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Long-term monitoring of soil management effects on runoff and soil erosion in sloping vineyards in Alto Monferrato (North-West Italy).

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Abstract

Long-term runoff and soil erosion data have been collected from differently managed field-scale vineyard plots within the “Tenuta Cannona Experimental Vine and Wine Centre of Regione Piemonte”, located in the Alto Monferrato vine production area (NW Italy). The primary intent of the program was to evaluate the effects of agricultural management practices on the hydrologic, soil erosion, nutrient transport and soil compaction processes in vineyards. Field runoff data have been collected for every event since the year 2000 until now. Sediment and nutrient concentrations in water have been also monitored. Regarding soil properties and initial conditions, surveys have been carried out to investigate spatial and temporal variability of soil bulk density, soil saturated conductivity, soil water content, and penetration resistance. The Cannona Data Base (CDB) includes data for more than 300 runoff events and over 90 soil loss events; moreover, periodic measurements for soil physical characteristics are included for the three plots.

Runoff and sediment yield showed high annual and seasonal variability and were strongly affected by the adoption of different soil management in the vineyard inter-rows, especially after some years of observation. Grass cover reduced runoff by at least 37% , in comparison with management by tillage, and average annual sediment yield ranged from 1.8 Mg ha^{-1} year^{-1} to 20.7 Mg ha^{-1} year^{-1}, respectively for the “grass covered” and the “reduced tillage” vineyards. Furthermore, results showed the effect of the adopted soil management on soil properties. The Cannona Data base (CDB) can be accessed via a website (http://sustag.to.cnr.it/index.php/cannona-db) supported by the IMAMOTER-CNR.

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Key words: soil management; vineyards; runoff; soil erosion; soil compaction; database.

1 *Introduction*

Piemonte, NW Italy, is a long established and specialized wine region and produces some of the best-known, top quality Italian wines (e.g. Asti Spumante, Barolo, Barbera) and it is the second largest (after Veneto) Italian wine exporting region. In Piemonte the vine growing and oenological industry greatly contribute to the agricultural income and vineyards cover more than 52,000 hectares, accounting for around to 7.3% of the Italian wine production area (725,267 hectares) (ISTAT, 2014). According to the agricultural statistical database of the Piemonte Regional Administrat*i*on (Regione Piemonte, 2014a), more than 95% of the vineyard surface of the region is on hilly area and near 1% on mountain area, and the vineyards are concentrated in the southern part of the region, in the hilly territory Provinces of Asti, Cuneo and Alessandria. Hilly vineyards are easily subject to soil erosion, depending on the adopted soil management system. Water and soil protection are key issues for European countries, as the European Commission demonstrated by adopting the Water Framework Directive in 2000 (Directive 2000/60/EC) and the Soil Thematic Strategy in 2006 (CEC, 2006a; CEC, 2006b). Erosion has been identified as one of the major threats that affect European agricultural soils. An estimated 12% of Europe's total land area is subject to water erosion. Cerdan et al. (2010) estimated a mean erosion rate of 2.3 t ha^{-1} $year^{-1}$ for Italy, corresponding to 12.5% of the total European erosion. They predicted the highest erosion rates in vineyards and arable lands. Measured data (Maetens et al., 2012) showed that in the Mediterranean region runoff rates higher than 9% are related to vineyard land use. Among agricultural uses only tree crops showed higher runoff rates in the same region. More than 50% of the hills of the Piemonte region (NW Italy) is characterized by soils with moderately high or high erodibility, with values of the RUSLE K-factor (Wischmeier and Smith, 1978) higher than 0.047 Mg ha h ha^{-1} MJ^{-1} mm^{-1} (Ipla, 2007; van der Knijff et al., 2000). In Piemonte, Tropeano (1984) ran the first soil erosion measurements in vineyards in the 1980's, for about 2 years. In some vineyards located in the Alto Monferrato area, Tropeano measured soil losses ranging from 0.2 Mg ha^{-1}, in a vineyard where dry agents were used in no-tilled inter-rows, to 47.4 Mg ha^{-1} in a deeply ploughed vineyard. In 2007 the Regional Rural Development programme introduced environmental payments to encourage the adoption of best soil management practices, i.e. the use of grass cover in vineyards and orchards in order to protect soil from degradation. In recent years several studies have been carried out across Europe in order to evaluate the effect of vineyard's soil management on water and soil losses, with measurements both under simulated (Arnaez et al., 2007; Blavet et al., 2009) and under natural rainfall (Raclot et al., 2009; Novara et al., 2011; Ruiz-Colmenero et al., 2011). Experiments under natural rainfall are usually based on data collected during a monitoring period ranging from two to five years. Data collection on a wider temporal scale allow a better assessment of the temporal variability of water and soil losses. In fact, hydrological and soil erosion response can be very different from one year to another one (Casalí et al., 2008), and with the exception of extraordinary erosive rainfall events, erosion shows visible effects only after a few years. Furthermore, once they are established, vineyards are cultivated for some decades. In order to evaluate the long-term effects of agricultural management practices on the hydrologic system, soil erosion, and soil compaction processes in vineyards, the Institute for Agricultural and Earthmoving Machines (IMAMOTER) of the National Research Council of Italy (CNR) initiated a research program in the "Tenuta Cannona Experimental Vine and Wine Centre of Regione Piemonte" (Tenuta Cannona Centre) in 2000, with support of the Office for Agricultural Development of Regione Piemonte. The experiment consists of monitoring natural rainfall events producing runoff and erosion on three field-size vineyard plots with different soil management. In addition, recurrent measurements have been carried out to investigate spatial and temporal variability of the soil bulk density, soil water content, and penetration resistance. The Cannona Erosion Plots are representative of a real vineyard, since every plot is a hillslope portion of a vineyard field, that is managed according to traditional farming practices, with different inter-row's soil management. Data from 10 years of observation were analyzed and previously reported in order to evaluate the effect of soil management and seasons on runoff and soil erosion processes in sloping vineyards (Corti et al., 2011; Biddoccu et al., 2013; Biddoccu et al., 2014). The monitoring activities at the Tenuta Cannona Experimental Centre are currently carried out and implemented in order to improve the understanding of the soil management effects on soil hydrology, erosion, and compaction in sloping vineyards. Other natural processes are strictly related to the hydrologic behavior of the soil that drives infiltration, runoff formation on slopes, soil erosion, and the consequent sediment delivery to water courses. Costantini and Lorenzetti (2013) underlined the need of better understanding of soil degradation processes in a multi-disciplinary approach, with particular regard to Italy, due to the great variability of environmental conditions.

The aim of this paper is to provide a description of the Tenuta Cannona Erosion Plots and of the Cannona Data Base (CDB), and to present the main results of the 14-years runoff and sediment losses monitoring. The CDB represents a data collection which is unique in Italy for vineyards, showing the long-term response of soil to natural rainfall in terms of runoff and soil erosion during more than a decade of experimentation. It includes data for more than 300 runoff events and over 90 soil loss events, and data of some soil physical characteristics monitored in the plots. Instrumentation and methods used in data collection and analysis are described in the following paragraphs. The CDB is available on a website supported by the CNR, for water and land management researchers and professionals. Data from the CDB are available to calibrate and validate both runoff and soil erosion models. Also, it allows to investigate the interactions between land use, soil management, and natural processes at different scales.

2 *Materials and methods*

2.1 Site description

The "Tenuta Cannona Experimental Vine and Wine Centre of Regione Piemonte" (44°40' N, 8°37' E, 296 m asl) is located in the municipality of Carpeneto (AL), 85 km south-east of Torino, Northern Italy (Fig.1). The experimental site is located in the Orba watershed, within the southern part of the Tanaro basin; the area belongs to the Alto Monferrato hilly region, which is a valuable vine-growing and DOC wine production area. The Cannona vineyards lie on Pleistocenic fluvial terraces in the Tertiary Piedmont Basin, including highly altered gravel, sand and silty-clay deposits, with red alteration products (Carta Geologica d'Italia, scala 1:100.000, Foglio 70). The soils derived from reworked Pleistocene alluvium, have a clay to clay-loam texture. The climate is sublitoranean, with an average annual precipitation of 965 mm at the Ovada (187 m asl) weather station (1951-1990), mainly concentrated in Autumn (October and November) and Spring (March). The driest month was July. The mean annual temperature measured at Alessandria (96 m asl) during the same period of observation was 12.6°C (Biancotti et al. 1998). Mean annual air temperature measured at the experimental site in the period 2000-2013 was 13°C and the average annual precipitation was 849 mm.

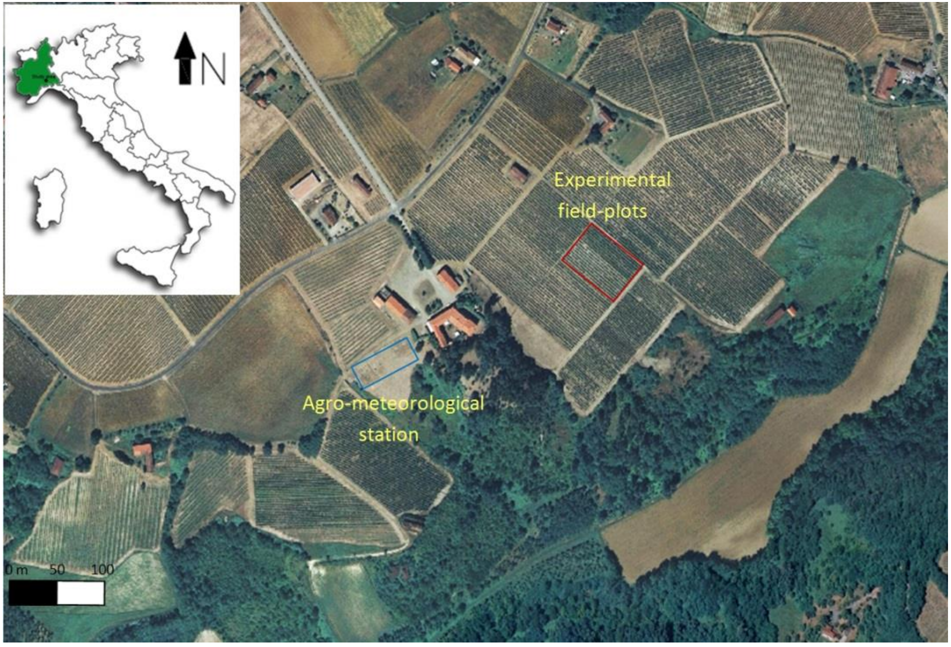

Fig.1. Location of the Tenuta Cannona Experimental Centre. Rectangles show the experimental field plots and of the Agro-meteorological station.

2.2 The experimental plots

The three experimental vineyard plots (Fig.2) are part of a larger vineyard, that was planted in 1988 with Barbera vines, managed in according to conventional farming for wine production. Each plot is 1221 m^2 (74 m long and 16.5 m wide). The three plots lie adjacent to each other on a hillslope with SE aspect and average gradient of 15%. Soil is classified as *Typic Ustorthents, fine-loamy, mixed, calcareous, mesic* (Soil Survey Staff, 2010) or *Dystric Cambisols* (FAO/ISRIC/ISSS, 1998).

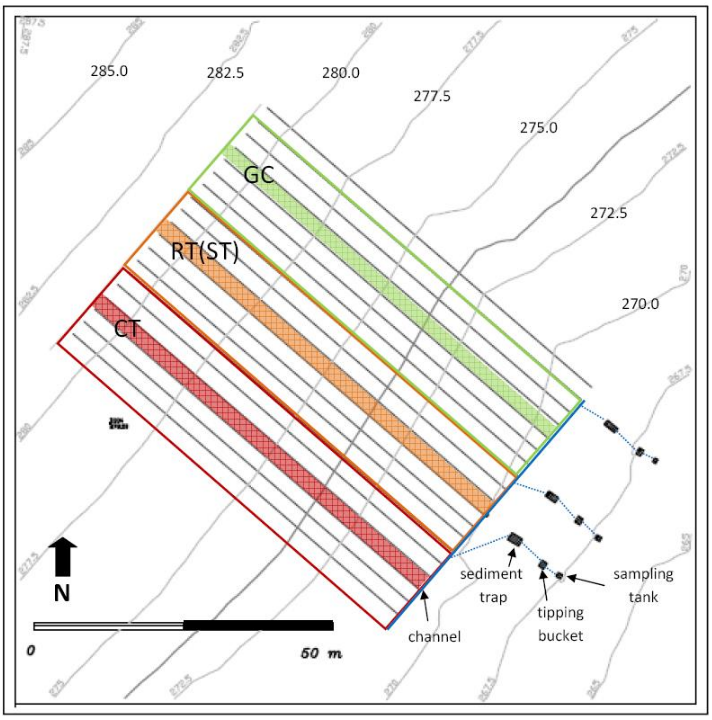

Fig.2. Sketch of the three vineyard erosion plots and the runoff collection/measuring system. Since 2000, the plots have been managed with conventional tillage (CT), reduced tillage (RT), converted in conventional tillage with grass strip, ST, in 2012, and grass cover (GC). The coloured inter-rows are those where SWC measurements and sampling are carried out.

Each plot includes 7 vine rows aligned along the slope, where the vines are spaced 1.0 m along the row and 2.75 m between the rows. Since 2000, different cultivation techniques have been adopted on the soil between the vine rows of the 3 plots: the first plot has been managed with conventional tillage (CT, processed with chisel at a depth of about 0.25 m), in the second plot reduced tillage has been used (RT, with rotary cultivator to a depth of 0.15 m), and in the third plot controlled grass cover has been adopted (GC, with spontaneous grass controlled with mulcher during the year). In Autumn 2011, the inter-rows of this plot were tilled and a grass mixture was sown, to renew the grass cover. The grass mixture was composed by: *Lolium perenne* 20%, *Festuca rubra* 60%, *Poa nemoralis* 15%, *Poa trivialis* 5%. Since 2012, the soil management with reduced tillage (RT) has been abandoned and replaced with conventional tillage with a 10-meters wide grassed strip at the bottom of each inter-row (ST). Tillage (in CT and RT(ST)) and grass mulching (in GC) were usually carried out twice a year, in spring and autumn, or in spring and summer. Weeds under the rows of the three plots are controlled with a single herbicide application (Glifosate®) in spring, for a width of about 0.6 m across the vine row. Chemical fertilizer was applied in the vineyard until 2004, by distributing once per year (in spring or autumn) the equivalent of 30 kg ha^{-1} of N, 20 kg ha^{-1} of P and 45 kg ha^{-1} of K in form of complex fertilizers. The calendar with description of the soil management operations is available in the database (CANNONA_MGMT.txt).

2.3 Climate data

Since 1998 meteorological data have been collected by means of an agro-meteorological station placed at about 200 m from the plots, within the Tenuta Cannona Centre. Rainfall, air temperature and air relative humidity have been continuously measured and recorded by means of mechanical instruments. Since 2003 data have been also measured by electro-mechanical station that is included in the RAM (Agro-meteorological Regional Network). Daily and hourly data are available from the "Banca Dati Agrometeorologica" of Regione Piemonte at http://www.sistemapiemonte.it/cms/privati/agricoltura/servizi/378-ram-banca-dati-agrometeorologica-consultazione-dati-giornalieri-dati-storici-statistiche (Regione Piemonte, 2014b). Another automatic weather station was set up in 1992, which is included in the RAN (National Agro-meteorological Network) (MiPAF, 2015). It measures and records data of soil temperature, air temperature and humidity, precipitation, wind direction and speed, leaf wetness, solar radiation, atmospheric pressure, and evapotranspiration. Details on the stations and daily, decadal, and monthly data from 2003 to 2013 were obtained by the "Banca Dati Agrometeorologica Nazionale"(MiPAF, 2014).

Data from the three stations were used to obtain rainfall characteristics for events producing runoff and soil erosion (see following paragraphs).

A meteorological station of the Regional Agency for the Protection of the Environment (ARPA) network is located at Ovada (AL), about 4 km from the experimental plots. At this site rainfall has been monitored with a 10 min interval since 2000.

2.4 Runoff

Each plot was hydraulically bounded: a channel at the top of the plots collects upstream water and there was no surface lateral flow between contiguous inter-rows, since the overland flow was along the main slope direction. Runoff and sediments were collected at the bottom of each plot by a channel, which was connected to a sedimentation trap and then to a tipping bucket device to measure the discharge of runoff (Fig.3). Tipping bucket devices were calibrated to measure runoff with resolution of 0.1 mm tip^{-1} and total runoff was obtained by means of analogical counters after each rainfall event producing runoff. In 2011, electro-magnetic counters were installed to obtain hourly data of runoff volumes, which are available on the website. A portion of the runoff-sediment mixture was sampled for each tip and was collected in a sample tank.

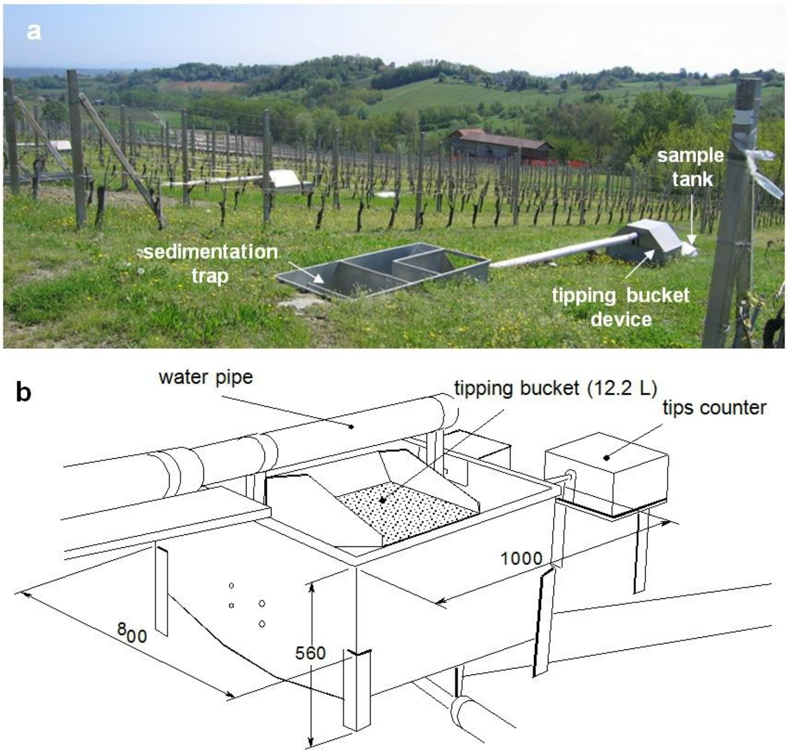

Fig.3. The runoff collection/measuring system (3a) and the tipping bucket measurement device (3b).

Rainfall characteristics were calculated from the data recorded by the agro-meterological stations for each rainfall event. For rainfall events of long duration and low intensity and snowfall events, which occurred in autumn and winter and rarely in early spring, each recorded event included days with precipitation and the following days with runoff measurements due to drainage flow. Snowfall events were considered in cases where they were followed by rain that caused snow melting. In such occasions, snow and rain contributed to produce runoff and, occasionally, to generate soil erosion. Each precipitation event was considered responsible for the amount of runoff and sediment yield that was measured during rainy days and immediately after them.

The runoff events dataset (CANNONA_RUNOFF.txt) includes the following rainfall and runoff variables as description as each runoff event: *i*) duration of each meteorological event (D_Ev, h), that was calculated as previously described; *ii*) duration of rainfall within each event of precipitation (D_R, h); *iii*) rainfall depth (R, mm); *iv*) maximum rainfall intensity over a 60-min period (I_{60}, mm h^{-1}); *v*) mean rainfall intensity, obtained as the ratio between R and D_R (Im, mm h^{-1}) *vi*) runoff measured in each plot (RO, in mm); *vi*) source of data used to obtain the rainfall variables (Station). Since 2011, hourly and daily rainfall data and runoff volumes were made available in raw format through the "Real-time runoff" section of the CDB website. Daily measurements can be obtained by selecting a period of observation from the web interface. Hourly data can be accessed by selecting a single day. Since August 2013, rainfall data are recorded every 10 minutes. All data available from this web-page are provisional and subject to validation process.

2.5 Soil and nutrient losses

After each erosive event, a 1.5 L sample of runoff-sediment mixture was collected from each sampling tank and then the sediment concentration was determined. Sediments deposited along drains and in the sedimentation traps were also collected and dry-weighted. To obtain the sediment yield due to each erosive event, sediment concentration was multiplied by the runoff volume and added to weight of deposited sediments. The soil losses dataset (CANNONA_SOIL_LOSSES.txt) includes the rainfall and runoff variables (the same as the runoff dataset) and the soil losses from the three plots (SL, kg ha^{-1}), which were measured for the erosive events.

A portion of collected runoff samples was used to determine nutrient concentrations in runoff. Ammonium, nitrate, phosphate and potassium were analyzed by Ion Cromatography (IC). No data were available for events that occurred in years 2005 and 2010. The nutrient losses were obtained by multiplying the concentration by the runoff.

2.6 Soil properties

Since 2004 recurring surveys were carried out to measure soil physical properties in the Cannona Erosion Plots. The measurements were performed once or twice at year, before tillage operations, on three transects in each plot . As the traffic of agricultural machinery was repeated on fixed routes, the measurements of penetration resistance, bulk density and volumetric soil water content were done both in the central part of the inter-row (or no-track, NT) and in the track position (T) , that is the portion of soil affected by the passage of tractor wheels or tracks,. Soil penetration resistance was measured by means of a recording penetrometer with a cone angle of 30° and 1 cm^2 area (Walczak et al., 1973) to a depth of 25 cm with vertical separation distance of 2.5 cm. Bulk density of the soil was determined by the core method (Blake and Hartge, 1986), sampling the soil at depths: 0-7, 10-17, 20-27 cm using 100 cm^3 cores. The same cores were used to determine gravimetric soil water content. Volumetric water content was calculated on the basis of gravimetric water content and bulk density. Data of soil penetration resistance and bulk density are included in the CANNONA_SOIL_PH.txt file.

Several series of infiltration tests were carried out in a 2-years period of observation, using the simplified falling head technique (SFH), proposed by Bagarello et al. (2004), in order to detect the variability of the field-saturated hydraulic conductivity at the surface of the vineyard inter-rows with different conditions depending on soil management. The tests were done in the CT plot, before and after the execution of tillage operations (indicated as undisturbed soil, CT-US, and processed soil, CT-PS, respectively), and in the GC plot at the same time. To assure one-dimensional flow, we used a second ring that was inserted concentric to the inner one. We used PVC cylinders having height of 0.30 m, inner diameter of 0.305 m (the inner cylinder) and 0.486 m (the outer one). The applied volumes of water were 7.0 L in the inner ring and 10.8 L in the bigger cylinder. Each SFH experiment included from 4 to 8 measurements, which were carried out in the T and in the NT position of the inter-row. The field-saturated hydraulic conductivity can be then determined by knowing: the time t_a from the application of water to the instant at which the water is infiltrated in the soil; ΔSWC, which is the difference between the field-saturated and the initial volumetric soil water content, $D=V/A$ (the depth of water corresponding to V) and α^* (a soil texture/structure parameter that can be estimated according to Elrick and Reynolds, 1992a and to Elrick and Reynolds, 1992b). Soil samples were collected to analyze soil physical and chemical properties in 1998, before the beginning of the experiment, in 2004 and 2012. Only texture was analyzed in 2004. Data are included in the CANNONA_TEXTURE.txt and CANNONA_SOIL_CH.txt).

2.7 Soil water content

Continuous monitoring of soil water content and soil temperature was performed starting from august 2011 to provide information about space-time variability of hydrological processes, determining the surface runoff response to a given precipitation events. Integrated temperature-soil water content sensors were installed in the topsoil and measures were recorded in one-hour intervals by a data logger. Four 5 TM sensors (Decagon Devices) were installed at 10 cm depth in each plot, to deliver temperature, measured by an onboard thermistor, along with volumetric soil water content. Measurements were taken on two transects, NT and T positions. Volumetric water content was obtained by measuring the dielectric constant of the soil using capacitance/frequency domain technology and the Topp equation (Topp et al., 1980), resulting in accuracy of ±

0.03 m^3/m^3 (± 3% VWC). Accuracy for temperature was ±1°C. Measurements were recorded every 60 minutes and data are stored by a Decagon EM50 Datalogger.

2.7 Data availability

The main objective of the research programs carried out on the Cannona Erosion Plots was the investigation of the effects of soil management on hydrology and soil degradation in vineyards. The aim of the CDB is to make the collected data available for consultation and for use by the public, researchers, students, authorities, farmer organizations and other stakeholders. The CDB website (http://sustag.to.cnr.it/index.php/cannona-db) contains the collected and validated datasets (Table 1) that can be downloaded from the website. The publically available sections of website also include general information and description of the Cannona Erosion Plots, results of the research activities, reports, publications, images, and links to other useful databases.

Table 1. Hydrological and soil data available in the Cannona database

	Period of data availability	Recurrence of measurement	Data source	Method	File name
Real-time rainfall and runoff (raw data)	2003-present (rainfall) 2011-present (runoff)	daily, hourly	RAM station and runoff gauges	-	Available from CDB website (real-time data section)
Climate (Rainfall and Temperature)	2000-2013	daily, hourly	Tenuta Cannona Centre, RAM and RAN Databases	-	Available from RAN and RAM Databases
Runoff events	2000-2013	at occurrence	Field measurements (runoff gauges)	Tropeano, 1984	CANNONA_RUNOFF
Soil loss events	2000-2013	at occurrence	Runoff water samples and sediment collection	Tropeano, 1984	CANNONA_SOIL_LOSSES
Texture	1998; 2004; 2012		Field samples	Details in the data file	CANNONA_TEXTURE
Chemical	1998; 2012		Field samples	Details in the data file	CANNONA_SOIL_CH
Bulk density	2004-2006 2009-2011	once/twice a year	Field samples	Sample cores (Black and Hartge, 1986)	CANNONA_SOIL_PH
Soil penetration resistance	2004-2006 2009-2011	once/twice a year	Field measurements	Static penetrometer (Walczak et al., 1973)	
Soil Water Content	2004-2006 2009-2011	once/twice a year	Field samples	Gravimetric (Black, 1965)	
Saturated Hydraulic Conductivity	2012-2014	from 2 to 4 times each year	Field measurements	Bagarello et al. (2004)	
Soil Water Content & Temperature -continue	2011-2013	hourly	Field measurements	TDR (Topp et al., 1980)	CANNONA_SWC-TEMP
Management	2000-2013	-	Farm report	-	CANNONA_MGMT

3 Results and discussion

3.1 Rainfall

The rainfall observed at the Cannona Experimental Centre are typical for sublitoranean climate (Table 2 and Fig.4). The inter-annual variability of the precipitation was quite high, with the maximum variability observed in autumn (especially in October and November), and the minimum in summer (June). The accumulated annual rainfall ranged from a minimum of 539 mm (year 2007) to a maximum of 1336 mm (year 2002), with an average of 849 mm. The rainfall showed a seasonal pattern: autumn was the wettest period (average 40% of the annual precipitation), whereas summer was usually the driest (12% on average).

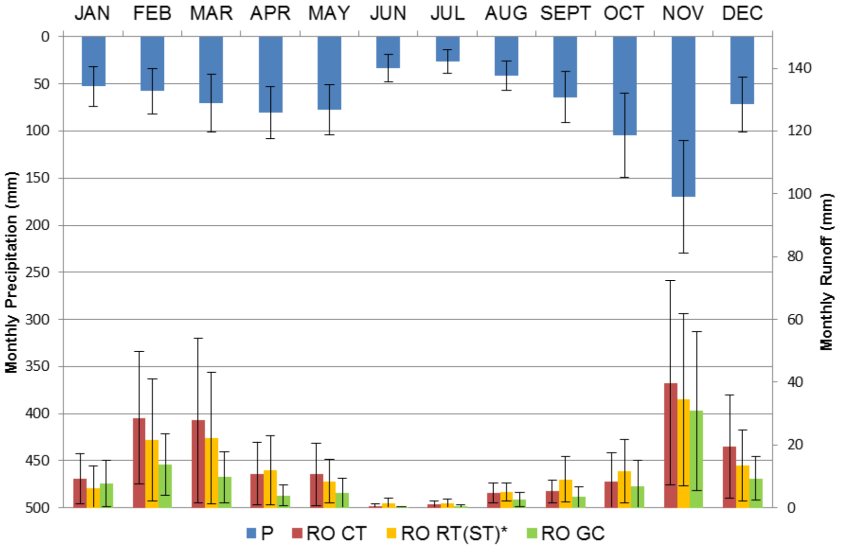

Fig.4. Measured monthly precipitation (P) and annual cumulative runoff (RO) from the Cannona Erosion Plots (CT = conventional tillage; RT (ST) = reduced tillage, converted in conventional tillage with grass strip (ST); GC = grass cover).

Table 2. Mean seasonal values (and standard deviation, SD) of precipitation (P), runoff (RO) and runoff coefficients (RC) measured at the Cannona Erosion Plots (CT = conventional tillage; RT (ST) = reduced tillage converted in conventional tillage with grass strip; GC = grass cover) during the period 2000-2013.

		Sept-Oct-Nov	Dec-Jan-Feb	Mar-Apr-May	Jul-Jun-Aug	Total
P (mm)	Mean	338.4	181.7	228.3	100.5	848.9
	SD	-150.4	-97.5	-102.5	-52.6	-234.3
RO CT (mm)	Mean	53.3	57.4	49.4	6.3	166.3
	SD	-70.3	-56.1	-65.5	-7.1	-121.2
	Mean	55.2	41.4	42.5	8	147.1

RO RT (ST) (mm)	SD	-59.2	-43.3	-54.2	-7.3	-94.9
RO GC (mm)	Mean	41.1	30.7	18.3	3.1	93.3
	SD	-59.4	-23.7	-19.6	-4.9	-67.8
RC CT (%)	Mean	11.8	27.8	17.5	5.8	17.9
	SD	-11.4	-23.7	-23	-6.1	-10.9
RC RT(ST) (%)	Mean	13.4	19.7	15	7.6	16.1
	SD	-9.2	-18.1	-17.7	-6.5	-8.3
RC GC (%)	Mean	8.7	15.2	6.4	2.8	10
	SD	-9.3	-9.4	-6.5	-3.9	-5

Rainfall data at the Ovada weather station were used to obtain the EI_{30} rainfall erosivity index (Morgan, 2005) and rainfall events were classified following the cumulated rainfall depth (Table 3). More than 80% of the rainfall occurred during events cumulating less than 100 mm. The mean erosivity of each of those classes was lower than 200 MJ mm ha^{-1} h^{-1} and the corresponding cumulated erosivity accounted for the 59% of the total. Rainfall events with more than 100 mm of precipitation showed higher mean rainfall erosivity, up to more than 2,000 MJ mm ha^{-1} h^{-1}. Less than 20 events accounted for more than 40% of the total erosivity. Just few events had very high erosivity (>1000 MJ mm ha^{-1} h^{-1}) and they occurred mainly during autumn.

Table 3. Rainfall characteristics for categorized precipitation events in the period 2000-2013, measured at the Ovada weather station. EI_{30} was calculated in according to Brown and Foster (1987).

Rainfall events category	Number of events	Av. rainfall depth	Av. storm duration	Av. Rainfall Erosivity EI_{30}	Cumulated rainfall	Cumulated Rainfall Erosivity EI_{30}
(mm)	-	(mm)	(h)	MJ mm ha^{-1} h^{-1}	(%)	(%)
0-10	810	2.4	3.7	1.4	15	4
10-20	131	14.1	12.7	20.9	29	15
20-30	68	24.7	16.6	51.7	42	28
30-40	22	34.2	26.8	34.8	47	31
40-50	26	45.6	29.2	58.0	56	37
50-60	13	54.6	26.5	82.0	62	41
60-70	12	64.8	37.8	115.4	68	47
70-80	8	74.1	42.7	196.8	72	53
80-90	9	84.4	40.8	138.1	78	57
90-100	4	91.7	66.1	91.3	81	59
100-150	10	118.3	51.6	255.7	90	68
150-200	4	184.9	50.0	964.1	96	83
>200	2	292.5	65.7	2,185.5	100	100

3.2 Runoff

3.2.1 Seasonal distribution

The inter-annual variability of the runoff volumes measured at the Cannona Erosion Plots was very high, especially in autumn when the maximum variability was observed for the three treatments, meanwhile the minimum variability was in summer (Table 2 and Fig.4). Average runoff discharges during the year followed a pattern similar to precipitation. In all treatments, runoff showed high values in autumn and winter. The highest runoff amounts were measured in November, in response to mean rainfall depth greater than 150 mm. High mean runoff values in February and March were likely due to snowmelting. The highest mean runoff rates were obtained in winter: in this season snowfalls occurred nearly every year, sometimes followed by rainfall, and soil moisture conditions were thus close to saturation for long periods, fostering runoff formation. During spring, mean runoff was about 30% of the annual volume for the tilled plots, with runoff rates higher than in autumn, partly due to early-spring snowfalls. From April through early autumn, new grass has usually grown spontaneously in the inter-rows of the three plots, resulting in different grass cover depending on the adopted soil management treatment. After the execution of tillage and grass mulching, the vegetation was mechanically eliminated and incorporated into the soil (in CT and RT(ST)) and, in GC, grass was cut with mulcher and residues were left on the soil surface. Thus, in spring and autumn, the inter-row surface of the three plots was partially covered by grass, which affect differently the hydrological processes. Spring runoff was reduced to 20% of the annual amount with the GC treatment, resulting in mean runoff rate lower than in autumn, because of the effect of the new grass cover. Nevertheless, during spring and autumn mean rainfall were more abundant, runoff rates were lower than in winter for all treatments. Beyond the before-mentioned reasons, this was likely due to the high infiltration rates that soil exihibits closer to the tillage operations (Ruiz-Colmenero et al., 2011; Biddoccu et al., 2013) which were usually made in spring and autumn. Less than 5% of the annual runoff was measured in summer time from the three plots. This was due to the low rainfall depth and high evapotraspiration, but also to the effect of the late-spring tillage, in

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Table 4. Annual cumulated precipitation (P) (measured at the Cannona Centre and at Ovada), annual cumulated erosivity (EI_{30}) (obtained from Ovada rainfall data), runoff coefficients (RC) and sediment yields (SY) measured in the Cannona Erosion Plots (CT = conventional tillage; RT (ST) = reduced tillage converted in conventional tillage with grass strip (ST); GC = grass cover).

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Mean	Stand.Dev.
P Cannona (mm)	1184	675	1336	695	675	614	652	539	914	918	1082	870	751	980	849	234
P Ovada (mm)	1135	689	1458	835	702	586	773	598	1105	1042	1213	955	911	1086	935	254
EI_{30} Ovada ($MJ\ mm\ ha^{-1}\ h^{-1}$)	2095	1452	3061	1092	889	1454	1520	1539	1820	1414	3746	4001	1391	1279	1911	978
RC CT (%)	0.17	0.19	0.25	0.13	0.11	0.07	0.08	0.01	0.1	0.3	0.28	0.37	0.11	0.33	0.18	0.11
RC RT (ST) (%)	0.14	0.17	0.22	0.13	0.11	0.08	0.11	0.03	0.11	0.3	0.2	0.29	0.1	0.27	0.16	0.08
RC GC (%)	0.17	0.14	0.19	0.06	0.07	0.05	0.08	0.02	0.07	0.13	0.12	0.14	0.04	0.11	0.1	0.05
SY CT ($Mg\ ha^{-1}$)	1.2	4.1	47.5	3.4	2.8	16.7	0.7	2.8	0.9	2.2	11.1	2.7	0.6	0.7	7	12.5
SY RT (ST) ($Mg\ ha^{-1}$)	2.5	7.3	45.5	6.4	6.8	28.5	13	7.7	38.4	38.8	74.6	15.7	0.8	3.4	20.7	21.6
SY GC ($Mg\ ha^{-1}$)	1.5	1.4	4.7	0.7	0.8	2.7	3.6	0.2	0.3	4.6	1.6	0.9	0	1.8	1.8	1.6

CT and RT(ST) treatments, and to the presence of grass cover in the GC plot and also in other treatments, in late summer.

The highest runoff mean volumes were measured in the RT plot from April to October, with exclusion of May, when the soil was usually tilled. From November to March (and in May) the highest mean runoff was observed in the CT plot. The GC treatment showed the lowest runoff during the whole year (excepted January). During spring and summer the use of grass cover resulted in a mean runoff reduction higher than 50% with respect to the tilled treatments, but it was less effective in autumn and winter, when the grass is sparsely developed. In summer and early autumn many farming operations, including harvest, are usually carried out in the vineyard using tractors, with traffic going in the direction of the maximum slope. This causes a reduction of grass cover and increasing compaction level just before the most rainy season, and tractor tracks become path of preferential flows in runoff generation.

3.2.1 Annual distribution

Accumulated annual runoff (Table 4) ranged between 6.6 and 339.1 mm for CT, 15.2 and 293.9 mm for RT, 10.9 and 247.3 mm for GC, measured respectively in 2007 and 2002, which were above mentioned as the dryer and wetter years, respectively. With the exclusion of the driest year, during which the runoff rates were lower than 3% for all treatments, the yearly runoff rates ranged between 7% and 37% for CT, 8% and 30% for RT(ST), and 5% and 19% for GC (Fig. 5). For most of the years, runoff measured in each treatment was higher than 7.4%, which is the mean value obtained from values by 123 plot-year measurements carried out

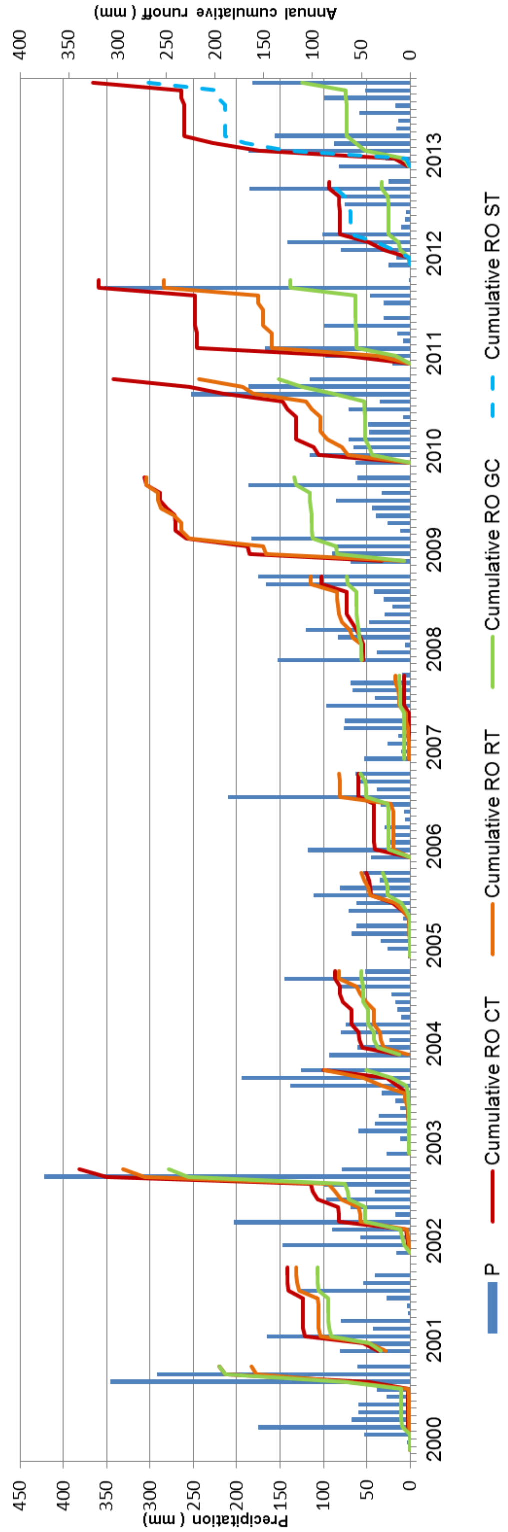

Fig.5. Monthly averages of precipitation (P) and monthly runoff (RO) from Cannona Experimental Plots (CT = conventional tillage; RT (ST) = reduced tillage converted in conventional tillage with grass strip (ST); GC = grass cover) in the period 2000-2013. Error bars indicate standard deviation. *Since 2012 the RT management was converted in ST.

in vineyards managed with different techniques in the European region (Maetens et al., 2012). The results of the current study were consistent with runoff rates obtained over 12 years in ploughed vineyards (with vine rows perpendicular to maximum slope direction), which ranged from 7.5% to 40.7%. (Ramos & Martínez-Casasnovas, 2010). The non-parametric test Mann-Whitney showed the significativity of the difference between runoff rates measured in CT and RT(ST) treatments during years 2000-2008 and years 2009-2013 for the spring months (March and April, at least at the 0.1 probability level) and for the whole year (at 0.05 probability level for CT and 0.1 for RT(ST)), but not in October and November, which are the most rainy months. No significant differences were found between the two periods for the GC runoff rates. Increase in the runoff rates measured in the CT and RT(ST) plot is likely an effect of the adoption of tillage for 9 consecutive years, which caused soil degradation and higher runoff in following years, especially during spring months, which was not so evident in the GC treatment.

3.3 Bulk density, soil penetration resistance and saturated hydraulic conductivity

Soil bulk density and penetration resistance were measured in the three plots over the period 2004-2011, before tillage in spring and autumn. Soil penetration resistance was significantly higher in the GC treatment than in the tilled plots, because of the presence of grass roots. In the CT and RT plots soil penetration resistance was significantly higher in the T position and in autumn rather than in spring (Fig.6). Bulk density results in Table 5 showed that the tilled plots were subjected to a greater extent to soil compaction

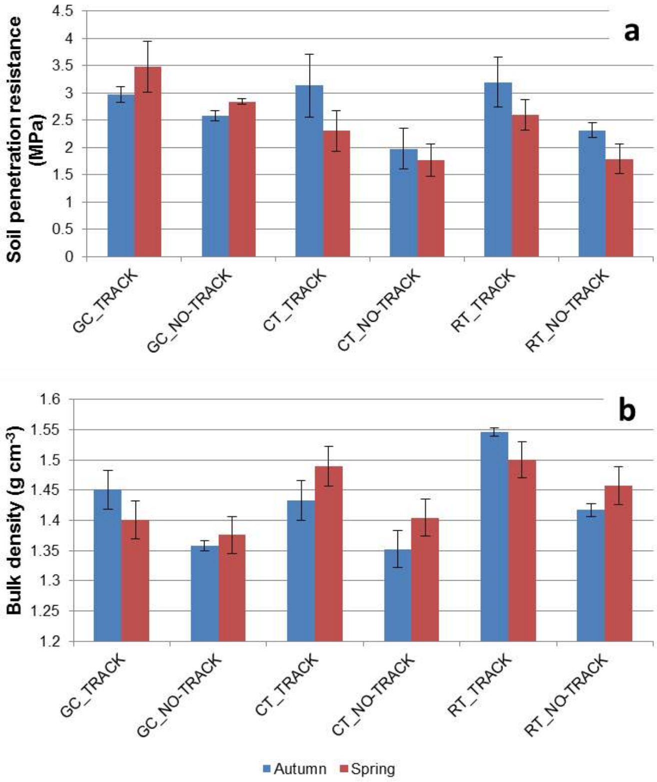

Fig.6. Mean values of soil penetration resistance (a) and bulk density (b), obtained from yearly measurements varied out in autumn and spring (before tillage operations), from 2004 to 2011. Error bars indicate standard deviation.

induced by tractor traffic, particularly in the T position, where mean values were significantly higher than in the NT position. Saturated hydraulic conductivity (Table 5) was also significantly lower in the T position than in NT, both in the GC treatment than in the CT-US condition. Significantly higher hydraulic conductivity was measured in the CT-PS condition, within a month after tillage operation, without differences in T and NT positions. Low water infiltration in the CT and RT(ST) plots is likely caused by high soil compaction, especially long time after the tillage operations, fostering the runoff formation.

Table 5. Mean and coefficient of variation (CV, in %) of the soil parameters measured in the experimental plots in the No Track and Track position. Soil penetration resistance and bulk density were measured in the period 2004-2011 in the three plots (GC = grass cover; CT = conventional tillage; RT = reduced tillage). Field-saturated hydraulic conductivity was measured with the SFH technique in three soil conditions: GC = grass cover, CT-US = conventional tillage with undisturbed soil, CT-PS = conventional tillage after soil tillage. Mean values in **bold** showed a significant difference between the two positions, according to the t-test at the 0.05 probability level; means followed by different letters differ at the same test and probability level.

			GC			CT			RT	
		NT	T	Tot	NT	T	Tot	NT	T	Tot
Soil Penetration Resistance (MPa)	Mean	2.74	3.28	3.01a	**1.85**	**2.64**	2.25b	**2.03**	**2.87**	2.45b
	CV	7.0	23.3	20.3	33.6	36.8	39.7	24.9	26.7	31.2
Bulk Density ($g\ cm^{-3}$)	Mean	1.36	1.41	1.39a	**1.37**	**1.47**	1.42ab	**1.43**	**1.51**	1.47b
	CV	3.6	4.8	4.5	6.4	4.4	6.4	4.7	3.3	4.9
			GC			CT-US			CT-PS	
		NT	T	Tot	NT	T	Tot	NT	T	Tot
Saturated Hydraulic Conductivity ($mm\ h^{-1}$)	Mean	**327.8**	**139.3**	204.3a	**362.2**	**29.5**	107.6a	1501.9	549.6	951.0b
	CV	48.3	58.2	57.3	58.7	35.2	81.4	43.4	159.9	211.3

3.4 Soil water content

The daily average values of soil water content (SWC), measured in different positions in the topsoil of the three plots are shown in Figure 7 (a,b,c). The measured SWC ranged between 0.15 and 0.59 m^3/m^3, with highest values obtained in winter 2013 in the CT plot, in the track position. In the wet seasons (autumn, winter, and spring), runoff seemed to be mainly generated by saturation of the uppermost soil layers, according to Castillo et al. (2003).

In the CT treatment, SWC in the track (T) position was usually higher than in central or no-track (NT) position, with exclusion of the first month after tillage in 2012 (spring and autumn). SWC

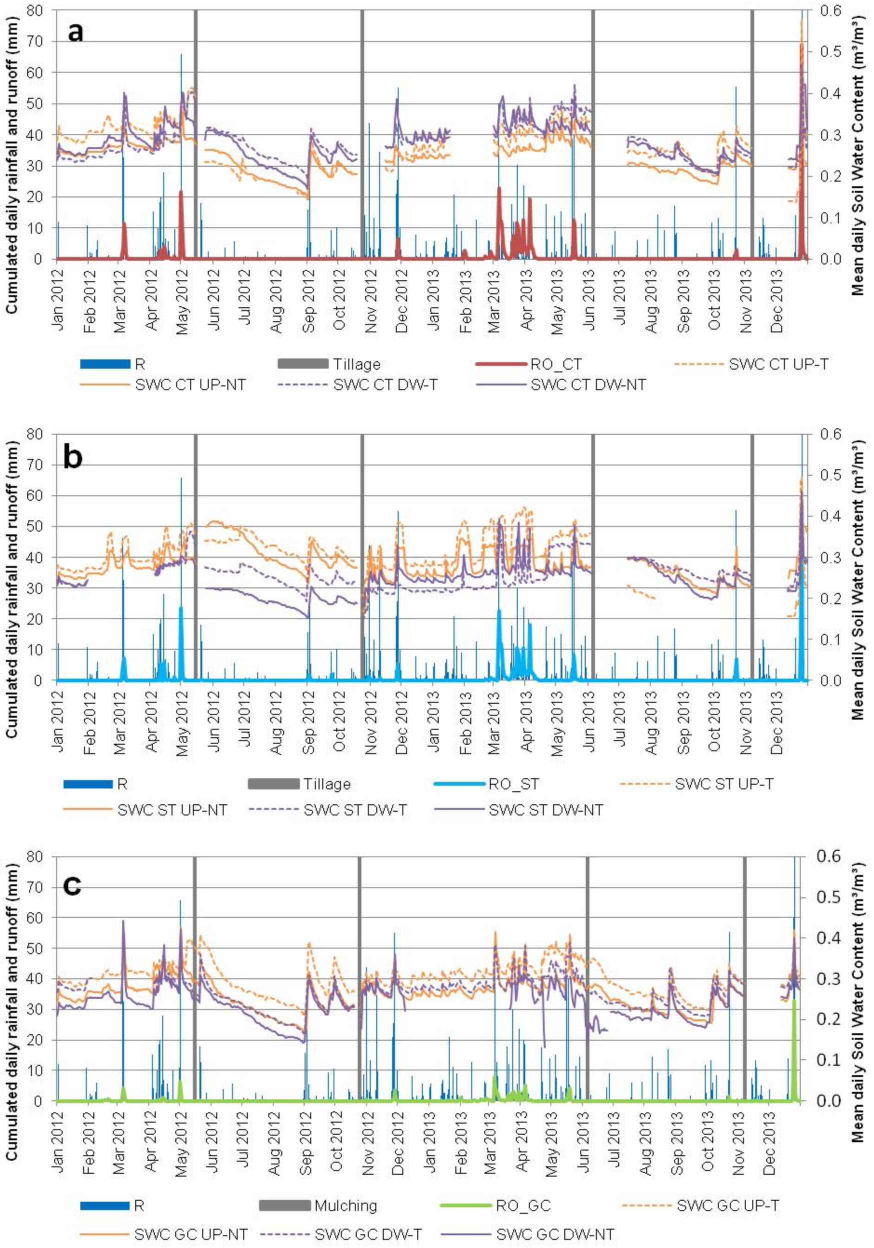

Fig.7. Soil water content (SWC) measured at 10 cm depth in two transects (UP = upwards, DW = downwards) and two positions of the inter-rows (T = track, NT = no-track) in each of the Cannona Erosion Plots: (a) conventional tillage (CT) (b) conventional tillage with grassed strip (ST) (c) grass cover (GC) in the period 2012-2013.

values measured in the two positions were very similar in the lower portion of the plot. During the first months of 2012 and in autumn 2013, SWC was higher in the upper portion than in the lower part of the vineyard, otherwise the bottom was usually the wettest portion of the inter-rows. In the ST plot, SWC was usually higher in the T position than in the NT position in the upper transect, except for first period after tillage in spring 2012. In the lower portion of the plot, the SWC was also higher in the T position than in NT for most of the time, with exception of the period from 11/2012 to 5/2013. The SWC was usually higher in the upper part of the plot than in the lower portion, with the exception of the driest summer months in 2013. Hajabbasi and Hemmat (2000) observed in clay-loam soil a change in soil properties, following the use of rotary cultivator for some years. The history of cultivation and the structure of the first centimeters of the soil were found also to be major causes in variability of infiltration rates in vineyards (Leonard and Andrieux, 1999). Thus, we can suppose that the history of the soil management could be the major cause of differences in spatial distribution of SWC between CT and ST. Nevertheless, both in the CT and in the ST plot, in which soil is managed with tillage, the SWC was usually higher in the T position than in NT, with exclusion of a period (up to two months) after the tillage operation. In the GC plot, the SWC measured in the T position was higher than in the NT position along the two years. SWC was slightly higher in the upper portion of the slope during most of year 2012 and during summer months of 2013. From 11/2012 to 6/2013, SWC was very similar in the upper and lower portion of the GC plot. As already observed by Ferrero et al. (2005) and Opsi et al. (2012) the tractor traffic in vineyards has a great influence on the spatial variability of soil physical properties, which are strictly related to the topsoil water content. The recurrence of tillage could temporarily decrease this effect, but it affects the variability of soil properties over a long period.

3.5 Soil erosion

3.5.1 Seasonal distribution

Main sediment yield occurred in August for CT, in October for RT(ST) and in November for GC, in response to increasing erosivity of rainfall from August to November (Fig.8). High average values that were measured for soil losses in autumn were likely due to high mean erosivity (>400 MJ mm ha^{-1} h^{-1}) and, in November, also to the highest runoff amounts. On the contrary, in July and August rainfall events were characterized by mean erosivity lower than 200 MJ mm ha^{-1} h^{-1} and generated low runoff mean values. The erosive events were concentrated in summer and autumn. In summer, the late spring/summer tillage and the absence (or scarcity) of soil cover were the most likely reasons for high soil losses in the tilled plots. A previous study by Biddoccu et al. (2013) showed that the effect of spring and autumn tillage in reducing runoff was limited only to one or two rainfall events, but during the following events higher runoff rates were recorded. Moreover, rotary cultivator tends to break up soil clods into smaller sizes, which are more susceptible to breakdown with respect to soil treated with chisel cultivation. Consequently, few rainfall events that occurred during summer were able to generate high sediment yield, especially where soil was processed with RT, even if the mean runoff was not so high. In autumn the occurrence of highly erosive events was due to the combination of severe soil compaction (in October, before tillage) or high soil water content (in November, after tillage), and low cover. As discussed before, those factors were responsible for large runoff, especially in November, and thus high energy rainfall resulted in high erosion of the poorly protected soil. The grass cover was especially effective in reducing soil losses in GC during summer months, but its protective effect decreased in autumn, as was also observed in a olive farm by Gomez et al. (2014). Farming operations that are usually carried out in summer and especially in autumn on wet soil results in soil compaction and low cover, and finally the autumn mowing expose soil to increasing soil erosion. During winter and spring months, mean soil losses were negligible (<1 Mg ha^{-1}) for CT and GC, and slightly higher for the RT treatment.

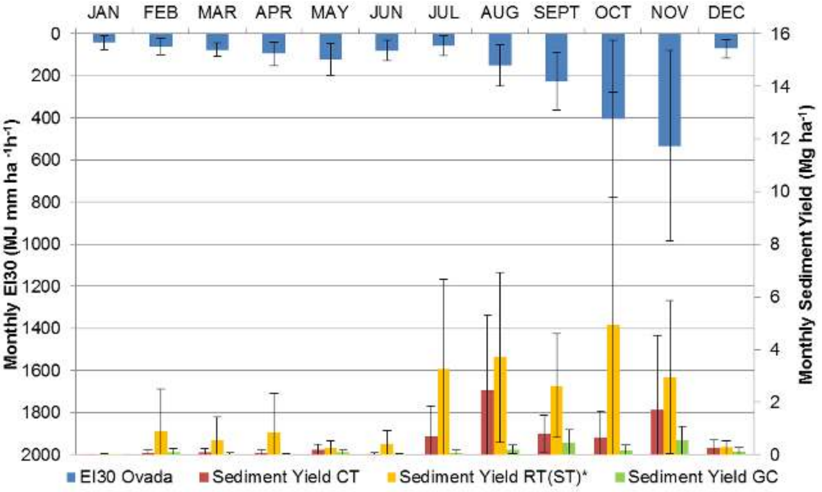

Fig.8. Monthly averages of rainfall erosivity (EI$_{30}$) at Ovada station and monthly sediment yield measured from the experimental plots in the period 2000-2013. Error bars indicate standard deviation. *Since 2012 the RT management was converted in ST.

3.5.2 Annual distribution

Figure 8 displays the monthly averages of rainfall erosivity (EI30), obtained from rainfall data recorded at the Ovada station, and averages of monthly sediment yield measured from the experimental plots in the period 2000-2013. Sediment yield presented very high inter-annual variability, with the highest values for RT(ST) treatment, especially for months from July to November. Annual sediment yield ranged from 0.06 to 47.5, 0.8 to 74.6, and 0.0 to 4.7 Mg ha^{-1} year^{-1}, respectively for the CT, RT(ST), and GC treatments.

Annual sediment yield was similar for the three plots in 2000 (Fig.9), then it was usually highest in RT plot (excepted 2002) and lowest for GC treatment (with exclusion of years 2006 and 2009), which resulted in a mean sediment yield of about 1.8 Mg ha^{-1} year^{-1} (Table 5). The mean sediment yield in RT was 20.7 Mg ha^{-1} year^{-1}, nearly three times greater than mean soil losses measured in the CT plot. In 2008, 2009 and 2010 the sediment yield was up to 43 times higher for RT than in CT treatment. Rainfall intensity, rainfall erosivity, and soil condition at event occurrence were responsible for such high soil erosion. We can observe that one of the most erosive event (about 2500 MJ mm ha^{-1} h^{-1}) occurred in October, 2010, resulting in the highest monthly soil losses ever recorded for the RT plot (65.88 Mg ha^{-1}). The highest erosive event event occurred in November, 2011, 20 days after the execution of tillage operations, and resulted in soil losses lower than 1.5 and 4 Mg ha^{-1} year^{-1}, for CT and RT, respectively. In this case, the high hydraulic conductivity due to the tillage effect was responsible for relatively low soil erosion. The considerable

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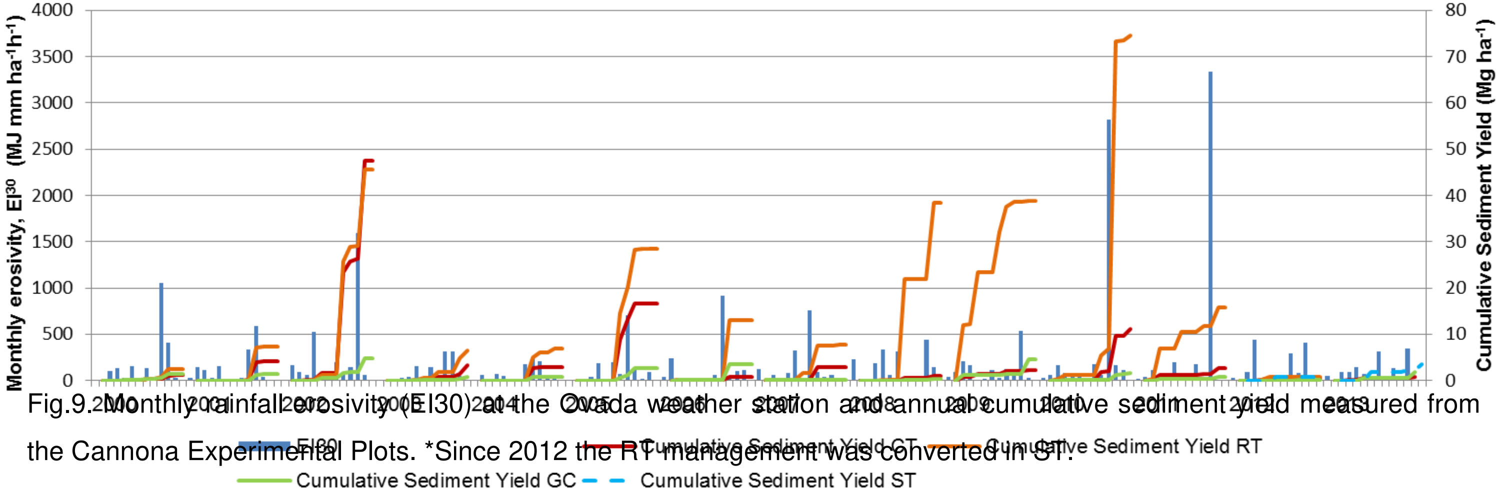

Fig.9. Monthly rainfall erosivity (EI30) at the Ovada weather station and annual cumulative sediment yield measured from the Cannona Experimental Plots. *Since 2012 the RT management was converted in ST.

increase in soil losses that the RT treatment showed from 2008 onwards is likely due to the degradation of soil properties as a consequence of the recurring tillage with rotary cultivator, for more than 8 consecutive years. Similarly, in a clay-loam soil, Hajabbasi and Hemmat (2000) observed that the use of rotary cultivator resulted, in some years, in a decrease of aggregate stability and organic content in the topsoil. Furthermore Barthès and Roose (2002) reported that runoff rate and soil losses were negatively correlated with topsoil aggregate stability, especially on vineyard hillsides.

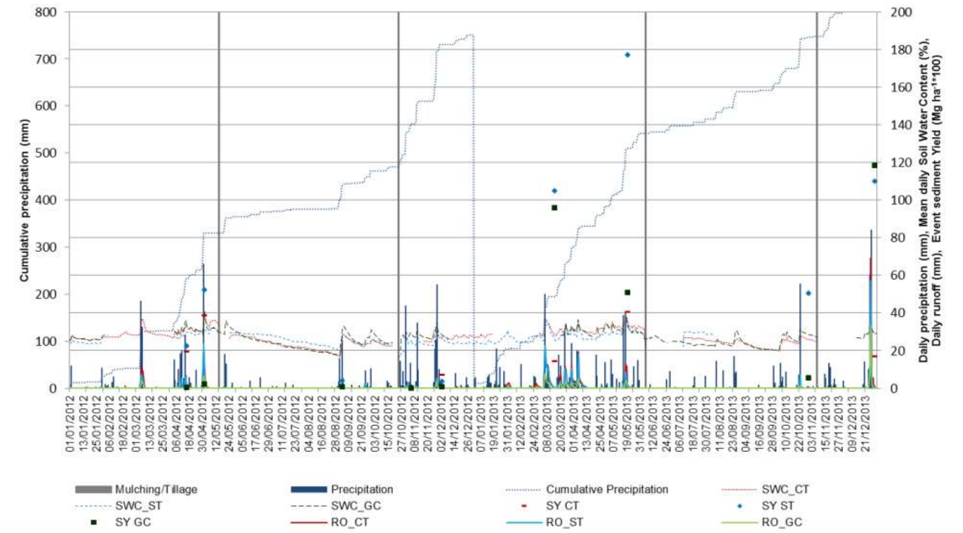

Fig.10. Daily and annual cumulative precipitation measured at the Cannona meteorological station; daily mean soil water content at 10 cm depth (SWC), daily runoff (RO), event sediment yield (SY) measured in each Erosion Plot (CT = conventional tillage; ST = conventional tillage with grass strip; GC = grass cover) in the years 2012 and 2013.

Figure 10 shows the measured rainfall events, mean daily topsoil water content, daily runoff and event sediment yield during the years 2012 and 2013. No erosive events occurred in summer months, as they were very dry. The main erosive events were concentrated from late fall to late spring, when the soil presented high soil water content, and usually long time after the execution of tillage (in CT and RT(ST)) and mulching (in GC) operations. The response of topsoil in increasing soil water content was evident for daily rainfall higher than 20 mm. Largest runoff and erosive events occurred when large or intense rainfall fell on a moist soil. Sediment yield was much higher in CT and ST than in GC in spring 2012, and it was the lowest in CT for all events occurred in 2013. For all erosive events, the highest sediment yield was measured in the ST treatment. The GC plot also produced high soil losses during the rainfall events occurred on March and December 2013, both occurred when grass cover was poorly developed. Despite the soil management being the same in

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the CT and ST plot since 2012, except for the presence of the grass strip at the bottom of the ST plot, noticeable differences in sediment yield were observed. They could be ascribed to the history of the soil management, that resulted in degradation of soil properties and, thus, high runoff and soil erosion. In the first two years of installation, the grass strip had no effect in reducing the runoff and soil erosion. Nevertheless, the results suggest that it is difficult to evaluate all the effects of the strip in the ST plot compared to the CT, since the different management of the two plots in the previous period had a great influence in determining the response of the soil to rainfall events, as was also observed in terms of soil water content.

3.6 Nutrient losses

The seasonal and total losses of nutrients obtained from the analysis of water samples collected after 80 runoff events are presented in Table 6. The total yield of ammoniacal nitrogen (NH_4-N) was highest from the CT plot, with a 38% and 61% reduction, the RT and GC plots, respectively. The seasonal losses were the highest in CT during all seasons, with the exception of autumn, when the amount of ammoniacal nitrogen lost in RT was slightly higher than in CT. The nitrate (NO_3-N) losses were also maxima in the CT plot and reduced by 34% and 78% in the RT and GC plots, respectively. Only during summer events the nitrates losses were higher in the RT plot than in other treatments. More than 50% of the nitrate losses were measured during runoff events that occurred in autumn in all plots, whereas during summer, losses were negligible in CT and GC treatments. With some exceptions, the seasonal yields of nitrates reflect the runoff distribution, as was expected because of nitrate solubility. Despite runoff from the GC plot being the highest, losses of ammoniacal nitrogen, and especially of nitrate, were considerably reduced with the adoption of grass cover.

The total phosphate (PO_4^{3-}) yields was highest in the GC plot, and was reduced by at least 20% in the tilled plots. According to these results, the presence of grass cover had no effect in reducing the total quantity of phosphate losses in the vineyard, especially during winter events. Phosphate losses were highest in GC during winter and summer events, whereas in autumn and spring the RT plot showed the highest losses. Most of phosphate losses occurred during winter events in CT and GC and in autumn in RT. No clear seasonal pattern was evidenced, in relation with the measured rainfall and runoff amounts.

Table 6. Total nutrients yields measured in the period 2000-2013 (data not available for years 2005 and 2010) from the Cannona Erosion Plots (CT = conventional tillage; RT (ST) = reduced tillage converted in conventional tillage with grass strip (ST); GC = grass cover). Analyzed nutrients are: ammoniacal nitrogen (NH_4-N), nitrates (NO_3-N), phosphate (PO_4^{3-}), Potassium (K).

		Autumn	Winter	Spring	Summer	Total
Number of events		34	9	22	15	80
P (mm)		2409.4	672.2	1348.8	505.4	4935.8
Runoff	CT	446.7	250.8	401.7	43.7	1142.9
(mm)	RT(ST)	415.8	140.2	153.0	22.3	731.4
	GC	567.3	196.0	346.6	66.3	1176.3
NH_4-N						
(kg ha^{-1})	CT	3.7	4.5	3.1	0.8	12.1
	RT(ST)	4.0	1.7	1.0	0.8	7.5
	GC	3.0	0.7	0.7	0.3	4.7
NO_3-N						
(kg ha^{-1})	CT	45.2	17.6	19.2	0.3	82.3
	RT(ST)	33.1	3.8	10.1	7.1	54.0
	GC	9.4	5.0	3.1	0.2	17.7
PO_4^{3-}						
(kg ha^{-1})	CT	0.9	3.2	0.5	0.2	4.8
	RT(ST)	1.9	0.3	1.3	0.2	3.7
	GC	1.2	3.8	0.5	0.4	6.0
K						
(kg ha^{-1})	CT	8.0	9.5	7.4	1.8	26.8
	RT(ST)	11.1	6.2	7.1	2.5	26.9
	GC	7.5	3.4	3.1	2.2	16.2

Potassium (K) losses were very similar in the tilled plots, nearly 40% greater than in GC plot. The seasonal distribution of the potassium losses was similar to the rainfall/runoff pattern.

Indeed, most of the losses in RT and GC were due to runoff events, which occurred in autumn, and to winter precipitation in CT. Potassium losses were the lowest in summer for all treatments.

Most of the nutrient losses, excepted phosphate, occurred during spring and autumn, which coincide with time when they were distributed (only during first 4 years of experimentation) and which were also the most rainy seasons.

4 Conclusions

The results of 14-year monitoring in experimental vineyard plots in Piedmont show that runoff and sediment losses, despite high seasonal and inter-annual variability, were concentrated in autumn and, only for soil losses, in summer. Furthermore water and soil losses presented high yearly amounts, which were very often higher than reference values proposed for vineyards in Europe. Regardless the soil management adopted in the inter-rows, averages for annual sediment losses were greater than the tolerable soil erosion rates proposed for Europe (Verheijen et al., 2009). Overall, the vineyards managed with tillage lost up to 20.7 Mg ha^{-1} year^{-1}. In Piedmont and other Italian regions grass cover of the inter-row is one of the most effective and used practices for controlling soil degradation, usually adopted thanks to payments of agricultural subsidies. Nevertheless, vineyards on sloping hillsides or mountainsides are still managed with tillage for mechanical grass removal within the rows. Results show that the soil management adopted in the vineyard inter-rows and the repeated tractor traffic during farming operations have a relevant effect on the soil physical properties, and thus on the runoff and soil erosion processes and their spatial and temporal variability. At yearly scale, and especially over a long-time observation, the grassed vineyard showed lower runoff and soil erosion if compared with tilled plots. The grass cover was especially effective in reducing soil losses during summer months, when very erosive storms usually occur, but its protective effect decreased in autumn, when soil is more compacted and the cover is low. Nutrient losses were also the lowest (except phosphorus) in the plot where grass cover was adopted. Moreover, the results show that the negative effect of adoption of tillage in the inter-rows, rather than grass cover, is particularly evident after some years, as well the degradation (or not) of physical properties of the soil in the vineyard is related to the history of the soil management. In any case, tractor traffic in vineyards has a great influence on the spatial variability of soil properties affecting water infiltration, runoff, and soil erosion processes. The soil and water conservation in the vine-growing systems will be more and more relevant, taking in account climate changes that predict increase in rainfall intensity and erosivity. The results indicate the need of improving conservation measures in order to reduce water and soil losses in vineyards, especially in autumn, which is the season where extraordinary meteorological events have occurred in the Piedmont during the last decades. The results obtained from the Cannona long-term monitoring program could be useful in a multidisciplinary approach to investigate interactions among land use/ soil management and hydrological/sediment transport processes at different scales, raising up from hillslope to small basin scale.

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