch as a source of pests and as being unsightly on their farm. However, the farmer’s perception of CPB is that they would use it if it is subsidized. The desires of the stakeholders are important when making such decisions, or at least they should be, and there is a need for a framework that will integrate biophysical and economic land use and management issues (Bouman et al., 1999; Hondebrink et al., 2017) that also incorporates stakeholder’s opinions (Bouma and Kamp-Roelands, 2000; Brevik et al., 2016).

4.1. Biophysical benefits of CPB

The use of CPB is very efficient to lower soil erosion rates, as was demonstrated in this study, and CPB can be the decisive factor controlling soil surface properties in citrus orchards. Confirmation of our hypothesis that the CPB would efficiently control soil losses was demonstrated through the relationships between litter cover and soil erosion as shown in Fig. 4. This relationship demonstrates the importance of the chipped branches mulch in two ways: i) the CON plots delivered more sediment than the CPB plots did; and, ii) the relationship within the CPB plots between litter cover and soil erosion is negative. Soil erosion decreased when litter cover increased. Litter cover from the CPB also contributed to increased organic matter in the surface layer, potentially resulting in improved infiltration rates and

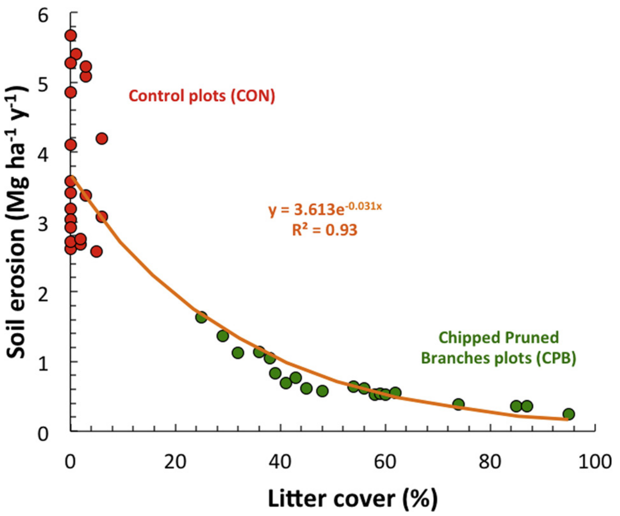

Fig. 4. Relationship between soil loss and vegetation/litter cover. CON: Control plots; CPB: Chipped pruned branches plots.

reduced surface flow and soil erosion. Fig. 5 clearly shows this relationship. It also demonstrated that the chipped branches increased soil organic matter when CON and CPB plots were compared and that within the CPB there was an increase in soil organic matter with increasing CPB cover.

The relationship between the runoff coefficient and sediment concentration showed the importance of CPB in changing the hydrologic properties of the soils. Fig. 6 shows that the CON plots produced more runoff and sediment load than the CPB plots and that the increase in runoff also resulted in an increase in soil erodibility as shown by the sediment concentration. The implication of this finding is that once a soil is covered with CPB the runoff discharge decreased due to the increase in organic matter and infiltration. However, there was a second positive effect, and this was that the sediment concentration in the runoff was reduced by the cover of chipped pruned branches that protected the soil surface from direct raindrop impact. Therefore, chipped pruned branches offered two major benefits: i) they reduced runoff discharge; and, ii) they reduced soil erodibility. Both changes contributed to an immediate and efficient reduction of the soil erosion rates.

4.2. Farmer's perception and economic constraints

Farmer's perceptions about the use of pruned branches in the study area are that they are not a viable solution for crop management. The following reasons were given: i) it is more expensive than removing and burning the branches; ii) the soil is not as clean as they wish (a tidy farm is important for the farmers' good reputations); and, iii) this is not part of the tradition in terms of land management in this region. This is not a new response by farmers in the area, who tend to base their farm management decisions on traditions, as demonstrated by Green and Heffernan (1987). The tradition in this region is to use the branches as forage or burn them. This tradition was established in 1960s, as before that time all the pruned branches were used for forage or fuel. Therefore, the opinion of the farmers is based on a fairly recent perception of the issue.

An important issue that should be taken into account when addressing the implementation of management strategies is the perception of farmers towards specific strategies, because if farmers are not willing to adopt a management strategy it will fail (Critchley et al., 1994; Hellin and Haigh, 2002). In this sense, it is important to indicate that the effectiveness of a management strategy from a soil biophysical point of view is not the only relevant issue. Whether a policy measure for land management will become successful will depend to a large extent on the perception of the farmers who must implement it. Gould et al. (1989) found that farmers' views on conservation tillage as a way to reduce soil erosion was not as positive as expected. Napier et al. (1988) confirmed that the willingness of land operators to participate in soil erosion control programs was often low, and Osterman and Hicks (1988) found that farmers often do not perceive soil erosion as a problem in its own right in a study in Washington, USA. Ervin and Ervin (1982) found that the opinion and support of the farmers was important for the successful implementation of conservation practices and policies; Okoba and de Graaff (2005) reported similar findings in the Central Highlands of Kenya, where the perception and knowledge of the farmers was the most important issue determining the success of the policies. Research carried out in different parts of Africa demonstrates that the success of land use policies is related to the knowledge and perception of the farmers (Okoye, 1998; Visser et al., 2003; Zegeye et al., 2010). We found a similar response from the farmers in eastern Spain, which means there is a worldwide need to find better ways to engage these stakeholders in the implementation of better soil management techniques.

Several issues hamper the adoption of chipped pruned braches by farmers in eastern Spain as protective mulch to reduce runoff and erosion. First, and probably most important, is the economic issue. Burning the branches, as farmers currently do, is less expensive than applying CPB. Therefore, farmers need to receive subsidies to promote the use of CPB to compensate them for their increased costs. The economic survey demonstrated that chipping the branches in orange plantation is costlier at small farms (Fig. 7) and that the increase in cost to switch from burning the branches to chipping them is related to the size of the farm (Fig. 8). Therefore, subsidies or incentives need to take farm size into account to effectively influence the management practices of smallholder farmers.

The research presented here is new for the Mediterranean belt. Rainfall simulation experiments have frequently been used to determine the sustainability of agriculture management practices, but this has not previously been done in combination with a stakeholder perception analysis. European agricultural policies that seek to achieve better land management (Glæsner et al., 2014) and reduce soil erosion rates (Boellstorff and Benito, 2005) or increase biodiversity (van Buskirk and Willi, 2004) have achieved success in Belgium (van Rompaey et al., 2001) and Iceland (Arnalds and Barkarson, 2003). However, examples of such success are not found in other regions, as Berger et al. (2006) highlighted, due to the characteristics of voluntary agri-environmental measures at a regional scale. This is because each region in Europe has different environmental, social and economic conditions. Andersen et al. (2007) showed that farm management and typologies must be relevant before farmers will apply the set-aside programs, making it necessary to change the policy environment in Europe such that it recognizes these differences and can adjust to them. Bourgeon et al. (1995) already identified the need for appropriate incentives to achieve the target of sustainable agricultural management in Europe. Lahmar (2010) states that there is still no scientific documentation of the long-term socio-economic and ecological impact of reduced tillage, such as he found in Norway and Germany, which are well subsidized by the national governments. In the Mediterranean, recent European Union policy that sustains less favoured areas and supports intense terracing in vineyards supports techniques that may actually result in a worsening of slope instability phenomena (Martínez-Casasnovas and Concepcion Ramos, 2009; Stanchi et al. 2012). This is a consequence of incentives to expand crops that negatively affect soil and water conservation management, either in developed or developing countries (Barbier, 1997; Barbier and Bishop, 1995; Lundekvam et al., 2003). The impact of policies on biodiversity (van Buskirk and Willi, 2004) and how policy environments affect agricultural land use (van Meijl et al., 2006) are also clear examples of the impacts of the interaction of policy development and biophysical changes in agricultural land.

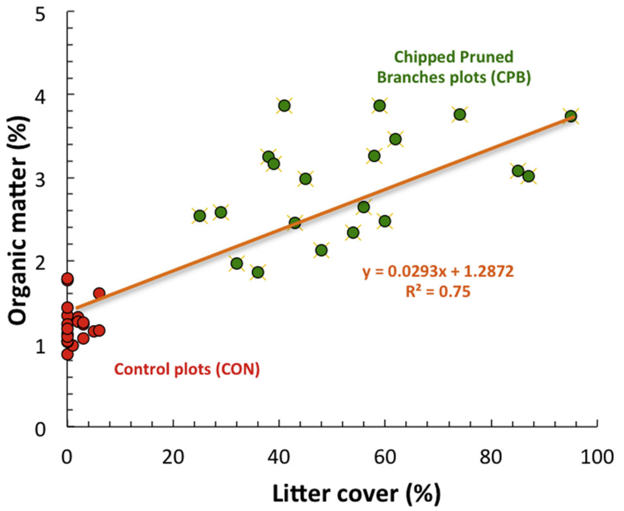

Fig. 5. Relationship between litter cover and organic matter. CON: Control plots; CPB: Chipped pruned branches plots.

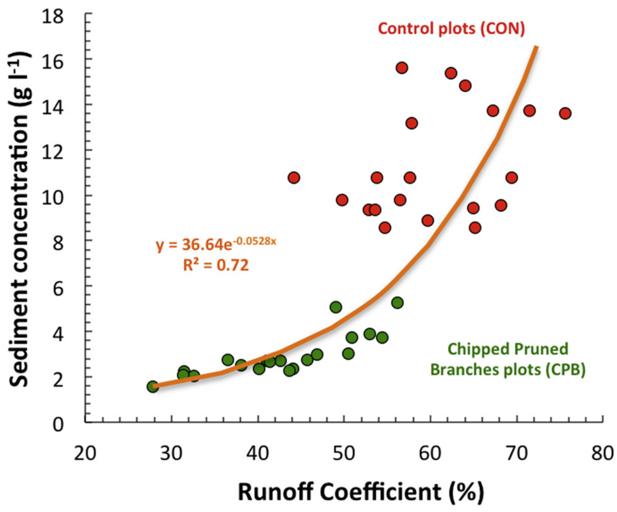

Fig. 6. Linear correlation between runoff coefficient and sediment concentration. CON: Control plots; CPB: Chipped pruned branches plots.

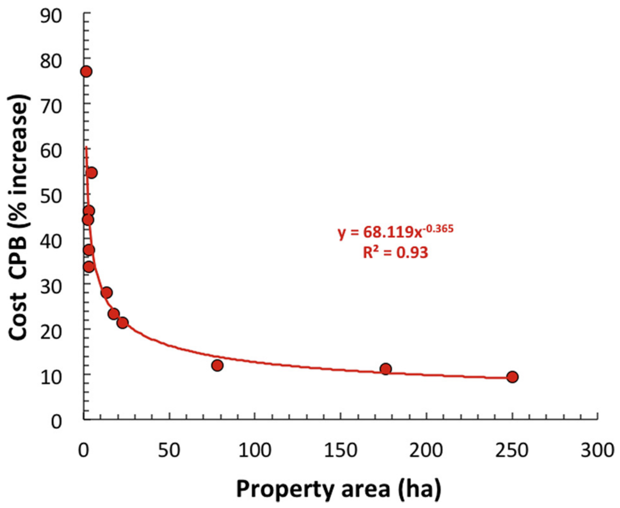

Fig. 7. Relationship between the cost of CPB and property area. CPB: Chipped pruned branches plots.

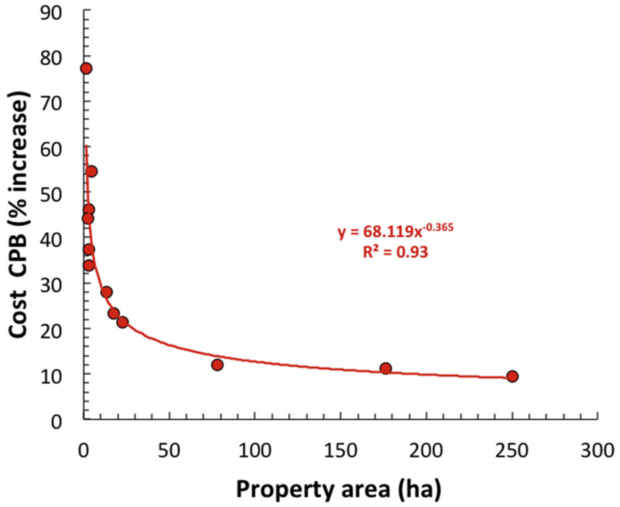

Fig. 8. Relationship between the increase (% increase relative to CON) of the cost of CPB to the traditional burning of branches and property area. CPB: Chipped pruned branches plots.

Our research in citrus plantations shows that there is a need to develop different policies for different types of farms. For the large farms in the study area, applying CPB strategies would result in a 10% increase in expenses compared to removing the branches and burning them. However, for medium size owners (10–30 ha) the increased expenses would be between 20 and 30%, and for the small farms (< 10 ha) expenses may increase as much 80% for the very small operations (< 2 ha), especially the farms that have multiple small fields at different locations within the same municipality. EU policies do not currently adapt their subsidies and incentives to address these contingencies, and thus end up supporting only large farms, leaving the small operations with a lack of opportunity to update their machinery or to apply new technologies. However, small farmers are the ones that most effectively promote biodiversity and landscape diversity due to their diversity in crops and in the borders between farms that are frequently occupied by hedgerows, irrigation, or drainage boundaries (Lin et al., 2009).

4.3. Ways ahead

The issues described above demonstrate the need for new types of policies that are adapted to regional socioeconomic and cultural conditions. Panagos et al. (2012) presented the European Soil Data Centre, which is a key database to support success in European agricultural and soil policies. However, information in this data set is not accurate or detailed enough to facilitate a sound understanding of the behaviour of farmers and their requirements at a regional level in order to achieve a more sustainable agriculture. De Graaff and Eppink (1999) identified weak points in EU subsidies that made it difficult to achieve a green policy for olive production. Such policies can sometimes even increase environmental problems instead of reducing them (Boardman et al., 2003). A good example for this is the implementation of drip irrigated citrus orchards on sloping terrain, which drives very high erosion rates (Cerdà et al., 2009). In addition, there is a need to educate farmers about how they can contribute to more sustainable land-use management options. Subsidies and financial incentives help to achieve these goals as Marques et al. (2015) found, but the knowledge of the farmers and their contribution as citizens is relevant as well. In a study in Peru, Swinton (2000) found that social capital is important to reduce soil erosion. Therefore, we need to ask ourselves if Europe is investing enough in the social and cultural capital of rural areas. Are we building a European policy merely based on subsidies? The research carried out in the La Costera district says yes.

As mentioned before a second important issue is the farmers' tradition of keeping their fields tidy. In general, farmers in this region prefer their soil clean of any cover such as growing vegetation, straw, or chipped branches. This is not a unique situation as other regions within the Mediterranean show similar farmer behaviours. Our research in the citrus plantations in Eastern Spain indicates the importance of conservation techniques in reducing runoff and soil loss, therefore confirming the findings of Prats et al., (2014) and demonstrating that CPB can act as mulch. This confirms previous findings by Fernández and Vega (2014) in fire-affected land and by Ruiz-Colmenero et al. (2013) in vineyards where vegetation cover reduced soil erosion and enhanced organic carbon in soils of Central Spain. However, there is a major constraint to successfully using those strategies in citrus orchards as farmers dislike them and consider them an imposition by policy makers who know little about practical farming needs and care little about farmers' perceptions.

The third important obstacle in the road to implementing CPB is the lack of knowledge by farmers about the negative effects of their current practices and the benefits that sustainable new strategies such as CPB can have for their soils. There is therefore a lag in the system for educating farmers that could be covered by policies that lead to an improvement in farmers' education. In other words, farmers need to be encouraged to be lifelong learners, just as other professionals are encouraged to be lifelong learners (Jarvis, 1987; Ballou et al., 1999; Westover, 2009). The European Union, National, and Regional fund offices are actively subsidizing the use of chipped branches, but there is a lack of farmer education about the benefits this strategy brings to the soil and to the economic situation of the farmers. Even though it is well accepted that soil conservation management strategies contribute to a healthier environment, there is a need to better translate the scientific knowledge into socially-acceptable environmental policies, and each region is different in this issue (Bouma and Droogers, 2007). There is a need to co-construct, in cooperation and collaboration with farmers and other stakeholders, an environmental policy strategy for Europe.

We propose here that European policies should be more realistic, better adapted to unique regional needs, developed from the bottom-up, designed for the farmers and with the farmers. We must co-construct the agricultural fate of Europe based on the knowledge and opinions of farmers, scientists, policy makers and citizens. Soil environmental quality is a key issue for the future of European agriculture and also for European sustainability (Bouma, 1997), and we need to take action as scientists, as citizens and as consultants for the policy-makers. The key mistake over the last 20 years of European agricultural policy was to develop subsidies that seek to have immediate success and can therefore be evaluated over the short-term. In Mediterranean areas there is a need to reorganize, rebuild and co-construct new policies and strategies to achieve sustainable agriculture, and should be based in nature-base solutions (Keesstra et al., 2018). Over the long term, success can only reached if education programs for farmers accompany the subsidies. The CPB survey conducted in the La Costera District for this study is a good example of this need. Farmers did not find the CPB technique attractive unless there was financial support from public entities. European policies must make soil conservation and building management practices attractive from more than the short-term economical point of view, they should also be socially and environmentally suitable (Bouma et al., 2012).

5. Conclusions

CPB are very efficient at improving soil quality, although their effect is restricted to the soil´s surface at least over the time period covered by this study. CPB controls soil and water losses in chemically managed citrus plantations where vegetation cover is absent due to the tradition of farmers to keep their fields “clean” and “tidy”, resulting in a bare soil surface. After ten years of CPB mulch use, we found increased organic matter and reduced bulk density at the soil surface (0–2 cm) level. This resulted in decreased sediment concentration ($11.3\ \mathrm{g\,l^{-1}}$–$3\ \mathrm{g\,l^{-1}}$) and soil erosion ($3.8\ \mathrm{Mg\,ha^{-1}\,h^{-1}}$ vs $0.7\ \mathrm{Mg\,ha^{-1}\,h^{-1}}$). However, the use of CPB is not popular within the farmers’ community and there is a need to subsidize (or incentivize) this technique for it to be accepted as a viable management option that offers an alternative to removing the pruned branches. There is a need for European agriculture policies will be based not only on subsidies, but also on the education of farmers that will provide farmers with a holistic perspective of how their management choices impact the land they manage and make them feel that they are part of a larger society effort, and not merely servants of subsidies or policymakers. This is especially relevant in the Mediterranean context where farmers have the perception that they do not matter to the European policy makers. There is a need to incentivize a new sustainable (societally, environmentally and economically) agriculture that will include cooperating with farmers and having them work closely with scientists, policy-makers, and other relevant members of society.

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