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Effect of land set up systems on soil losses

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Abstract

Agricultural land set up systems comprise those agronomic structures able to preserve the soil fertility from water erosion, such as: ditching, contouring, earth-riser and stonewall terracing, draining, and channelization, *etc*.. However, in the past 60 years, agricultural mechanization has led to an expansion of the field size and reduction in land set up system intensity to make machine operation more feasible and cheaper. As a consequence, these transformations have made sloping fields less resilient to the storms and accelerated the soil erosion processes. Based on an 8-year field study in '*Chianti Classico*' area (Tuscany, Central Italy), this research aimed to evaluate the effectiveness of the land set up systems such as diversion ditch, earth-riser and stonewall terracing on reducing water erosion from field crops, olive orchards, and vineyards. The results showed that diversion ditches were effective on herbaceous crop fields with slope steepness lower than 9%. While, for higher slopes, diversion ditches were not sufficient to contain the soil loss within OECD 2008 tolerable limits in none of the considered land uses. On the opposite, in steep slopes, earth-riser terraces and stonewall terraces have shown their value as land set up system capable of reducing the erosive process. Their greatest drawback is the reduction of the cultivable surface deriving from the presence of the riser and the walls. However, their added value as a precious element characterizing the local landscape was of considerable importance for the local economy linked to tourism.

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Introduction

Over the centuries the Mediterranean hilly landscape has been shaped by human activity to obtain cultivated surfaces (Agnoletti *et al*., 2015a, 2015b; Cots-Folch *et al*., 2006). The evolution of agricultural land set up system in Italy can be dated back to the Neolithic period (Agnoletti *et al*., 2015a). Until the 18th century, the up and down hill ditching (locally called *rittochino*) was the main land set up system characterizing the Italian hilly territory where the large estate prevailed (Landi, 1989). On large estates, only the best surfaces were used for cultivation, while the inaccessible and degraded areas were destined for grazing or scrub. On the contrary, in the hilly areas where the family farm property prevailed, farmers realized flat surfaces by terracing even on very steep slopes to cultivate field crops in crop rotation (cereals, legumes, fodder, *etc*.) (Landi, 1989; Agnoletti *et al*., 2015a). Following serious famines that occurred in the mid-18th century, a new period of demographic growth occurred, leading to a growing need of food and cultivable soil. The search for new arable land led to the cultivation of steep hilly surfaces and the parallel increased interest in complex agronomic techniques able to preserve the soil fertility from water erosion, such as: ditching, contouring, earth-riser and stonewall terracing, draining and channelization, *etc*. As reported by Agnoletti *et al*. (2015a), this process of landscape evolution had also marked the countryside of Tuscany (central Italy) until the middle of the 20th century, when most of the hilly fields of central Tuscany were made cultivable by means of earth-riser and stonewall terracing. However, economic development in the past 60 years has led to profound social and demographic changes worldwide (MacDonald *et al*., 2000; Stonestrom *et al*., 2009) that reflected in the hilly countryside with depopulation, abandonment of traditional activities, changes of land uses and land cover classes such as the change of crops and crop rotations (Stonestrom *et al*., 2009). These changes also occurred in Tuscany from 1950s, where agricultural mechanization has led to an expansion of the field size and reduction of ditching, terracing, tile draining and channelization to make machine operation more feasible and cheaper, but negatively affecting the drainage effectiveness (Landi, 1989; Napoli and Orlandini, 2015; Napoli *et al*., 2016). As a consequence, these transformations have made sloping fields less resilient to storms and accelerated the soil erosion processes (Borselli *et al*., 2006; Bazzoffi *et al*., 2011, 2016; Tarolli *et al*., 2014). Nowadays, several studies indicated water erosion as one of the most important soil degradation processes, resulting in a reduction of soil fertility and long-term productivity (Lal, 1995; Gunatilake and Vieth, 2000; Ramos and Martínez-Casasnovas, 2006; Pulighe *et al*., 2020). The European governments, increasingly concerned about the issue of soil fertility, have funded several agricultural development plans aiming at the conservation of water resources and limitation of soil erosion, thus linking farmers to the respect of environmental conditions in order to receive the public contribution (Altobelli *et al*., 2019).

However, there is a lack of studies that evaluate the role of the diversion ditch, earth-riser terraces, and stonewall terraces in the reduction of the soil loss. The aim of this study was to evaluate the effectiveness of the land set up systems such as diversion ditch, earth-riser terraces, and stonewall terraces in reducing soil loss by water erosion from different land uses (field crops, olive orchards, vineyards) on two steepness classes (higher and lower than 9%). The study was performed by measuring soil loss over 8 years in 695 cultivated fields within the '*Chianti Classico*' area, one of the most renowned wine producing area of the World.

Materials and methods

Study area and soil descriptions

The study was conducted in the '*Chianti Classico*' area, Tuscany, Italy (WGS84, 11°4′ - 11°33′ E, 43°17′ - 43°42′ N) (Figure 1). A total of eight municipalities comprised the area: Barberino Val d'Elsa, Castellina in Chianti, Castelnuovo Berardenga, Gaiole in Chianti, Greve in Chianti, Radda in Chianti, San Casciano in Val di Pesa, and Tavarnelle Val di Pesa (Napoli *et al*., 2014). The elevation of the area ranged from 72 to 890 m, while the slope from ≈0 to ≈122%. According to our analysis of the soil map of Gardin and Vinci (2016), the most represented soils of the area are: i) sandstone-derived soils with sandy-loam texture (sandy or sandy-skeletal, mixed, mesic, Typic Haploxerept), which characterise the hilly relief of the Chianti Mountains, on the eastern border of the '*Chianti Classico*' area; ii) soils derived from calcareous marl (*alberese*) with clay-loam texture (fine, mixed, mesic Typic Haplustepts), which are present in the central and southern parts of the '*Chianti Classico*' area; iii) soil derived from conglomerates with clay-loam texture (fine□loamy, mixed, mesic Typic Haplustepts), which dominate the San Casciano in Val di Pesa and Barberino Val d'Elsa territories; iv) soils derived from calcareous marl with silty clay loam texture(fine, carbonatic, mesic Typic Calciustepts), which are diffused in the southern Castellina in Chianti hillslopes; v) sandstone-derived soils with sandy loam texture (coarse-loamy, mixed, mesic Typic Haplustepts), which are characteristic of the Castelnuovo Berardenga hills.

Climatic conditions, rainfall height, and erosivity index

The climate was typical of the European Mediterranean area, with relatively cold humid winters characterized by average daily temperature around 4-5°C, and warm dry summers in which the daily maximum temperatures may exceeded 35°C (Napoli *et al*., 2016). The average annual rainfall height (RH) ranged between 700 and 800 mm, with a maximum rainfall period from September to December accounting for 50% of the annual RH. A second rainy period occurs in spring, with a RH maximum up to 60 mm in April. In summer, the area frequently does not experience any rainfall from June to July.

RH data for the period 2005–2012 were provided by the Regional Hydrological Service (SIR, 2019). The RH values were recorded at 15-min intervals from a total of 11 rain gauges (from RG1 to RG11) in or near the study area (Figure 1). According to Wischmeier and Smith (1978), rainfall events with a RH value of more than 13 mm and separated from other rain events by more than 6 hours were considered single storm events (SSE). Then, the rainfall erosivity (EI_{30}, expressed as MJ mm ha^{-1} h^{-1}) was estimated for each SSE over the study period as proposed by Wischmeier and Smith (1978) and averaged on monthly and annual basis. The annual EI_{30} point data were then spatialized in ArcGIS 10.3 by mean of the regularized spline with tension as suggested by Napoli *et al*. (2014, 2016) and Massetti *et al*. (2020).

Field surveys and land set up system parameters

Fields selection was based on the proximity to roads and the permission given by the farm owners. Fields were grouped into three classes according to the cultivations: fields crops, vineyard, and olive orchard. The soil losses associated to four land set up systems were considered: i) level ditches with a distance between successive diversion ditch (DDD) larger than 80 m (DDD>80); ii) level ditches with DDD smaller than 80 m (DDD<80); iii) earth-riser terraces; iv) stonewall terraces. The impact of the land set up systems was evaluated as function of two hillslope steepness classes: lower than 9% and higher than 9%. The distance between successive ditches was selected according to the GAEC Cross-compliance Standard 1.1 (commitment a) (Reg. (EC) No. 1782/2003), which, for the slopes affected by soil erosion, requires the 'Realization of temporary ditches' at distance between them of no more than 80 m.

During field survey, the land set up systems were characterized by measuring some design parameters. For diversion ditches, the survey concerned measuring the ditch cross sections (m^2) and the distance between consecutive ditch along the slope (m). For earth-riser terraces, the parameters measured comprise the height of riser (m), the slope of riser (%), the length of riser (m), the terrace bed width (m), and the percentage of the field area occupied by the risers (%). For stonewall terraces, the design parameters comprised height of the wall (m), terrace bed width (m), and percentage of the field area occupied by the wall (%).

Soil loss measures

Soil loss measurements were carried out over a period of eight years, from 2005 to 2012, in 695 fields. A total of 10 undisturbed soil core samples were collected from each field (once in tree crops and once a year in field crops) to determine the bulk density (ρd) (kg m^{-3}) in the surface layer (0-10 cm). The yearly volume of soil loss (V, m^3 y^{-1}) by water erosion from field cultivated with field crops was determined as indicated by Evans and Boardman (1994). Fields were annually checked for rills and gullies after harvesting. The volume of rills and gullies was calculated by measuring the whole length and the cross-sectional area at 5-10 m intervals.

$$Aa = V \cdot \rho d \cdot FA^{-1} \quad (1)$$

where, Aa was the annual soil losses (kg ha^{-1}) and FA was the field area (ha).

$$SL = \frac{\sum_{i=1}^{8} Aa_i}{8} \quad (2)$$

where, SL was the average annual soil loss value (kg ha^{-1} y^{-1}) and Aa_i was the annual soil losses (kg ha^{-1}) determined in the *i-th* year.

The SL from vineyard and olive orchards was determined according to the method proposed by Napoli *et al*. (2016). Briefly, as suggested by Novara *et al*. (2011), all trees of the same plantation were considered as planted with the same aboveground height of the root collar. Therefore, the erosion and deposition effect may be highlighted by averaging yearly changes in surface level with respect to the root collar (Δh, m y^{-1}). The initial root collar aboveground height (d_i, mm) and number of years from plantation (Δy, y) were provided by the plantation owners. As the trees were planted by hand, a deviation of ±0.01 m was considered for d_i. The exposed aboveground height of the root collar (h_m, m) was measured every 0.20 m along a cross section between two adjacent trees, perpendicularly to the slope, and then averaged (Napoli *et al*., 2016). As significant changes in bulk density can occur in the first years after the initial planting of trees and vines, the surface height could be changes independently of erosion. The average exposed aboveground height of the root collar for the plantation (H_m, m) was calculated by averaging the measured h_m of 10% of the plants present.

Finally, the SL was calculated for each tree plantation as follows (Eq. 3):

$$SL = F \cdot \rho d \cdot (H_m - d_i) \cdot \Delta y^{-1} \quad (3)$$

where F was the conversion constant from meters to Mg per hectare (10 m^3 ha^{-1} m^{-1}).

On stonewall terraced fields, the SL measurements were carried out on 50% of the terrace beds and then averaged over the whole field surface. On earth-riser terraced fields, the SL from the

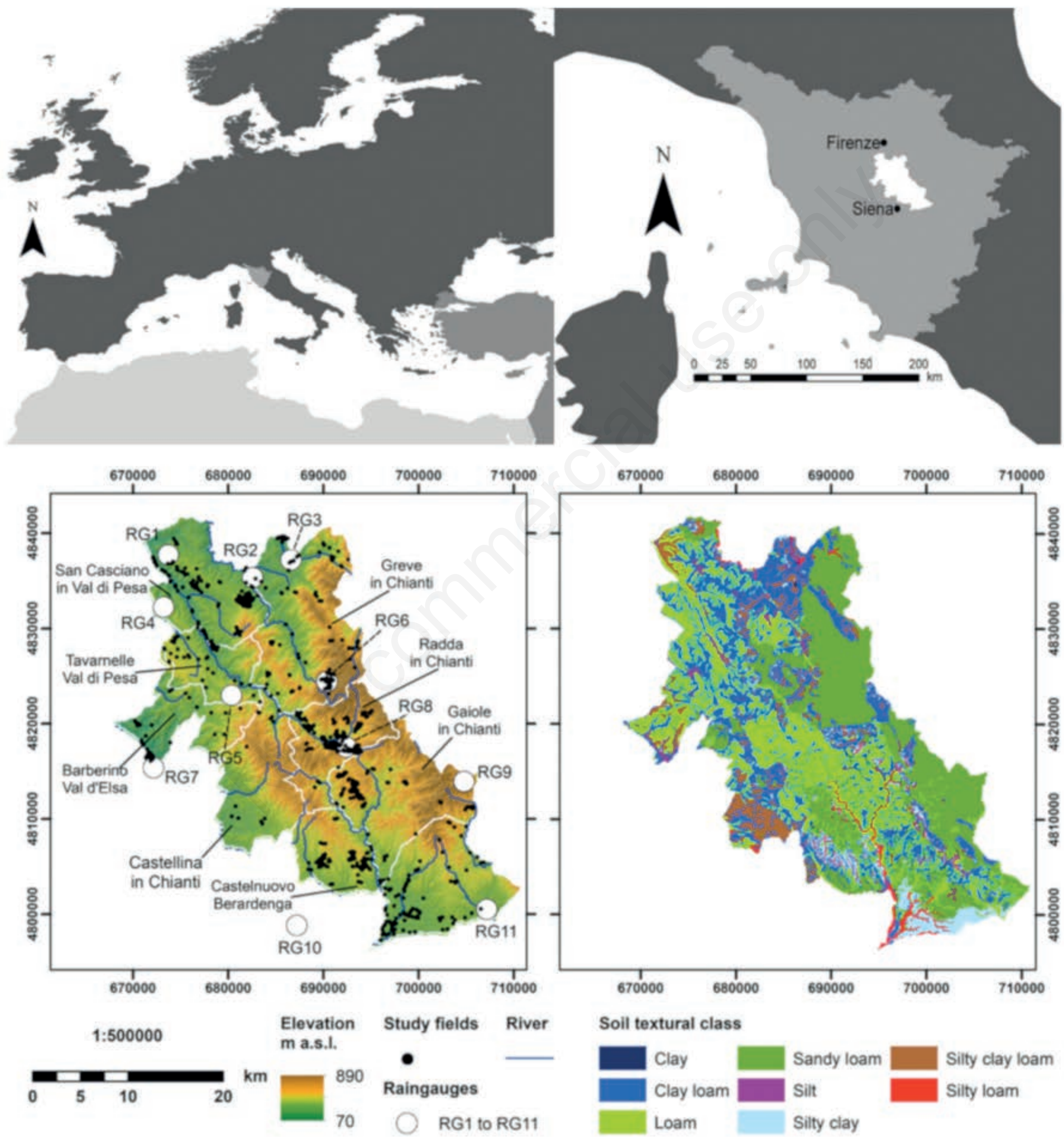

Figure. 1. Maps of the study area. On the top left corner, a map of Europe with highlighted Tuscany. On the top right corner, a map of Tuscany with highlighted '*Chianti Classico*' area. On the bottom left corner, a digital elevation model of the '*Chianti Classico*' area, with administrative boundaries, position of the study fields and rain gauges. On the bottom right corner, map of the soil textural class of the '*Chianti Classico*' area derived from Gardin and Vinci (2016).

field accounted for the soil losses from both the risers and beds. For each terrace the SL was calculated by averaging the SL from the bed and the risers on the basis of their surface. The SL from a riser was calculated using the above mentioned method by Evans and Boardman (1994), while the SL from the beds were measured by using the methods proposed by Evans and Boardman (1994) and Napoli *et al*. (2016) for field crop and tree crops, respectively. The SL measurements were carried out on 50% of both the terraces and then averaged over the whole field surface.

Statistical analysis

The K-W test was applied to check SL difference between land set up system, within the same land use and steepness class, at significance level of P<0.05. Pairwise multiple comparisons for detected significant differences were analysed by applying the Dunn's post-hoc tests with Bonferroni's p value adjustment method. The SL values were also compared with the OECD (2008) tolerable average annual soil loss limit (T: 6 t ha^{-1} y^{-1}) to evaluate the land set up systems effectiveness in reducing the soil losses.

Significant difference in the mean of monthly and annual RH and R between the meteorological stations were analysed by means of the Kruskal–Wallis (K-W) test, at a significance level P<0.05.

Results and discussion

Distribution of rainfall height and erosivity during the study period

According to the Kruskal-Wallis test, no significant differences in measured RH were detected between the 11 rain gauges on monthly and annual basis (Table 1).

The analysis of rain gauges data indicated that the annual average RH value in the study area was 819.0 (82.6) mm, ranging between 546.8 (45.9) mm and 1230.1 (123.9) mm in 2011 and 2010, respectively. At a spatial scale, the annual average RH value ranged between 695.2 (200.1) mm to 1000.6 (267.2) mm, registered at RG1 and RG6, respectively. Excluding data for the months without rain, the monthly RH ranged from 0.3 mm in July 2007 to 248.0 mm in November 2010. The highest average monthly RH values were recorded in November, with values ranging between 106.8 (80.6) and 148.6 (98.1) mm at RG1 and RG6, respectively, while the average monthly RH values were recorded in July, with values ranging between 17.7 (20.6) and 38.5 (24.2) mm at RG4 and RG6, respectively. No significant differences in EI_{30} were detected between all the rain gauges both on monthly and annual

Table 1. Monthly and yearly average rainfall height (RH) and average EI30 calculated over the study period, from 2005 to 2012.

	RG1	RG2	RG3	RG4	RG5	RG6	RG7	RG8	RG9	RG10	RG11
					Average RH (mm)						
Jan	53.1 (39.9)	56.7 (49.9)	53.9 (45.3)	61.4 (46.5)	58.3 (55.5)	77.4 (64)	59.2 (51.8)	68.8 (62.5)	73.2 (63.9)	56.9 (42.8)	53.8 (45.4)
Feb	54.5 (30.8)	58.9 (27.5)	54.9 (23.8)	62.1 (33.1)	57.2 (29.9)	70 (34.6)	54.1 (24.9)	65 (32.9)	61.7 (32.5)	55.1 (27.2)	47.9 (30.4)
Mar	59.6 (41.5)	58.4 (33.8)	56.6 (32)	65.8 (40.1)	62.4 (30.9)	78.7 (43)	60.2 (26.6)	72.7 (36.9)	64.2 (33.6)	62.3 (37.9)	76.6 (75.2)
Apr	51.7 (35.5)	54.8 (34)	52 (35.8)	59.6 (42)	57.8 (39.4)	72.8 (44.3)	53.2 (36.5)	66.8 (40.6)	63 (47.2)	55.6 (38.7)	61 (53.1)
May	46.4 (30.8)	67.7 (48.3)	69.8 (54.2)	68.3 (48)	68.7 (44.6)	80.4 (52.6)	65.8 (41)	76.9 (48.3)	64.5 (46.4)	53 (31.8)	41.6 (38.9)
Jun	34.5 (23.9)	49.2 (26)	53.2 (31.6)	54.6 (37)	57.5 (22.2)	59.2 (34.6)	62.1 (45.4)	57.4 (44.4)	52.7 (37.3)	45.1 (34)	40.3 (40.8)
Jul	24.2 (22.8)	34.9 (36)	37.4 (36.4)	17.7 (20.6)	18.8 (14.8)	38.5 (24.2)	37.6 (28.3)	30.4 (25.7)	30.3 (27.8)	27.5 (22)	37.9 (48.9)
Aug	44.8 (34.8)	55.2 (48.2)	56.1 (47.3)	44.3 (32.2)	36.1 (30.3)	43.2 (39.6)	33.1 (31.4)	52.9 (50)	35.4 (18.9)	32.7 (22.5)	21.4 (13.5)
Sep	74 (41.6)	70.1 (40.9)	69.7 (38.8)	81.8 (50.8)	76.2 (42.3)	93.1 (51.6)	83.3 (42.5)	82.8 (42.6)	84.9 (31.1)	74.5 (41.2)	74.2 (47)
Oct	68 (39.1)	77.4 (40.7)	82.3 (57.7)	80 (48.6)	81.8 (39.7)	108 (62)	77.8 (25.7)	88.8 (49.1)	84.2 (40.7)	85.1 (61.7)	89.9 (55.1)
Nov	106.8 (80.6)	120.8 (82.9)	112.9 (85)	128.2 (83.3)	127.4 (84.3)	148.6 (98.1)	118.6 (76.9)	132.3 (90.2)	134.7 (104.4)	115.5 (87)	124.6 (103.5)
Dec	77.6 (29.5)	102.2 (40.8)	97.4 (39.8)	107.9 (39)	99.4 (43.3)	130.7 (57.6)	96.3 (36.1)	116.5 (48.6)	109.4 (53.9)	90.9 (59.1)	84.8 (50.2)
Year	695.2 (200.1)	806.3 (214.1)	796 (215.3)	831.5 (245.2)	801.3 (246.5)	1000.6 (267.2)	801.2 (220.2)	911.1 (264.2)	858 (245.2)	754.1 (251.1)	754 (266.7)
					Average EI_{30} (MJ mm ha^{-1} h^{-1})						
Jan	19.9 (31.3)	24 (34.7)	18.1 (32.7)	23.9 (35.8)	26.4 (38.5)	33.9 (50.4)	25.1 (36.6)	30.9 (46.5)	32.6 (46.6)	22.3 (34.7)	17.9 (39.5)
Feb	38.6 (45.2)	27.6 (43.8)	29.8 (33.8)	44.2 (55.6)	38.1 (44.5)	64 (59.2)	30.2 (36.9)	49.2 (60.7)	46.2 (49.2)	37.1 (39.1)	31.1 (34.9)
Mar	45.2 (64.9)	40.9 (45)	38.6 (38.5)	54.7 (57.5)	45.9 (38.2)	71.8 (62.3)	41.5 (32.1)	60 (58.5)	48.1 (38.6)	44.3 (55.5)	93 (160.9)
Apr	75.4 (88.5)	83.3 (85.9)	74.3 (93)	105.2 (127.5)	82.4 (117.4)	153.7 (172.6)	81.7 (86.1)	114.1 (153)	132.9 (142.1)	85 (111.9)	129.4 (199.1)
May	57.3 (60.5)	110.2 (158.1)	119.6 (172.4)	125.8 (120)	115.5 (126.9)	155.3 (160.2)	103.6 (109.5)	139 (144.5)	111.2 (119.4)	74.5 (64.7)	49.1 (90.9)
Jun	45.1 (69.8)	93.1 (84.5)	129.1 (144.1)	139.8 (192.4)	125.5 (97.1)	149.3 (182.9)	195.4 (252.3)	172.3 (287.6)	142.4 (191)	104 (128.7)	96.5 (180.3)
Jul	55.9 (71.7)	24.9 (52.8)	19.3 (54.6)	44.2 (67)	48.4 (66.3)	58.9 (52.1)	23.9 (35.7)	21.4 (30.8)	37.7 (40.3)	51.6 (56.9)	25.9 (39.8)
Aug	222.9 (203.3)	309.6 (353.5)	304 (332.3)	220.7 (200.6)	157.1 (186.8)	167 (277.6)	149.4 (183.7)	246.9 (377)	103.7 (125.5)	118.3 (152.9)	84.6 (84)
Sep	228.8 (217.2)	213.8 (195.7)	217.3 (212)	250.1 (221)	235 (225.5)	281.5 (223.9)	267.7 (226)	253.9 (225.7)	268.9 (196.7)	235.6 (200.8)	225.4 (203.2)
Oct	170.1 (278.1)	190.2 (271.1)	205.9 (287.8)	196.7 (291.2)	199.8 (255.1)	274.2 (338.3)	186.6 (251.8)	220.2 (280.6)	205.8 (273.1)	219.2 (264.5)	218.4 (223.9)
Nov	155.1 (140.3)	174.7 (152.9)	152.9 (165.6)	193.6 (151.9)	186 (159.2)	238 (184.6)	165.8 (142.8)	204.3 (167.6)	211 (202)	169 (158.2)	196.4 (186.6)
Dec	56.6 (51.5)	122.8 (75)	107.6 (61.2)	138.4 (87)	119.6 (97.4)	260.9 (200.8)	96.5 (73)	183.9 (164.8)	172.2 (195.5)	133.3 (242.8)	82.7 (81.1)
Year	1171 (599.4)	1415.1 (665.9)	1416.4 (697)	1537.3 (656)	1379.6 (752)	1908.5 (835)	1367.3 (709.1)	1696 (906.1)	1512.7 (729.6)	1294 (637.3)	1250.2 (616.3)

Standard error for monthly average RH and EI30 values are reported in brackets.

basis. The average annual cumulated EI_{30} value was 1449.8 (209.4) MJ mm ha^{-1} h^{-1}, ranging between 752.0 (368.3) and 2595.2 (509.1) MJ mm ha^{-1} h^{-1} in 2010 and 2005, respectively. The annual average EI_{30} value ranged between 1171.0 (599.4) and 1696.0 (906.1) MJ mm ha^{-1} h^{-1}, registered at RG1 and RG6, respectively. Results indicated that monthly cumulated EI_{30} was irregularly distributed throughout each year and among the years. About 57% of the average annual EI_{30} was registered between August and November, with the largest share in annual average EI_{30} values occurring in September (16.7% of the average annual EI_{30}). The highest average monthly EI_{30} values were recorded in September, with values ranging between 217.3 (212) and 281.5 (223.9) MJ mm ha^{-1} h^{-1} at RG3 and RG6, respectively, while the lowest average monthly EI_{30} values were recorded January, with values ranging between 17.9 (39.5) and 33.9 (50.4) MJ mm ha^{-1} h^{-1} at RG11 and RG6, respectively. The results indicated lower EI_{30} values in the north-west and south-east of the study area than those found in the Chianti Mountains area located along the eastern border. Considering all the rain gauges, the average EI_{30} value was consistent with those calculated in the same study area by Diodato and Bellocchi (2010) and Napoli *et al*. (2016) during the periods 1997–2005 and 1996-2010, respectively.

Land set up systems design

The main characteristics of the diversion ditches are reported in Table 2. Field crops were equally found on both steepness classes (Table 2). While the number of fields with DDD<80 was higher than that with DDD>80 for hillslope steepness lower than 9%, the opposite was found on higher slopes. In fact, on steep slopes, as the distance between diversion ditch increased, local farmers commonly create several ephemeral level ditches within the fields to collect runoff. Results indicated that within the same steepness class, the average slope was quite similar for both DDD>80 and DDD<80. Within the same land set up system, small differences were observed in the average length between steepness classes. Contrary to what is observed for field crops, olive groves and vineyards were characterized by hillslope steepness higher than 9%, with an average steepness around the 20%, and the number of fields with DDD>80 was found higher than that with DDD<80. The cross-sectional area of the diches was found to increase from field crops to olive groves and, then, to vineyards, but without a justification related to the slope steepness. Further, the average distance between two consecutive diversion ditches was longer in olive orchards and vineyards than in field crops for both DDD>80 and DDD<80. Traditionally, in the study area, level ditching constituted the main land set up system to control surface water movement and prevent soil erosion in field crops. In fact, none of the examined field crops had stonewall terraces, while a small number of earth-riser terraced fields (about 5.5% of the total field crops) were found on hillslope with inclination higher than 9%. Until the early 1950s, Tuscan farmers traditionally set up olive orchards and vineyards by planting the tree rows up and down the hill on gentle slopes, while planting them across the slope by terracing on steep slopes. However, since late 1950s, the up and down the hill land set up system was adopted also on steep slopes, being cheaper and more suitable to a mechanized agriculture than terracing (Landi, 1989). Napoli *et al*. (2016) reported that terraced vineyards covered a surface representing only 0.4% of the total vineyard area in the municipalities of Barberino Val d'Elsa, Greve in Chianti, San Casciano in Val di Pesa, and Tavarnelle Val di Pesa, while the remaining vineyard surface were nowadays planted up and down the slope also on steep slopes. The diversion ditches were commonly designed without technical advice but rather on the basis of local farmers' experience. Earth-riser terraces resulted uncommon in the study area for large cropped surfaces (Table 3). Although widespread in the past, most earth-riser terraces were land levelled

Table 2. Design parameters of diversion ditch measured in the study area.

Hillslope steepness class	Crop	Land set up system	Fields (no.)	Slope (%)	Ditch cross section (m^2)	Distance between ditches (m)
Equal or lower than 9%	Field crops	DDD>80 m	28	5.5 (0.4)	0.33 (0.02)	97.4 (1.9)
		DDD<80 m	85	3.9 (0.2)	0.37 (0.01)	41.5 (0.7)
Higher than 9%	Field crops	DDD>80 m	88	18.0 (0.5)	0.34 (0.01)	97.4 (1.1)
		DDD<80 m	22	14.0 (0.8)	0.30 (0.03)	38.5 (1.3)
	Olive orchards	DDD>80 m	74	19.5 (0.8)	0.51 (0.02)	174.1 (1.5)
		DDD<80 m	35	20.4 (1.2)	0.53 (0.03)	54.8 (1.3)
	Vineyards	DDD>80 m	163	19.1 (0.4)	0.64 (0.02)	169.6 (1.0)
		DDD<80 m	52	20.0 (0.7)	0.68 (0.03)	62.8 (1.1)

The average values (standard error in brackets) are reported as function of the hillslope steepness classes, type of crops and land set up systems. Diversion level ditches with a distance between successive diversion ditches (DDD) higher than 80 m (DDD>80); Level ditches with DDD lower than 80 m (DDD<80).

Table 3. Design parameters of earth-riser terraces measured in the study area.

Crop	Fields (no.)	Slope (%)	Height of riser (m)	Slope of riser (%)	Length of riser (m)	Terrace bed width (m)	Field area occupied by the riser (%)
Field crops	13	19.7 (1.2)	1.6 (0.4)	71.3 (2.3)	2.8 (0.5)	8.7 (0.8)	26.4 (1.4)
Olive orchards	9	24.4 (1.1)	2.3 (0.5)	86.8 (3.1)	3.5 (0.6)	9.7 (1.0)	28.5 (1.8)
Vineyards	19	23.9 (1.1)	2.0 (0.3)	78.3 (2.0)	3.2 (0.4)	8.8 (0.7)	29.5 (1.2)

The average values (standard error in brackets) are reported as function of the crop type.

and converted in up down the slope land set up system over the past 70 years. The average earth-riser terrace width was slightly larger than that suggested by Sheng (1988) for machine built earth-riser terraces (less than 8 m). No significant difference was found in the main design parameters between the three different land uses considered. However, differences were observed related to the steepness of the original slope and the type of soil. In particular, soil texture greatly influenced the dimensioning of slope of risers, often causing high variability within the same field. The slope of risers ranged between 54% on loamy soil to 98% on clayey soil. The field area occupied by the risers was about 28.1% on average, ranging between 17.7 and 38.9%.

The stonewall terraces (Table 4) were mainly diffused in steep terrains with an average slope of about 25.2% and ranging from 17.2 to 40.6%. The average terrace bed width was 8.5 m for olive groves, ranging between 5.3 and 16.2 m, and 8.0 m for vineyards, ranging between 4.5 and 18.3 m. The average stonewall height was 1.9 m for olive orchards, ranging between 0.9 and 2.6 m, and 2.2 m for vineyards, ranging between 1.2 to 2.6 m. These values were slightly different from those measured by Agnoletti *et al*. (2015a) in Tuscany, reporting an average terrace bed width of 10.5 m, ranging between 2.7 to 30 m, and an average wall height of about 1.4 m, ranging between 0.5 and 2.4 m. Further, results indicated that the average field surface occupied by the walls was about 11.8%, ranging between 6.3 and 17.4%.

Comparison of land set up system in terms of soil loss

Statistically significant differences (P<0.05) were found in terms of average SL between fields having a DDD>80 and those having a DDD<80 for the 1st steepness class (Table 5). However, the average SL did not exceed T for both land set up systems. For the 2nd steepness classes, statistically significant differences (P<0.05) were found in average SL between different land set up systems, with the highest average SL being found in fields with DDD>80, followed by fields with DDD<80, and then earth-riser terraced fields. The average SL in the 2nd steepness class was found to be lower than T for earth-riser terraced fields and fields with DDD<80, while exceeding T for fields with DDD>80. The average SL found on fields in the 1st steepness class were significantly lower (P<0.05) than that of the 2nd class, both for fields with DDD>80 and those with DDD<80. These results suggested that the effectiveness of the DDD<80 in controlling the soil erosion process, with respect to DDD>80, consistently increased from the 1st to the 2nd steepness class.

The effectiveness of DDD<80 in reducing the soil erosion with respect to DDD>80 resulted higher than that reported by Bazzoffi *et al*. (2016). However, differences can be determined in terms of soil types, rainfall erosivity regimes, and ditch designs. The average SL values in the 1st steepness class were in accordance with those reported for field crops on erosion plots by Cerdan *et al*. (2006). In contrast, Porqueddu and Roggero (1994) in Sardinia

Table 4. Design parameters of earth-riser terraces measured in the study area.

Crop	Fields (no.)	Slope (%)	Height of wall (m)	Terrace bed width (m)	Field area occupied by the wall (%)
Olive orchards	54	24.3 (0.9)	1.9 (0.3)	8.5 (0.4)	11.2 (0.9)
Vineyards	53	26.8 (0.8)	2.2 (0.2)	8.0 (0.4)	11.9 (0.5)

The average values (standard error in brackets) are reported as function of the crop type.

Table 5. Estimated average rainfall erosivity index (EI_{30}) and average measured soil losses (SL).

Hillslope steepness class	Crop	Land set up system	Fields (no.)	EI30 (MJ mm ha^{-1} h^{-1} y^{-1})	SL (t ha^{-1} y^{-1})
Equal or lower than 9%	Field crops				
		DDD>80 m	28	1409.7 (19.2)	0.7 (0.2)^{Bb}
		DDD<80 m	85	1357.8 (6.2)	2.3 (0.3)^{Ba}
Higher than 9%	Field crops				
		DDD>80 m	88	1488.8 (14.5)	11.2 (1.6)^{Aa}
		DDD<80 m	22	1400.9 (10.6)	4.5 (0.7)^{Ab}
		Earth-riser terrace	13	1565.7 (29.7)	3.1 (0.7)^{c}
	Olive orchards				
		DDD>80 m	74	1499.2 (13.1)	12.1 (1.3)^{a}
		DDD<80 m	35	1484.3 (21.0)	7.1 (1.1)^{b}
		Earth-riser terrace	9	1444.9 (17.7)	4.5 (0.9)^{c}
		Stonewall terrace	54	1571.3 (8.6)	3.4 (0.4)^{d}
	Vineyards				
		DDD>80 m	163	1562.0 (9.7)	43.0 (2.4)^{a}
		DDD<80 m	52	1506.0 (16.6)	15.9 (1.7)^{b}
		Earth-riser terrace	19	1517.1 (16.6)	3.3 (0.5)^{c}
		Stonewall terrace	53	1751.3 (6.3)	3.9 (0.3)^{c}

The average values (standard error in brackets) are reported as function of the hillslope steepness classes, type of crops and land set up systems: Diversion level ditches with a distance between successive diversion ditches (DDD) higher than 80 m (DDD>80); Level ditches with DDD lower than 80 m (DDD<80); Earth-riser terraces; Stonewall terraces. Uppercase letters indicate significant differences in average standardized soil loss between steepness classes according to the Dunn post hoc test (P<0.05). Lowercase letters indicate significant differences in average standardized soil loss between land set up systems according to the Dunn *post hoc* test (P<0.05).

(Italy), Romero-Díaz *et al*. (1999) in Spain, and Kisić *et al*. (2002) in Croatia measured lower SL values than those we measured. The SL values measured in fields with a slope steepness higher than 9% and with DDD>80 were consistent with those reported by Bazzoffi *et al*. (2016) in Central Italy.

Statistically significant differences ($P<0.05$) were found in average SL from olive orchards, with the highest value being found in fields with DDD>80, followed in decreasing order by DDD<80, earth-riser terraces, and stonewall terraces. The average SL in DDD>80 was not effective in reducing the soil erosion since the soil losses were 2 times higher than T. Despite the average SL in DDD<80 were 1.7 lower than those measured in DDD>80, it too was higher than T. On the contrary, the average SL values in earth-riser terraced and stonewall terraced fields were 0.2 and 0.4 times lower than T, respectively. Earth-riser terraced fields were found reducing average SL by about 2.5 and 1.5 times with respect to the average SL from DDD>80 and DDD<80 fields, respectively. The average SL values on stonewall terraced fields were found to be about 3.6, 2.2, and 1.4 times lower than the average SL from DDD>80, DDD<80, and earth-riser terraced fields, respectively, thus resulting the most conservative land set up system among those tested.

The average SL measured in olive groves were consistent with those found in other sites in the European Mediterranean area. On a 18% slope in Tuscany (Italy), Napoli and Orlandini (2015) measured average SL of 3.1 and 1.4 t ha^{-1} y^{-1} in conventionally tilled and grass covered fields, respectively. On erosion plots near Cordoba (Spain), Gómez *et al*. (2009) measured the highest average SL (6.9 t ha^{-1} y^{-1}) in no-tilled plots, kept weed-free with herbicides, followed in decreasing order by conventionally tilled (2.9 t ha^{-1} y^{-1}) and grass covered (0.8 t ha^{-1} y^{-1}) plots. On a 30% slope in Andalusia (Spain), Francia Martínez *et al*. (2006) measured average SL of 25.6, 5.7, and 2.1 t ha^{-1} y^{-1}, from no-tilled, conventionally tilled, and grass covered fields, respectively. In Greece, Kosmas *et al*. (2006) measured average SL of less than 0.03 t ha^{-1} y^{-1} in an olive grove with 90% of the soil covered by spontaneous grass. Higher SL values were found by Raglione *et al*. (1999), who measured average SL losses up to 82.8 t ha^{-1} y^{-1} in a plot experiment in southern Italy. As far as we know, only Arhonditsis *et al*. (2000) analysed soil losses from terraced olive groves. These latter authors detected negligible SL from terraced olive groves in Lesvos (Greece) ranging between 0.24 and 0.56 kg ha^{-1} y^{-1}.

Statistically significant differences ($P<0.05$) were found in average SL from vineyards, with the highest value being found in fields with DDD>80, followed by fields with DDD<80 and then earth-riser and stonewall terraced fields. However, no significant difference was found in average SSL values between the earth-riser terraced fields and those in the stonewall terraced fields. The reduced distance between ditches in DDD<80 resulted in significantly lower rates of erosion with respect to DDD>80. Nevertheless, the average SL values in field with DDD<80, as well as those in DDD>80, were found to be 2.6 and 6.9 times higher than T, respectively. On the contrary, the average annual soil losses from earth-riser and stonewall terraced fields did not exceed the tolerable average annual soil loss limit (OECD, 2008). The average SL from terraced vineyards, considering earth-riser and stonewall terraced vineyards as whole, resulted 12.3 and 4.7 times lower than that measured the DDD>80 and DDD<80 vineyards, respectively.

These results indicated that the sole ditching was not sufficient to control the erosion process in vineyard planted in steep hillslope. In fact, Napoli *et al*. (2016) reported that most local farmers implemented inter-row grassing as conservation practice to reduce the soil loss. These results were consistent with those reported in other studies in Italy and in other European countries. For example, on a 9-years-old Sicilian (Italy) up and down the slope vineyard, Novara *et al*. (2011) found an average SL of about 60 t ha^{-1} y^{-1} in conventionally tilled rows, compared to SL rates from 15 to 36 t ha^{-1} y^{-1} in rows planted with cover crops. On an up and down the slope vineyard in Alto Monferrato (North-West Italy), Biddoccu *et al*. (2016) measured average SL rates from 1.8 to 20.7 t ha^{-1} y^{-1} in grass covered and tilled rows, respectively. In the '*Chianti Classico*' area, Napoli *et al*. (2017) measured on an up and down the slope vineyard average SL of about 10.1 and 3.2 t ha^{-1} y^{-1} in tilled and permanent grass covered rows, respectively. Marques *et al*. (2010) measured SL on vineyard in the centre of Spain of about 0.2 and 7.9 t ha^{-1} y^{-1} in grass covered and tilled rows, respectively. In Cyprus, Camera *et al*. (2018) measured on a terraced vineyard SL rates of about 2.4 t ha^{-1} y^{-1}. Moreover, these latter authors found that SL from standing terrace sections was 3.8 less than the erosion from the collapsed sections, thus highlighting the importance of the correct management of the terraces in order to prevent erosion.

Conclusions

We presented results demonstrating the effectiveness of the land set up systems in reducing soil erosion. Regardless their DDD, diversion ditches can be effective on field crops when the slope is less than 9%. On the contrary, only diversion ditches with DDD<80 m resulted effective in containing the soil loss from field crops within the OECD 2008 tolerable limit. The results indicated that diversion ditches were not sufficient to contain the soil loss within the tolerable limit in the olive groves and vineyards. This may be attributable to a number of causes such as the higher average slope and average DDD of these fields with respect to those under field crops; the absence of ephemeral ditches due to the up and down the slope arrangement of the olives and vines tree rows. On steep slopes, both earth-riser terraces and stonewall terraces have instead shown their value as land set up system capable of reducing the erosive process. Their greatest drawback is the reduction of the cultivable surface deriving from the presence of the riser and of the walls. However, their added value as a precious element characterizing the local landscape was of considerable importance for the local economy linked to tourism.

Highlights

- Diversion ditches reduce soil erosion on herbaceous crop fields with slope lower than 9%.
- Diversion ditches did not contain the soil loss within acceptable limits on steep slopes.
- Earth-riser terraces and stonewall terraces reduced soil losses within acceptable limits.
- Terraces reduced soil loss by 4.7-12.3 times with respect to diversion ditches.
- The analysis was performed on measured average annual soil loss data from 695 fields.

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