



Università degli Studi Mediterranea di Reggio Calabria
Archivio Istituzionale dei prodotti della ricerca

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

This is the peer reviewed version of the following article:

Original

Long-term effects of different arable cropping systems on surface erosion processes and C-factor in hilly Mediterranean environment / Preiti, G., Antonio, C., Porto, P., Romeo, M., Monti, M., Bacchi, M.. - In: SOIL & TILLAGE RESEARCH. - ISSN 0167-1987. - 223:(2022), p. 105480. [10.1016/j.still.2022.105480]

Availability:

This version is available at: <https://hdl.handle.net/20.500.12318/129966> since: 2022-11-23T11:51:38Z

Published

DOI: <http://doi.org/10.1016/j.still.2022.105480>

The final published version is available online at: <https://reader.elsevier.>

Terms of use:

The terms and conditions for the reuse of this version of the manuscript are specified in the publishing policy. For all terms of use and more information see the publisher's website

Publisher copyright

This item was downloaded from IRIS Università Mediterranea di Reggio Calabria (<https://iris.unirc.it/>) When citing, please refer to the published version.

(Article begins on next page)

1 This is the peer reviewed version of the following article

2

3 *Giovanni Preiti, Calvi Antonio, Paolo Porto, Maurizio Romeo, Michele Monti,*
4 *Monica Bacchi, 2022. Long-term effects of different arable cropping systems*
5 *on surface erosion processes and C-factor in hilly Mediterranean environment.*
6 *Soil and Tillage Research 223 (2022) 105480*

7

8

9

10

11

12

13 which has been published in final doi <https://doi.org/10.1016/j.still.2022.105480>

14

15

16 The terms and conditions for the reuse of this version of the manuscript are specified
17 in the publishing policy. For all terms of use and more information see the publisher's
18 website

19

20

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

23 **Name of the authors:** Giovanni Preiti*, Calvi Antonio, Paolo Porto, Maurizio Romeo, Michele
24 Monti, Monica Bacchi.

25 **E-mail address for corresponding author:** giovanni.preiti@unirc.it

26 **Postal address of all authors:** Department of Agriculture, University Mediterranea of Reggio
27 Calabria, Loc. Feo di Vito 89122 Reggio Calabria, Italy.

28 **Keywords:** C-factor, USLE, soil loss, runoff, conservation tillage, erosivity index.

29

30 **Abstract**

31 Soil erosion is an environmental threat strongly amplified by agricultural activity and, in the
32 last decade, by climate change; it affects many European countries and in particular Italy. Water
33 erosion is currently considered the most important cause of soil degradation. The vegetation
34 cover represents a natural soil protection against water erosion phenomena as it reduces the
35 rainfall impact energy, hinders surface runoff and promotes soil infiltration. For these reasons,
36 identifying appropriate crop systems able to reduce soil loss is a key issue for proposing
37 economical solutions in management planning. This work reports the results of a long-term
38 study (12 years) aimed at determining the vegetation cover effectiveness, diversified by
39 structure and duration of the crops in rotation, and the soil tillage impact on erosion and surface
40 runoff. The *C-factor* determination, without resorting to very detailed measures, is provided by
41 the indirect application of Universal Soil Loss Equation (USLE). Five different soil
42 managements were included in this study. Four experimental plots were cultivated with
43 different cropping systems and intensification tillage degree (CS), and a standard plot (SP)
44 maintained in bare conditions by up and down slope tillage operations. The annual value of soil
45 loss, calculated as mean for the five treatments, was 35.84 t ha⁻¹, and ranged between 4.11 and
46 72.07 t ha⁻¹.

47 The results showed that CS₄ and CS₁ presented, on average, the lowest soil loss values of 9.38
48 and 13.93 t ha⁻¹, respectively. The soil conservative management (minum tillage, strip tillage,
49 shredded crop residues and grassy crops) allowed, in these two CS, to reach, on average, a soil
50 cover degree ($\geq 50\%$) for 260 and 210 days and to obtain a *C-factor* of 0.12 and 0.14,
51 respectively. In the CS₃ (mixed conservative and conventional) with a soil cover degree $\geq 50\%$
52 for 182 days and a *C-factor* of 0.19, the soil loss was equal to 18.65 t ha⁻¹. The conventional
53 farming system (CS₂) recorded an average value of soil loss of 55.04 t ha⁻¹ with a maximum
54 value of 138.20 t ha⁻¹ in 2015/16; this CS also presented the lowest number of days (135) with
55 a land cover level $\geq 50\%$ and the highest *C* value (0.50).

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

59

60 **1. Introduction**

61 Soil is a fragile resource that needs time to regenerate. Every year, an estimated 12 million ha
62 are lost through soil degradation and 24 billion tons of fertile soils are lost due to erosion (FAO,
63 www.fao.org, 2016). Soils are particularly susceptible to many threats; climate change, rainfall,
64 deforestation, unsustainable farming practices. Resource extraction methods affect their fertility
65 and trigger land degradation (*a negative trend in land condition, caused by direct or indirect*
66 *human-induced processes including anthropogenic climate change, expressed as long-term*
67 *reduction or loss of ecosystem goods and services) and several phenomena related to it as*
68 erosion, nutrient depletion and other disasters such as floods and landslides (Assennato et al.,
69 2020).

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

73 functions and leads to environmental damage.

74 The negative effects of soil erosion, that where the human activities are increasing shift from
75 natural to accelerated, include water pollution and siltation, crop yield depression, organic
76 matter and carbon loss, reduction in water quality and storage capacity, which may lead to
77 fundamental social challenges such as land abandonment and decline of rural communities
78 (Cerdan et al., 2010). For these reasons, prevention of soil erosion has become a mondial issue
79 for natural resources management and conservation (Lal et al., 2007; Tejada and Gonzales,
80 2006; Martínez-Mena et al., 2020).

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

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

93 Despite several studies highlight that in semi-arid environment the rainfall intensity is higher
94 in winter or autumn, in South Mediterranean area, some authors estimated summer erosivity to
95 be equal or slightly higher than the one during winter. The same intensity of rainfall erosivity
96 can result in more or less effectiveness on soil erosion according to the time of year when it
97 occurs depending on different variable factors, like tillage management and crop cover.
98 Therefore, knowledge about the time of year when the highest erosivity occurs is critical for

99 choosing more suitable management practices (Baiamonte et al., 2019). In this context, land
100 use and preservation management strategies (reduced tillage and crop residues as mulch) are
101 key factors for preserving soil quality, increasing water retention and controlling the intensity
102 and the frequency of soil loss and runoff (Bogunovic et al., 2020; Bombino et al., 2019;
103 Martinez-Mena et al., 2020).

104 Conservation management has been reported in many studies as an effective strategy for
105 controlling soil erosion, maintaining soil fertility, increasing soil C sequestration, preserving
106 biodiversity and improving cropping systems sustainability (Lal et al., 2007; Kurothe et al.,
107 2014; Ruisi et al., 2014; Baiamonte et al., 2021). These goals require a correct assessment of
108 erosion rates and their geographical distribution (Cerdan et al., 2010). In addition, the reduction
109 of stress soil factors, including tillage, could strongly influence the magnitude of erosion
110 processes; therefore, sustainable crop systems become particularly important for reducing soil
111 losses in hot-arid climates with irregular rainfall distribution as in Mediterranean environment
112 (Sasal et al., 2010; Sanesi et al., 2013; Kurothe et al., 2014). Protection of soil and its resources,
113 threatened by various stressors, has amplified the need of soil erosion field-experimental
114 measurements, taking into account different land use and/or climate change (Cerdan et al.,
115 2010).

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

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

$$126 \quad C = A/R K L S P \quad (1)$$

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

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

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

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

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

151 studies, was integrated by a replacement of vegetable crop with tall fescue or natural vegetation
152 in crop rotations.

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

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

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

162

163 **2. Materials and methods**

164 *2.1. Site description*

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

168 Arable and vegetable crops are traditionally cultivated in this area.

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

175 The analysis carried out on monthly average data shows, for both cumulative rainfall and daily
176 maxima, a similar trend with higher values during autumn and winter seasons and maxima in

177 the months between October and February (Fig. 2).

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

181 The field experiment was carried out on a silty loam soil (61.7% sand, 7.5% clay, 30.8% silt)
182 classified as a Typic Hapludands, medial, amorphic, mesic according to USDA soil taxonomy
183 (Soil Survey Staff, 2006). The soil (0–30 cm depth) contained 7.8% organic matter (Walkley-
184 Blach), 2.34 g kg⁻¹ total N (Kjeldahl), 1.0 mg kg⁻¹ P (Olsen), 213.5 mg kg⁻¹ K (Merwin Peach)
185 and had a pH of 5.9, a cation exchange capacity (CEC) of 10.46 cmol kg⁻¹ and an electrical
186 conductivity (EC) at 25 °C of 0.72 dS m⁻¹. Values of bulk density were provided from specific
187 measurements carried out in 2006 (Porto and Walling, 2012). In that study, collection of
188 sectioned soil cores from 5 sites, one for each plot, was undertaken to a depth of ca. 50 cm,
189 using a steel core tube (11 cm internal diameter). The core tube was driven into the ground by
190 a motorised percussion hammer and the extraction was operated using a winch. After removal
191 from the core tube, each core was sectioned into 2–4 cm depth increments and the bulk density
192 was calculated for each layer. Values ranging from 0.7 to 1.6 g cm⁻³ (with a mean value = 1.02
193 g cm⁻³) were obtained. The lower values (0.7-1.2 g cm⁻³) were obtained for the upper layers (0-
194 20 cm) in which continuous tillage, high content of organic matter, and retention of crop
195 residuals have affected the soil porosity. The higher values (1.2-1.6 g cm⁻³) were observed for
196 the deeper layers. Measurements of hydraulic conductivity were carried out, during the same
197 period, using a Guelph Permeameter (Reynolds and Elrick, 1987). In that case, two
198 measurements on each plot were conducted. Values ranging from 4.4 ·10⁻⁴ cm s⁻¹ to 16.0 ·10⁻⁴
199 cm s⁻¹ (with a mean value = 9.9 ·10⁻⁴ cm s⁻¹) were obtained. The field capacity and permanent
200 wilting point, determined using the pressure plate method (Klute, 1986), were respectively
201 52.5% and 28.9%.

202

203 *2.2 Experimental design and soil management*

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

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

212 In the present paper, a twelve-year trial, from 23rd September 2006 to 22nd September 2018,
213 were discussed. Four plots supported various cropping systems (CS), while one was kept in
214 bare condition (four tillages each year) by up and down slope tillage to maintain the ground
215 cover always below 10% as standard plot (SP). The different crop system managements are
216 listed below (Table 1). Up and down tillage was always performed to simulate conventional
217 tillage of sloping land; for vegetable crops, post-plant management included in-row cultivation
218 and/or hilling tools; for grain crops, when necessary, weeds were controlled by herbicides. Note
219 that the CS₃ system differs from other crop systems for having adopted a mixed
220 conventional/conservative management.

221

222 *2.3. Measurements and rainfall data*

223 Rainfall data were recorded by a high-temporal-resolution weather station (CR₁₀-Campbell
224 Scientific), located in the experimental area. During the twelve-year study period, one hundred
225 and fifty-six events that had generated both runoff and soil loss were observed. In some cases,
226 due to the short time occurring between events, separated runoff sampling was not possible and
227 the resulting measurements are related to cumulative events. The collecting tanks were emptied
228 shortly after each rainfall and the suspension remained on the bottom was well mixed and

229 sampled (four samples of five liters, used as replicas, for each plot). The samples were then
 230 oven-dried at 60 °C, until constant weight and, successively, used for laboratory physical and
 231 chemical analysis (data not shown). Clear water volume was recorded to measure the amount
 232 of runoff from each plot. The soil loss and runoff data collected in the different samplings were
 233 used to obtain the cumulated quantity for each cropping system.

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

$$239 \quad EI = E i_{30} = \left(\sum_{j=1}^m e_j \Delta V_j \right) i_{30} \quad (2)$$

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

$$244 \quad e_j = 0.119 + 0.0873 \log_{10}(i_j) \quad \text{if } i_j \leq 76 \text{ mm h}^{-1} \quad (3a)$$

$$245 \quad e_j = 0.283 \quad \text{if } i_j > 76 \text{ mm h}^{-1} \quad (3b)$$

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

$$248 \quad i_j = \frac{\Delta V_j}{\Delta t_j} \quad (4)$$

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

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

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

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

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

260

261 *2.4 The calibration of the USLE model using the experimental data*

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

$$264 \quad C_i = \frac{A_i}{R_i K L S P} \quad (5)$$

265 where C_i is the cover and management factor (dimensionless); A_i , the soil loss, expressed in t
266 $\text{ha}^{-1} \text{yr}^{-1}$; R_i , the rainfall erosivity factor, expressed in $\text{MJ mm ha}^{-1} \text{h}^{-1} \text{yr}^{-1}$; K , the soil erodibility
267 factor, expressed in $\text{t ha h MJ}^{-1} \text{mm}^{-1} \text{ha}^{-1}$; LS is the topographic factor (dimensionless); and P
268 indicates the support practice factor (dimensionless) (McGregor, 1978; Alberts et al., 1985;
269 Cinnirella et al., 1998; Bacchi et al., 2010). The application of (5) is possible only if there are
270 adequate means to measure soil loss, continuous measurements of precipitation (for R
271 determination), soil erosion factor K , and LS ; P -factor set equal to 1 in absence of support
272 practices.

273

274 *2.5. Statistical analysis*

275 Analysis of variance (ANOVA) was performed on soil and water samples, using the GLM
276 univariate procedure of IBM SPSS (Advanced Statistics 22). The variables considered in the

277 analysis were runoff (mm) and soil loss (t ha^{-1}). The statistical significance of the effect was
278 analysed using F-tests whereas the differences between means were tested using the Tukey's
279 Test HSD. The relationships between rainfall amount, erosivity index and soil loss were
280 evaluated by regression analysis while the relationships of the same climate variables with *C-*
281 *factor* were evaluated by correlation analysis.

282

283 **3. Results**

284 *3.1 Seasonal characteristics of rainfall events*

285 The rainfall showed a marked seasonal and annual variation during the experimental period
286 (Table 2). Twelve-year average rainfall was 1308.8 mm with more than 65% splitted between
287 autumn (450.3) and winter (455.3). During the experimental period, 100 rainfall events were
288 observed on average each year out of about 128 recorded rainfall days; only 33 rainfall events
289 were equal or superior 13.0 mm, threshold beyond which a rainfall is able to generate significant
290 erosion phenomena, according to Wischmeier and Smith (1978). However, in the present study,
291 all rainfall events > 0.5 mm were considered, since in the Mediterranean area rainfall less than
292 13 mm can trigger erosion phenomena, mainly during the summer and/or autumn season on
293 soil without vegetation cover or on soil with high water content (Renschler et al., 1999; Panagos
294 et al., 2015).

295 The average erosivity index during the twelve years was $5214.1 \text{ MJ mm ha}^{-1} \text{ h}^{-1} \text{ y}^{-1}$. This value
296 is higher than the historic average value of the R factor of Calabria, equal to $3847.0 \text{ MJ mm ha}^{-1}$
297 $\text{y}^{-1} \text{ h}^{-1} \text{ y}^{-1}$ (among Italian regions in fourth position behind Friuli Venezia Giulia, Liguria and
298 Campania) but is between the average multi-year max and min values (4984.0 and 6942.0 MJ
299 $\text{mm ha}^{-1} \text{ h}^{-1} \text{ y}^{-1}$, respectively) recorded by Italian meteorological bureau in Bagnara Calabria -
300 Reggio Calabria.

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

303 766.0 MJ mm ha⁻¹ h⁻¹ in 2016/17. In the winter season, despite higher average precipitation of
304 455.3 mm, the rainfall erosivity index averaged 1055.1 MJ mm ha⁻¹ h⁻¹. The spring season
305 averaged the lowest rainfall erosion index at 695.4 MJ mm ha⁻¹ h⁻¹. In contrast, the summer
306 season recorded an erosivity index of 1418.2 MJ mm ha⁻¹ h⁻¹. The summer erosivity index varies
307 between a maximum value of 3335.5 MJ mm ha⁻¹ h⁻¹ recorded in 2018 and a minimum value
308 of 69.6 MJ mm ha⁻¹ h⁻¹ recorded in 2007. In the autumn 2015, between 31st October and 2nd
309 November, the longest event of the whole period (30 h 50') was recorded with 209.2 mm of
310 rain, with an R value of 1483.7 MJ mm ha⁻¹ h⁻¹ and an I₃₀ of 13.0 mm h⁻¹.

311 The event with the highest R value was recorded in the autumn 2010; in particular, a rainfall
312 (time: 21 h 20') of 165.5 mm with an R value of 2813.8 MJ mm ha⁻¹ h⁻¹ with an I₃₀ of 34.8 mm
313 h⁻¹ was observed on 18 October 2010. In summer 2018, between 24 and 25 August, the rainfall
314 event with the highest I₃₀ max value (39.0 mm h⁻¹) of the entire experimental period was
315 recorded, with a rainfall of 80.7 mm (duration: 5 h) and an R of 1372.1 MJ mm ha⁻¹ h⁻¹. These
316 high magnitude events in summer season are becoming more and more frequent in the
317 Mediterranean environment as demonstrated by the R values of the last few years. The R of the
318 summer season of the last six years is 2048.1 MJ mm ha⁻¹ h⁻¹ y⁻¹, slightly higher than the average
319 R value of the autumn season of the whole test period (2045.3 MJ mm ha⁻¹ h⁻¹). Furthermore,
320 of the I₃₀ max values recorded in the individual test years, six occurred during autumn and six
321 during summer; four of those recorded in summer occurred in the last six years.

322

323 *3.2 The soil erodibility factor K and the topographic factor*

324 The soil erodibility factor K, as defined by Wischmeier and Smith (1978), represents the mean
325 annual value of the relative inherent resistance of a soil to the detachment, entrainment and
326 transport actions operated by rainfall and runoff. The K-factor can be determined according to
327 certain soil characteristics that include texture, presence of organic matter, permeability. In this
328 respect, Wischmeier et al. (1971) provided a nomograph, supported by an explicit equation, to

329 determine the value of K based on the above variables. However, if soil loss measurements are
 330 available at a plot scale, a direct evaluation of K is possible. The method is based on a simple
 331 regression analysis between soil loss measurements and rainfall erosivity, as proposed by
 332 Wischmeier and Mannering (1969).

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

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

$$343 \quad LS = \left(\frac{\lambda_i}{22.13}\right)^{m_i} (10.8 \sin \alpha_i + 0.03) \quad \tan \alpha_i < 0.09$$

$$344 \quad LS = \left(\frac{\lambda_i}{22.13}\right)^{m_i} (16.8 \sin \alpha_i - 0.05) \quad \tan \alpha_i \geq 0.09$$

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

$$347 \quad m_i = \frac{f_i}{1 + f_i}$$

348

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

$$350 \quad f_i = \frac{\sin \alpha_i}{(0.0896 (3 \sin^{0.8} \alpha_i + 0.56))}$$

351 Considering the very close values of plots slope and length, also the values of the topographic

352 factor were very similar, on average equal to 1.29 (1.20 in SP; 1.27 in CS₁; 1.36 in CS₂; 1.35
353 in CS₃; 1.25 in CS₄) (McCool et al., 1989; Renard et al., 1997).

354

355 *3.3 Soil erosion and runoff*

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

360 Statistical analysis, for both eroded material and runoff, showed significant differences between
361 the tested treatments, confirming the different protection degree of vegetation cover and various
362 cultivation systems. The total annual amount of eroded material, as average obtained from the
363 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
364 (2015/16).

365 The annual cumulative value of surface runoff, averaged over five plots and twelve years, was
366 124.4 mm. The highest surface runoff values, statistically equal to each other, were recorded in
367 the rainiest years 2008/09 (1612.9 mm) and 2017/18 (1621.2 mm) with 196.3 and 198.1 mm,
368 respectively. In contrast, in the lowest rainfall years (<1000 mm) 2007/08 and 2016/17 the
369 lowest values were 77.5 and 67.0 mm, respectively.

370 Table 4 shows the average number of days with canopy cover $\geq 50\%$ as well as the average,
371 min and max values of soil loss and runoff in the four CS and SP. CS₄ presented, on average,
372 the highest number of days (260 days) with a soil coverage degree $\geq 50\%$; conservative soil
373 management (minimum tillage, strip tillage and shredded crop residues) and the presence of a
374 grassland crop (tall fescue) for almost 6 years allowed a soil cover level $\geq 50\%$ to be reached
375 for 71.3% of evaluated period. The use of conservation techniques also allowed CS₂ to reach a
376 high number of days (> 200) with a soil cover level $\geq 50\%$. In the CS₃ managed with a mixed
377 system (conservative and conventional) where a conventional tillage was foreseen every five

378 years, it allowed to reach a soil cover degree $\geq 50\%$ for 182 days, equal to 50.3%. On the other
379 hand, the conventional cropping system (CS₂) presented the lowest number of days (135) with
380 a ground cover degree $\geq 50\%$, equal to 37.1% of all studied period (2006-2018).

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

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

390 The two conservative cropping systems (CS₁ and CS₄), although statistically different,
391 presented an average soil loss value of 11.66 t ha⁻¹ with a range of variability between 0.03 and
392 36.53 t ha⁻¹. CS₃ recorded a value of 18.65 t ha⁻¹ while CS₂ had an average value of 55.04 t ha⁻¹
393 with a maximum value of 138.20 t ha⁻¹ in 2015/16.

394 The cumulative values of surface runoff, in multi-years average of the five plots, was higher,
395 as expected, in the standard plot and CS₂ reaching a total amount of 156.0 mm and 142.8 mm,
396 respectively. On the other hand, the CS₁, CS₃ and CS₄ plots recorded a runoff quantity between
397 90.6 and 123.8 mm.

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

401 ANOVA reported significant differences among treatments and a significant “year” x “cropping
402 system” interaction. The analysis of single cropping systems (Fig. 4) highlight the CS₄ highest
403 erosion control effect. Soil loss during five (meadows) of the twelve years’ trial remained below

404 1.00 t ha⁻¹, confirming the high erosion control efficacy of polyannual turf. The maximum value
405 in this cropping system was recorded in 2006/07 with a soil loss of 33.10 t ha⁻¹, mainly due to
406 a high rainfall event (24/10/2006) of 72 mm with an erosion index of 812.5 MJ mm ha⁻¹ h⁻¹.
407 The total amount of soil eroded in CS₄ represented 11.4% and 16.9% of the SP and conventional
408 system (CS₂), respectively.

409 CS₁ presented an average annual soil loss of 13.93 t ha⁻¹. The highest annual erosion was
410 recorded in the years 2010/11, 2015/16 and 2017/18; in particular, on 18 October 2010 there
411 was a rainfall event of rare intensity (180.8 mm) with a maximum I₃₀ of 34.8 mm h⁻¹ and a
412 remarkably high erosion index of 2815.88 MJ mm ha⁻¹ h⁻¹ that triggered more intense erosion
413 phenomena, moreover on soil with a high degree of humidity due to previous rainfalls and in
414 experimental plots (36.53 t ha⁻¹ in CS₁) recently sown, extremely vulnerable at this stage.

415 2015/16 and 2017/18 were characterized by high rainfalls (1590.0 and 1621.2 mm,
416 respectively) with the highest erosivity index of trial period (8591.0 and 8180.2 MJ mm ha⁻¹ h⁻¹
417 ¹, respectively); in the first year repeated autumn erosion events on land affected by minum
418 tillage for sowing cereal (rye) resulted in significant soil loss of 25.65 t ha⁻¹, while in the second
419 year, high-magnitude events in June and August caused significant soil loss (26.44 t ha⁻¹) even
420 in this cropping system due to the presence of a vegetable crop (potato) despite the use of strip
421 tillage.

422 The total amount of soil eroded in CS₃ averaged 18.65 t ha⁻¹. The years 2010/11, 2014/15 and
423 2015/16 recorded an annual soil loss of 42.73, 39.62, and 43.49 t ha⁻¹. In the first and third
424 years, the aggressiveness of autumn rainfall events, described above (October 2010), led to
425 significant soil losses. In the second year (fennel/potatoes), soil preparation (minum tillage) for
426 transplanting/planting, hilling and the low degree of soil cover especially in the autumn (fennel)
427 contributed to making CS₃ extremely vulnerable.

428 The conventional CS₂ is managed using crops and techniques widely consolidated by local
429 farmers; his average erosion over the considered period was 55.04 t ha⁻¹, 67%, compared to the

430 SP. In the years 2015/16 and 2017/18, with a high rainfall erosion index, soil losses of more
431 than 100.00 t ha⁻¹ were recorded; in these two years, in addition to the soil losses recorded in
432 the autumn and winter seasons, the rainfall events recorded at the end of August amounting to
433 230.6 mm (1799.16 MJ mm ha⁻¹ h⁻¹) and 146.8 mm (1946.11 MJ mm ha⁻¹ h⁻¹), which found the
434 soil tilled (conventional tillage) and without vegetation cover, had a decisive influence.

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

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

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

446 Soil losses in the four cropping systems, during the twelve years of trial, were significantly
447 higher during the autumn season, especially in correspondence with particularly aggressive
448 rainfall events (Fig. 5 A). Conventional soil management in CS₂ was decisive in increasing soil
449 losses during autumn season by an average of 31.08 t ha⁻¹, with a high variability among years.

450 Erosion was also high in the CS₃ mixed cropping system (conservative/conventional),
451 amounting to 11.16 t ha⁻¹, while soil losses were lower in the conservative cropping systems
452 (CS₁ and CS₄). The same trend was observed in the winter season, with slightly higher rainfall
453 (455.3 mm) but a halved erosion index, on average, (1055.1 MJ mm ha⁻¹ h⁻¹) compared to the
454 autumn, when soil losses were on the whole around 46% lower.

455 It should also be underlined that in the summer period, with a rainfall of 190.5 mm but with a

456 high erosion index, on average ($1418.2 \text{ MJ mm ha}^{-1} \text{ h}^{-1}$), soil losses were high (7.11 t ha^{-1}) in
457 CS₂, a system where in this season the soil was bare, because, crop residues were removed and
458 the main tillage was carried out after the harvest of winter crops.

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

464

465 *3.4 Cover management and C-factor*

466 The use of equation (5) allows calculating, for each year, the *C-factor* value corresponding to
467 each cropping system. The histograms in Fig. 6, which show the values of the *C-factor*, suggest
468 some reflections on the hydrological response of each cropping system. If we exclude the results
469 of the SP (in which the *C* values are all higher and close to unity), *C-factor* values, although
470 dependent on pluviometric aggressiveness, is also linked to crop growth dynamic (aerial and
471 radical) and agronomic management. This justifies the different behaviour of the cultivation
472 systems when compared on an annual scale; all this is even more evident if the same analysis
473 is carried out on an event scale. With reference to 2017/18 and in particular during spring and
474 summer, five samples of sediment were taken, two of which intercepted particularly aggressive
475 events that had a completely different impact on the four cultivation systems. Specifically, on
476 28th June 2018, a sampling was carried out that intercepted four consecutive events between
477 14th and 18th June with a cumulative rainfall of 260.4 mm, $R 2019.7 \text{ MJ mm ha}^{-1} \text{ h}^{-1}$ and with
478 $I_{30} \text{ max}$ equal to 34.4 mm h^{-1} that triggered significant erosive phenomena. In CS₂ 30.62 t ha^{-1} ,
479 slightly lower than standard plot, due to weeding and hilling operations and the low cover
480 degree (potato) contributed to making the CS extremely vulnerable. On the other hand, in CS₁,
481 the presence of the same crop but with strip-tillage, soil losses amounted to 12.32 t ha^{-1} . CS₃

482 and CS₄, exhibited low values of soil loss (1.50 and 2.42 t ha⁻¹, respectively).

483 In addition, on 31st August 2018, there was a sampling that intercepted two consecutive events
484 between 24th and 25th August with a cumulative rainfall of 146.8 mm, R 1946.1 MJ mm ha⁻¹ h⁻¹
485 and with I₃₀ max of 39.0 mm h⁻¹ that triggered high erosion phenomena; in CS₂ 39.12 t ha⁻¹,
486 on the other hand in CS₁ the soil losses were 2.31 t ha⁻¹ while in CS₃ and CS₄, the presence of
487 shredded crop residues, after lupin and broad bean harvesting, has significantly reduced the
488 eroded material (0.35 and 0.53 t ha⁻¹, respectively).

489 CS₁ and CS₄ involved minimum tillage and/or strip-tillage with crops sown in wide rows, and
490 use of crop residues as mulch after harvest contributed to low *C-factor* values (0.14 and 0.12,
491 respectively) in the twelve-year average and demonstrated the high efficiency of these
492 agronomic techniques against soil erosion. In addition, tall fescue inclusion in CS₄, with a long
493 soil cover (260 days ≥ 50%), further reduced the *C-factor* values, which were close to zero in
494 the following five years, except in the first sowing year (2010/11).

495 A relatively low *C-factor* value (albeit higher than those mentioned above) can be found for
496 CS₃, which presented a *C* value of 0.19 on average over the years. The highest values in this
497 CS were recorded in 2010/11 (0.34) and 2014/15 (0.42); in the first year this was due to a very
498 aggressive rainfall recorded in October 2010, which found CS₃ with oats in emergence on tilled
499 soil, while in the second year the close rotation between two vegetables (fennel and potato),
500 with tillage on all surface of the plot (minum tillage) and consecutive tillage on both crops
501 (hilling), determined the triggering of important erosion phenomena.

502 Among the four cropping systems, CS₂ showed, on average over the years, the highest *C-factor*
503 value (0.50), highlighting the vulnerability to erosion of conventional management. This
504 cropping system, in presence of aggressive rainfall events, was extremely vulnerable during the
505 autumn period with tilled soil and no vegetation cover; this vulnerability is even more marked
506 when the presence of vegetable crops necessitates cultivation operations during their biological
507 cycle. In addition, the susceptibility of this crop system to erosion during the summer season

508 with tilled soil should be emphasised, as demonstrated by the *C* values in recent years due to
509 intense rainfalls during this season, increasingly frequent in the Mediterranean environment.

510

511 **4. Discussion**

512 The different management of the five plots in the long term had a different impact on both
513 surface runoff and soil losses. The seasonal rainfall characteristics during the trial period, shown
514 in Table 2, confirm the aggressiveness of rainfall during the autumn season. Soil loss, averaged
515 over the five plots, was found to be significantly correlated with the rainfall erosivity index ($R=$
516 0.809) but not with the amount of rainfall falling ($R= 0.453$), similarly to what was reported on
517 different herbaceous cropping systems and under different experimental conditions (Wei et al.,
518 2007; Mohamadi and Kavian, 2015; Anache et al., 2017). CS_4 and CS_1 presented, on average,
519 the lowest soil loss values, 9.38 and 13.93 t ha^{-1} , respectively. The greater effectiveness against
520 erosion in these cropping systems can be attributed to conservative soil management (minimum
521 tillage, strip tillage, shredded crop residues) and to introduction of polyannual grassland crops.
522 The use of these techniques, in fact, ensured greater soil coverage (Table 5) exposing the soil
523 for a shorter time to the erosive rainfall action (on average, 105 and 155 days with $<50\%$
524 coverage), especially during summer and autumn periods. Minimum tillage, residue mulch and
525 canopy cover provided by natural vegetation in CS_1 and tall fescue in CS_4 limited water erosion
526 in those treatments. Furthermore, in CS_1 permanent meadows seemed to be able to control the
527 erosion due to dense growth root systems as shown by the soil loss data over the six years of
528 meadow presence, as previously reported in similar environmental conditions (Novara et al.,
529 2011). These results were in agreement with several authors, also under rainfall events of high
530 intensity (Wischmeier and Smith, 1978; Veihe et al., 2003; Maetens et al., 2012; Bargiel et al.,
531 2013; Kurothe et al., 2014; Anache et al., 2017; Baiamonte et al., 2019). On the other hand, soil
532 losses in the conventional cropping system (CS_2), averaging 55.04 t ha^{-1} , can be attributed to
533 the low degree of soil cover (on average, 230 days with $<50\%$ cover), the high degree of soil

534 stress (ploughing), and subsequent tillage for sowing/transplanting, moreover in a period with
535 high rainfall erosion such as the summer and autumn seasons in Mediterranean environment.
536 These results confirm that the adoption of conventional tillage on sloping land increases soil
537 erosion (Bombino et al., 2019; Sasal et al., 2010; Kurothe et al., 2014).

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

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

550 These data show that in the Mediterranean environment the aggressiveness of the rainfall and
551 the degree of ground cover affect these two parameters. This is confirmed by the fact that in the
552 summer season, with a rainfall of 190.5 mm (-58% compared to the winter season), a soil loss
553 of 4.28 t ha⁻¹ was recorded, mainly related to CS₂, which in this season, after the harvest of the
554 winter crop, is affected by main tillage. In addition, the quantity of runoff intercepted in the
555 collection tanks, on average 9.5%, shows that it is the erosive nature of the autumn rains, and
556 now summer rains too, that causes surface runoff (12.2 and 7.9%, respectively).

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

560 In addition, it should be noted that soil moisture before rainfall events occur, even if not of
561 high intensity, plays an important role on runoff and soil loss and affects the partitioning of
562 rainfall into infiltration and runoff and, consequently, influences soil erosion. Water potential
563 values close to field capacity predispose the soil to erosion risks and increase surface runoff
564 (Wei et al., 2007) even in the presence of rainfall events characterised by a low erosion index.
565 The runoff coefficient was exponentially correlated to the inverse of antecedent soil water
566 potential in the rainy season, while the runoff coefficient was negatively and linearly correlated
567 to antecedent soil water potential in the dry season. These results suggest that saturation excess
568 runoff may be dominant in the rainy season and infiltration excess runoff may become dominant
569 in the dry season (Grayson et al., 1997; Fitzjohn al., 1998; Wei et al., 2007).

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

572 The C -factor values (fig. 6) for each year allows us to consolidate some statements and to make
573 some reflections on hydrological response of each crop system. From the results presented
574 above, excluding SP, can be stated that C -factor values do not seem to follow a similar trend;
575 the correlation analysis between the climatic variables (rainfall and erosivity) and the C -factor
576 shows a significant relationship only in CS₂ cropping system.

577 However, this result is not unexpected since the C -factor, although dependent on the
578 aggressiveness of the rainfall, is linked not only to tillage (tool and season) but also to crops
579 development (aerial and radical) as well as the management of crop residues (mulch or
580 removed). This would justify the low C value, denoting a high protective efficacy, in CS₄ and
581 even more so in the five years in which meadow was present.

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

586 The different management of close rotation between two vegetables (fennel/potato) in 2017/18
587 in the CS₁ and CS₂ cropping systems generated very different *C* values (0.19 and 0.71,
588 respectively), confirming what above reported. An even more pronounced difference between
589 these two cropping systems resulted in 2014/15 and 2015/16 in the presence of autumn-winter
590 crops, sown in narrow rows (lupin/cereal) with *C* values averaging 0.17 and 0.87, respectively,
591 where an important role was played by the erosivity of rain during the summer period on tilled
592 soil (CS₂). In addition, the presence of natural cover in CS₁ in 2006/07 in autumn and winter
593 period up to the preparation of the soil for potato planting had a significant influence on *C* value
594 reached in this year (0.05), (Ayalew et al., 2021).

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

598

599 **5. Conclusions**

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

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

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

615 Crops sown with narrow row spacing (cereals and/or legumes) showed a high capacity to
616 control erosion during the spring period when they reach a high degree of soil cover; soil and
617 crop residue management after their harvest (July) plays a key role in containing erosion risk.
618 In the two conservative cropping systems CS₁ and CS₄ the protective effect (+36% and +38%,
619 compared to CS₂) is attributed to the presence of crop residues as well as the basal part of plants
620 and roots and the wild flora canopy. These two cropping systems proved to be effective in
621 reducing soil losses during the summer season and limiting them during the autumn period by
622 minimum tillage close to sowing time. The effectiveness of minimum tillage, on erosion
623 control, the introduction of cover crops, natural cover, polyannual grass, significantly improve
624 soil protection and efficacy in containing soil losses.

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

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

634

635 **References**

636

637 Alberts, E.E., Wendt, R.C., Burwell, R.E., 1985. Corn and soybean effects on soil losses and C
638 factors. Soil Sci. Soc. Am. J. 49, 721-728.
639 <https://doi.org/10.2136/sssaj1985.03615995004900030038x>.

640 Almagro, A., Thomè, T.C., Colman, C.B, Pereira, R.B., Marcato Junior, J., Rodrigues, D. B.B.,
641 Oliveira, P.T.S., 2019. Improving cover and management factor (C-factor) estimation using
642 remote sensing approaches for tropical regions. International Soil and Water Conservation
643 Research 7, 325-334. <https://doi.org/10.1016/j.iswcr.2019.08.005>.

644 Anache, J.A.A., Wendland, E.C., Oliveira, P.T.S., Flanagan, D.C, Nearing, M.A., 2017. Runoff
645 and soil erosion plot-scale studies under natural rainfall: A meta-analysis of the Brazilian
646 experience. Catena 152, 29–39.

647 Assennato, F., Di Leginio, M., d’Antona, M., Marinosci, I., Congedo, L., Riitano, N., Luise,
648 A., Munafò, M., 2020. Land degradation assessment for sustainable soil management. Italian
649 Journal of Agronomy 15:1770, 299-305. <https://doi.org/10.4081/ija.2020.1770>.

650 Ayalew, D.A., Deumlich, D., Sarapatka, B., 2021. Agricultural landscape-scale C factor
651 determination and erosion prediction for various crop rotations through a remote sensing and
652 GIS approach. European Journal of Agronomy 123, 126203

653 Bacchi, M., Ferro, V., Monti, M., Porto, P., 2010. Effetto di differenti sistemi culturali sulla
654 perdita di suolo in parcelle sperimentali ubicate in Calabria. QUADERNI DI IDRONOMIA
655 MONTANA, 29/2, 157-176.

656 Baiamonte, G., Minacapilli, M., Novara, A., Gristina, L., 2019. Time Scale Effects and
657 Interactions of Rainfall Erosivity and Cover Management Factors on Vineyard Soil Loss
658 Erosion in the Semi-Arid Area of Southern Sicily. Water 11, 978.
659 <https://doi.org/10.3390/w11050978>.

660 Baiamonte, G., Gristina, L., Minacapilli, M., Novara, A., 2021. Aridity index, soil erosion and
661 climate drive no-till ecosystem services trade-off in Mediterranean arable land. *Catena* 203,
662 105350. <https://doi.org/10.1016/j.catena.2021.105350>.

663 Bargiel, D., Herrmann, S., Jadczyzyn, J., 2013. Using high-resolution radar images to
664 determine vegetation cover for soil erosion assessments. *J. Environ. Manage.* 124, 82–90.

665 Bogunovic, I., Telak, L.J., Pereira, P., Filipovic, V., Filipovic, L., Percin, A., Durdevic, B.,
666 Birkás, M., Dekemati, I., Comino, J.R., 2020. Land management impacts on soil properties
667 and initial soil erosion processes in olives and vegetable crops. *J. Hydrol. Hydromech.* 68.

668 Bombino, G., Denisi, P., Gómez, J.A., Zema, D.A., 2019. Water Infiltration and Surface Runoff
669 in Steep Clayey Soils of Olive Groves under Different Management Practices. *Water* 11(2),
670 240. <https://doi.org/10.3390/w11020240>.

671 Cerdan, O., Govers, G., Le Bissonnais, Y., Van Oost, K., Poesen, J., Saby, N., Gobin, A., Vacca,
672 A., Quinton, J., Auerswald, K., Klik, A., Kwaad, F.J.P.M., Raclot, D., Ionita, I., Rejman, J.,
673 Rousseva, S., Muxart, T., Roxo, M.J., Dostal, T., 2010. Rates and spatial variations of soil
674 erosion in Europe: a study based on erosion plot data. *Geomorphology* 122, 167–177.
675 <https://doi.org/10.1016/j.geomorph.2010.06.011>.

676 Cinnirella, S., Iovino, F., Porto, P., Ferro, V., 1998. Anti-erosive effectiveness of Eucalyptus
677 coppices through the cover management factor estimate, *Hydrological Processes*, 12(4),
678 635-649. [https://doi.org/10.1002/\(SICI\)1099-1085\(19980330\)12:4<635::AID-
679 HYP598>3.0.CO;2-Q](https://doi.org/10.1002/(SICI)1099-1085(19980330)12:4<635::AID-HYP598>3.0.CO;2-Q).

680 Fitzjohn, C., Ternan, J.L., Williams, A.G., 1998. Soil moisture variability in a semi-arid gully
681 catchment: implications for runoff and erosion control. *Catena* 32, 55–70.
682 [https://doi.org/10.1016/S0341-8162\(97\)00045-3](https://doi.org/10.1016/S0341-8162(97)00045-3).

683 Food and Agriculture Organization, 2016. Food and Agriculture Data. www.fao.org>home
684 (accessed 10 May 2021).

685 Foster G.R., McCool D.K., Renard K.G., Moldenhauer W.C., 1981. Conversion of the universal
686 soil loss equation to SI metric units. *J Soil Water Conserv* 36(6), 355-359

687 Gabriels, D., Ghekiere, G., Schiettecatte, W., Rottiers, I., 2003. Assessment of USLE cover-
688 management C-factors for 40 crop rotation systems on arable farms in the Kemmelbeek
689 watershed, Belgium. *Soil & Tillage Research*, 74 47–53. [https://doi.org/10.1016/S0167-](https://doi.org/10.1016/S0167-1987(03)00092-8)
690 [1987\(03\)00092-8](https://doi.org/10.1016/S0167-1987(03)00092-8).

691 Grayson, R.B., Western, A.W., Chiew, H.S., Bloschl, G., 1997. Preferred states in spatial soil
692 moisture patterns: local and nonlocal controls. *Water Resour. Res.* 33, 2897–2908.
693 <https://doi.org/10.1029/97WR02174>.

694 Guo, Q., Liu, B., Xie, Y., Liu, Y., Yin, S., 2015. Estimation of USLE crop and management
695 factor values for crop rotation systems in China. *Journal of Integrative Agriculture* 14(9):
696 1877–1888. [https://doi.org/10.1016/S2095-3119\(15\)61097-8](https://doi.org/10.1016/S2095-3119(15)61097-8).

697 Klute A 1986 Water retention: Laboratory methods; In: *Methods of soil analysis. Part I:*
698 *Physical and Mineralogical Methods. Agronomy Series 9, 2nd edn, American Society of*
699 *Agronomy, Madison, WI, USA, pp. 635–662.*

700 Kurothe, R.S., Kumar, G., Singh, R., Singh, H.B., Tiwari, S.P., Vishwakarma, A.K., Sena, D.R.,
701 Pande, V.C., 2014. Effect of tillage and cropping systems on runoff, soil loss and crop yields
702 under semiarid rainfed agriculture in India. *Soil & Tillage Research* 140, 126-134.
703 <https://doi.org/10.1016/j.still.2014.03.005>.

704 Lal, R., Reicosky, D.C., Hanson, J.D., 2007. Evolution of the plow over 10,000 years and the
705 rationale for no-till farming. *Soil and Tillage Research* 93, 1-12.

706 Maetens, W., Vanmaercke, M., Poesen, J., Jankauskas, B., Jankauskine, G., Ionita, I., 2012.
707 Effects of land use on annual runoff and soil loss in Europe and the Mediterranean: A meta-
708 analysis of plot data. *Progress in Physical Geography: Earth and Environment* 36, 599-653.
709 <https://doi.org/10.1177/0309133312451303>.

710 Martínez-Mena, M., Carrillo-López, E., Boix-Fayos, C., Díaz Pereira, E., Castillo, V., de Vente,
711 J., Almagro, M., García Franco, N., 2019. Long-term effectiveness of Sustainable Land
712 Management practices to control runoff, soil erosion and nutrient loss in Mediterranean
713 rainfed agroecosystems. Proceedings Global Symposium on Soil Erosion. - 15–17 may
714 2019, FAO headquarters, Rome, Italy.

715 Martínez-Mena, M., Carrillo-López, E., Boix-Fayos, C., Almagro, M., García Franco, N.,
716 Díaz-Pereira, E., Montoya, I., de Vente, J., 2020. Long-term effectiveness of sustainable
717 land management practices to control runoff, soil erosion, and nutrient loss and the role of
718 rainfall intensity in Mediterranean rainfed agroecosystems. *Catena* 187, 104352.

719 McCool, D. K., Foster, G. R., Mutchler, C. K., Meyer, L. D., 1989. Revised slope length factor
720 for the Universal Soil Loss Equation. *Trans. of the ASAE* 32(5), 1571-1576.

721 McGregor, K., 1978. C factors for no-till and conventional-till soybeans from plot data, *Trans.*
722 *of the ASAE* 21, 1119-1122.

723 Mohamadi, M.A., Kaviann, A., 2015. Effects of rainfall patterns on runoff and soil erosion in
724 field plots. *International Soil and Water Conservation Research* 3, 273–281.
725 <https://doi.org/10.1016/j.iswcr.2015.10.001>.

726 Novara, A., Gristina, L., Saladino, S.S., Santoro, A., Cerdà, A., 2011. Soil erosion assessment
727 on tillage and alternative soil managements in a Sicilian vineyard. *Soil & Tillage Research*
728 117, 140–147.

729 Novara, A., Stallone, G., Cerdà, A., Gristina, L., 2019. The Effect of Shallow Tillage on Soil
730 Erosion in a Semi-Arid Vineyard. *Agronomy* 9, 257.
731 <https://doi.org/10.3390/agronomy9050257>.

732 Novara, A., Cerdà, A., Barone, E., Gristina, L., 2021. Cover crop management and water
733 conservation in vineyard and olive orchards. *Soil & Tillage Research* 208, 104896.

734 Nyakatawa, E.Z., Jakkula, V., Reddy, K.C., Lemunyon, J.L., Norris, Jr. J.L., 2007. Soil erosion
735 estimation in conservation tillage system with poultry litter application using RUSLE 2.0
736 model. *Soil & Tillage Research* 97, 410-419.

737 Onori, F., De Bonis, P., Grauso, S., 2006. Soil erosion prediction at the basin scale using the
738 revised universal soil loss equation (RUSLE) in a catchment of Sicily (southern Italy).
739 *Environ Geol.* 50, 1129–1140. DOI 10.1007/s00254-006-0286-1

740 Panagos, P., Ballabio, C., Borrelli, P., Meusburger, K., Klik, A., Rouseva, S., Tadic Percec,
741 M., Michaelides, S., Hrabalíková, M., Olsen, P., Aalto, J., Lakatos, M., Rymaszewich, A.,
742 Dumitrescu, A., Begueria, S., Alewell, C., 2015. Rainfall erosivity in Europe. *Sci. Total*
743 *Environ.* 511, 801–814. <https://doi.org/10.1016/j.scitotenv.2015.01.008>

744 Porto P., 2016. Exploring the effect of different time resolutions to calculate the rainfall
745 erosivity factor R in Calabria, southern Italy. *Hydrological Processes* 30, 1551–1562.
746 <https://doi.org/10.1002/hyp.10737>

747 Porto P, Bacchi M, Preiti G, Romeo M, Monti M 2022. Combining plot measurements and a
748 calibrated RUSLE model to investigate recent changes in soil erosion in upland areas in
749 Southern Italy. *Journal of Soils and Sediments* 22, 1010–1022.
750 <https://doi.org/10.1007/s11368-021-03119-2>

751 Porto P and Walling D.E., 2012. Using plot experiments to test the validity of mass balance
752 models employed to estimate soil redistribution rates from ^{137}Cs and $^{210}\text{Pb}_{\text{ex}}$ measurements.
753 *Applied Radiation and Isotopes* 70, 2451-2459.
754 <https://doi.org/10.1016/j.apradiso.2012.06.012>

755 Preiti, G., Romeo, M., Bacchi, M., Monti, M., 2017. Soil loss measure from Mediterranean
756 arable cropping systems: Effects of rotation and tillage system on C-factor. *Soil & Tillage*
757 *Research* 170, 85–93. <https://doi.org/10.1016/j.still.2017.03.006>

758 Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.C., 1997. Predicting soil
759 erosion by water: a guide to conservation planning with the revised universal soil loss
760 equation (RUSLE). USDA ARS Agriculture Handbook n. 703.

761 Renschler, C.S., Mannaerts, C., Diekkruger, B., 1999. Evaluating spatial and temporal
762 variability in soil erosion risk-rainfall erosivity and soil loss ratios in Andalusia, Spain.
763 *Catena* 34, 209–225. [https://doi.org/10.1016/S0341-8162\(98\)00117-9](https://doi.org/10.1016/S0341-8162(98)00117-9).

764 Reynolds W.D. and Elrick D.E., 1987. A laboratory and numerical assessment of the Guelph
765 permeameter method. *Soil Sci.* 144, 282-299

766 Ruisi, P., Giambalvo, D., Saia, S., Di Miceli, G., Frenda, A.S., Plaia, A., Amato, G., 2014.
767 Conservation tillage in a semiarid Mediterranean environment: results of 20 years of
768 research. *Ital. J. Agron.* 9(560), 1–7. <https://doi.org/10.4081/ija.2014.560>.

769 Sanesi, G., Laforteza, R., Colangelo, G., Marziliano, P.A., Davies, C., 2013. Root system
770 investigation in sclerophyllous vegetation: an overview. *Ital. J. Agron.* 8(2), 121– 126.
771 <https://doi.org/10.4081/ija.2013.e17>.

772 Sasal, M.C., Castiglioni, M.G., Wilson, M.G., 2010. Effect of crop sequences on soil properties
773 and runoff on natural-rainfall erosion plots under no tillage. *Soil Tillage Res.* 108, 24–29.

774 Şen, Z., Altunkaynak, A., 2005. A comparative fuzzy logic approach to runoff coefficient and
775 runoff estimation. *Hydrol. Process.* 20, 1993–2009. <https://doi.org/10.1002/hyp.5992>.

776 Soil Survey Staff, 2006. *Keys to Soil Taxonomy*, 10th ed. U.S. Dep. Agric. Nat. Resour.
777 Conserv. Serv., Washington, D.C.

778 Sriwongsitanon, N., Taesombat, W., 2011. Effect of land cover on runoff coefficient. *J of*
779 *Hydrology* 410, 226-238.

780 Tejada, M., Gonzales, J.L., 2006. The relationship between erodibility and erosion in a soil
781 treated with two organic amendments. *Soil & Tillage Research* 91,186-198.

782 Veihe, A., Hasholt, B., Schiøtz, G., 2003. Soil erosion in Denmark: processes and politics.
783 *Environmental Science & Policy* 6, 37-50. [https://doi.org/10.1016/S1462-9011\(02\)00123-5](https://doi.org/10.1016/S1462-9011(02)00123-5).

784 Wei, L., Zhang, B., Wang, M., 2007. Effects of antecedent soil moisture on runoff and soil
785 erosion in alley cropping systems. *Agricultural water management* 94, 54 – 62.
786 <https://doi.org/10.1016/j.agwat.2007.08.007>.

787 Wischmeier, W. H., Mannering, J. V., 1969. Relation of soil properties to its erodibility. *Soil*
788 *Sci Soc Am Proc.* 39, 131-137.
789 <https://doi.org/10.2136/sssaj1969.03615995003300010035x>.

790 Wischmeier, W.H., Johnson, C., Cross, B., 1971. A soil erodibility nomograph for farmland,
791 construction sites, *Journal of Soil Water Conservation* 26 (3), 189-193.

792 Wischmeier, W. H., Smith, D. D., 1978. Predicting rainfall erosion losses - a guide to
793 conservation planning, agriculture handbook No. 537, USDA/Science and Education
794 Administration, US. Govt. Printing Office, Washington D.C.

795 Zhang, B., Horn, R., 2001. Mechanisms of aggregate stabilization in Ultisols from subtropical
796 China. *Geoderma* 99, 123–145.

797

798 **TABLES AND FIGURES CAPTIONS**

799

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

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

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

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

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

810

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

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

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

817

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

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

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

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

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

836

837 **TABLES AND FIGURES**

838
839
840
841

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

CS₁

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

842
843

CS₂

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

844
845

CS₃

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

846
847

CS₄

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

848
849
850
851
852
853
854
855
856
857

(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 (HL); (7) mulch (M - shredded crop residues and left on soil surface); (8) – crop residues removed (RR); (9) – green manure (NV – natural vegetation).

858
859
860

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

861
862
863
864
865

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

866
867
868

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

869

870
871
872

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

Crop system	Canopy cover $\geq 50\%$		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

873 * 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.

874

875

876

877

878 **Table 5** – Seasonal averages of rainfall, runoff, runoff coefficient and soil loss of different land use treatments
879 (2006/2007 - 2017/18)

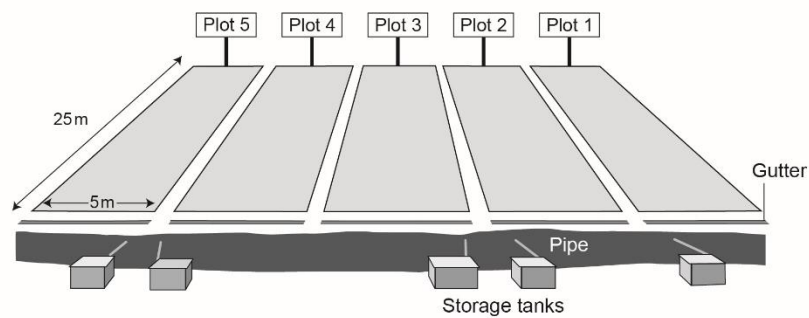
	Autumn	Winter	Spring	Summer	Annual
Rainfall (mm)	450.3	455.3	212.8	190.5	1308.8
Runoff (mm)	54.9	45.8	8.6	15.1	124.4
Runoff coefficient (%)	12.2	10.1	4.0	7.9	9.5
Soil loss (t ha ⁻¹)	18.94	9.40	3.22	4.28	35.84

880

881

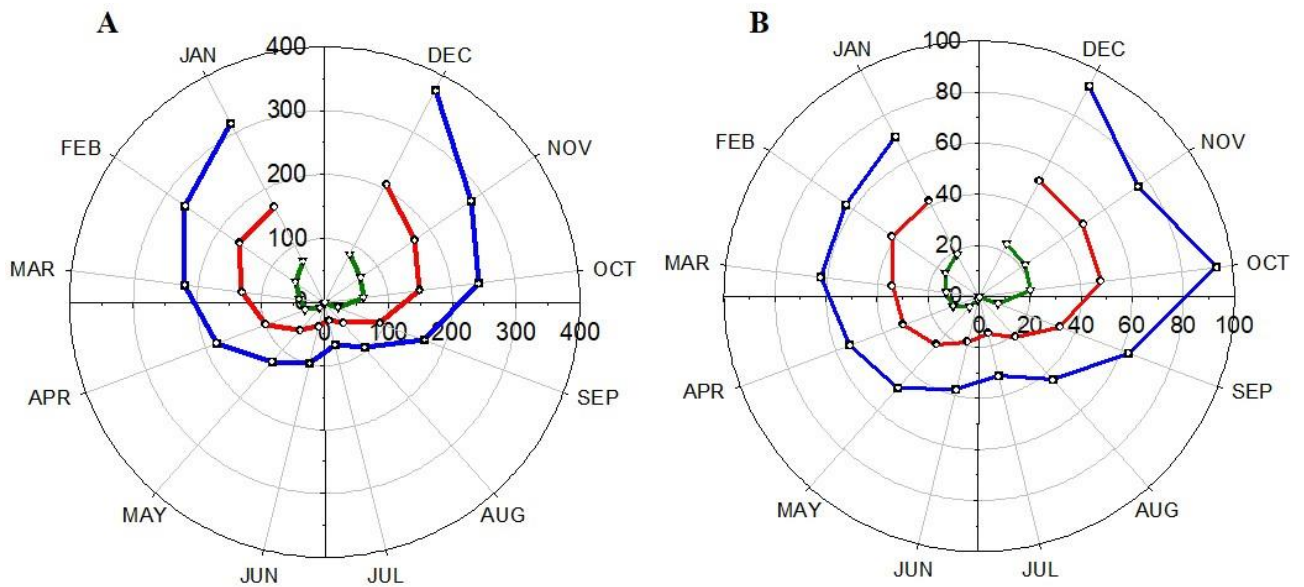
882

883



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

886
887
888
889
890
891



892 **Fig. 2** - Polar diagrams (monthly averages 1961-2020): monthly rainfall cumulates (A) and
893 daily rainfall maxima (B). The red line indicates the mean value, the green and blue lines
894 indicate the 10% and 90% percentiles, respectively.
895
896

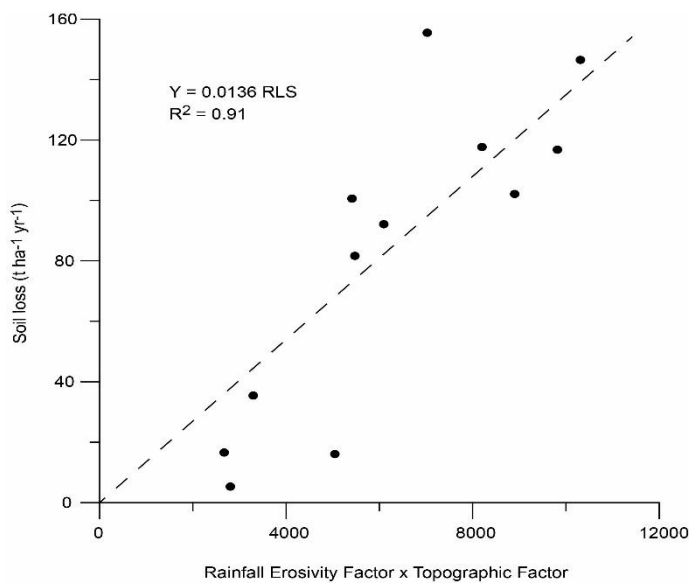


Fig. 3 - Regression analysis for calculation of soil erodibility factor K. Relationship between standard plot (SP) soil loss and rainfall erosivity per topographic factor (LS) in the twelve years.

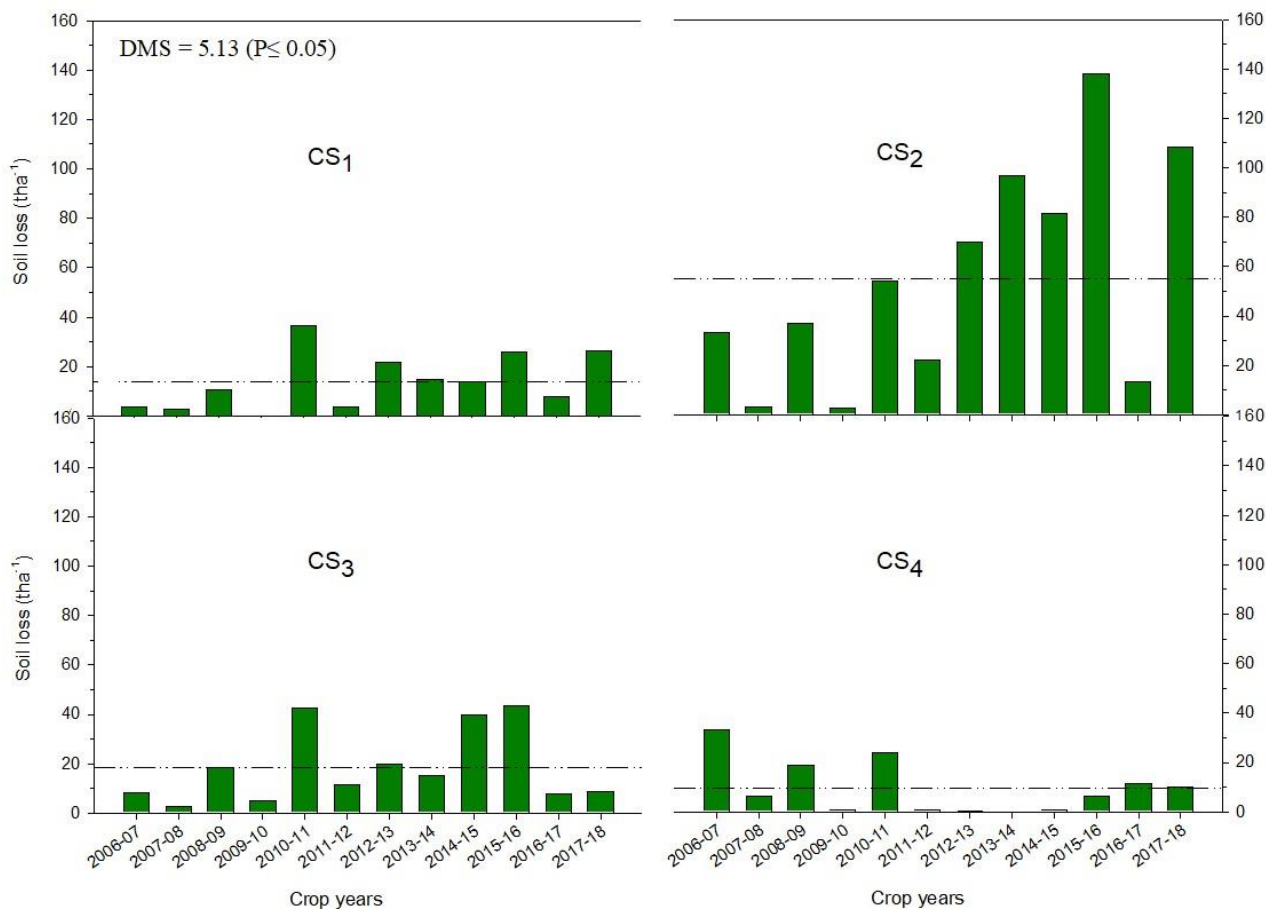
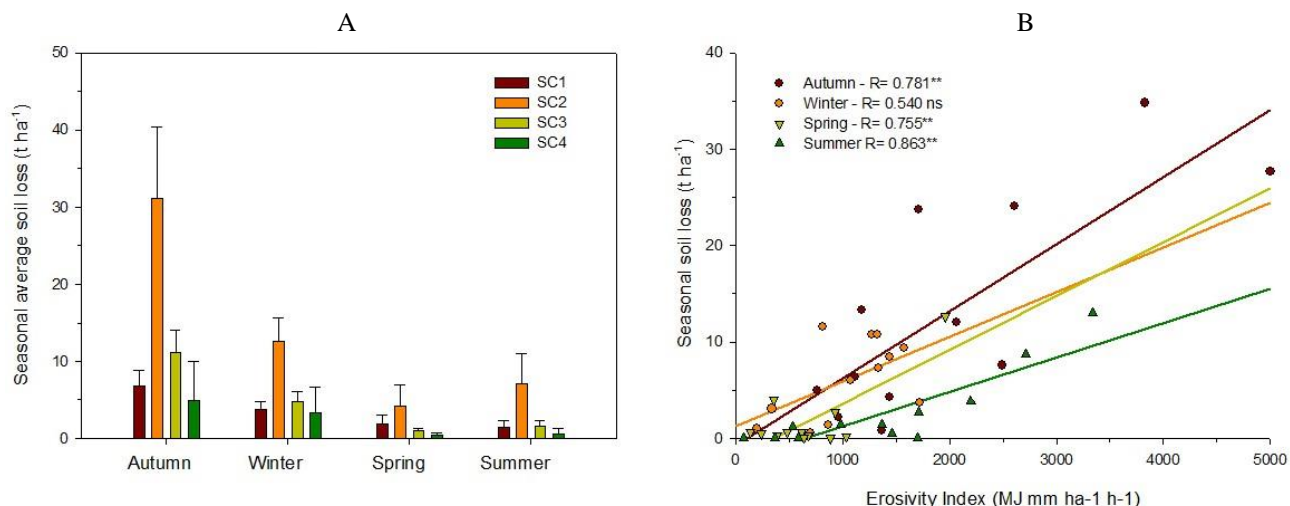


Fig. 4 - Effect of year x cropping system interaction on soil loss. The dashed line shows the average soil loss value over twelve years of the four cropping systems. DMS indicates the least significant difference between the averages.

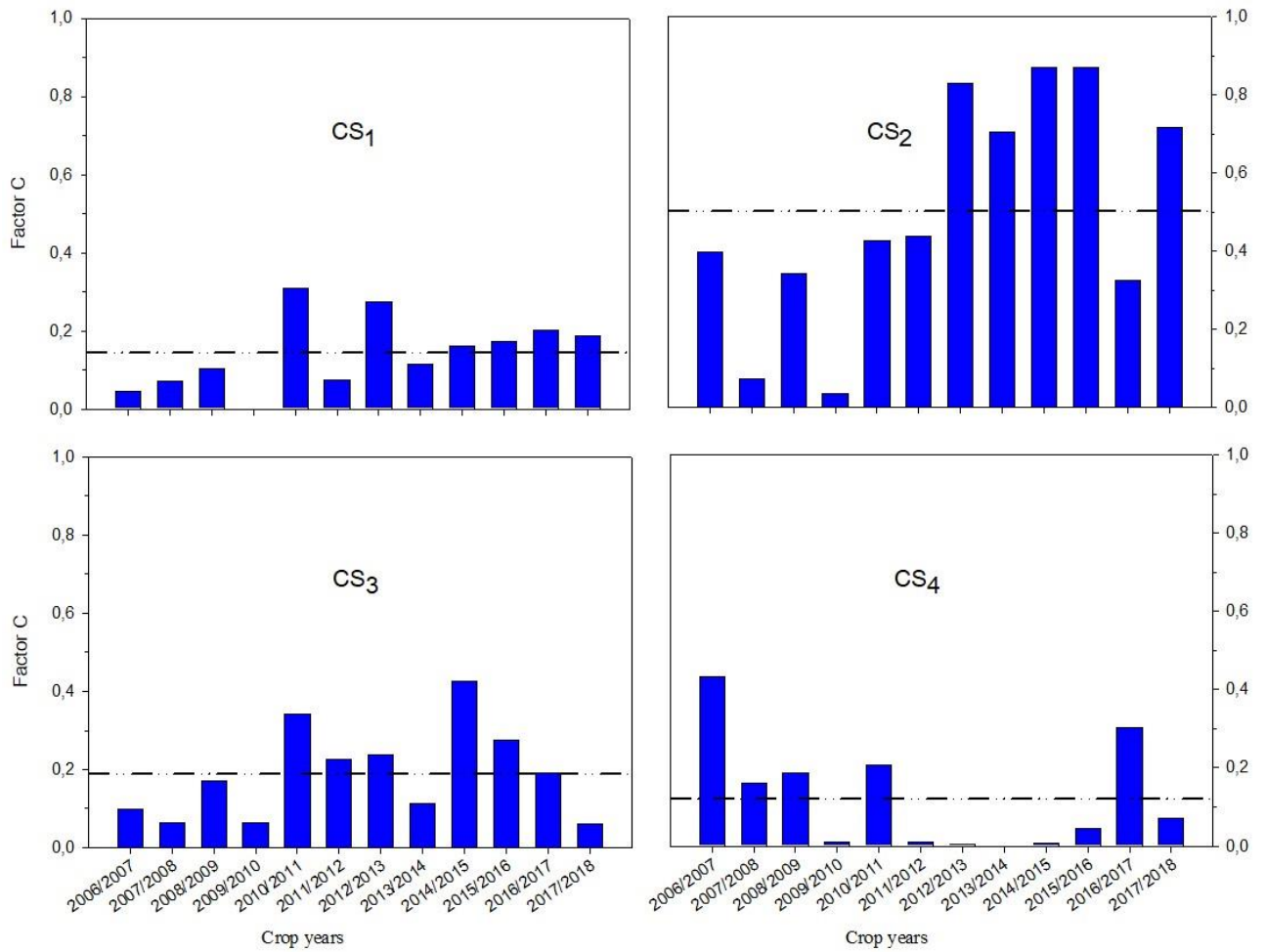


930

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

937

938



939
 940
 941
 942
 943
 944
 945

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/minimum tillage and conventional tillage; CS4-Minimum tillage and crop residues left on soil surface.