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Hydrological Effects of Different Soil Management Practices in Mediterranean Areas

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1. Introduction

In Mediterranean environment intensive agricultural activities are often practiced in steep slopes, where sometimes climatic, geomorphologic and land use factors (e.g. the high rainfall intensity, the scarce vegetal coverage, especially on the occasion of the early rainfalls, the low organic matter content of soils, etc.) worsen the impacts of soil erosion. In such contexts agriculture may play an important role both in terms of economic and social spin-offs (e.g. peopling of hilly marginal lands) as well as under the environmental aspect (e.g. control of erosion phenomena). This is the case of olive growing practiced in hilly lands with a low tree density (e.g. in Southern Italy), often subjected to torrential rainstorms. Therefore, soil degradation problems in such agricultural steep lands under semi-arid conditions must be accounted for through proper soil management systems with low environmental impacts (mainly on soil hydrology).

Until recently, the most common practice for soil conservation in many Mediterranean regions, as Andalusia (Spain, Gomez et al., 2003) and Sicily or Calabria (Italy) has been tillage: however, the tradition of frequent tillage, aimed at preventing competition from natural vegetation for water and nutrients with the olive tree and at facilitating olive harvesting, has exacerbated the problems of erosion and soil degradation (Gomez et al., 2009a). Alternative practices to tillage include: no-tillage with herbicides to maintain a bare and weed-free soil (which sometimes results in accelerated soil erosion due to an increase in water runoff) or the use of a cover crop to protect the soil during autumn and winter, either sown in early autumn or from the regeneration of the natural vegetation after the onset of rains (Gomez et al., 2009a, 2009c). The cover crop is controlled by mowing or by herbicide in spring to reduce the risk of competition for water with the trees, which represents the main limiting factor for plant growth in semi-arid lands, where the evapo-transpiration rate is very high and water resource is scarce.

Studies on soil erosion in orchards in Mediterranean environment have analyzed the hydrological effects of the traditional different managements systems (e.g. Dastgheib & Frampton, 2000; Gago et al., 2007; Gomez et al., 2003, 2009b, 2009c; Monteiro & Moreira, 2004); the important role for soil conservation played by the crop cover has been also highlighted, thanks to the rainfall interception and infiltrability increase (Kosmas et al., 1997; Gomez et al., 2003, 2009b, 2009c; Ramos & Martinez-Casasnovas, 2004).

In spite of the results achieved in these studies, the information about the impacts of different management practices on soil losses is still insufficient and does not allow a proper evaluation of the erosive risks in hilly olive groves across the different local conditions. This consideration is reflected in the contradictory results found in the literature. For example, Pastor et al. (1999) reported that, despite more rill erosion, no-tillage reduced soil losses as compared to conventional tillage, but Francia et al. (2000) measured the opposite effect in runoff plots. The few short term experiments mentioned can not capture the long-term effects of soil management and, to the present knowledge, no previous work has attempted to assess systematically the effects of all soil management practices on soil losses in olive orchards (Gomez et al., 2003). These latter Authors argued as well that “the scarcity of experimental results is the bottleneck for improving the estimation of management effects on the rate of soil losses in olive plantations. Until additional field experiments measuring actual soil loss rates, and field surveys estimating historical rates of soil loss, are carried out at different conditions and scales, erosion rates will remain highly uncertain. On the other hand, qualitative observations indicate that the magnitude of the erosion problem in olive groves on steep slopes is such that the role of alternative soil management in limiting soil loss should be urgently assessed”.

However, because of the high variability that characterizes the Mediterranean environments, soil erosion varies considerably over space and time and in most cases it is inappropriate to extrapolate these measures to other spatial units, where different hydrological and erosive processes take place (Taguas et al., 2010). Thus further detailed investigations also at plot scale could integrate literature data, in order to estimate in different contexts the magnitude of the erosive risk: this latter, considering that monitoring activities of surface runoff and soil loss are time consuming and expensive tasks, can be assessed also through a modeling approach by mathematical simulation of water runoff and soil erosion processes.

As well known, prediction models are useful tools for monitoring and controlling the impacts of soil erosion (e.g. Engel et al., 1993; Licciardello et al., 2007; Zema et al., 2011). While the potential of process based models is greater in comparison to empirical ones, their complexity means larger data requirements, potentially greater problems of error propagation and increased difficulty in understanding the way the model simulates the erosion processes (Favis-Mortlock et al., 2001). Published comparisons between the two types show that the average error and model efficiency in predicting soil loss are similar (Morgan & Nearing, 2000; Tiwari et al., 2000). Thus, empirical models, mainly the Universal Soil Loss Equation (USLE; Wischmeier & Smith, 1978) or its derivatives (e.g. RUSLE; Renard et al. 1997), are still widely used (Gomez et al., 2003): in fact, the reduced data requirement and simplicity of USLE-type models (compared to process-based ones) make them useful tools for planning activities destined to soil conservation workers (e.g. Taguas et al., 2010).

Such considerations have stimulated research activities to evaluate and predict the erosion risks in hilly olive groves of Calabria region (Southern Italy), where olive growing represents a fundamental sector of local economy and the most important land use. Within such research activities, this paper aims at: (i) integrating the literature data on the hydrologic effects of three soil management practices (conventional tillage, no tillage and crop cover) typical of the Mediterranean olive groves; (ii) drawing indications on erosion prediction capability of the RUSLE model for the experimental conditions.

2. Materials and methods

2.1 The study area

The study area is located on the northern side of the torrent Menga valley near Gallina di Reggio Calabria in Southern Italy (Figure 1). The site lies at an altitude of approximately 250 m above sea level; predominant aspect is south. Soil has been classified as sandy-loam (USDA SCS, 1984). The climate of the area is typically Mediterranean, with a mean yearly precipitation of ca. 600 mm, most of which are concentrated in fall and winter periods. Mean monthly temperatures range from 11.5 °C in January, which is the coldest month in the year, to 26.5 °C in July (Bombino et al., 2004).

2.2 The experimental design

In 1991 a research group of the University of Reggio Calabria established nine experimental plots at the site (Figure 2), in order to monitor runoff and soil erosion under different slope and vegetation conditions (Bombino et al., 2002). The plots were characterized by different lengths and slope; the three longer (33 m) plots had a 9% slope, whereas three of the six shorter (22 m) plots had a 9% slope and three an 18% slope. A sheet metal cutoff wall, fixing 30 cm into the soil and protruding 20 cm above the ground surface, was installed around the upper and the two adjacent sides of each plot in order to hydrologically isolate the plots. On the lower side of each plot, a 1-m^3 tank was installed to collect runoff volumes and sediment loads. Rainfall has been recorded at the site since 1990, using a tipping bucket rain gauge, but measurements of runoff and sediment concentrations from the plots have been available since February 2002. Monthly and after each storm event, the sediment load collected in the tank was well mixed and several 1-liter suspended sediment samples were taken from different depths within the tank. The sediment concentration in each sample was determined by oven drying at 105 °C and the mean value of the samples was calculated. The sediment load from each plot was then calculated as the product of the mean sediment concentration and the water volume measured in the tank.

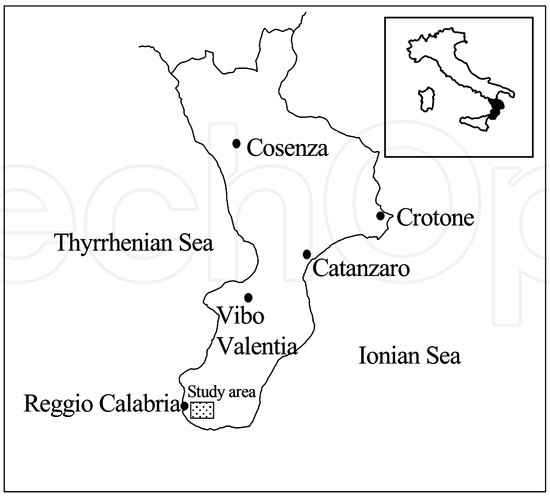

Fig. 1. Location of the study area.

In order to determine the plot vegetal coverage, monthly surveys have been performed in each plot since October 2001. The canopy cover of herbaceous and shrub layers (in %) was evaluated within 1 x 1-m^2 sample areas (at least 1 every 25 m^2).

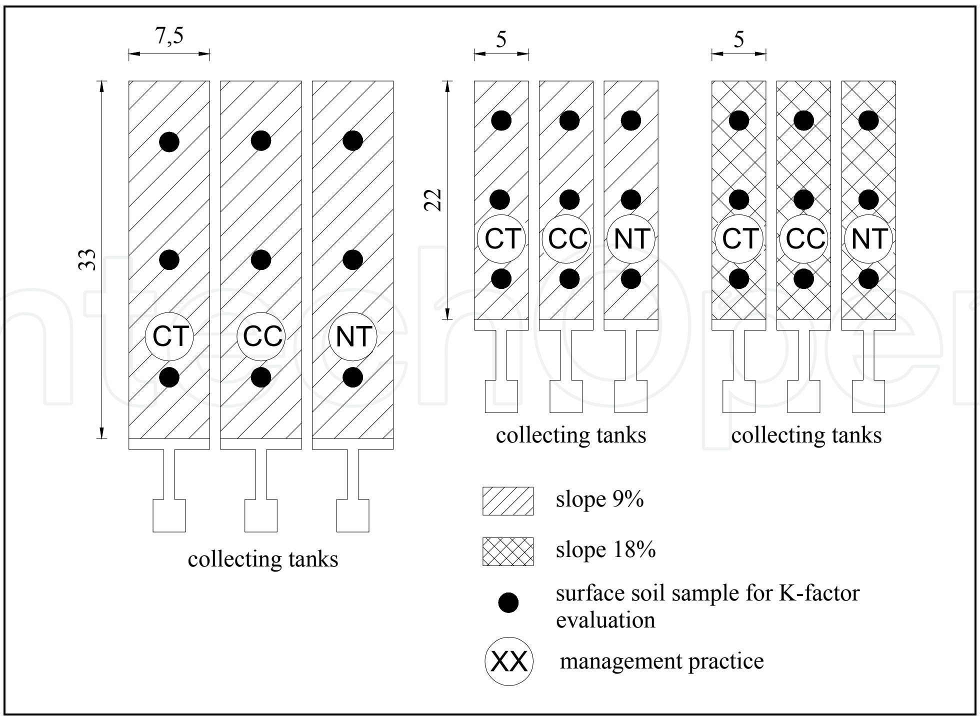

Fig. 2. Layout of the experimental plots (linear measures in metres) (CT = Conventional Tillage; NT = No Tillage; CC = Crop Cover).

2.3 Evaluation of the soil management practices

In the experimental plots three soil management practices commonly adopted in hilly olive groves of the Mediterranean areas were simulated and their hydrological effects were measured and compared. Conventional tillage (hereafter CT) and total weed killing through herbicide (hereafter no tillage, NT) were compared with a conservative practice (hereafter crop cover, CC) based on Low Dosage Herbicide Treatments (LDHT).

CT consisted of two to three passes, 10-15 cm deep, with a trough milling machines with subsequent soil compaction, generally starting after the first rain in October to control weeds in the whole plot. NT consisted of maintaining the soil weed-free and bare with 3 to 4 herbicide applications (acid glyphosate at a dose of 2.1 kg a.e. ha^{-1} distributed manually or through a backpack sprayer) per year, mostly concentrated in late autumn (November-December). In CC practice the plots were subjected to two herbicide treatments in October and April (acid glyphosate at a dose of 0.23 kg a.e. ha^{-1} distributed manually or through a backpack sprayer).

For all thesis runoff volumes and sediment concentrations were measured during a 7-year monitoring period (February 2002-December 2008); such values together with calculated soil losses were aggregated at monthly and yearly scales and then averaged among the plots subjected to the same experimental soil management practice (Figure 2).

2.4 Implementation of the RUSLE model

The RUSLE model was implemented at yearly scale in order to verify its prediction capability of soil erosion for the investigated soil management practices.

To calculate the R-factor, a simple equation correlating the erosivity index for the e-th event (R_e, MJ mm ha^{-1} h^{-1}) and the corresponding rainfall height (h_e, mm) was utilized, due to the unavailability of rainfall records at sub-hourly scale in the meteorological database:

$$R_e = \alpha h_e^{\beta}, \tag{1}$$

α and β are empirical coefficients for which the values of 0.18 and 1.59 respectively, calculated for the very close meteorological station of Messina (Bagarello & D'Asaro, 1994), were assumed (Table 1).

The K-factor (0.65 t ha^{-1} per R-factor unit, Table 1) was averaged from K factors established for several soil samples collected within the investigated plots (Figure 2).

Topographic factor values L_iS_i for the i-th plot were calculated by using the following relationship (McCool et al., 1989) (Table 1):

$$L_iS_i = \left(\frac{\lambda_i}{22.13}\right)^{m_i}\left(16.8\ \sin\alpha_i - 0.5\right), \tag{2}$$

where λ_i (m) is the slope length of the i-th plot, α_i is the slope angle (Figure 2); m_i was calculated as follows:

$$m_i = \frac{f_i}{\left(1+f_i\right)} \tag{3}$$

being:

$$f_i = \frac{\sin\alpha_i}{0.0896\ \left(3\ \sin 0.8\ \alpha_i + 0.56\right)}. \tag{4}$$

Because the C-factor changes continuously with cover and residue among cutting operations, the related values need to be established for different periods during the year, according the guidelines of Wischmeier & Smith (1978). Therefore, the monthly C-factors for the three soil management practices (Table 1) were calculated as a function of the plot vegetal coverage (reported for the investigated soil management practices in Table 2) through a regression equation (r^2 = 0.98; n = 6), correlating the C-values - in the range 0.0032-0.45, reported by Bazzoffi (2007) for vegetated or unvegetated olive orchards - to the corresponding per cent vegetal coverage.

RUSLE factor	**Value or range**
Max R_e (MJ mm ha^{-1} h^{-1})	416.96
K (t ha^{-1} h t^{-1} m^{-1} mm^{-1} ha)	0.65
LS (-)	1.0 to 2.45
C (-)	0.01 to 0.40
P (-)	0.6 to 1.0

Table 1. Value or range of RUSLE factors for the experimental plots.

According to the guidelines of Wischmeier & Smith (1978), the P-factor was assumed equal to 0.6 (slope of 9%) or 0.8 (slope of 18%) in occurrence of tillage operations along contour lines for CT; otherwise a value of 1.0 was considered, because no erosion control practice was adopted (Table 1).

Month	**Plot vegetal coverage (%)**		
	CT	*NT*	*CC*
January	25.9	16.7	58,1
February	36.8	21.8	71,3
March	40.9	29.5	82,2
April	52.8	33.0	22,4[1]
May	57.1	34.2	43,4
June	54.5	32.8	45,6
July	48.3	25.6	41,1
August	32.1	19.8	36,9
September	36.5	21.2	44,3
October	49.6	26.7	19,4[1]
November	2.3[1]	9.8[1]	33,9
December	10.8	11.2	47,1

[1] Treatment date

Table 2. Monthly values of plot vegetal coverage for the investigated soil management practices (CT = Conventional Tillage; NT = No Tillage; CC = Crop Cover).

2.5 Evaluation of the RUSLE model

Model performance was evaluated at yearly scale by qualitative and quantitative approaches. The qualitative procedure consisted of visually comparing observed and simulated values. For quantitative evaluation a range of both summary and difference measures were used.

The summary measures utilized were the mean and standard deviation of both observed and simulated values. Given that coefficient of determination (r^2) is an insufficient and often misleading evaluation criterion (Licciardello et al., 2007; Zema et al., 2011), the Nash & Sutcliffe (1970) coefficient of efficiency (E) was also used to assess model efficiency. As suggested by Krause et al. (2005) and Legates & McCabe (1999), E was integrated with the Root Mean Square Error (RMSE), which describes the difference between the observed values and the model predictions in the unit of the variable. The values considered to be optimal for these criteria were 1 for r^2 and E and 0 for RMSE. According to common practice, simulation results are considered good for values of E greater than or equal to 0.75, satisfactory for values of E between 0.75 and 0.36, and unsatisfactory for values below 0.36 (Van Liew & Garbrecht, 2003).

3. Results and discussion

3.1 Evaluation of the soil management practices

The results of the comparison among the hydrologic effects of the three investigated soil management practices (conventional tillage, no tillage and crop cover), typical of Mediterranean hilly olive groves, are reported in this section.

3.1.1 Analysis at yearly scale

There was a clear difference in the runoff volumes yielded in the investigated management practices, with NT having the highest runoff coefficient and CC the lowest. The LDHT (CC practice) produced average surface runoff volumes lower by 28% than CT; conversely, complete removal of vegetal coverage through herbicide (NT) resulted in average runoff volume higher by 28% and 79% than CT or CC respectively. Consequently mean yearly values of the runoff coefficient for CC (10.7%) were appreciably lower than those recorded for CT (15.0%) and NT (19.4%) practices (Table 3).

The differences among the soil management practices in the average yearly runoff coefficients measured in this study are basically coherent with those measured in other investigations available in literature. Raglione et al. (1999) reported runoff coefficients of 3.5 and 12.8% for CC and CT respectively in Calabria (southern Italy). Bruggeman et al. (2005) measured average runoff of 184 and 66.5 mm year^{-1} for orchards under CT and CC, respectively, in Syria, in an area with an average yearly precipitation of 400 mm year^{-1}. Francia et al. (2006) measured, in a loamy soil on a 30% slope, higher runoff coefficients in the treatment under NT (5.3%) and lower values for CT and CC (1.5 and 2.7%) respectively. Gomez & Giraldez (2007), in a sandy-loam soil on a 11% slope, measured runoff coefficients of 20 and 5.7% for CT and CC respectively. More recently, in Andalusia (Spain) Gomez et al. (2009b) in a 4-year experiment carried out in an olive tree farm on a sandy-loam soil found runoff coefficients of 6 and 16% for CC and CT practices respectively; in the same environment, Gomez et al. (2009c) recorded during a 7-year experiment in a young olive grove installed on a heavy clay soil the highest average yearly runoff coefficient (11.9%) for NT, which decreased to 1.2% for CC and to 3.1% for CT.

Sediment concentration in collected runoff samples was lower for plots subjected to LDHT (54% less than in CT plots) and higher for NT treatment (18% higher than CT) (Table 3).

The advantages induced by application of low doses of herbicide (CC) were particularly remarkably in terms of soil loss, decreased in this soil management practice by 57% and 71% with respect to CT and NT (Table 3). As well known, the soil loss depends not only on the runoff generation, but also on the sediment concentration of the water stream; both were greater under CT and NT treatments, which left for some periods along the year the soil unprotected and then exposed to the erosion risk. The records of the yearly soil losses for the three experimental soil management practices show a large inter-annual variability, with average values of 28.8 t ha^{-1} year^{-1} (with a standard deviation of 34.1 t ha^{-1} year^{-1}) in the CT practice and 42.2 t ha^{-1} year^{-1} (± 50.0 t ha^{-1} year^{-1}) under NT with the lowest average value recorded for CC (12.3 ± 14.7 t ha^{-1} year^{-1}) (Table 3).

In all the observation years CC practice allowed to achieve soil losses very close to the tolerable value of 11-12 t ha^{-1} year^{-1} suggested by several Authors (e.g. Montgomery, 2007; Stone et al., 2000); conversely under CT and NT treatments such a threshold was always exceeded (Table 3).

A comparison between the yearly soil losses measured during the 7-year monitoring period of the present study and the values reported by other Authors in experimental runoff plots to evaluate soil erosion in olive groves has been carried out; the main results are reported in Table 4.

Kosmas et al. (1996) measured soil losses between 0 and 0.03 t ha^{-1} year^{-1}in semi-natural olive groves in Greece with 90% of the soil covered by vegetation. Raglione et al. (1999) measured in Calabria total soil losses of 0.36 and 41 t ha^{-1} year^{-1} for CC and CT respectively in a 2-year plot experiment. In Syria Bruggeman et al. (2005) measured average soil losses of 11.2 and 41.4 t ha^{-1} year^{-1} in orchards under CC and CT respectively in an area with a slope of 24% for a 4-year period. Gomez et al. (2004) reported average soil losses of 4.0, 8.5 and

Year	**Rainfall (mm)**	**Cumulated surface runoff (mm)**			**Runoff coefficient (%)**		
		CT	**NT**	**CC**	**CT**	**NT**	**CC**
2002[1]	689.2	105.8	155.2	86.0	15.4	22.5	12.5
2003	843.3	136.5	180.2	103.2	16.2	21.4	12.2
2004	522.2	72.5	105.6	52.4	13.9	20.2	10.0
2005	690.4	113.4	120.6	76.4	16.4	17.5	11.1
2006	521.4	71.0	89.0	47.5	13.6	17.1	9.1
2007	690.4	113.4	120.6	76.4	16.4	17.5	11.1
2008	622.0	82.2	120.6	56.2	13.2	19.4	9.0
Cumulated	*4578.9*	*694.7*	*891.8*	*498.1*	-		
Mean[2]	*654.1*	*99.2*^{a}	*127.4*^{a}	*71.2*^{b}	*15.0*^{a}	*19.4*^{b}	*10.7*^{c}

(a)

Year	**Rainfall (mm)**	**Mean sediment concentration (g l^{-1})**			**Cumulated soil loss (t ha^{-1})**		
		CT	**NT**	**CC**	**CT**	**NT**	**CC**
2002[1]	689.2	14.1	12.4	3.7	28.4	47.2	8.8
2003	843.3	6.0	5.6	3.6	40.9	52.9	17.3
2004	522.2	6.4	6.5	5.7	19.0	28.4	10.1
2005	690.4	6.7	8.1	4.4	32.2	44.6	14.8
2006	521.4	14.9	12.6	5.7	18.2	29.5	6.8
2007	690.4	6.3	8.4	4.7	32.2	44.6	14.8
2008	622.0	7.9	19.7	1.1	30.2	48.3	13.3
Cumulated	*4578.9*	-			*201.3*	*295.4*	*86.0*
Mean[2]	*654.1*	*8.9*^{a}	*10.5*^{a}	*4.1*^{b}	*28.8*^{a}	*42.2*^{b}	*12.3*^{c}

(b)

[1] February-December

[2] Values followed by the same letter are not significantly different at $P < 0.05$.

Table 3. a, b. Yearly values of the hydrological observations for the investigated soil management practices (CT = Conventional Tillage; NT = No Tillage; CC = Crop Cover) in the experimental plots.

1.2 t ha^{-1} year^{-1} from CT, NT and CC in a 3-year experiment on a heavy clay soil in Andalusia. In a 2-year study carried out n the same region, Francia et al. (2006) measured soil losses of 5.7, 25.6 and 2.1 t ha^{-1} from CT, NT and CC respectively. Also in Andalusia, Gomez & Giraldez (2007) reported average soil losses of 21.5 and 0.4 t ha^{-1} year^{-1} for CT and CC in a different 4-year experiment. More recently, Gomez et al. (2009c) in a 7-year study reported soil losses of 2.9 t ha^{-1} year^{-1} for CT, 6.9 t ha^{-1} year^{-1} for NT and 0.8 t ha^{-1} year^{-1} for CC in a young olive grove installed on a heavy clay soil of Andalusia; in the same environment, Gomez et al. (2009b) in a 4-year experiment carried out in an olive tree farm on a sandy-loam soil recorded soil losses of 1.9 and 0.4 t ha^{-1} year^{-1} for CT and CC treatments respectively. Average soil losses measured in our experimental plots subjected to CT management practice (28.8 t ha^{-1} year^{-1}) are coherent with the studies by Raglione et al. (1999), Bruggeman et al. (2005) and Gomez & Giraldez (2007), but generally higher than the observations reported in the other investigations (Francia et al., 2006; Gomez et al., 2004; Gomez et al., 2009b, 2009c). Also soil losses observed in the present study for NT and CC soil management practices (42.2 and 12.3 t ha^{-1} year^{-1} respectively) were generally higher than the observations found in the mentioned studies, except for data reported by Bruggeman et al. (2005) for CC, which are very close to the value achieved in the present study (Table 3). Even though the comparison of these values must be made with care due to relevant variability in the experimental climatic, morphological and management conditions among the examined studies and the limited duration of many of these databases (at most 4 years), the magnitude of the soil losses achieved in the present study highlighted the severity of the erosion phenomena in the experimental conditions and, as a consequence, the need of countermeasures to control and mitigate the erosive risks.

Study area	**Authors**	**Soil losses (t ha^{-1} year^{-1})**		
		CT	**NT**	**CC**
Calabria, Italy	Present study	28.8	42.2	12.3
	Raglione et al. (1999)	41.0	-	0.36
Andalusia, Spain	Gomez et al. (2004)	4.0	8.5	1.2
	Francia et al. (2006)	5.7	25.6	2.1
	Gomez & Giraldez (2007)	21.5	-	0.4
	Gomez et al. (2009b)	1.9	-	0.4
	Gomez et al. (2009c)	2.9	6.9	0.8
Syria	Bruggeman et al. (2005)	41.4	-	11.2
Greece	Kosmas et al. (1996)	0 to 0.03		

Table 4. Soil losses in experimental plots to evaluate soil erosion in olive groves reported in the available literature.

3.1.2 Analysis at monthly scale

Figures 3 a, b and c illustrate the values (aggregated or averaged for 3-month periods) of surface runoff, sediment concentration and soil loss achieved in the experimental plots during the monitoring period. It is evident the remarkable reduction of all the hydrological variables recorded in the plots subjected to LDHT in comparison with the other soil management practices (and particularly with NT treatment). Gomez et al. (2009c) remarked a general reduction of runoff for all the hydrological variables along the monitoring period as the experiment progressed, contrary to what found in our experimental plots.

The analysis made at monthly scale highlighted that runoff was mainly concentrated from October to March, i.e. in the months characterized by the highest rainfalls and when the soil was moist after the dry season.

Month	Rainfall (mm)	Surface runoff (mm)			Runoff coefficient (%)		
		CT	NT	CC	CT	CT	CT
January[1]	47.3	8.2	10.8	6.7	17.3	22.9	14.3
February	47.5	7.4	9.8	6.0	15.7	20.7	12.7
March	60.7	8.8	11.7	6.9	14.5	19.2	11.4
April	46.7	6.0	7.7	5.0	12.9	16.5	10.8
May	31.5	3.7	4.5	2.7	11.8	14.4	8.7
June	22.6	1.3	1.7	0.9	5.8	7.6	3.9
July	20.7	1.3	2.6	1.2	6.4	12.4	5.7
August	15.3	0.2	0.6	0.1	1.1	4.0	0.7
September	52.2	5.3	8.4	3.6	10.1	16.2	6.9
October	77.7	13.9	16.6	9.1	17.9	21.3	11.7
November	69.0	12.6	15.3	9.5	18.3	22.2	13.7
December	128.1	26.4	35.2	18.3	20.6	27.5	14.2

(a)

Month	Rainfall (mm)	Sediment concentration (g l^{-1})			Soil loss (t ha^{-1})		
		CT	NT	CC	CT	NT	CC
January[1]	47.3	9.3	28.5	2.3	2.1	3.3	1.0
February	47.5	11.1	14.5	8.3	2.7	4.5	1.2
March	60.7	8.2	7.9	2.5	2.7	3.4	1.0
April	46.7	7.8	8.8	3.7	2.1	2.8	0.9
May	31.5	7.8	9.2	2.2	1.6	2.2	0.4
June	22.6	2.1	2.3	1.5	0.7	0.9	0.3
July	20.7	9.61	5.0	1.3	1.5	1.9	0.2
August	15.3	16.4	11.5	4.3	0.2	0.3	0.1
September	52.2	7.2	6.2	4.2	1.7	2.5	0.7
October	77.7	5.6	5.9	2.6	3.3	4.6	1.5
November	69.0	5.5	6.7	3.3	2.4	3.8	1.1
December	128.1	5.3	6.6	3.1	5.5	8.3	2.5

(b)

[1] The mean values of January are calculated for the years 2003-2008

Table 5 a, b. Mean monthly values of the hydrological observations for the investigated soil management practices (CT = Conventional Tillage; NT = No Tillage; CC = Crop Cover) in the experimental plots.

Soil losses recorded under CC were systematically lower than under other soil management practices, particularly in the late autumn-winter-early spring (up to 60% and 72% less than CT and NT treatments respectively), when rainfall erosivity was higher; this is attributable to the reduction of both surface runoff and sediment concentration, linked to the higher vegetal coverage (in the range 33.9-82.2% of the plot area, Table 2), which helped to reduce soil erosion. In fact, the herbicide application at low doses assured the survival of some spontaneous species (represented mainly by *Crepis versicaria, Reichardia picroides, Inula viscosa, Salvia verbenacea, Oxalis pescapre, Arundo donax, Cynodon dactylon, Hedysarum coronarium, Foeniculum vulgare* and *Verbascum simatum*) and the presence of

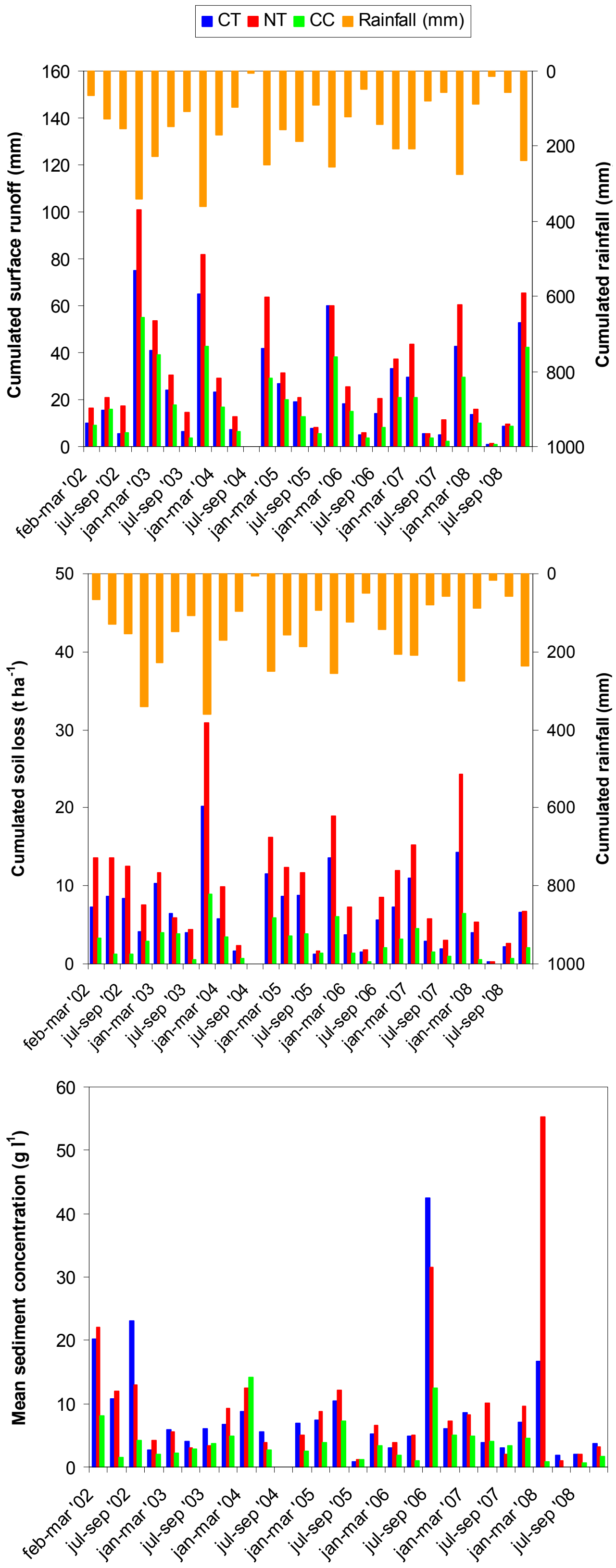

Fig. 3. a, b, c. 3-month values of the hydrological observations for the investigated soil management practices (CT = Conventional Tillage; NT = No Tillage; CC = Crop Cover) in the experimental plots.

biomass residues (consisting of the depressed species laid on the soil) during the wettest months, shielding wide portions of soil from the erosive impact of rainfall. Conversely, total weed killing through herbicide (NT treatment), which destroyed crop residues, exposed the bare soil to the rainfall erosivity and thus to the erosion risks. In the summer months, characterized by low values of rainfall erosivity, the decay effects of weeds due to LDHT remarked since April helped to reduce competition for water between weeds and crop trees.

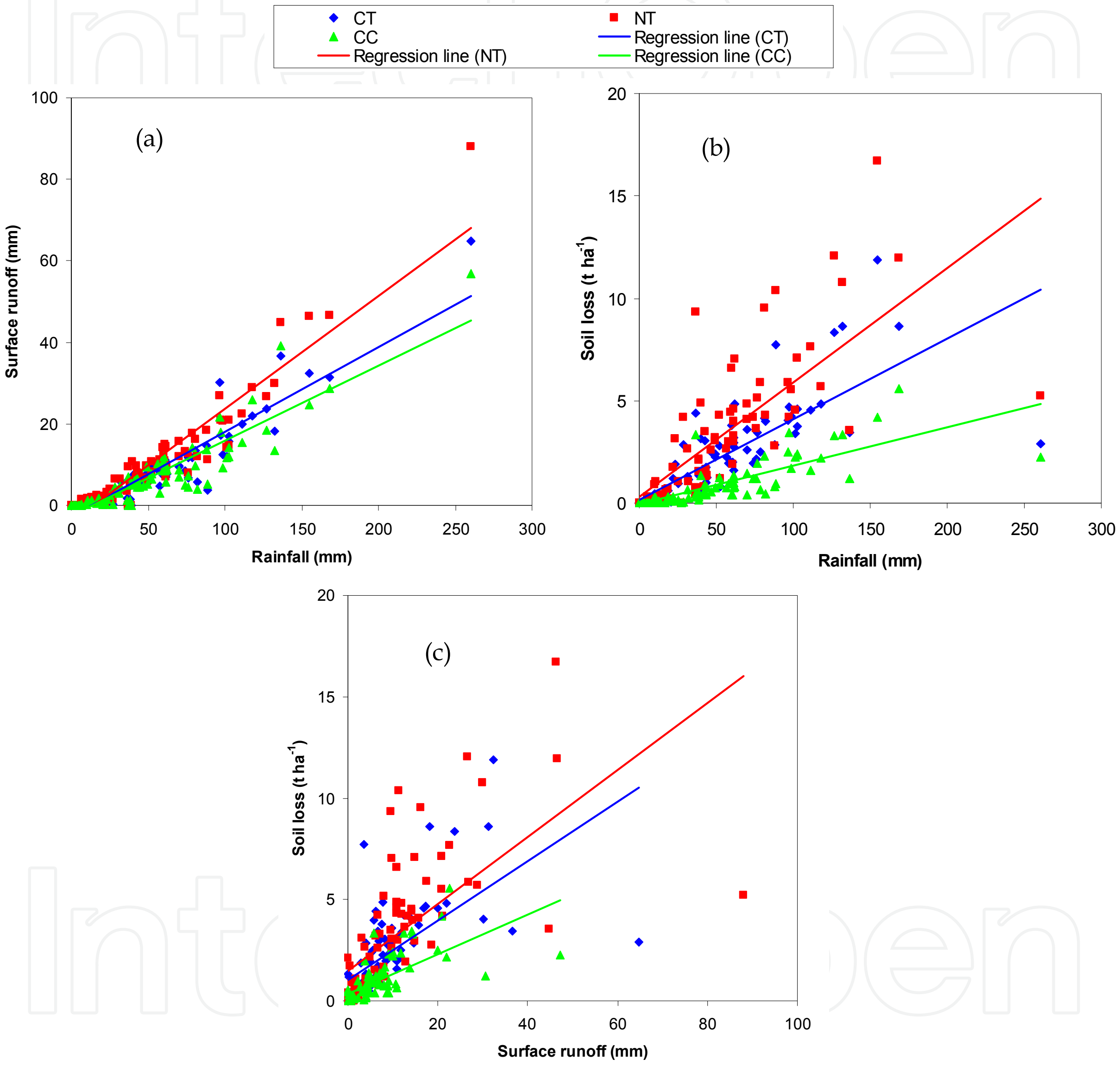

Fig. 4. a, b, c. Linear regressions among monthly hydrological observations for the investigated soil management practices (CT = Conventional Tillage; NT = No Tillage; CC = Crop Cover) in the experimental plots.

The highest reduction of soil erosion was recorded for CC in December (which is characterized by the highest mean rainfall amount), when a soil loss lower by over 55% than in the other soil management practices was achieved (Table 5).

As expected, monthly runoff volumes were well correlated with the corresponding rainfalls (r^2 always higher than 0.83, with the maximum value of 0.89 achieved for NT treatment).

Lower values ($r^2 = 0.58\text{-}0.62$) were found in the regression relationships between monthly rainfall and soil loss. Finally the latter was weakly correlated with the corresponding runoff ($r^2 = 0.41\text{-}0.47$, Table 6), highlighting that sediment losses generally did not follow the same patterns as runoff volumes (Figure 4).

On the whole, LDHT led to average soil losses lower by about 60-70% than in the other soil management practices investigated in the present study. Reduced soil losses depended not only on the lower runoff volumes (presumably due to the increased interception induced by the wider vegetal cover, to the higher soil infiltration capacity and to the greater flow resistance linked to the presence of vegetation stems, which helps to dissipate water stream energy), but also on the lower sediment concentration (Tables 2 and 5). These positive effects seem to influence erosion rates more efficiently than CT treatment, which in its turn increases the water retention within surface hollows left by tillage (due to the increased soil roughness) or infiltration capacity induced by the higher soil surface porosity in comparison with NT treatment.

Soil management practice	**Runoff-rainfall**	**Soil loss-rainfall**	**Soil loss-runoff**
CT	0.87	0.60	0.41
NT	0.89	0.58	0.43
CC	0.83	0.62	0.47

Table 6. Coefficients of linear regression among monthly hydrological observations for the investigated soil management practices (CT = Conventional Tillage; NT = No Tillage; CC = Crop Cover) in the experimental plots.

The results of the present study are consistent with the other similar experiences aiming at evaluating the effects of some management practices on soil erosion: such studies in general suggest to adopt CC practice in olive groves, which, establishing a proper vegetal coverage of the soil in olive grove lanes, thus reduces runoff volumes and, as a consequence, soil losses more efficiently than the most common CT treatment. No tillage should be avoided, due to the fact that keeping the soil bare by herbicide application just in the months characterized by the highest rainfall erosivity (i.e. in late autumn, early spring or during the winter) reduces soil infiltration capacity and roughness, increasing water runoff and stream velocity as well as yielding the maximum erosion rates.

3.2 Evaluation of the RUSLE model

The comparison among the soil losses measured in the experimental plots and the corresponding values predicted by the RUSLE model highlighted an unsatisfactory prediction capability at yearly scale. It is shown by the low coefficients of determination and efficiency as well as the high RMSE; also the differences between the measured and predicted standard deviations were high (Tables 7 and 8; Figure 5). The RUSLE model tended to overestimate soil losses for CT and, particularly, CC; on the contrary, soil losses measured for NT soil management practice were slightly underestimated (Figure 5).

For two (CT and NT) of the three simulated soil management practices the mean values of the predicted soil losses were close to the corresponding measured values with differences lower than 7%; also the differences between the measured and predicted cumulated soil losses, calculated for the entire 7-year monitoring period (201.3 versus 211.9 t ha^{-1} year^{-1} for CT treatment and 295.4 versus 273.8 t ha^{-1} year^{-1} for NT), were low. For CC soil management practice mean and total soil losses measured in the experimental plots and predicted by the RUSLE model differed instead by about 75-80% (Table 7). It means that, at least for the experimental conditions, estimations of soil losses performed by the RUSLE model must be considered with care, due to the fact that RUSLE is mainly meant to be used for long-term estimates of soil loss (Shrestha et al., 2006; Yoder et al., 2001).

Year	**Soil loss (t ha^{-1} year^{-1})**					
	Measured			**Predicted**		
	CT	**NT**	**CC**	**CT**	**NT**	**CC**
2002	28.4	47.2	8.8	42.4	66.2	21.4
2003	40.9	52.9	17.3	56.1	61.0	37.3
2004	19.0	28.4	10.1	30.1	37.6	11.0
2005	32.2	44.6	14.8	24.7	29.9	25.2
2006	18.2	29.5	6.8	18.8	25.6	15.3
2007	32.2	44.6	14.8	18.2	27.5	20.8
2008	30.2	48.3	13.3	21.6	26.0	19.1
Cumulated	*201.3*	*295.4*	*85.9*	*211.9*	*273.8*	*150.1*

Table 7. Yearly and cumulated values of soil losses measured in the experimental plots and predicted by the RUSLE model for the investigated soil management practices (CT = Conventional Tillage; NT = No Tillage; CC = Crop Cover).

Soil management practice	**Soil loss**	**Mean (t ha^{-1} year^{-1})**	**Std. Dev. (t ha^{-1} year^{-1})**	**r^2**	**E**	**RMSE (t ha^{-1} year^{-1})**
CT	*Measured*	28.8	8.0	0.26	-1.11	10.70
	Predicted	30.6	13.1			
NT	*Measured*	42.2	9.5	0.14	-1.27	13.25
	Predicted	39.9	14.5			
CC	*Measured*	12.3	3.8	0.57	-10.04	11.65
	Predicted	22.0	9.3			

Table 8. Statistics, efficiency and difference indexes of the RUSLE model at yearly scale for the investigated soil management practices (CT = Conventional Tillage; NT = No Tillage; CC = Crop Cover) in the experimental plots.

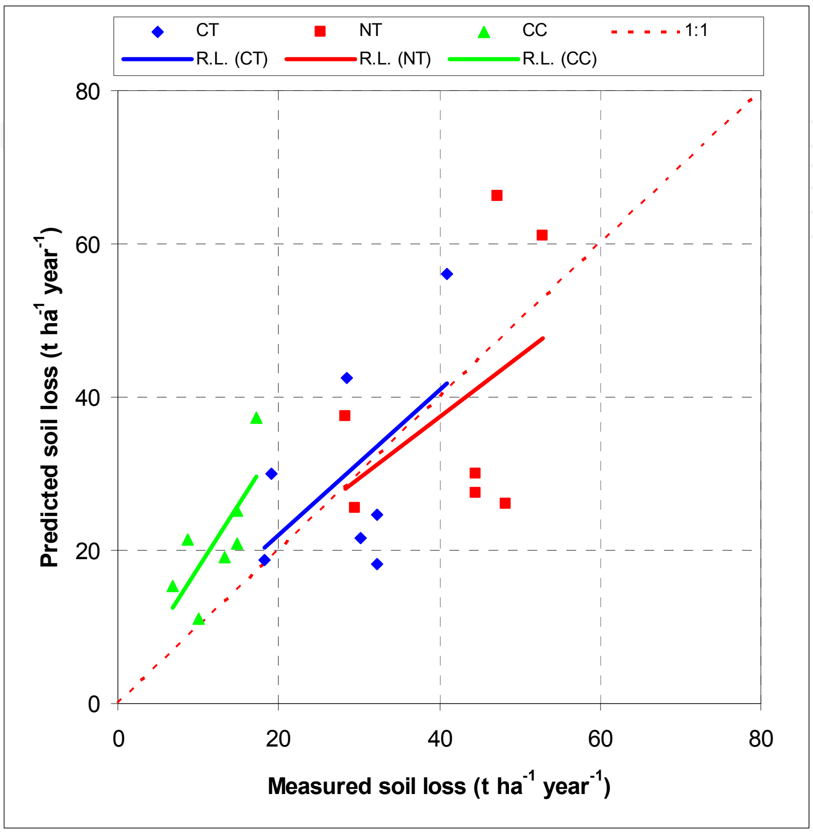

Fig. 5. Comparison between soil loss measured in the experimental plots and predicted at yearly scale by the RUSLE model for the investigated soil management practices (CT = Conventional Tillage; NT = No Tillage; CC = Crop Cover) (R.L. indicates the regression lines).

It can not be excluded that the unsatisfactory prediction capability of soil loss shown at yearly scale by the RUSLE model for the experimental plots can be attributable to:

- the unavailability of rainfall records at sub-hourly scale in the meteorological database, which, as mentioned above, forced the modeler to turn to an empiric regression equation for calculating RUSLE R-factors;
- the uncertainty of the calculated values of the C-factor (which is perhaps the most important USLE factor, because it represents conditions that can be managed most easily to reduce erosion, Ferreira et al., 1995; Renard et al., 1991; Renard & Ferreira, 1993; Yoder et al., 2001); it comes from the fact that the available soil management database lacked some important parameters (e.g. surface roughness and soil moisture) which can strongly influence soil loss estimation performed through the RUSLE model.

4. Conclusions

The present investigation has evaluated and simulated at plot scale the hydrological effects of three different soil management practices (conventional tillage, no tillage and crop cover through LDHT), commonly adopted in hilly olive groves of the Mediterranean environment. Although the monitoring of the erosion risk carried out in this paper is based on only 7 years of data and therefore results may change over a longer time period, the findings of this investigation highlight that, under the experimental conditions, the soil losses recorded for CT and NT practices are of high magnitude and thus unsustainable to avoid land degradation. Conversely, although the erosion rates achieved for CC practice in this study are generally higher than the observations reported by other Authors, LDHT, allowing to keep soil losses close to the tolerable value of 11-12 t ha^{-1} $year^{-1}$ suggested by some Authors (e.g. Montgomery, 2007; Stone et al., 2000), results in a more efficient conservation practice in comparison to CT and NT and represents a valid alternative to these soil conservation practices. As a matter of fact, LDHT, assuring a suitable soil coverage during wet periods and a greater water availability to the olive trees in the dry seasons (thus reducing water competition with weeds), allows to mitigate the erosion risks and avoids negative impacts on crop productivity.

Unfortunately, also farmers operating in southern Italy, as remarked by other Authors (Gomez et al., 2009b; Helling & Haigh, 2002) in their respective countries, are in general reluctant to adopt soil management practices assuring a suitable crop cover and then high hydrological benefits during the wettest months (as LDHT), especially if they do not represent an immediate increase in the crop yield. Gomez (2005, 2009b) argued that the reasons for this reluctance is the need for a careful management of the cover crop to avoid competition for water with the olive tree (which is however basically limited) as well as the lower cost, for many farmers, of tillage (especially surface tillage) in comparison to cover crop soil management. This suggests the need of information activities by experts of soil conservation and farm advisers, purposing at illustrating the environmental benefits of cover crop soil management in olive groves, in particular: (i) immediately after olive planting; (ii) in young olive groves; or even (iii) in mature plantations with a very low tree density (especially in steep lands), where the canopy cover is low and the interception is rather limited. Thus, this kind of investigations may help to improve the countermeasures against soil erosion in Mediterranean slope zones, encouraging farmers to adopt soil conservation practices also through proper criteria of public financial support.

On a modeling approach, the present study has highlighted that the utilization of the RUSLE erosion model under the experimental conditions must be done with care, given that soil loss estimations have been reliable only for CT and NT treatments at a multi-year scale; presumably, a more complete hydrologic and geomorphologic database could improve model predictions.

Even though the outcomes of this study might contribute to soil conservation through sustainable management systems in agricultural lands characterized by high erosion risks, further research activities are finally needed not only to validate these results under different geomorphologic conditions, but also to assure a better understanding of runoff and erosion processes and to predict its effects with time.

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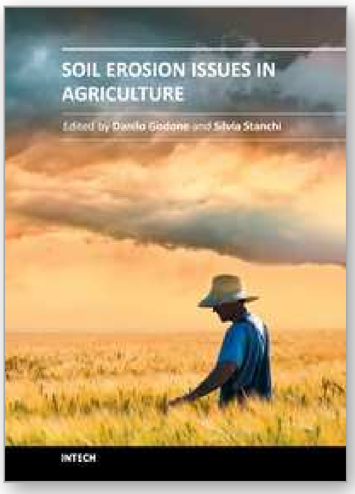

Soil Erosion Issues in Agriculture

Edited by Dr. Danilo Godone

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The book deals with several aspects of soil erosion, focusing on its connection with the agricultural world. Chaptersâ€™ topics are various, ranging from irrigation practices to soil nutrient, land use changes or tillage methodologies. The book is subdivided into fourteen chapters, sorted in four sections, grouping different facets of the topic: introductive case studies, erosion management in vineyards, soil erosion issue in dry environments, and erosion control practices. Certainly, due to the extent of the subject, the book is not a comprehensive collection of soil erosion studies, but it aims to supply a sound set of scientific works, concerning the topic. It analyzes different facets of the issue, with various methodologies, and offers a wide series of case studies, solutions, practices, or suggestions to properly face soil erosion and, moreover, may provide new ideas and starting points for future researches.

Giuseppe Bombino, Vincenzo Tamburino, Demetrio Antonio Zema and Santo Marcello Zimbone (2011). Hydrological Effects of Different Soil Management Practices in Mediterranean Areas, Soil Erosion Issues in Agriculture, Dr. Danilo Godone (Ed.), ISBN: 978-953-307-435-1, InTech, Available from: http://www.intechopen.com/books/soil-erosion-issues-in-agriculture/hydrological-effects-of-different-soil-management-practices-in-mediterranean-areas

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