The influence of cover crops and tillage on water and sediment yield, and on nutrient, and organic matter losses in an olive orchard on a sandy loam soil.

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Abstract.

Is the cover crop practice suitable for soil and water conservation in olive tree cropping? Rainfall, runoff, sediments, nutrient and organic carbon losses from 8 x60-m plots were measured during four hydrological years (2002 to 2007) in a field trial, in which two different soil management systems were used to confirm this hypothesis: a cover crop, (CC), and conventional tillage, (CT). The plots were located in a private olive tree farm on a sandy-loam soil, near Seville, southern Spain. The cover crop, as compared to conventional tillage, efficiently reduced runoff and sediment yield down to tolerable levels, 5.68% of the rainfall being converted to runoff, and the soil loss reaching 0.04 kg $m^{-2}$$year^{-1}$, as the average of four years. Additionally, in the cover crop treatment, the values of the nutrient export either dissolved in the runoff water or adsorbed in the sediment, were lower than the analogous values of the conventional tillage treatment: 0.631 and 0.065 kg m^{-2} $year^{-1}$ of organic carbon and nitrogen, respectively, 0.175 and 0.0333 kg m^{-2} $year^{-1}$ of soluble K and P, respectively, and 0.010 and 0.002 kg m^{-2} $year^{-1}$ of available K and P, respectively. The adoption of a cover crop as a soil management practice can be a feasible way to reach sustainability in many olive-cropped soils of southern Spain, although this method is not always easy to implement due to technical problems such as seed selection, its maintenance, and the choice of the correct killing date to avoid water competition. These difficulties could explain the slow rate of its adoption by many farmers. Further exploration of these aspects is required, as well as a specific agricultural extension campaign.

Keywords: olive, erosion, runoff, organic carbon, nutrients.

INTRODUCTION

Olive is an essential crop for the Mediterranean basin, where it covers around 9.2 Mha (FAO, 2008). The characteristics of the tree, able to support very adverse climate conditions like long hot, dry periods, with some cold winter intervals, the good properties of its fruit, which is a substantial part of the Mediterranean diet, and the relatively simple agronomic practice required by olive orchards, explain the spread of this crop in the region.

Nevertheless, olive-tree cropping may have become a serious menace to natural resource conservation. The introduction of mechanization in the 1950's gave many farmers the opportunity of plowing steep virgin lands to start new plantations, as well as of intensifying tillage in old plantations to remove the weeds competing with the olive trees for water and other nutrients more effectively. Consequently, the soil loss rate increased with extensive on-site and ex-site damage. The soil became progressively less fertile, and the dispersion of the sediment with the associated agrochemicals deteriorated the environment.

The development of chemical herbicides in the 1970's initiated a new era for soil and water conservation, allowing the farmer to control more precisely the weeds growing either between the cropped trees or over the whole cultivated area until the new crop was sown (Tripplet and Dick 2008). After an initial period of experiments with the use of no tillage combined with herbicides to keep the soil bare all year round, which resulted in accelerated soil erosion due to an increase in water yield, cover crop practices were introduced into olive tree cropping, following the example of other crops (*e.g.* Pastor *et al.* 1999). Despite a significant expansion of the use of cover crop in olive-growing areas in Southern Spain, many olive farmers are still reluctant to fully adopt this practice. This raises several unsolved problems, but possibly the most important one is the limited amount of reliable experimental results on its efficiency in soil and water conservation, as happens in other crops (Clark 2007).

Several works have studied cover crop as a conservation practice in olive orchards: Gómez *et al.* (2004), Bruggeman *et al.* (2005); Francia *et al.* (2006); and Ordóñez-Fernández *et al.* (2007) have reported runoff and sediment yield data recorded in experimental erosion plots. The plot size and type in the above works differ. Ordóñez-Fernández *et al.* (2007) used square erosion plots of 1 m^2, located between olive tree rows. Gómez *et al.* (2004) had larger rectangular plots of 72 m^2 enclosing 2 olive trees each. Francia *et al.* (2006) installed larger rectangular erosion plots of 192 m^2 containing three olive trees. The study of Bruggeman *et al.* (2005) was made on the largest plots of all, as indicated in their plate 1, with 75 olive trees in each, although their area was not specified in their publication. Unfortunately, the plots of Bruggeman *et al.* (2005) were not closed ones, and collected the runoff water with a Gerlach trough, which does not usually represent the total runoff generated in the plot.

One of the main problems of soil erosion studies is the representativeness of the processes in the measurement field plots, since, as indicated by Parsons *et al.* (2004), the particle travel distances, which depend on the particle size, can be much larger than the plot size. Consequently, it is not easy to detect rills formed by erosion in many of the measurement plots, and this is a common erosive form on slopes with cropped trees like the olive.

How effective is the cover crop practice as a soil and water conservation strategy for the olive tree orchards of Southern Spain? How much does the cover reduce the nutrient concentration in runoff water? The purpose of this work is to analyze the efficiency of the cover crop practice in soil, water and nutrient conservation in the olive tree cropping of Southern Spain using plots long enough to follow up the development of rills observed on hill slopes during several rainfall-runoff events and cropping seasons.

METHODS

In 2002, a field experiment was established on the “Santa Marta” farm, about 26 km west of Seville, Spain, 37º 20´ 33.6” N 6º 13´ 44” W and an average elevation of 98 m above sea level. The olive plantation was established in 1985 with trees at 8 x 6 m spacing. The olive variety, Gordal, used as a table food, is very common in the area (Rallo et al. 2005). The climate is Mediterranean with an average annual precipitation of 534 mm, concentrated mostly in late fall and winter, and an average annual air temperature of 18.6 ºC. The slope is uniform, oriented in the north-west direction with an average steepness of 11%. The soil belongs to the Petrocalcic Palexeralf series (García del Barrio *et al.* 1975) and is well drained, with an average organic matter content of 1.3%, 28% of calcium carbonates, and a sandy loam texture class. Some relevant properties are shown in Table 1. Farm soil management included the maintenance of a cover crop of weeds in the area outside the vertical projection of the canopy controlled by two or three mowing passes during winter and spring, and a bare soil strip under the tree line maintained with chemical herbicides.

Two bounded runoff plots were established in the summer of 2003. Each plot was 8 m wide and 60 m long, laid out with the longest dimension parallel to the slope, as indicated in Figure 1. During the fall of 2002, two soil management methods were established in them. One plot was devoted to conventional tillage (hereafter CT) consisting of regular chisel plow passes (2-3 times a year at 10-15 cm depth) depending on weed growth. The other treatment was a cover crop (hereafter CC) of *Lolium* (*rigidum* or *multiflorum,* depending on seed availability) manually sown during early fall at 100 kg of seed per ha in the area outside the vertical olive canopy projection.

The intercrop strip was fertilized every year with Nitrogen (50 kg/ha of N) during the fall by direct application on the soil in the CC plots. Weeds were chemically killed, using a mixture of Paraquat 12% and Diquat 8% at a rate of 4 L ha^{-1} using 400 L ha^{-1} of solution, in late winter or early spring to avoid competition for water with the olive trees. In both treatments, soil surface in the tree line was kept bare through the periodical use of herbicide (Fluroxipir and Flazasulfuron). Olive trees were fertilized with ammonium sulphate in February (1.6 kg per tree) and from April to October, during the irrigation season. The fertilizer was applied with the irrigation water, at the rates required for replenishment, as indicated by periodic foliar analyses. The amount of water applied during the irrigation season was, on average, 240 mm, although it varied slightly from year to year depending on the rainfall conditions.

Runoff and sediment collection started in these two plots on September 1st 2003. During the summer of 2005, two additional runoff plots were installed as replications of the original CT and CC treatments. Differential soil management started in the area the season before the delimitation of the runoff plots, as it had been done in the previous ones. Monitoring in these additional plots started on September 1st 2005.

The runoff generated on each plot was directed to a system of three fiberglass collection tanks with flow splitters (ratio 1:15) allowing measurement of up to 110 m^3 equivalent to 230 mm of runoff. Once carefully leveled, the splitters were kept free of leaves, small branches and other organic residues with a small protection net located upstream. The experiment site was completed with an automatic weather station. On the first working day after a single large rain event, or after a weather front consisting of several rain pulses or events, the collection tanks were sampled. Runoff volume and wet sediment weight were measured in the tanks. A well-mixed water and sediment sample was taken for laboratory analysis. The NO_3-N, NO_2-N concentration was estimated by colorimetry, dissolved P by spectrophotometry and dissolved K using atomic absorption spectroscopy, in all cases following the standard methods of Sparks (1996). The concentration of soil organic carbon, hereafter SOC, in the sediment samples was estimated with the Walkley-Black method, that of available P by extraction with sodium bicarbonate i.e. the Olsen method, and subsequent spectrophotometry. The concentration of available K in the sediment was estimated by extracting the sample with ammonium acetate, and that of organic N with the Kjeldahl method, again following Sparks (1996). When there was a sufficient mass of sediment sample, the particle size distribution and the relative mass of clay, silt, and sand, were determined using the standard Bouyoucos method (*e.g.* Dane and Topp, 2002). From December 2004 to January 2005, the soil was sampled in the treatments at two soil depth intervals, 0-10 and 10-20 cm, to measure the concentrations of SOC, organic N, available P and K, with the same methods used in the sediment analysis, (Sparks 1996) and the fractions of clay, silt and sand again (Dane and Topp 2002). There were 4 replications for every case. The results are shown in Table 1.

The statistical analyses were made following standard methods (*e.g.* Press *et al.* 1992, Chap. 14).

RESULTS

The different rainfall-runoff events recorded in the plots under the two soil treatments are shown in Figure 2, and the sediment yield of the same events in Figure 3. In addition to the influence of the intense rainfall during the first year 2003-2004 on the runoff yield in both treatments, the cover crop treatment produced a smaller runoff volume than the conventional tillage treatment in all the events, except in those occurring in the fall of 2004. The hydrologic year 2004-2005 was one of the driest on record. During the following years, 2005-2006, and 2006-2007 the differences were very large, especially in the event on 9 May 2007, whose erosive effects were fairly obvious in the plots and in the collection tanks. Figures 4 and 5 compare the different extent of soil erosion in both treatments. In these Figures it can be seen how a rill developed in one of the CT plots, whereas no rill was apparent in the neighboring CC plot. The analysis made in the years when treatments were replicated indicates that these differences are statistically significant as can be observed in the cumulative annual data of Table 2. These results stress the importance of a proper soil management to reduce water loss and nutrient export. The cover crop produced a runoff volume of 6 % of the total rainfall, whereas conventional tillage produced 16% of annual rainfall as runoff.

The annual cumulative soil loss in both treatments, with a much greater one in CT than in CC, is shown in Table 2 The differences in soil loss in both treatments were significant during the years when the treatments were replicated (Table 2). The sediment yields depended not only on the runoff generation but on the intensity of the erosive effects of the rain, both of which were higher in the unprotected soil of the conventional tillage treatment.

The results reflect a large interannual variability of soil losses in the CT treatment that ranged from 1.98 to 50.1 t ha^{-1} year^{-1}. Annual soil loss in the CC treatment varied much less, ranging from 0.12 to 0.77 t ha^{-1} year^{-1}.

The annual dissolved nutrient losses in runoff water are shown in Table 3. There were higher losses of NO_3-N, NO_2-N, dissolved P and K in the CT than in the CC treatment, except in the very dry year of 2004/05, in which the trend was reversed, especially in the cases of phosphorus. Table 4 presents the every two months average nutrient concentrations in runoff water. The soluble nutrient concentration in the runoff originating in the CC treatment was higher than the corresponding losses with the CT treatment, although the great variability and the limited number of replications reduced the statistical significance in the period. The higher concentration of nutrients in the runoff water under the cover crop method was compensated for by the lower runoff generation of the treatment.

Table 5 summarizes nutrient and SOC losses in sediment during the whole period. The losses from the CT treatment were much greater, around one order of magnitude higher, than those recorded from the CC treatment. Year to year variations within each treatment followed a similar pattern to that of the sediment yield, with a greater variation in the CT treatment and a mitigation of the differences between both treatments in the driest year, 2004/05. Table 6 presents the average nutrient and SOC content in sediment during the experiment period. The same as in the case of the soluble nutrients in the runoff, the concentration of the adsorbed nutrients in the sediment tended to be higher in the cover crop treatment than in conventional tillage, made up for by the reduced mass of sediment produced in the former. Enrichment ratios of nutrient in sediment, calculated from the soil nutrient contents in Table 1, seemed to be higher in the CC treatment for organic N and SOC, and similar in both treatments for available P and K (data not shown) The scant mass of sediment collected in the CC treatment prevented a general comparison of the sediment particle size distribution between both treatments. In one case in which the analysis was made for CT there were average sediment enrichment ratios of 0.70, 1.23, 1.57 for sand, silt and clay, and for the CC treatment of 0.45, 1.95, and 1.45 for sand, silt and clay. These results suggest a net enrichment in fine particles of the sediment in both treatments, which was more evident in the CC treatment.

DISCUSSION

Soil management had an important impact on runoff yield in this experiment, with an average reduction of 59 mm year^{-1} in the CC compared to the CT treatment, roughly 10% of the average annual rainfall during the study period (Table 1). The average runoff rates and relative treatment differences were similar to those reported in previous studies. Gómez *et al.* (2004) measured average annual runoff coefficients of 7.4 and 2.5% for CT and CC, respectively, while Francia *et al.* (2006) measured average annual runoff coefficients of 15 and 2.5 % for CT and CC, respectively, in shorter plots. The results confirm that the cover crop, once established, reduces runoff yield more efficiently than the conventional tillage treatment, in spite of the potential retention of water due to increased roughness shortly after the tillage operation, or to the sponginess of the surface layer, whose bulk density was lower than the corresponding value for the cover crop treatment. The data of individual events, especially in the last two years, reinforce this conclusion.

Likewise, cover crop is a good soil conservation practice compared to conventional tillage. Average annual soil losses in the CC treatment were two orders of magnitude smaller than those measured in the CT treatment. This was the result not only of a lower runoff yield, but also of a lower sediment concentration in the CC treatment. The water infiltrated more easily into the soil under the protective plants, and, at the same time, the increased flow resistance dissipated the energy of the surface water, and the aerial part of the plant intercepted part of the sediment particles carried by the water (*e.g.* Dunkerley *et al.* 2001). Soil losses in the CT treatment were within the upper range of recorded values obtained in erosion plots in olive orchards. In a two year period, Francia *et al.* (2006) measured, in runoff plots of 192 m^2 on a loamy soil with a 30% slope, soil losses of 5.7 and 25.6 t ha^{-1} year^{-1} for CT and NT soil management. Bruggeman *et al.* (2005) found soil losses of 41.6 t ha^{-1} year^{-1} in a large plot on CT on a 24% slope in Syria in a four-year period. There are references in the literature of much lower rates of soil losses in CT; for instance, Gómez *et al.* (2004) measured 4 t ha^{-1} year^{-1} in 72 m^2 runoff plots on a 13.2 % slope during a three-year period. Measurements in small plots also yielded lower values, such as those of de la Rosa *et al.* (2005), who reported an average of 0.25 t ha^{-1} year^{-1} in runoff plots of 8 m^2 on a 6% slope during a 2 month period, and Ordóñez-Fernández *et al.* (2007) who determined an average of 1.4 t ha^{-1} year^{-1} losses using 1 m^2 plots with slopes ranging from 1.5 to 7% during a two year period. The results obtained in this experiment indicate that, under CT, erosion rates on a hillslope scale in olive groves can be much higher than the tolerable rates of 5-12 t ha^{-1} year^{-1} (Montgomery, 2007). These results recommend, as Parsons *et al.* (2004) pointed out, that, to adequately monitor the key processes of water erosion on a hillslope, a common setting for olive orchards in the Mediterranean region, erosion plots must be of a sufficient length for large rills to develop, as shown in Figure 4. Experiments with smaller plots do not seem appropriate for this purpose.

Intense isolated erosion events, like that of 9 May, 2007 (Figure 3), exert a great influence on the long term average erosion rates. This reinforces the need for continued studies, made not only on a representative scale, but also performed during a sufficiently long period.

A large reduction of soil loss with the cover crop treatment as compared to that with tillage has also been reported in previous studies; Bruggeman *et al.* (2005) and Francia *et al.* (2006) in their cover crop plots measured 5.08 and 2.1 t ha^{-1} year^{-1}, compared to 41.6 and 5.7 t ha^{-1} year^{-1}, respectively

Average annual nutrient losses both dissolved in runoff and adsorbed in the sediment were greater in the CT treatment, compared to the cover crop treatment. The differences between treatments were due to a higher runoff and sediment yield with the conventional tillage treatment, since nutrient concentration in runoff seemed to be similar or slightly higher in the CC treatment, see Table 4. The nitrogen data are within the range of those measured by

Franklin *et al.* (2007). The dissolved P concentrations of Table 4 are similar to those of Srinivasan *et al.* (2007). Francia *et al.* (2006) also found greater nutrient losses in runoff in the CT treatments compared to the CC management. The average annual nutrient losses in runoff of NO_3-N measured in this experiment were smaller than those determined by Francia *et al.* (2006), while losses in dissolved K were greater in our experiment than in theirs, and those in dissolved P were similar. These differences can be attributed to the chemical properties of the soils and to the fertilizer application rates on each farm. The average annual concentration of NO_3-N in runoff, Table 4, measured in this experiment was below the limit of the 10 mg L^{-1} recommended for drinking water by the US EPA (2004), although during many periods the average concentrations were above that limit, especially in the CC treatment. Average two-month concentrations of NO_2-N in runoff were also under the limit of 1 mg $L^{-1}$of the drinking water standards of the US EPA (2004) see Table 4. NO_3-N concentrations in runoff water were above the background levels indicated for European rivers, 0.4 to 4 mg L^{-1} (Nixon *et al.* 2003). Average dissolved P content in runoff water, Table 4, were significantly above the background level in European rivers, around 0.01 mg L^{-1} (Nixon *et al.*, 2003), for both treatments. They were also above the range, 0.025 to 0.1 mg L^{-1}, proposed by MacDonald *et al.* (1991) to limit the increase in productivity of aquatic ecosystems. NO_3-N and dissolved P concentrations indicate a significant potential for eutrophication of the runoff. Given the larger amount of runoff generated from the tilled areas, the water pollution risk is much higher than in the orchards where the cover crop has been adopted as a soil and water conservation practice. In our experiment, this risk is still not negligible under CC management, when heavy rain occurs. Average dissolved K concentrations were almost always below the upper limit of 12 mg L^{-1} recommended for drinking water, Table 4.

Organic N, SOC, available K and P losses in sediment were higher in the CT treatments, especially in the years with large erosive events, due to the high sediment yield rates, Table 5. Higher total N, P and K losses in sediment from tilled olive orchards as compared to orchards with a cover crop have also been reported by Francia *et al.* (2006) and Ordóñez-Fernández *et al.* (2007) for the P data only. The magnitude of the losses measured in this experiment was in the lower range of the values presented by Francia *et al.* (2006) and in the upper range of those presented by Ordóñez-Fernández *et al*. (2006). Overall available P and K losses in sediment were too low to induce nutrient deficiency in the orchards either in the short or medium term, but can contribute significantly to the nutrient discharge to surface water bodies, especially in the CT treatment. In the CT treatment the main source of P in the water was in the sediment transported by runoff (Tables 3 and 6). This is in line with the distribution of P losses in other agricultural systems suffering high erosion rates (Hart *et al.* 2004) as was the case of the CT treatment. With the CC treatment, with low sediment losses, most of the P losses were as dissolved P in runoff. In the CT treatment, P losses were highly correlated with the years with a large runoff and sediment losses, Tables 3 and 6, indicated the importance of the effect of large single events on P losses, as previously noted by several authors for high erosion risks under Mediterranean conditions (*e.g.* Torrent *et al.* 2007). Differences in the average nutrient concentration in sediment in our experiment might be associated with differences in the enrichment ratio of the sediment in organic N, SOC and available K, related to a selective enrichment with soil fine fraction compared to the CT treatment. The CC treatment presented a significantly higher content of available P, Table 1, which could be an additional reason for the higher dissolved P concentration of sediment in the CC treatment. These results show that water erosion was a significant mechanism of carbon losses in the CT plots, with average annual losses in the upper range of carbon losses due to erosion reported in other runoff plot studies in temperate (Quinton *et al.* 2006) and Mediterranean climates (Roose and Barthès 2005). The carbon losses in the CC treatment were in the lower range of values reported for Mediterranean areas (Roose and Barthès 2005).

In spite of the cover crop environmental advantages, the farmers in the area are, in general, reluctant to adopt it. This behavior is a general feature of farmers in different regions (Helling and Haigh 2002), especially if the proposed practice does not represent an immediate increase in the crop yield. One of the key reasons for this reluctance is the need for a careful management of the cover crop to avoid competition for water with the olive tree (Gómez et al., 2005), especially under rainfed conditions in which there is no possibility of compensating for excessive water consumption by the cover crop during spring time through irrigation. Another reason is that, for many farmers, tillage (especially surface tillage as performed in this experiment) is still less expensive than cover crop soil management. The cost of management by the CT treatment used in this experiment has been estimated at 75 € ha^{-1} $year^{-1}$ while the average costs of a soil management based on cover crops in this orchard has been estimated at 211 € ha^{-1} $year^{-1}$ (Baena, 2008).

Nevertheless, farmers do use practices of what is called better land husbandry (Shaxson *et al.* 1997), which are not aggressive to the environment and, at the same time, are relatively easy to maintain and which will produce at least medium and long term benefits. The environmental benefits of cover crop soil management in olive orchards suggest that is worth pursuing the adoption of this technique by olive farmers and for this it is necessary to address the reasons indicated above.

CONCLUSIONS

These results indicate that for the experiment conditions, which are representative of large areas of olive cultivation in the Mediterranean, tillage-based soil management in olive orchards results in erosion rates (average of 19 t ha^{-1} $year^{-1}$) that are well above the tolerable ones (Montgomery, 2007), and also produce heavy losses of soil carbon due to water erosion. Most of the sediment losses in the CT treatment occurred in a few intense events. Sediment losses in CT were associated with large runoff losses that not only reduced the infiltration of rainfall to be used later by the crop, but that were also a significant source of nutrients loss, thus increasing the risk of eutrophication. The results were obtained in a situation in which CT used a reduced number of shallow passes as compared to the common practice of many passes in many olive growing areas. The alternative system based on a cover crop managed with herbicides in spring reduced soil losses down to tolerable rates of 0.4 t ha^{-1} $year^{-1}$. Reduction in runoff and sediment losses also triggered a significant reduction in organic matter and nutrient losses. This indicates that, although there is a clear and significant decrease in the risk of eutrophication of surface waters when CC is used as compared to CT, runoff waters from an orchard under CC management could also have episodes of a significant nutrient contribution to surface waters.

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Depth	***$N_{organic}$ %***		***SOC %***		***$P_{available}$ $\mu g\ g^{-1}$***		***$K_{available}$ $\mu g\ g^{-1}$***	
	CT	CC	CT	CC	CT	CC	CT	CC
0-10 cm	0.07	0.09	0.75	0.93	9.8a	20.3b	150.4	230.8
10-20 cm	0.04	0.04	0.46	0.58	9.1	7.3	126.0	106.7

	Clay %		***Silt %***		***Sand %***		***Bulk density $kg\ m^{-3}$***	
	CT	CC	CT	CC	CT	CC	CT	CC
0-10 cm	15.1	15.4	31.8	34.0	53.1	50.6	1440	1680
10-20 cm	16.1	20.1	37.4	43.6	46.5	36.3	1560	1460

Table 1: Average values of chemical and physical soil properties measured in January-February 2005 in the experiment plots. Except for available P values, in the top soil layer, indicated by different letters, the data were not significantly different at $P>0.90$ level.

Year	*Rainfall mm*	*Runoff mm*		*Soil loss kg m^{-2} $year^{-1}$*		**Sediment concentration kg m^{-3}**	
		CT	CC	CT	CC	CT	CC
2003/04	858	210.8	85.4	5.01	.049	23.8	0.6
2004/05	268	12.4	21.1	.198	.076	16.0	3.6
2005/06	603	39.0a	9.4a	.303*a*	.012*b*	8.0**a**	1.6**b**
2006/07	573	105.1**a**	14.8**b**	2.24**a**	.023**b**	21.3**a**	1.6**b**
Average	576	91.9	32.7	1.94	.040	17.3	1.9

Table 2: Average annual soil loss and runoff yield. For years with replicated plots (2005/06 and 2006/07) average values followed by different letters are significantly different at $P > 0.99$, in **Bold**, or $P>0.90$, in *Italics*.

Year	**NO_3-N**		***NO_2-N***		***dissolved P***		***dissolved K***	
	kg ha^{-1}year^{-1}							
	CT	CC	CT	CC	CT	CC	CT	CC
2003/04	2.05	1.23	-	-	0.34	0.09	4.57	3.27
2004/05	0.46	3.67	-	-	0.16	1.08	0.60	2.34
2005/06	1.11a	0.65a	0.04*a*	0.01*b*	0.02a	0.02a	1.80a	0.62a
2006/07	9.51*a*	1.43*b*	0.07*a*	0.01*b*	0.25*a*	0.13*b*	4.80*a*	0.77*b*
Average	3.28	1.75	0.06	0.01	0.19	0.33	2.94	1.75

Table 3: Average annual nutrient losses in the runoff. For years with replicated plots (2005/06 and 2006/07) average values followed by different letters are significantly different at P > 0.99, in **bold**, or P>0.90, in *italics*.

Year	***Period***	**NO_3-N**		**NO_2-N**		***dissolved P***		***dissolved K***	
					mg L^{-1}				
		CT	CC	CT	CC	CT	CC	CT	CC
2003/04	**Sep-Oct**	3.27	0.33	-	-	0.00	0.01	7.38	0.92
	Nov-Dec	0.70	0.93	-	-	0.17	0.04	2.02	3.28
	Jan-Feb	5.82	6.21	-	-	0.16	0.27	3.94	5.89
	Mar-Apr	3.84	3.43	-	-	0.10	0.63	4.60	6.96
	May-Jun	1.50	0.81	-	-	0.14	0.25	2.15	9.35
	Jul-Aug	-	-	-	-	-	-	-	-
Annual	**Average**	0.97	1.44	-	-	0.16	0.11	2.17	3.83
2004/05	**Sep-Oct**	4.02	18.0	-	-	1.25	5.27	4.92	11.1
	Nov-Dec	1.74	5.50	-	-	1.85	5.71	4.24	9.00
	Jan-Feb	-	-	-	-	-	-	-	-
	Mar-Apr	1.67	1.12	-	-	1.25	0.11	6.62	12.0
	May-Jun	-	-	-	-	-	-	-	-
	Jul-Aug	-	-	-	-	-	-	-	-
Annual	**Average**	3.71	17.4	-	-	1.29	5.11	4.84	11.1
2005/06	**Sep-Oct**	2.64a	14.1a	0.02a	0.06a	0.05a	0.58a	2.73a	5.84a
	Nov-Dec	7.48a	12.4a	0.03a	0.03a	0.06a	0.05a	5.29a	4.65a
	Jan-Feb	2.37a	5.61a	0.10*a*	0.05*b*	0.04a	0.07a	5.52a	5.55a
	Mar-Apr	3.98a	4.29a	0.12**a**	0.06**b**	0.06a	0.18a	6.11a	7.62a
	May-Jun	4.81a	4.72a	0.16a	0.04a	0.08a	0.19a	7.03a	4.30a
	Jul-Aug	5.80a	5.65a	0.08a	0.05a	0.09a	0.33a	8.80a	5.00a
Annual	**Average**	2.85a	6.91a	0.10a	0.11a	0.05a	0.21a	4.62a	6.59a
2006/07	**Sep-Oct**	2.94*a*	5.46*b*	0.08a	0.05a	0.51a	2.20a	4.62a	5.94a
	Nov-Dec	1.10*a*	3.16*b*	0.04*a*	0.03*b*	0.06a	0.14a	1.86*a*	2.33*b*
	Jan-Feb	7.54a	14.9a	0.03a	0.03a	0.11a	0.54a	3.56a	4.28a
	Mar-Apr	14.1a	33.2a	0.03a	0.05a	0.11a	0.42a	3.82a	4.66a
	May-Jun	24.0a	14.1a	0.05a	0.05a	0.09a	0.18a	6.95a	6.00a
	Jul-Aug	14.2a	21.6a	0.04**a**	0.05**b**	0.08*a*	0.27*b*	5.73a	5.70a
Annual	**Average**	9.05a	9.66a	0.07a	0.07a	0.24**a**	0.88**b**	4.57a	5.20a
Average 2003/07		3.57	5.35	0.08	0.08	0.21	1.01	3.20	5.35

Table 4: Average bimonthly nutrient concentration in the runoff. For years with replicated plots (2005/06 and 2006/07) average values followed by different letters are significantly different at P > 0.95, in **bold**, or P>0.90, in *italics*.

Year	***N*** $_{organic}$		***SOC***		***P*** $_{available}$		***K*** $_{available}$	
	kg ha^{-1}year^{-1}							
	CT	CC	CT	CC	CT	CC	CT	CC
2003/04	49.4	0.72	404.	7.42	0.86	0.01	6.62	0.08
2004/05	1.61	1.08	21.7	10.5	0.05	0.06	0.32	0.24
2005/06	4.65a	0.22a	40.9a	1.84a	0.04a	0.004a	0.60a	0.03a
2006/07	25.4**a**	0.56**b**	470.**a**	5.44**b**	0.31**a**	0.014**b**	1.95*a*	0.04*b*
Average 2003/07	20.3	0.65	234.	6.31	0.32	0.02	2.37	0.10

Table 5: Average annual nutrient losses adsorbed in the sediment. For years with replicated plots (2005/06 and 2006/07) average values followed by different letters are significantly different at P > 0.95, in **bold**, or P>0.90, in *italics*.

Year	***Period***	***N** $_{organic}$* %		***SOC*** %		***P** $_{available}$* $\mu g\ g^{-1}$		***K** $_{available}$* $\mu g\ g^{-1}$	
		CT	CC	CT	CC	CT	CC	CT	CC
2003/04	**Sep-Oct**	-	-	-	-	-	-	-	-
	Nov-Dec	0.10	0.09	0.80	0.94	17.2	26.8	132.	140.
	Jan-Feb	0.13	-	1.11	-	16.7	-	99.5	-
	Mar-Apr	0.10	0.02	0.89	0.56	16.5	18.9	158.	111.
	May-Jun	-	0.33	-	3.22	-	26.7	-	237.
	Jul-Aug	-	-	-	-	-	-	-	-
Annual	**Average**	0.10	0.15	0.81	1.51	17.2	20.4	132.	163.
2004/05	**Sep-Oct**	0.07	0.14	1.01	1.37	24.2	73.5	144.	313.
	Nov-Dec	0.20	0.04	2.13	0.39	54.5	96.1	376.	454.
	Jan-Feb	-	-	-	-	-	-	-	-
	Mar-Apr	0.15	0.31	3.46	2.46	48. 9	69.1	557.	845.
	May-Jun	-	-	-	-	-	-	-	-
	Jul-Aug	-	-	-	-	-	-	-	-
Annual	**Average**	0.08	0.14	1.09	1.36	25.3	78.9	162.	316.
2005/06	**Sep-Oct**	0.10a	0.10a	0.78a	0.53a	1.06a	21.1a	14.9a	168.a
	Nov-Dec	0.10a	0.12a	0.68a	0.80a	13.5a	32.6a	375.a	195.a
	Jan-Feb	0.19a	0.27a	1.75a	2.10a	13.6a	41.1a	299.a	362.a
	Mar-Apr	0.14a	0.24a	1.18a	1.91a	10.5a	44.0a	171.a	229.a
	May-Jun	0.08a	0.18a	1.40a	1.39a	14.9a	36.1a	40.5a	116.a
	Jul-Aug	0.18**a**	0.00**b**	2.78**a**	0.00**b**	36.7**a**	0.00**b**	138.**a**	0.00**a**
Annual	**Average**	0.19a	0.18a	1.35a	1.53a	13.2a	33.3a	198.a	250.a
2006/07	**Sep-Oct**	0.15a	0.24a	2.17*a*	2.47*b*	28.6a	64.0a	263a	198.a
	Nov-Dec	0.12a	0.24a	1.89a	2.17a	21.0a	56.9a	32.8a	68.0a
	Jan-Feb	0.17a	0.22a	2.04a	1.94a	15.0a	82.5a	22.0a	159.a
	Mar-Apr	0.32a	0.28a	1.79a	2.37a	7.10**a**	107.**b**	17.9a	199.a
	May-Jun	0.09a	0.23a	2.06a	2.42a	9.28**a**	54.3**b**	33.2a	103.a
	Jul-Aug	0.18a	0.23a	2.88a	2.40a	18.5a	76.3a	60.8**a**	151.**b**
Annual	**Average**	0.11a	0.24a	2.10a	2.37a	13.8**a**	60.9**b**	87.1a	174.a
Average 2003/07		0.11	0.16	1.21	1.56	16.5	50.0	122.	250.
Enrichment ratio		1.57	1.78	1.30	2.08	1.68	2.46	0.81	1.08

Table 6: Average bimonthly nutrient losses adsorbed in the sediment. For years with replicated plots (2005/06 and 2006/07) average values followed by different letters are significantly different at P > 0.95, in **bold**, or P>0.90, in *italics*.

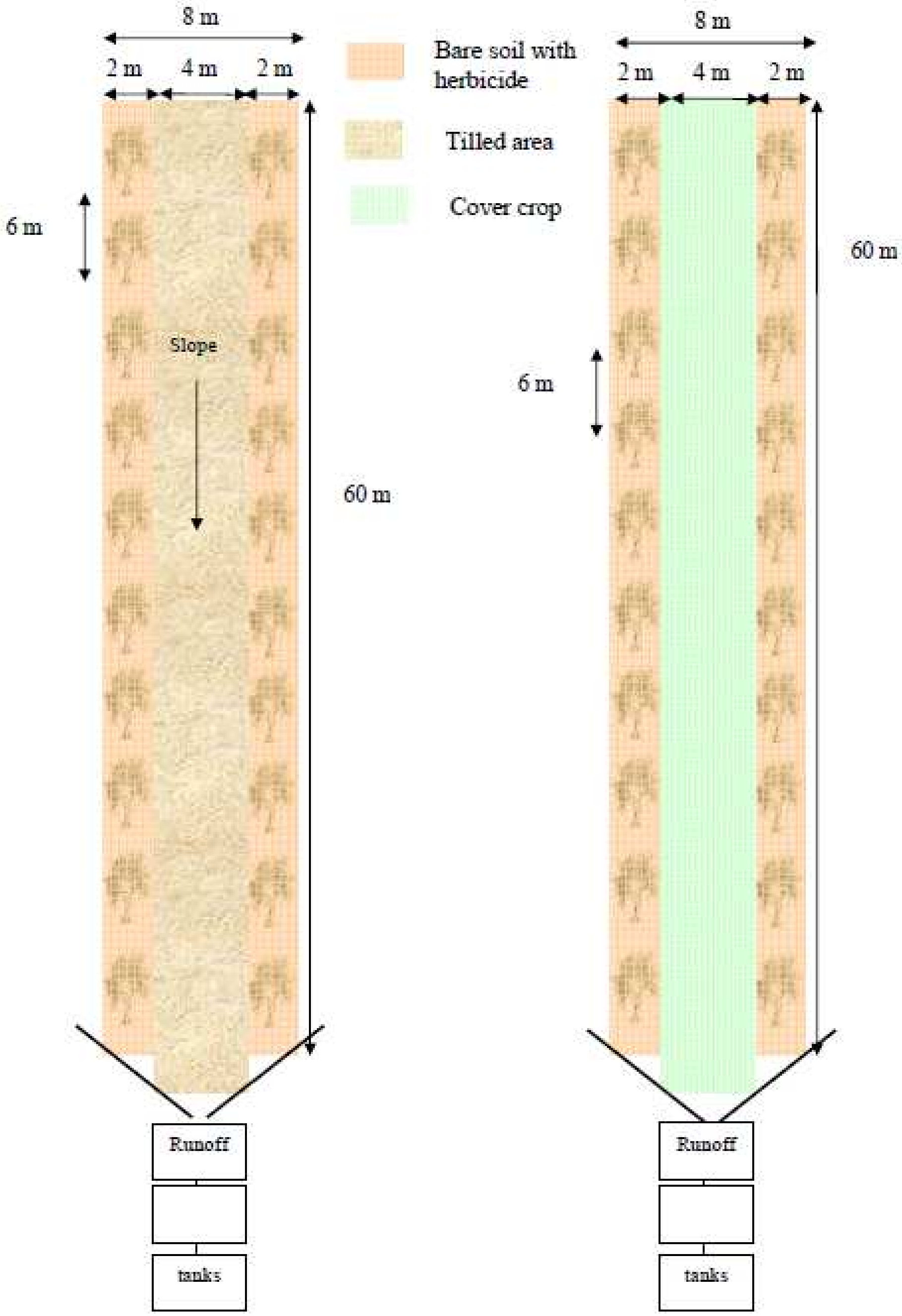

Figure 1. Description of the runoff plots under conventional tillage (leftt) and cover crop (right) management

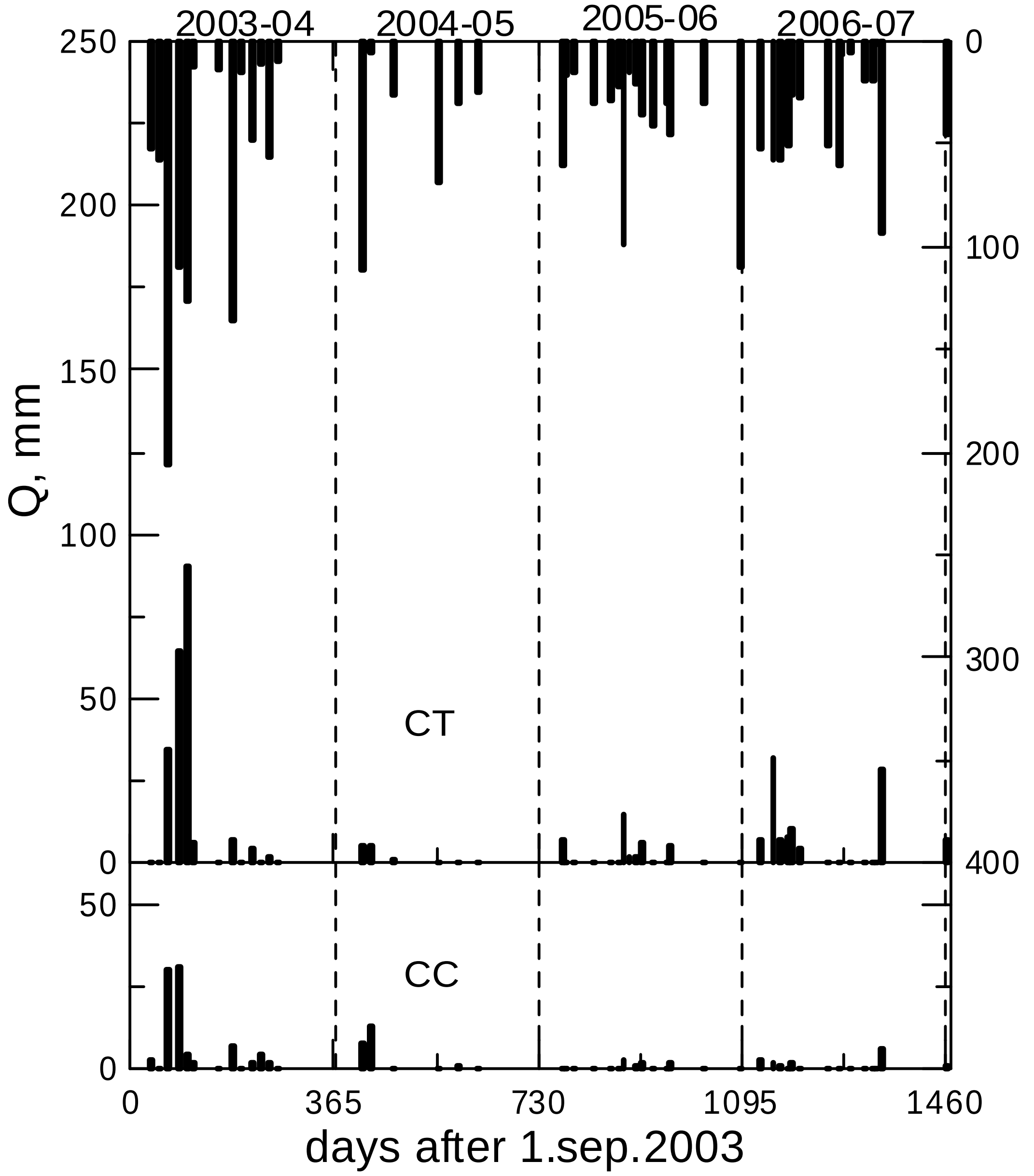

Figure 2. Rainfall and runoff produced in the different events in the hydrologic years of the period 2003-2007, under the conventional tillage, CT, and cover crop treatments. The runoff data of the last two years are the average values of the data recorded in the two replications.

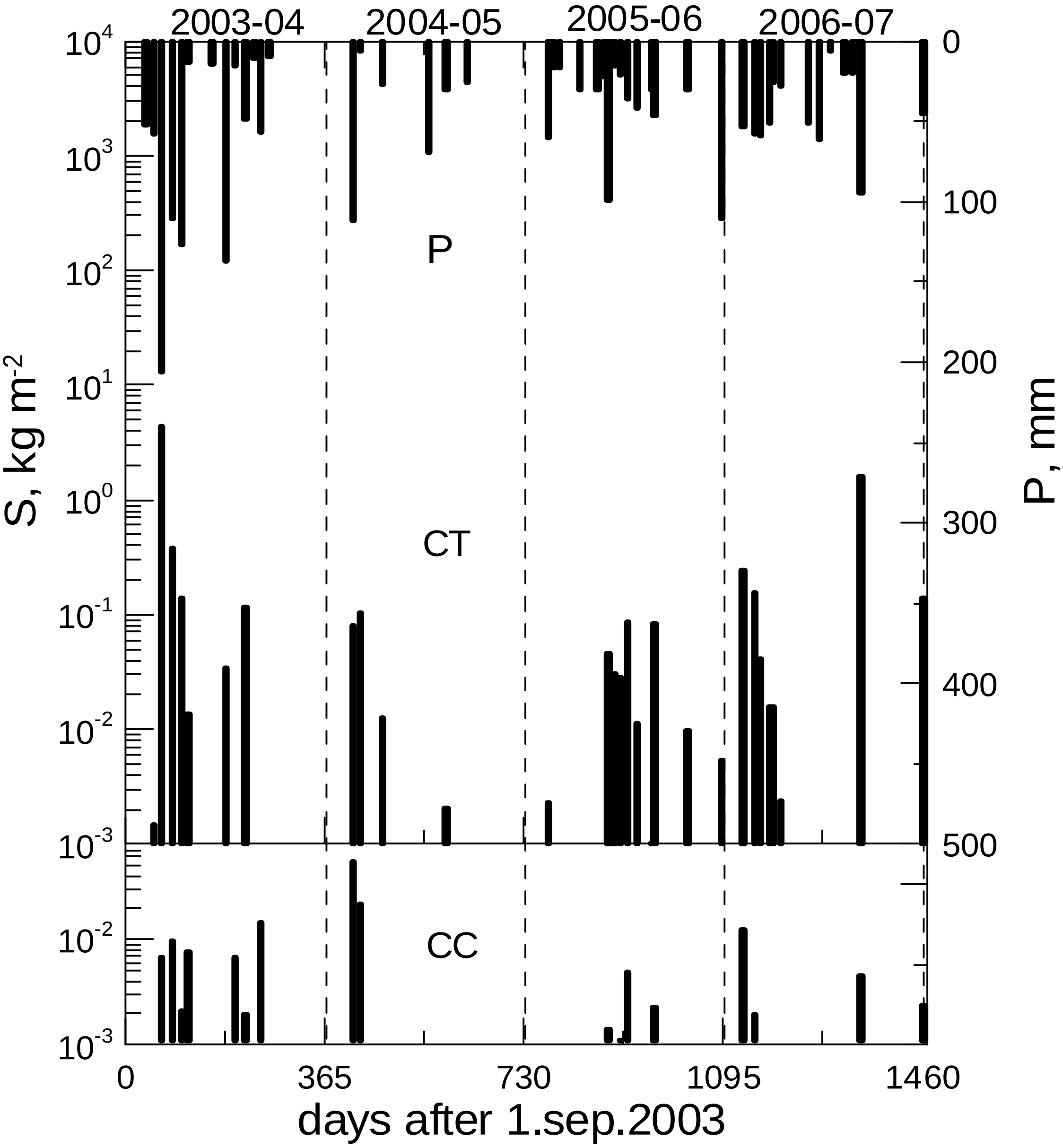

Figure 3. Rainfall and sediment yield produced in the different events in the hydrologic years of the period 2003-2007, under the conventional tillage, CT, and cover crop treatments. The runoff data of the last two years are the average values of the data recorded in the two replications.

Figure 4. Downstream view of one of the CT plots after the intense rainfall event of 9 May 2007, with a long rill developed in the left, northern side.

Figure 5. Downstream view of one of the CC plots after the intense rainfall event of 9 May 2007, where there are no rills developed.