Long-term effects of different arable cropping systems on surface erosion processes and C-factor in hilly Mediterranean environment

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Article title: Long-term effects of different arable cropping systems on surface erosion processes and C-*factor* in hilly mediterranean environment.

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Abstract

Soil erosion is an environmental threat strongly amplified by agricultural activity and, in the last decade, by climate change; it affects many European countries and in particular Italy. Water erosion is currently considered the most important cause of soil degradation. The vegetation cover represents a natural soil protection against water erosion phenomena as it reduces the rainfall impact energy, hinders surface runoff and promotes soil infiltration. For these reasons, identifying appropriate crop systems able to reduce soil loss is a key issue for proposing economical solutions in management planning. This work reports the results of a long-term study (12 years) aimed at determining the vegetation cover effectiveness, diversified by structure and duration of the crops in rotation, and the soil tillage impact on erosion and surface runoff. The *C-factor* determination, without resorting to very detailed measures, is provided by the indirect application of Universal Soil Loss Equation (USLE). Five different soil managements were included in this study. Four experimental plots were cultivated with different cropping systems and intensification tillage degree (CS), and a standard plot (SP) maintained in bare conditions by up and down slope tillage operations. The annual value of soil loss, calculated as mean for the five treatments, was 35.84 t ha^{-1}, and ranged between 4.11 and 72.07 t ha^{-1}.

The results showed that CS_4 and CS_1 presented, on average, the lowest soil loss values of 9.38 and 13.93 t ha^{-1}, respectively. The soil conservative management (minum tillage, strip tillage, shredded crop residues and grassy crops) allowed, in these two CS, to reach, on average, a soil cover degree ($\geq$ 50%) for 260 and 210 days and to obtain a *C-factor* of 0.12 and 0.14, respectively. In the CS_3 (mixed conservative and conventional) with a soil cover degree $\geq$ 50% for 182 days and a *C-factor* of 0.19, the soil loss was equal to 18.65 t ha^{-1}. The conventional farming system (CS_2) recorded an average value of soil loss of 55.04 t ha^{-1} with a maximum value of 138.20 t ha^{-1} in 2015/16; this CS also presented the lowest number of days (135) with a land cover level $\geq$ 50% and the highest *C* value (0.50).

The analysis allowed consolidating previous information and identifying strategies to be adopted in the Mediterranean hillside environment to significantly reduce soil losses due to water erosion.

1. Introduction

Soil is a fragile resource that needs time to regenerate. Every year, an estimated 12 million ha are lost through soil degradation and 24 billion tons of fertile soils are lost due to erosion (FAO, www.fao.org, 2016). Soils are particularly susceptible to many threats; climate change, rainfall, deforestation, unsustainable farming practices. Resource extraction methods affect their fertility and trigger land degradation (*a negative trend in land condition, caused by direct or indirect human-induced processes including anthropogenic climate change, expressed as long-term reduction or loss of ecosystem goods and services*) and several phenomena related to it as erosion, nutrient depletion and other disasters such as floods and landslides (Assennato et al., 2020).

Soil erosion by water is one of the most important environmental problems in the world causing great losses every year as well as affecting sustainable economic development. In many cases, water erosion determines an almost irreversible decline in soil productivity and other soil functions and leads to environmental damage.

The negative effects of soil erosion, that where the human activities are increasing shift from natural to accelerated, include water pollution and siltation, crop yield depression, organic matter and carbon loss, reduction in water quality and storage capacity, which may lead to fundamental social challenges such as land abandonment and decline of rural communities (Cerdan et al., 2010). For these reasons, prevention of soil erosion has become a mondial issue for natural resources management and conservation (Lal et al., 2007; Tejada and Gonzales, 2006; Martínez-Mena et al., 2020).

A previous assessment referred to land degradation processes, based on vegetation land cover and climatic data, showed an increasing pressure on land and revealed that themost vulnerable areas to environmental degradation were mainly detected in Mediterranean environments, higlly exposed to soil erosion due to soil features and rainfall distribution. In this context, millennia of agricultural management, recent intensification of agricultural practices, vulnerable environment, extreme climate conditions (intense and irregular rainfall events, long dry periods and heavy bursts of erosive rainfall) are recognized as drivers for increasing runoff and soil loss (Preiti et al., 2017; Bogunovic et al., 2020).

Current soil management practices (under intensive agriculture) are exacerbating the degradation of several lands carrying to a widespread decline of agricultural sustainability due to the loss soil quality (Novara et al., 2021). This is dramatic in semi-arid zones particularly prone to soil erosion where soil can be lost suddenly during intense rainfall events.

Despite several studies highlight that in semi-arid environment the rainfall intensity is higher in winter or autumn, in South Mediterranean area, some authors estimated summer erosivity to be equal or slightly higher than the one during winter. The same intensity of rainfall erosivity can result in more or less effectiveness on soil erosion according to the time of year when it occurs depending on different variable factors, like tillage managment and crop cover. Therefore, knowledge about the time of year when the highest erosivity occurs is critical for choosing more suitable management practices (Baiamonte et al., 2019). In this context, land use and preservation management strategies (reduced tillage and crop residues as mulch) are key factors for preserving soil quality, increasing water retention and controlling the intensity and the frequency of soil loss and runoff (Bogunovic et al., 2020; Bombino et al, 2019; Martinez-Mena et al., 2020).

Conservation management has been reported in many studies as an effective strategy for controlling soil erosion, maintaining soil fertility, increasing soil C sequestration, preserving biodiversity and improving cropping systems sustainability (Lal et al., 2007; Kurothe et al., 2014; Ruisi et al., 2014; Baiamonte et al., 2021). These goals require a correct assessment of erosion rates and their geographical distribution (Cerdan et al., 2010). In addition, the reduction of stress soil factors, including tillage, could strongly influence the magnitude of erosion processes; therefore, sustainable crop systems become particularly important for reducing soil losses in hot-arid climates with irregular rainfall distribution as in Mediterranean environment (Sasal et al., 2010; Sanesi et al., 2013; Kurothe et al., 2014). Protection of soil and its resources, threatened by various stressors, has amplified the need of soil erosion field-experimental measurements, taking into account different land use and/or climate change (Cerdan et al., 2010).

The use of calculation models, more or less complex, able to provide detailed information about the most vulnerable areas and the use of management criteria capable of reducing the erosion phenomenon are particularly functional for these purposes. The (R)USLE equation – which is today still considered the most reliable system for water erosion estimation – considers six factors: rainfall erosivity (R), soil erodibility (K), slope length (L), slope steepness (S), vegetation covers and management (C) and erosion-control practice (P). Product of the six factors, R, K, and LS, modified by P and C (Wischmeier et al. 1971; Renard et al., 1997), calculates the long-term average annual soil loss. (R)USLE equation allow calculating *C-factor*, resorting to measures of great detail, by indirect application of equation (McGregor, 1978;

Alberts et al., 1985; Cinnirella et al., 1998; Bacchi et al., 2010):

$$C=A/R\ K\ LS\ P \tag{1}$$

The cover management parameter (*C factor*) assesses the effect of soil and crop management on soil loss. This factor affects by tillage management (time and type), crops, seasonal erosivity index distribution, cropping history (rotation) and crop yield level (organic matter production potential). By definition, *C* is considered as one (1), under standard fallow conditions. As the surface cover increasingly is added to the soil, the *C factor* value approaches zero, resulting in a reduction of soil erosion (Gabriels et al., 2003; Nyakatawa, 2007).

For computing the *C-factor* is necessary to use experimental soil erosion plots under natural rainfall, however these studies are expensive and time-consuming and available measured data in experimental plots are scarce or inexistent (Almagro et al., 2019).

In this sense, despite globally there are many erosion plot data available for different locations; there is a lack of long-term studies testing the effectiveness of conservative managment towards runoff and soil erosion reduction. Having identified this lacking information, with the present study we aim to offer a valuable contribution to reduce this gap.

This work integrates runoff and erosion in relation to rainfall characteristics after twelve years of sustainable land management practices in four cropping systems representative of a large area of the driest Mediterranean regions. Our long-term field trial was specifically designed to measure some USLE factors and to estimate protective efficacy of different cropping systems on erosion process.

In particular, *C-factor* was used, on plot scale, to evaluate effect on soil loss and runoff of four crop systems diversified in structure and duration. A traditional crop system was compared, in a specific system placed in Calabria, to diverse systems managed by different conservation tillage techniques to verify how the adoption of low-impact soil management techniques, together with a fodder crop insertion, could reduce the erosion phenomenon. The effectiveness in erosion control of conservative soil management techniques, already widely proven in many studies, was integrated by a replacement of vegetable crop with tall fescue or natural vegetation in crop rotations.

The use of equation (1), at scale of single, seasonal and annual rainfall events, has allowed consolidating the information on cropping systems less affecting fragile Mediterranean hilly environments.

The aims of this trial are: i) to evaluate the role of conservative techniques in controlling the erosion process in a long period; ii) to assess the ability of different cropping systems to reduce the erosion by calculating the *C-factor* with indirect application of USLE model.

Our results provide stakeholders (including farmers) a useful parameter to minimize environmental risks associated with soil losses, even in fragile environments characterized by marginal land and climate.

2. Materials and methods

2.1. Site description

The study area (38°16’ N, 15°49’ E) is located in Bagnara, Calabria, Southern Italy at 585 m a.s.l. (Fig. 1). The climate is typically Mediterranean, characterized by a rainy season extending from October to March and a dry summer during which occasional thunderstorms may occur. Arable and vegetable crops are traditionally cultivated in this area.

Daily metereological data series recorded at Sinopoli (502 m s.l.m. - 38°15’N, 15°54’E), station located 3.5 km from the experimental site, were taken into account to characterize the climate of the trial site. The area falls within a thermo-climate zone included between 14 °C e 15 °C annual average isotherms. The annual precipitation is approximately 1350 mm (averages over the 1961–2020). Soil thermal and moisture regimes are thermic and udic (first 150 cm), respectively.

The analysis carried out on monthly average data shows, for both cumulative rainfall and daily maxima, a similar trend with higher values during autumn and winter seasons and maxima in the months between October and February (Fig. 2).

The orography, the altitude, the distance from the sea and the prevailing winds of the experimental site exert a considerable influence on pluviometric variability and thermal regimes.

The field experiment was carried out on a silty loam soil (61.7% sand, 7.5% clay, 30.8% silt) classified as a Typic Hapludands, medial, amorphic, mesic according to USDA soil taxonomy (Soil Survey Staff, 2006). The soil (0–30 cm depth) contained 7.8% organic matter (Walkley-Blach), 2.34 g kg^{-1} total N (Kjeldahl), 1.0 mg kg^{-1} P (Olsen), 213.5 mg kg^{-1} K (Merwin Peach) and had a pH of 5.9, a cation exchange capacity (CEC) of 10.46 cmol kg^{-1} and an electrical conductivity (EC) at 25 °C of 0.72 dS m^{-1}. Values of bulk density were provided from specific measurements carried out in 2006 (Porto and Walling, 2012). In that study, collection of sectioned soil cores from 5 sites, one for each plot, was undertaken to a depth of ca. 50 cm, using a steel core tube (11 cm internal diameter). The core tube was driven into the ground by a motorised percussion hammer and the extraction was operated using a winch. After removal from the core tube, each core was sectioned into 2–4 cm depth increments and the bulk density was calculated for each layer. Values ranging from 0.7 to 1.6 g cm^{-3} (with a mean value = 1.02 g cm^{-3}) were obtained. The lower values (0.7-1.2 g cm^{-3}) were obtained for the upper layers (0-20 cm) in which continuous tillage, high content of organic matter, and retention of crop residuals have affected the soil porosity. The higher values (1.2-1.6 g cm^{-3}) were observed for the deeper layers. Measurements of hydraulic conductivity were carried out, during the same period, using a Guelph Permeameter (Reynolds and Elrick, 1987). In that case, two measurements on each plot were conducted. Values ranging from $4.4 \cdot 10^{-4}$ cm s^{-1} to $16.0 \cdot 10^{-4}$ cm s^{-1} (with a mean value = $9.9 \cdot 10^{-4}$ cm s^{-1}) were obtained. The field capacity and permanent wilting point, determined using the pressure plate method (Klute, 1986), were respectively 52.5% and 28.9%.

2.2 Experimental design and soil management

The experiment started in 2006; five (5m x 25m) experimental plots (Fig. 1) were placed to evaluate the effect of different cropping systems on runoff and soil loss. In particular, the treatments included a conventional cultivation system, two conservation systems, one mixed (conventional / conservative) and one standard plot according to Wischmeier and Smith (1978). Plots placement and device characteristics for collecting runoff are the same reported in the previous work by Preiti et al. (2017).

Data recorded during the first years suggest us, at the end of 2009, to change some cropping systems inserting conservative systems to assess their effectiveness on erosion reduction.

In the present paper, a twelve-year trial, from 23rd September 2006 to 22nd September 2018, were discussed. Four plots supported various cropping systems (CS), while one was kept in bare condition (four tillages each year) by up and down slope tillage to maintain the ground cover always below 10% as standard plot (SP). The different crop system managements are listed below (Table 1). Up and down tillage was always performed to simulate conventional tillage of sloping land; for vegetable crops, post-plant management included in-row cultivation and/or hilling tools; for grain crops, when necessary, weeds were controlled by herbicides. Note that the CS_3 system differs from other crop systems for having adopted a mixed conventional/conservative management.

2.3. Measurements and rainfall data

Rainfall data were recorded by a high-temporal-resolution weather station (CR_{10}-Campbell Scientific), located in the experimental area. During the twelve-year study period, one hundred and fifty-six events that had generated both runoff and soil loss were observed. In some cases, due to the short time occurring between events, separated runoff sampling was not possible and the resulting measurements are related to cumulative events. The collecting tanks were emptied shortly after each rainfall and the suspension remained on the bottom was well mixed and sampled (four samples of five liters, used as replicas, for each plot). The samples were then oven-dried at 60 °C, until constant weight and, successively, used for laboratory physical and chemical analysis (data not shown). Clear water volume was recorded to measure the amount of runoff from each plot. The soil loss and runoff data collected in the different samplings were used to obtain the cumulated quantity for each cropping system.

The rainfall erosivity factor R, as defined by Wischmeier and Smith (1978), represents the mean annual value of the rainfall erosion index, EI, calculated by summing the EI values of each erosive event. The calculation of EI (MJ mm ha^{-1} h^{-1}) for each individual storm required a continuous record of rainfall intensity and it was determined by the product of total storm energy E (MJ ha^{-1}) and maximum 30-min intensity i_{30} (mm h^{-1}):

$$EI = E\, i_{30} = \left(\sum_{j=1}^{m} e_j \, \Delta V_j \right) i_{30} \tag{2}$$

with e_j indicating the rainfall energy per unit depth of rainfall per unit area, and ΔV_j the rainfall depth for the j-th interval of the storm hyetograph which is divided into m parts with essentially constant intensity. The equations proposed by Foster et al. (1981) were used to calculate the rainfall energy e_j:

$$e_j = 0.119 + 0.0873 \log_{10}(i_j) \qquad \text{if } i_j \leq 76 \; mm\, h^{-1} \tag{3a}$$

$$e_j = 0.283 \qquad \text{if } i_j > 76 \; mm\, h^{-1} \tag{3b}$$

where i_j (mm h^{-1}) is the rainfall intensity calculated as follows

$$i_j = \frac{\Delta V_j}{\Delta t_j} \tag{4}$$

in which Δt_j indicates the interval duration over which intensity is assumed to be constant (Porto, 2016).

The calculation was facilitated by a computerised procedure based on datalogger, to make the

R-factor calculation faster and more objective (Preiti et al., 2017).

The geographical proximity of experimental site to the meteorological station suggested that the spatial variability of this parameter should be neglected. Therefore, each R_i value was considered unique for the different experimental treatments.

The runoff coefficient is widely used as a diagnostic variable to represent runoff generation and hydrological characteristics (Sriwongsitanon and Taesombat, 2011); it is defined simply as the ratio of runoff to rainfall (Sen and Altunkaynak, 2005), calculated for each rainfall event and averaged over the four replications.

2.4 The calibration of the USLE model using the experimental data

As reported above, the study period extended for 12 years. A possible approach, useful for determining *C* without detailed measures, is provided by the indirect application of USLE:

$$\mathrm{C}_i = \frac{A_i}{R_i\, K\, LS\, P} \tag{5}$$

where C_i is the cover and management factor (dimensionless); A_i, the soil loss, expressed in t ha^{-1} yr^{-1}; R_i, the rainfall erosivity factor, expressed in MJ mm ha^{-1} h^{-1} yr^{-1}; K, the soil erodibility factor, expressed in t ha h MJ^{-1} mm^{-1} ha^{-1}; LS is the topographic factor (dimensionless); and P indicates the support practice factor (dimensionless) (McGregor, 1978; Alberts et al., 1985; Cinnirella et al., 1998; Bacchi et al., 2010). The application of (5) is possible only if there are adequate means to measure soil loss, continuous measurements of precipitation (for R determination), soil erosion factor K, and LS; P-factor set equal to 1 in absence of support practices.

2.5. Statistical analysis

Analysis of variance (ANOVA) was performed on soil and water samples, using the GLM univariate procedure of IBM SPSS (Advanced Statistics 22). The variables considered in the analysis were runoff (mm) and soil loss (t ha^{-1}). The statistical significance of the effect was analysed using F-tests whereas the differences between means were tested using the Tukey's Test HSD. The relationships between rainfall amount, erosivity index and soil loss were evaluated by regression analysis while the relationships of the same climate variables with *C-factor* were evaluated by correlation analysis.

3. Results

3.1 Seasonal characteristics of rainfall events

The rainfall showed a marked seasonal and annual variation during the experimental period (Table 2). Twelve-year average rainfall was 1308.8 mm with more than 65% splitted between autumn (450.3) and winter (455.3). During the experimental period, 100 rainfall events were observed on average each year out of about 128 recorded rainfall days; only 33 rainfall events were equal or superior 13.0 mm, threshold beyond which a rainfall is able to generate significant erosion phenomena, according to Wischmeier and Smith (1978). However, in the present study, all rainfall events > 0.5 mm were considered, since in the Mediterranean area rainfall less than 13 mm can trigger erosion phenomena, mainly during the summer and/or autumn season on soil without vegetation cover or on soil with high water content (Renschler et al., 1999; Panagos et al., 2015).

The average erosivity index during the twelve years was 5214.1 MJ mm ha^{-1} h^{-1} y^{-1}. This value is higher than the historic average value of the R factor of Calabria, equal to 3847.0 MJ mm ha^{-1} y^{-1} h^{-1} y^{-1} (among Italian regions in fourth position behind Friuli Venezia Giulia, Liguria and Campania) but is between the average multi-year max and min values (4984.0 and 6942.0 MJ mm ha^{-1} h^{-1} y^{-1}, respectively) recorded by Italian meteorological bureau in Bagnara Calabra - Reggio Calabria.

The highest average value of R was recorded in autumn with 2045.3 MJ mm ha^{-1} h^{-1}, with the highest value of 5013.2 MJ mm ha^{-1} h^{-1} recorded in autumn 2010/11 and the lowest value of

766.0 MJ mm ha^{-1} h^{-1} in 2016/17. In the winter season, despite higher average precipitation of 455.3 mm, the rainfall erosivity index averaged 1055.1 MJ mm ha^{-1} h^{-1}. The spring season averaged the lowest rainfall erosion index at 695.4 MJ mm ha^{-1} h^{-1}. In contrast, the summer season recorded an erosivity index of 1418.2 MJ mm ha^{-1} h^{-1}. The summer erosivity index varies between a maximum value of 3335.5 MJ mm ha^{-1} h^{-1} recorded in 2018 and a minimum value of 69.6 MJ mm ha^{-1} h^{-1} recorded in 2007. In the autumn 2015, between 31st October and 2nd November, the longest event of the whole period (30 h 50') was recorded with 209.2 mm of rain, with an R value of 1483.7 MJ mm ha^{-1} h^{-1} and an I_{30} of 13.0 mm h^{-1}.

The event with the highest R value was recorded in the autumn 2010; in particular, a rainfall (time: 21 h 20') of 165.5 mm with an R value of 2813.8 MJ mm ha^{-1} h^{-1} with an I_{30} of 34.8 mm h^{-1} was observed on 18 october 2010. In summer 2018, between 24 and 25 August, the rainfall event with the highest I_{30} max value (39.0 mm h^{-1}) of the entire experimental period was recorded, with a rainfall of 80.7 mm (duration: 5 h) and an R of 1372.1 MJ mm ha^{-1} h^{-1}. These high magnitude events in summer season are becoming more and more frequent in the Mediterranean environment as demonstrated by the R values of the last few years. The R of the summer season of the last six years is 2048.1 MJ mm ha^{-1} h^{-1} y^{-1}, slightly higher than the average R value of the autumn season of the whole test period (2045.3 MJ mm ha^{-1} h^{-1}). Furthermore, of the I_{30} max values recorded in the individual test years, six occurred during autumn and six during summer; four of those recorded in summer occurred in the last six years.

3.2 The soil erodibility factor K and the topographic factor

The soil erodibility factor K, as defined by Wischmeier and Smith (1978), represents the mean annual value of the relative inherent resistance of a soil to the detachment, entrainment and transport actions operated by rainfall and runoff. The K-factor can be determined according to certain soil characteristics that include texture, presence of organic matter, permeability. In this respect, Wischmeier et al. (1971) provided a nomograph, supported by an explicit equation, to determine the value of K based on the above variables. However, if soil loss measurements are available at a plot scale, a direct evaluation of K is possible. The method is based on a simple regression analysis between soil loss measurements and rainfall erosivity, as proposed by Wischmeier and Mannering (1969).

In this contribution, we used the annual measurements of soil loss from the standard plot (SP) to obtain a representative value of K for the soils under investigation. Considering that our bare plot has a length of 25 m and a slope of 10%, an adjustment was necessary according to equation (5). The method (Porto et al., 2022) is illustrated in Fig. 3, in which the line of equation y=bx is superimposed on the experimental pairs. The slope b, that represents the value of K, resulted equal to 0.0136 (t ha h ha^{-1} MJ^{-1} mm^{-1}) and this value was used for our plots in equation.

The topographic factor LS determination required the measurement of the length and longitudinal slope of each parcel. These operations were carried out with a measuring wheel and a topographic level with fixed telescope. The value of the topographic factor was determined using the following expression:

$$LS = \left(\frac{\lambda_i}{22.13}\right)^{m_i} (10.8 \sin \alpha_i + 0.03) \qquad \tan \alpha_i < 0.09$$

$$LS = \left(\frac{\lambda_i}{22.13}\right)^{m_i} (16.8 \sin \alpha_i - 0.05) \qquad \tan \alpha_i \geq 0.09$$

where λ_i represents the length of the *i-th* parcel and α_i the slope of the *i-th* parcel. The exponent was calculated for m_i by applying the expression:

$$m_i = \frac{f_i}{1 + f_i}$$

where f_i represents the ratio $\frac{erorion\ rill}{erosion\ interill}$ which can be determined by the following formula:

$$f_i = \frac{\sin \alpha_i}{(0.0896\ (3\ sin^{0.8}\ \alpha_i + 0.56)}$$

Considering the very close values of plots slope and length, also the values of the topographic factor were very similar, on average equal to 1.29 (1.20 in SP; 1.27 in CS_1; 1.36 in CS_2; .1.35 in CS_3; 1.25 in CS_4) (McCool et al., 1989; Renard et al., 1997).

3.3 Soil erosion and runoff

Soil losses due to sheet erosion over the twelve years were assessed by evaluating 156 samplings at which liquid and solid sediment production was detected in the experimental device (Preiti et al., 2017). The annual distribution of these events and the amount of eroded soil and runoff are shown in Table 3.

Statistical analysis, for both eroded material and runoff, showed significant differences between the tested treatments, confirming the different protection degree of vegetation cover and various cultivation systems. The total annual aumont of eroded material, as average obtained from the five plots, was 35.84 t ha^{-1}, with a range between 4.11 t ha^{-1} (2007/08) and 72.07 t ha^{-1} (2015/16).

The annual cumulative value of surface runoff, averaged over five plots and twelve years, was 124.4 mm. The highest surface runoff values, statistically equal to each other, were recorded in the rainiest years 2008/09 (1612.9 mm) and 2017/18 (1621.2 mm) with 196.3 and 198.1 mm, respectively. In contrast, in the lowest rainfall years (<1000 mm) 2007/08 and 2016/17 the lowest values were 77.5 and 67.0 mm, respectively.

Table 4 shows the average number of days with canopy cover ≥ 50% as well as the average, min and max values of soil loss and runoff in the four CS and SP. CS_4 presented, on average, the highest number of days (260 days) with a soil coverage degree ≥ 50%; conservative soil management (minum tillage, strip tillage and shredded crop residues) and the presence of a grassland crop (tall fescue) for almost 6 years allowed a soil cover level ≥ 50% to be reached for 71.3% of evaluated period. The use of conservation techniques also allowed CS_2 to reach a high number of days (> 200) with a soil cover level ≥ 50%. In the CS_3 managed with a mixed system (conservative and conventional) where a conventional tillage was foreseen every five years, it allowed to reach a soil cover degree ≥ 50% for 182 days, equal to 50.3%. On the other hand, the conventional cropping system (CS_2) presented the lowest number of days (135) with a ground cover degree ≥ 50%, equal to 37.1% of all studied period (2006-2018).

The statistical analysis of eroded material and surface runoff, as cropping systems average, highlighted significant differences between the compared treatments, confirming diverse soil protection degree linked to canopy and agronomic management of the different cropping systems.

In the SP the highest quantity of eroded material was equal to 82.28 t ha^{-1} with variations between the years ranging from 5.30 t ha^{-1} (2007/2008) to 155.50 t ha^{-1} (2008/09), clearly greater than the four cropping systems. As expected, the absence of vegetation cover and the continuous tillage (four per year) were critical in increasing erosion, especially during particularly aggressive rainfall.

The two conservative cropping systems (CS_1 and CS_4), although statistically different, presented an average soil loss value of 11.66 t ha^{-1} with a range of variability between 0.03 and 36.53 t ha^{-1}. CS_3 recorded a value of 18.65 t ha^{-1} while CS_2 had an average value of 55.04 t ha^{-1} with a maximum value of 138.20 t ha^{-1} in 2015/16.

The cumulative values of surface runoff, in multi-years average of the five plots, was higher, as expected, in the standard plot and CS_2 reaching a total amount of 156.0 mm and 142.8 mm, respectively. On the other hand, the CS_1, CS_3 and CS_4 plots recorded a runoff quantity between 90.6 and 123.8 mm.

The different cropping sequences adopted in the four cropping systems determined a different evolution of the erosion phenomenon in relation not only to the crops used but above all to the soil cover time obtained also with the use of crop residues.

ANOVA reported significant differences among treatments and a significant “year” x “cropping system” interaction. The analysis of single cropping systems (Fig. 4) highlight the CS_4 highest erosion control effect. Soil loss during five (meadows) of the twelve years’ trial remained below

1.00 t ha^{-1}, confirming the high erosion control efficacy of polyannual turf. The maximum value in this cropping system was recorded in 2006/07 with a soil loss of 33.10 t ha^{-1}, mainly due to a high rainfall event (24/10/2006) of 72 mm with an erosion index of 812.5 MJ mm ha^{-1} h^{-1}. The total amount of soil eroded in CS$_4$ represented 11.4% and 16.9% of the SP and conventional system (CS$_2$), respectively.

CS$_1$ presented an average annual soil loss of 13.93 t ha^{-1}. The highest annual erosion was recorded in the years 2010/11, 2015/16 and 2017/18; in particular, on 18 October 2010 there was a rainfall event of rare intensity (180.8 mm) with a maximum I$_{30}$ of 34.8 mm h^{-1} and a remarkably high erosion index of 2815.88 MJ mm ha^{-1} h^{-1} that triggered more intense erosion phenomena, moreover on soil with a high degree of humidity due to previous rainfalls and in experimental plots (36. 53 t ha^{-1} in CS$_1$) recently sown, extremely vulnerable at this stage.

2015/16 and 2017/18 were characterized by high rainfalls (1590.0 and 1621.2 mm, respectively) with the highest erosivity index of trial period (8591.0 and 8180.2 MJ mm ha^{-1} h^{-1}, respectively); in the first year repeated autumn erosion events on land affected by minum tillage for sowing cereal (rye) resulted in significant soil loss of 25.65 t ha^{-1}, while in the second year, high-magnitude events in June and August caused significant soil loss (26.44 t ha^{-1}) even in this cropping system due to the presence of a vegetable crop (potato) despite the use of strip tillage.

The total amount of soil eroded in CS$_3$ averaged 18.65 t ha^{-1}. The years 2010/11, 2014/15 and 2015/16 recorded an annual soil loss of 42.73, 39.62, and 43.49 t ha^{-1}. In the first and third years, the aggressiveness of autumn rainfall events, described above (October 2010), led to significant soil losses. In the second year (fennel/potatoes), soil preparation (minum tillage) for transplanting/planting, hilling and the low degree of soil cover especially in the autumn (fennel) contributed to making CS$_3$ extremely vulnerable.

The conventional CS$_2$ is managed using crops and techniques widely consolidated by local farmers; his average erosion over the considered period was 55.04 t ha^{-1}, 67%, compared to the

SP. In the years 2015/16 and 2017/18, with a high rainfall erosion index, soil losses of more than 100.00 t ha^{-1} were recorded; in these two years, in addition to the soil losses recorded in the autumn and winter seasons, the rainfall events recorded at the end of August amounting to 230.6 mm (1799.16 MJ mm ha^{-1} h^{-1}) and 146.8 mm (1946.11 MJ mm ha^{-1} h^{-1}), which found the soil tilled (conventional tillage) and without vegetation cover, had a decisive influence.

The significant year x cropping system interaction revealed by the statistical analysis also for the surface runoff data has the same significance level as described for the erosion data.

More generally, in the average of the five plots, the highest values of soil loss and runoff (18.94 t ha^{-1} and 54.9 mm) were recorded in the autumn season (Table 5), while in the winter season, despite a slightly higher rainfall (455.3 mm), the amount of eroded material and runoff was significantly lower (9.40 t ha^{-1} and 45.8 mm).

In the summer season, a rainfall of 190.5 mm caused a soil loss of 4.28 t ha^{-1}. The runoff coefficient annual averaged 9.5%, with a range of variability between 12.2% in the autumn season and 4.0% in the spring season. This is due to the runoff coefficient being positively correlated with previous soil moisture, and, in general, runoff coefficient is increased throughout successive events as the soil become wetter (Sriwongsitanon and Taesombat, 2011).

Soil losses in the four cropping systems, during the twelve years of trial, were significantly higher during the autumn season, especially in correspondence with particularly aggressive rainfall events (Fig. 5 A). Conventional soil management in CS_2 was decisive in increasing soil losses during autumn season by an average of 31.08 t ha^{-1}, with a high variability among years. Erosion was also high in the CS_3 mixed cropping system (conservative/conventional), amounting to 11.16 t ha^{-1}, while soil losses were lower in the conservative cropping systems (CS_1 and CS_4). The same trend was observed in the winter season, with slightly higher rainfall (455.3 mm) but a halved erosion index, on average, (1055.1 MJ mm ha^{-1} h^{-1}) compared to the autumn, when soil losses were on the whole around 46% lower.

It should also be underlined that in the summer period, with a rainfall of 190.5 mm but with a high erosion index, on average (1418.2 MJ mm ha^{-1} h^{-1}), soil losses were high (7.11 t ha^{-1}) in CS_2, a system where in this season the soil was bare, because, crop residues were removed and the main tillage was carried out after the harvest of winter crops.

Regardless of adopted agronomic management, the eroded material removed, averaged over the four different cropping systems (Fig. 5 B), was significantly influenced, with the exception of the winter season ($R = 0.540$), by the rainfall erosivity index, $R = 0.781$ (autumn), $R = 0.755$ (spring) and $R = 0.863$ (summer). The different slope of the fall and winter season regression lines highlights that almost equal amount of rainfall had a different impact on soil loss.

3.4 Cover management and C-factor

The use of equation (5) allows calculating, for each year, the *C-factor* value corresponding to each cropping system. The histograms in Fig. 6, which show the values of the *C-factor,* suggest some reflections on the hydrological response of each cropping system. If we exclude the results of the SP (in which the *C* values are all higher and close to unity), *C-factor* values, although dependent on pluviometric aggressiveness, is also linked to crop growth dynamic (aerial and radical) and agronomic management. This justifies the different behaviour of the cultivation systems when compared on an annual scale; all this is even more evident if the same analysis is carried out on an event scale. With reference to 2017/18 and in particular during spring and summer, five samples of sediment were taken, two of which intercepted particularly aggressive events that had a completely different impact on the four cultivation systems. Specifically, on 28th June 2018, a sampling was carried out that intercepted four consecutive events between 14th and 18th June with a cumulative rainfall of 260.4 mm, R 2019.7 MJ mm ha^{-1} h^{-1} and with I_{30} max equal to 34.4 mm h^{-1} that triggered significant erosive phenomena. In CS_2 30.62 t ha^{-1}, slightly lower than standard plot, due to weeding and hilling operations and the low cover degree (potato) contributed to making the CS extremely vulnerable. On the other hand, in CS_1, the presence of the same crop but with strip-tillage, soil losses amounted to 12.32 t ha^{-1}. CS_3

and CS_4, exhibited low values of soil loss (1.50 and 2.42 t ha^{-1}, respectively).

In addition, on 31st August 2018, there was a sampling that intercepted two consecutive events between 24th and 25th August with a cumulative rainfall of 146.8 mm, R 1946.1 MJ mm ha^{-1} h^{-1} and with I_{30} max of 39.0 mm h^{-1} that triggered high erosion phenomena; in CS_2 39.12 t ha^{-1}, on the other hand in CS_1 the soil losses were 2.31 t ha^{-1} while in CS_3 and CS_4, the presence of shredded crop residues, after lupin and broad bean harvesting, has significantly reduced the eroded material (0.35 and 0.53 t ha^{-1}, respectively).

CS_1 and CS_4 involved minimum tillage and/or strip-tillage with crops sown in wide rows, and use of crop residues as mulch after harvest contributed to low *C-factor* values (0.14 and 0.12, respectively) in the twelve-year average and demonstrated the high efficiency of these agronomic techniques against soil erosion. In addition, tall fescue inclusion in CS_4, with a long soil cover (260 days ≥ 50%), further reduced the *C-factor* values, which were close to zero in the following five years, except in the first sowing year (2010/11).

A relatively low *C-factor* value (albeit higher than those mentioned above) can be found for CS_3, which presented a *C* value of 0.19 on average over the years. The highest values in this CS were recorded in 2010/11 (0.34) and 2014/15 (0.42); in the first year this was due to a very aggressive rainfall recorded in October 2010, which found CS_3 with oats in emergence on tilled soil, while in the second year the close rotation between two vegetables (fennel and potato), with tillage on all surface of the plot (minum tillage) and consecutive tillage on both crops (hilling), determined the triggering of important erosion phenomena.

Among the four cropping systems, CS_2 showed, on average over the years, the highest *C-factor* value (0.50), highlighting the vulnerability to erosion of conventional management. This cropping system, in presence of aggressive rainfall events, was extremely vulnerable during the autumn period with tilled soil and no vegetation cover; this vulnerability is even more marked when the presence of vegetable crops necessitates cultivation operations during their biological cycle. In addition, the susceptibility of this crop system to erosion during the summer season with tilled soil should be emphasised, as demonstrated by the *C* values in recent years due to intense rainfalls during this season, increasingly frequent in the Mediterranean environment.

4. Discussion

The different management of the five plots in the long term had a different impact on both surface runoff and soil losses. The seasonal rainfall characteristics during the trial period, shown in Table 2, confirm the aggressiveness of rainfall during the autumn season. Soil loss, averaged over the five plots, was found to be significantly correlated with the rainfall erosivity index (R= 0.809) but not with the amount of rainfall falling (R= 0.453), similarly to what was reported on different herbaceous cropping systems and under different experimental conditions (Wei et al., 2007; Mohamadi and Kavian, 2015; Anache et al., 2017). CS_4 and CS_1 presented, on average, the lowest soil loss values, 9.38 and 13.93 t ha^{-1}, respectively. The greater effectiveness against erosion in these cropping systems can be attributed to conservative soil management (minum tillage, strip tillage, shredded crop residues) and to introduction of polyannual grassland crops. The use of these techniques, in fact, ensured greater soil coverage (Table 5) exposing the soil for a shorter time to the erosive rainfall action (on average, 105 and 155 days with <50% coverage), especially during summer and autumn periods. Minimum tillage, residue mulch and canopy cover provided by natural vegetation in CS_1 and tall fescue in CS_4 limited water erosion in those treatments. Furthermore, in CS_1 permanent meadows seemed to be able to control the erosion due to dense growth root systems as shown by the soil loss data over the six years of meadow presence, as previously reported in similar environmental conditions (Novara et al., 2011). These results were in agreement with several authors, also under rainfall events of high intensity (Wischmeier and Smith, 1978; Veihe et al., 2003; Maetens et al., 2012; Bargiel et al., 2013; Kurothe et al., 2014; Anache et al., 2017; Baiamonte et al., 2019). On the other hand, soil losses in the conventional cropping system (CS_2), averaging 55.04 t ha^{-1}, can be attributed to the low degree of soil cover (on average, 230 days with <50% cover), the high degree of soil stress (ploughing), and subsequent tillage for sowing/transplanting, moreover in a period with high rainfall erosion such as the summer and autumn seasons in Mediterranean environment. These results confirm that the adoption of conventional tillage on sloping land increases soil erosion (Bombino et al., 2019; Sasal et al., 2010; Kurothe et al., 2014).

Some studies conducted in semi-arid Mediterranean environments on vineyards show that tillage is a threat to soil degradation (Novara et al., 2019). Other authors, in other environments, have shown that tillage also decreases dramatically aggregate stability, as compared with uncultivated soil, which can increase the susceptibility to rainfall detachment and soil loss (Zhang and Horn, 2001).

During the twelve-years experimental trial, the runoff and the soil losses were remarkable being significantly more intense during the autumn with extreme rainfalls (Figures 5, A and B) as also observed in other studies carried out in Mediterranean environment (Onori et al., 2006; Renschler et al., 1999; Novara et al., 2011). The surface runoff intercepted in the collection tanks was 124.4 mm (9.5%) on average over the years (Table 5). The runoff values were higher in the autumn season, 54.9 mm, than the winter season, 45.8 mm, with a rainfall slightly higher than in the autumn season.

These data show that in the Mediterranean environment the aggressiveness of the rainfall and the degree of ground cover affect these two parameters. This is confirmed by the fact that in the summer season, with a rainfall of 190.5 mm (-58% compared to the winter season), a soil loss of 4.28 t ha^{-1} was recorded, mainly related to CS$_2$, which in this season, after the harvest of the winter crop, is affected by main tillage. In addition, the quantity of runoff intercepted in the collection tanks, on average 9.5%, shows that it is the erosive nature of the autumn rains, and now summer rains too, that causes surface runoff (12.2 and 7.9%, respectively).

This could be explained by autumn and summer rainfalls (volume and erosivity) and their impact on cropping systems related to different management (tillage, seasonal growth, degree of cover and type of crop, crop residue management) (Guo et al., 2015).

In addition, it should be noted that soil moisture before rainfall events occurr, even if not of high intensity, plays an important role on runoff and soil loss and affects the partitioning of rainfall into infiltration and runoff and, consequently, influences soil erosion. Water potential values close to field capacity predispose the soil to erosion risks and increase surface runoff (Wei et al., 2007) even in the presence of rainfall events characterised by a low erosion index.

The runoff coefficient was exponentially correlated to the inverse of antecedent soil water potential in the rainy season, while the runoff coefficient was negatively and linearly correlated to antecedent soil water potential in the dry season. These results suggest that saturation excess runoff may be dominant in the rainy season and infiltration excess runoff may become dominant in the dry season (Grayson et al., 1997; Fitzjohn al., 1998; Wei et al., 2007).

The use of (5) allows calculating, for each of the 156 taken samples (data not shown) and on annual scale, the value of C corresponding to each cropping system.

The *C-factor* values (fig. 6) for each year allows us to consolidate some statements and to make some reflections on hydrological response of each crop system. From the results presented above, excluding SP, can be stated that *C-factor* values do not seem to follow a similar trend; the correlation analysis between the climatic variables (rainfall and erosivity) and the *C-factor* shows a significant relationship only in CS_2 cropping system.

However, this result is not unexpected since the *C-factor*, although dependent on the aggressiveness of the rainfall, is linked not only to tillage (tool and season) but also to crops development (aerial and radical) as well as the management of crop residues (mulch or removed). This would justify the low C value, denoting a high protective efficacy, in CS_4 and even more so in the five years in which meadow was present.

CS4 and CS1 subjected to minimum tillage and/or strip-tillage, in correspondence with crops sown in wide rows (vegetables), and mulched residues, on average over the 12 years, presented low C values (0.12 and 0.14, respectively), demonstrating the high efficiency of these agronomic techniques against soil erosion.

The different management of close rotation between two vegetables (fennel/potato) in 2017/18 in the CS_1 and CS_2 cropping systems generated very different *C* values (0.19 and 0.71, respectively), confirming what above reported. An even more pronounced difference between these two cropping systems resulted in 2014/15 and 2015/16 in the presence of autumn-winter crops, sown in narrow rows (lupin/cereal) with *C* values averaging 0.17 and 0.87, respectively, where an important role was played by the erosivity of rain during the summer period on tilled soil (CS_2). In addition, the presence of natural cover in CS_1 in 2006/07 in autumn and winter period up to the preparation of the soil for potato planting had a significant influence on *C* value reached in this year (0.05), (Ayalew et al., 2021).

Our results support the key role of conservative practices under semiarid conditions as useful tools for climate change mitigation and adaptation, given the expected increase in high-intensity rainfall events in semiarid areas (Martinez-Mena et al., 2019)

5. Conclusions

This long-term experiment, carried out in a hilly area of Southern Italy (Calabria), confirms that conservative cropping systems (minimum tillage, crop residues, grassland cultivation) represent an important tool for water erosion containment in Mediterranean area, environments recognised by many researchers as extremely vulnerable.

The results of this study have highlighted the increased rainfall erosiveness in autumn season but also an increasing aggressiveness in the summer season. In the near future, rainfall intensity will increase in Mediterranean areas, increasing erosion threath; all this suggests that conservation crop management can be used as an adaptation tool to mitigate the effects of climate change. This finding is very important in the Mediterranean environment and especially in cereal and/or mixed cropping systems where conventional management impose 25-30 cm depth soil tillages during summer period, after harvested crops.

The obtained results in twelve years of research show that tillage of vegetable crops (sowing in wide inter-rows) exposes soil to the erosive action of rainfall, as demonstrated by soil and runoff losses recorded during their cultivation. In these cropping systems, strip tillage was particularly effective in reducing soil stress, involving only half of cultivated area.

Crops sown with narrow row spacing (cereals and/or legumes) showed a high capacity to control erosion during the spring period when they reach a high degree of soil cover; soil and crop residue management after their harvest (July) plays a key role in containing erosion risk. In the two conservative cropping systems CS_1 and CS_4 the protective effect (+36% and +38%, compared to CS_2) is attributed to the presence of crop residues as well as the basal part of plants and roots and the wild flora canopy. These two cropping systems proved to be effective in reducing soil losses during the summer season and limiting them during the autumn period by minimum tillage close to sowing time. The effectiveness of minimum tillage, on erosion control, the introduction of cover crops, natural cover, polyannual grass, significantly improve soil protection and efficacy in containing soil losses.

The calculated *C-factor* was found to be a good indicator for assessing the erosion risk of different cropping systems and could be used as a criterion for selecting the most suitable crop rotation and tillage system to reduce the erosion risk.

The evaluation of soil erosion at a different temporal scale and its implications can help stakeholders (including farmers) and scientists formulate better soil conservation practices and agricultural management to minimize environmental risks associated with soil losses, even in fragile environments characterized by marginal land and climate; also considering that erosivity rates are expected to raise as consequence of increase of rainfall intensity linked to climate change.

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TABLES AND FIGURES CAPTIONS

Table 1 - Crop rotation and management techniques in the four plots during the twelve-year trial.

(1) conventional tillage (CT – ploughing at 25-30 cm); (2) harrowing (H); (3) minum tillage (MT - milling at 5–8 cm); (4) strip tillage (ST - tilled only 30% of surface; (5) – sowing/transplanting; (6) hilling (HI); (7) mulch (M - shredded crop residues and left on soil surface); (8) – crop residues removed (RR); (9) – green manure (NV – natural vegetation).

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In each column, values followed by the same letter are not significantly different at $P \leq 0.05$ according to Tukey's Test HSD.

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Fig. 5 – A. Seasonal soil loss in different cropping systems during the experimental period; mean value ± SE. B. Relationship between soil loss and rainfall erosivity in the four cropping systems; R value and significance of regressions ($P \leq 0.01$). Crops and management: CS1-Minimum tillage and crop residue left on soil surface; CS2-Conventional tillage with crop residues removed; CS3-Strip tillage/minum tillage and conventional tillage; CS4-Minimum tillage and crop residues left on soil surface.

Fig. 6 - Annual C-factor values of the twelve year-rotation. The dotted line indicates the average C-Factor value over the twelve years in the four different cropping systems. Crops and management: CS1-Minimum tillage and crop residue left on soil surface; CS2-Conventional tillage with crop residues removed; CS3-Strip tillage/minum tillage and conventional tillage; CS4-Minimum tillage and crop residues left on soil surface.

TABLES AND FIGURES

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CS$_1$

<table>
<tr><th>Season</th><th>Oct.</th><th>Nov.</th><th>Dec.</th><th>Jan.</th><th>Feb.</th><th>Mar.</th><th>Apr.</th><th>May</th><th>Jun.</th><th>Jul.</th><th>Aug.</th><th>Sep.</th></tr>
<tr><td>2006-07</td><td colspan="5">Natural vegetation</td><td colspan="7">(4) (5) Potato (6)</td></tr>
<tr><td>2007-08</td><td>(3) (5)</td><td colspan="8">Oat</td><td colspan="2">(7)</td><td>(3)</td></tr>
<tr><td>2008-09</td><td>(5)</td><td colspan="9">White lupin</td><td>(7)</td><td></td></tr>
<tr><td>2009-10</td><td colspan="11">(9) Natural vegetation</td><td>(3)</td></tr>
<tr><td>2010-11</td><td>(5)</td><td colspan="8">Rye</td><td colspan="2">(7)</td><td>(3)</td></tr>
<tr><td>2011-12</td><td>(5)</td><td colspan="9">White lupin</td><td>(7)</td><td>(4)</td></tr>
<tr><td>2012-13</td><td>(5)</td><td colspan="3">Cauliflower (6)</td><td colspan="2">(7) (4) (5)</td><td colspan="6">Potato (6)</td></tr>
<tr><td>2013-14</td><td>(3) (5)</td><td colspan="7">Plant nematocidal (3)</td><td colspan="3">(9)</td><td>(3)</td></tr>
<tr><td>2014-15</td><td>(5)</td><td colspan="9">Yellow lupin</td><td>(7)</td><td>(3)</td></tr>
<tr><td>2015-16</td><td>(5)</td><td colspan="8">Rye</td><td colspan="2">(7)</td><td>(3)</td></tr>
<tr><td>2016-17</td><td>(5)</td><td colspan="9">White lupin</td><td>(7)</td><td>(4)</td></tr>
<tr><td>2017-18</td><td>(5)</td><td colspan="3">Fennel (6)</td><td colspan="2">(7) (4) (5)</td><td colspan="6">Potato (6)</td></tr>
</table>

CS$_2$

<table>
<tr><th>Season</th><th>Oct.</th><th>Nov.</th><th>Dec.</th><th>Jan.</th><th>Feb.</th><th>Mar.</th><th>Apr.</th><th>May</th><th>Jun.</th><th>Jul.</th><th>Aug.</th><th>Sep.</th></tr>
<tr><td>2006-07</td><td>(2) (5)</td><td colspan="8">Wheat</td><td colspan="3">(8) (1)</td></tr>
<tr><td>2007-08</td><td>(2) (5)</td><td colspan="9">White lupin</td><td colspan="2">(8)</td></tr>
<tr><td>2008-09</td><td>(1)</td><td colspan="6">fallow</td><td colspan="5">(2) (5) Sorghum (1)</td></tr>
<tr><td>2009-10</td><td>(2) (5)</td><td colspan="8">Oat</td><td colspan="3">(8) (1)</td></tr>
<tr><td>2010-11</td><td>(2) (5)</td><td colspan="9">Yellow lupin</td><td colspan="2">(8) (1)</td></tr>
<tr><td>2011-12</td><td>(2) (5)</td><td colspan="3">Cauliflower (6)</td><td colspan="2">(1) (2) (5)</td><td colspan="6">Potato (6)</td></tr>
<tr><td>2012-13</td><td>(1) (2)</td><td colspan="8">Triticale</td><td colspan="3">(8) (1)</td></tr>
<tr><td>2013-14</td><td>(2) (5)</td><td colspan="9">White lupin</td><td colspan="2">(8) (1)</td></tr>
<tr><td>2014-15</td><td>(2) (5)</td><td colspan="8">Oat</td><td colspan="3">(8) (1)</td></tr>
<tr><td>2015-16</td><td>(2) (5)</td><td colspan="9">White lupin</td><td colspan="2">(1)</td></tr>
<tr><td>2016-17</td><td>(2) (5)</td><td colspan="8">Rye</td><td colspan="3">(8) (1))</td></tr>
<tr><td>2017-18</td><td>(2) (5)</td><td colspan="3">Fennel (6)</td><td colspan="2">(1) (2) (5)</td><td colspan="6">Potato (6)</td></tr>
</table>

CS$_3$

<table>
<tr><th>Season</th><th>Oct.</th><th>Nov.</th><th>Dec.</th><th>Jan.</th><th>Feb.</th><th>Mar.</th><th>Apr.</th><th>May</th><th>Jun.</th><th>Jul.</th><th>Aug.</th><th>Sep.</th></tr>
<tr><td>2006-07</td><td>(3) (5)</td><td colspan="6">Plant nematocidal (3)</td><td colspan="4">(9)</td><td>(1)</td></tr>
<tr><td>2007-08</td><td>(2) (5)</td><td colspan="8">Oat</td><td colspan="2">(7)</td><td>(3)</td></tr>
<tr><td>2008-09</td><td>(3) (5)</td><td colspan="9">White lupin</td><td colspan="2">(7)</td></tr>
<tr><td>2009-10</td><td>(4) (5)</td><td colspan="3">Cauliflower (6)</td><td colspan="2">(4) (5)</td><td colspan="6">Potato (6)</td></tr>
<tr><td>2010-11</td><td>(3) (2)</td><td colspan="8">Oat</td><td colspan="3">(1)</td></tr>
<tr><td>2011-12</td><td>(2) (5)</td><td colspan="9">White lupin</td><td colspan="2">(7)</td></tr>
<tr><td>2012-13</td><td>(3) (5)</td><td colspan="8">Triticale</td><td colspan="2">(7)</td><td>(3)</td></tr>
<tr><td>2013-14</td><td>(5)</td><td colspan="8">Field bean</td><td colspan="2">(7)</td><td>(3)</td></tr>
<tr><td>2014-15</td><td>(5)</td><td colspan="3">Fennel (6)</td><td colspan="2">(3) (5)</td><td colspan="6">Potato (6)</td></tr>
<tr><td>2015-16</td><td>(3) (5)</td><td colspan="6">Plant nematocidal (3)</td><td colspan="4">(9)</td><td>(3)</td></tr>
<tr><td>2016-17</td><td>(5)</td><td colspan="8">Oat</td><td colspan="3">(1)</td></tr>
<tr><td>2017-18</td><td>(5)</td><td colspan="9">Yellow lupin</td><td>(7)</td><td>(3)</td></tr>
</table>

CS$_4$

<table>
<tr><th>Season</th><th>Oct.</th><th>Nov.</th><th>Dec.</th><th>Jan.</th><th>Feb.</th><th>Mar.</th><th>Apr.</th><th>May</th><th>Jun.</th><th>Jul.</th><th>Aug.</th><th>Sep.</th></tr>
<tr><td>2006-07</td><td>(3) (5)</td><td colspan="8">Wheat/clover subterraneum</td><td colspan="2">(7)</td><td>Clover</td></tr>
<tr><td>2007-08</td><td>Clover</td><td colspan="7">(3) (5) Plant nematocidal (3)</td><td></td><td colspan="3">(9)</td></tr>
<tr><td>2008-09</td><td>(3) (5)</td><td colspan="8">Oat</td><td colspan="3">(7)</td></tr>
<tr><td>2009-10</td><td>(3) (5)</td><td colspan="9">White lupin</td><td colspan="2">(7)</td></tr>
<tr><td>2010-11</td><td>(3) (5)</td><td colspan="11">Tall fescue</td></tr>
<tr><td>2011-12</td><td colspan="12">Tall fescue</td></tr>
<tr><td>2012-13</td><td colspan="12">Tall fescue</td></tr>
<tr><td>2013-14</td><td colspan="12">Tall fescue</td></tr>
<tr><td>2014-15</td><td colspan="12">Tall fescue</td></tr>
<tr><td>2015-16</td><td colspan="10">Tall fescue</td><td colspan="2">(3)</td></tr>
<tr><td>2016-17</td><td>(4) (5)</td><td colspan="3">Fennel (6)</td><td colspan="2">(7) (4) (5)</td><td colspan="6">Potato (6)</td></tr>
<tr><td>2017-18</td><td>(3) (5)</td><td colspan="8">Field bean</td><td colspan="2">(7)</td><td>(3)</td></tr>
</table>

(1) conventional tillage (CT – ploughing at 25-30 cm); (2) harrowing (H); (3) minum tillage (MT - milling at 5–8 cm); (4) strip tillage (ST - tilled only 30% of surface; (5) – sowing/transplanting; (6) hilling (HI); (7) mulch (M - shredded crop residues and left on soil surface); (8) – crop residues removed (RR); (9) – green manure (NV – natural vegetation).

Table 2 Average seasonal characteristics of rainy events during the twelve-year experiment.

	Rainfall (mm)	Rainy days (n)	Rainfall events (n)	Events ≥ 13 mm (n)	I_{30} max (mm h^{-1})	Erosivity Index (MJ mm ha^{-1} h^{-1})
Autumn						
Mean	450.3	40	32	12	24.0	2,045.3
Max	*746.8*	*52*	*48*	*16*	*37.6*	*5,013.2*
Min	*275.8*	*31*	*25*	*7*	*11.8*	*766.0*
Winter						
Mean	455.3	47	35	13	12.5	1,055.1
Max	*611*	*57*	*46*	*17*	*26.2*	*1,725.0*
Min	*115*	*34*	*21*	*2*	*7*	*200.3*
Spring						
Mean	212.8	25	20	5	14.5	695.4
Max	*343.4*	*39*	*31*	*8*	*30.4*	*1,962.2*
Min	*78.2*	*16*	*11*	*1*	*6.6*	*136.5*
Summer						
Mean	190.5	16	13	5	23.6	1,418.2
Max	*331.6*	*27*	*27*	*9*	*39.0*	*3,335.5*
Min	*56*	*5*	*4*	*1*	*7.3*	*69.6*
12 years mean	1,308.8	128	100	35	30.8	5,214.1

Table 3 – Samples number and average soil loss and runoff over the twelve years.

Season	Samples (n.)	Soil loss (t ha^{-1})	Runoff (mm)
2006-07	15	35.93 d	150.6 f
2007-08	8	4.11 a	77.5 d
2008-09	19	48.06 f	196.3 i
2009-10	11	4.92 a	25.2 a
2010-11	14	55.04 g	71.1 c
2011-12	16	14.62 c	46.8 b
2012-13	13	38.79 e	181.2 g
2013-14	16	45.76 f	174.6 g
2014-15	11	45.62 f	116.3 e
2015-16	13	72.07 h	189.0 h
2016-17	8	11.52 b	67.0 c
2017-18	12	54.08 f	198.1 i
Average	13	35.84	124.4

In each column, values followed by the same letter are not significantly different at $P \leq 0.05$ according to Tukey's Test HSD.

Table 4 - Mean number of days with canopy cover degree ≥ 50%; mean, min, and max values of soil loss and runoff in the standard plot and in the four cropping systems.

Crop system	Canopy cover ≥ 50%		Soil loss (t ha^{-1})			Runoff (mm)		
	dd*	% year	Max	Min	Average	Max	Min	Average
SP	0	0	155.50	5.30	82.28 e	254.8	62.9	156.0 e
CS$_1$	210	57.6	36.53	0.03	13.93 b	203.4	34.7	108.0 b
CS$_2$	135	37.1	138.20	2.83	55.04 c	213.8	37.9	142.8 d
CS$_3$	182	50.3	42.73	2.73	18.65 d	197.9	66.8	123.8 c
CS$_4$	260	71.3	33.10	0.03	9.38 a	186.6	34.1	90.6 a

* dd – days. In each column, values followed by the same letter are not significantly different at $P \leq 0.05$ according to Tukey's Test HSD.

Table 5 – Seasonal averages of rainfall, runoff, runoff coefficient and soil loss of different land use treatmentes (2006/2007 - 2017/18)

	Autumn	Winter	Spring	Summer	Annual
Rainfall (mm)	450.3	455.3	212.8	190.5	1308.8
Runoff (mm)	54.9	45.8	8.6	15.1	124.4
Runoff coefficient (%)	12.2	10.1	4.0	7.9	9.5
Soil loss (t ha^{-1})	18.94	9.40	3.22	4.28	35.84

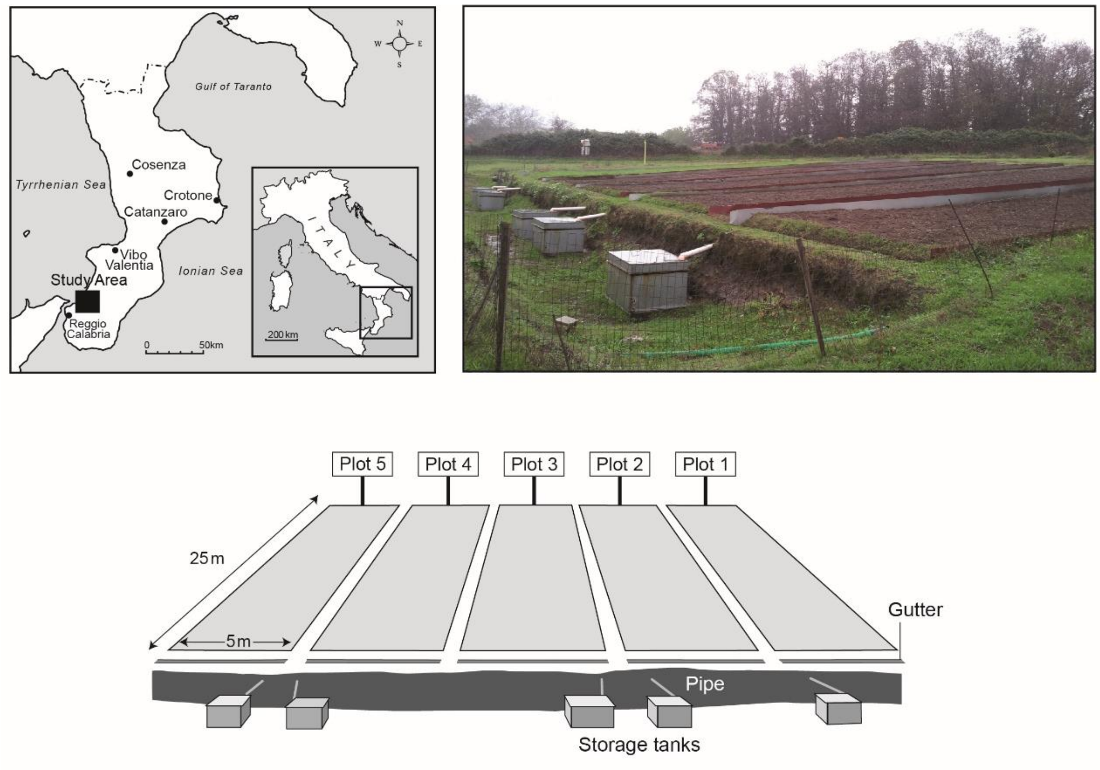

Fig. 1 - The study area and the experimental device.

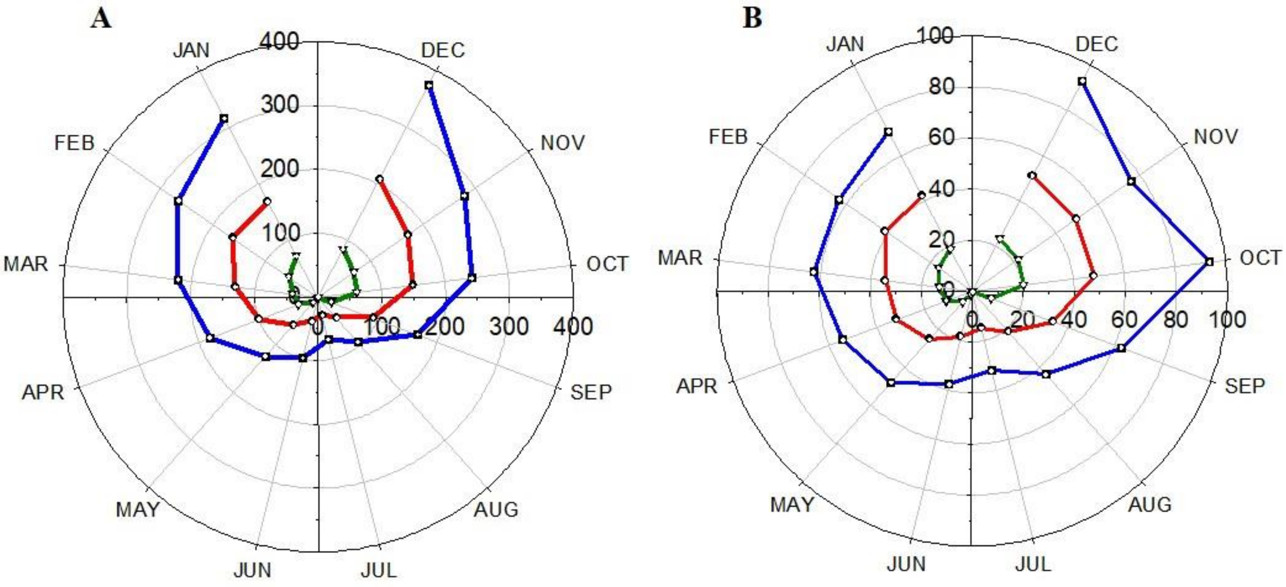

Fig. 2 - Polar diagrams (monthly averages 1961-2020): monthly rainfall cumulates (A) and daily rainfall maxima (B). The red line indicates the mean value, the green and blue lines indicate the 10% and 90% percentiles, respectively.

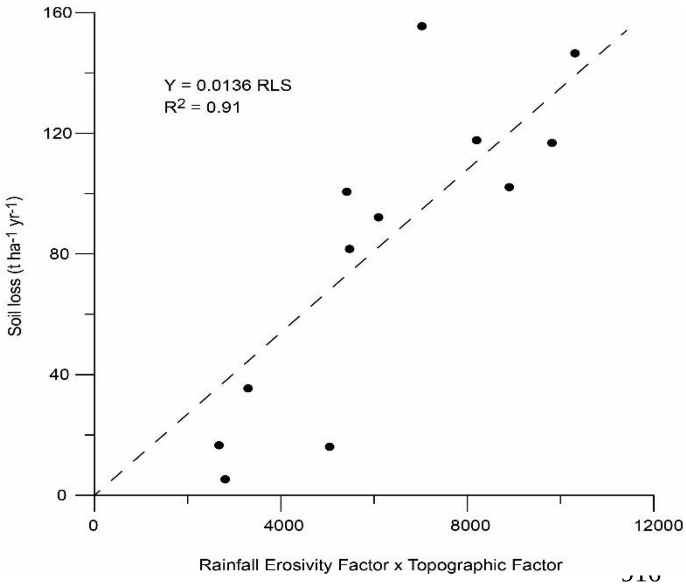

Fig. 3 - Regression analysis for calculation of soil erodibility factor K. Relationship between standard plot (SP) soil loss and rainfall erosivity per topographic factor (LS) in the twelve years.

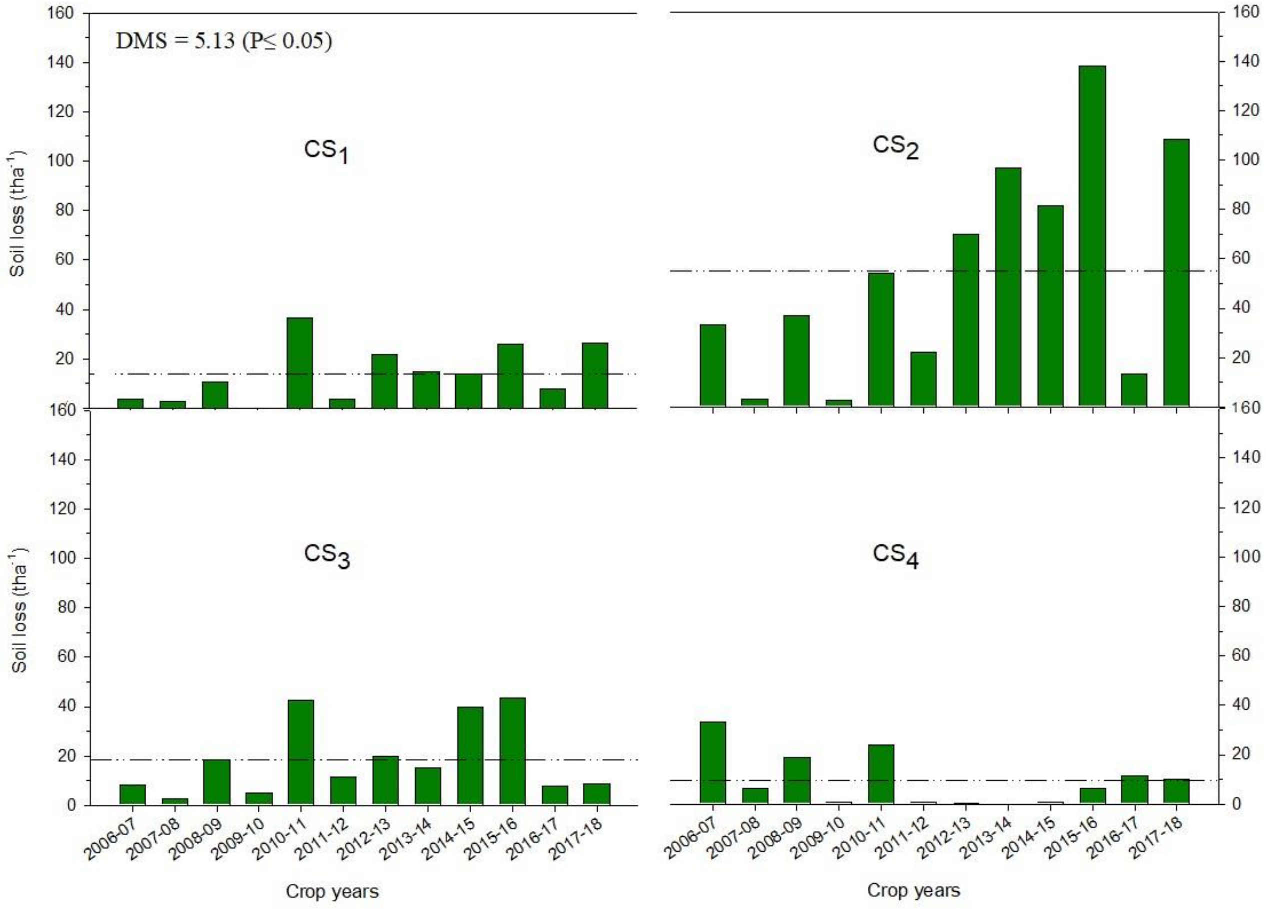

Fig. 4 - Effect of year x cropping system interaction on soil loss. The dashed line shows the average soil loss value over twelve years of the four cropping systems. DMS indicates the least significant difference between the averages.

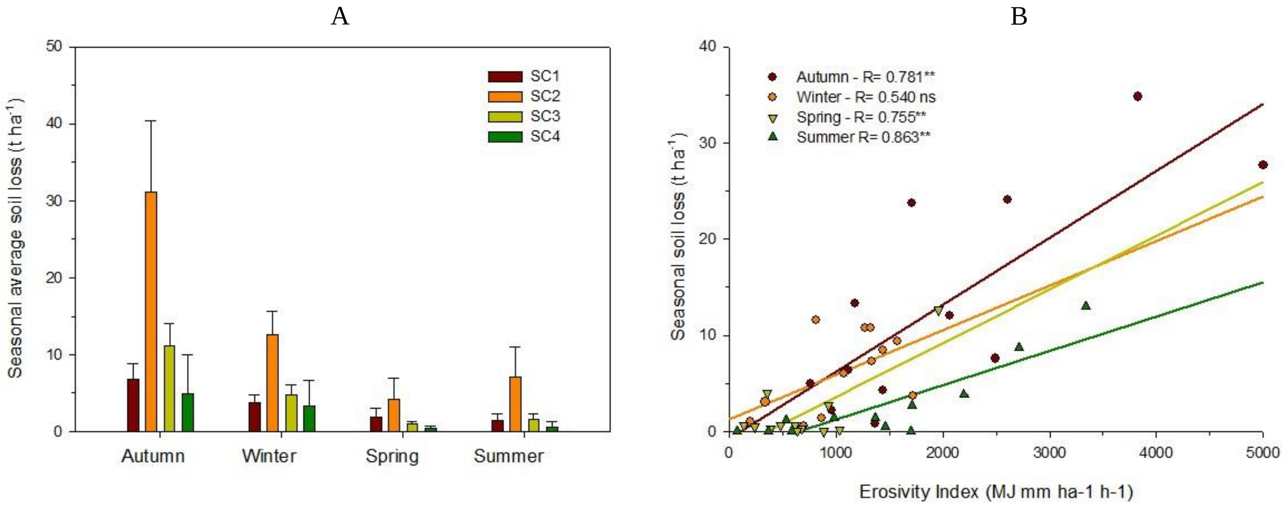

Fig. 5 – **A**. Seasonal soil loss in different cropping systems during the experimental period; mean value ± SE. **B**. Relationship between soil loss and rainfall erosivity in the four cropping systems; R value and significance of regressions ($P\leq 0.01$). Crops and management: CS1-Minimum tillage and crop residue left on soil surface; CS2-Conventional tillage with crop residues removed; CS3-Strip tillage/minum tillage and conventional tillage; CS4-Minimum tillage and crop residues left on soil surface.

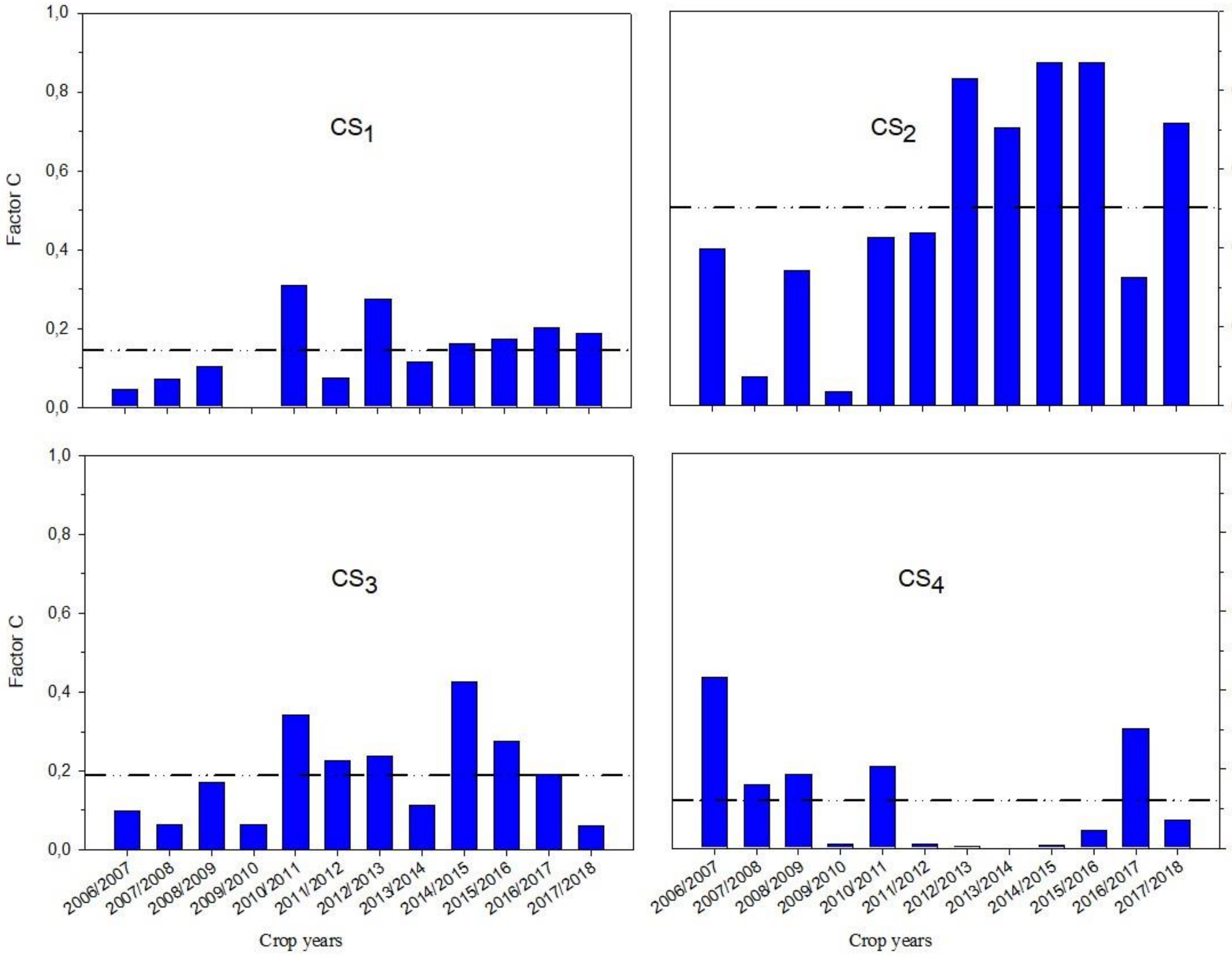

Fig. 6 - Annual *C-factor* values of the twelve year-rotation. The dotted line indicates the average *C-Factor* value over the twelve years in the four different cropping systems. Crops and management: CS1-Minimum tillage and crop residue left on soil surface; CS2-Conventional tillage with crop residues removed; CS3-Strip tillage/minum tillage and conventional tillage; CS4-Minimum tillage and crop residues left on soil surface.