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Year-Round Variability of Field-Saturated Hydraulic Conductivity and Runoff in Tilled and Grassed Vineyards

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The soil management adopted in vineyard inter-rows has a great influence on soil hydraulic properties, and, consequently, on runoff at the field scale. Conventional management with tillage is adopted by vine-growers to improve the soil water recharge during winter. Nevertheless, this practice is known to increase runoff and soil erosion in steep areas, especially in mechanized vineyards, thus grass cover is adopted to reduce these negative impacts.

The year-round values of field-saturated hydraulic conductivity and of the field-scale runoff were measured in vineyard plots from November, 2012 to March, 2016 in the Alto Monferrato vine-growing area (Piedmont, NW Italy). Field-saturated hydraulic conductivity values were obtained by 110 infiltration measurements. The tests were carried out by adopting the Simplified Falling Head methodology in two adjacent vineyards plots, where inter-rows were managed with conventional tillage (CT) and grass cover (GC), respectively. The runoff, the soil temperature and the soil water content in the two plots have also been recorded. As it was expected, the tillage increased the field-saturated hydraulic conductivity with respect to the plot with permanent grass cover. However, this effect was only temporary, since a decrease in field-saturated hydraulic conductivity was observed as a consequence of cumulative precipitation and tractor passages after the tillage operations. The field-saturated hydraulic conductivity ranged between 9 and 9119 mm h^{-1} in the tilled plot and between 4 and 1775 mm h^{-1} in the plot with grass cover. The response of the plots to precipitation events, in terms of runoff also varied considerably. Generally, during most of the events, the runoff in the tilled plot resulted higher (up to nearly 20 times) than in the grassed one. The grass cover was less effective in occasion of large precipitation events during the wet seasons than in other months.

1. Introduction

One of the land uses for which higher runoff rates and sediment losses are observed in Europe, especially in the Mediterranean area, is grapevine cultivation: runoff higher than 9% of annual precipitation (Maetens et al., 2012) and the highest erosion rates (17.4 Mg ha^{-1} $year^{-1}$) were measured throughout Europe (Cerdan et al., 2010). Runoff, erosion (García-Ruiz et al., 2015) and further threats such as compaction (Ferrero et al., 2005), nutrient or organic matter losses (Ramos and Martínez-Casasnovas, 2004) and reduction of soil water holding capacity (Ramos and Martínez-Casasnovas, 2007) are favoured by some typical features of the vine-growing system, such as location on hillslopes or mountain areas and disposition of rows along the slope, and by some practices usually adopted in vineyards' installation (land levelling works and deep tillage) and vineyard management (maintenance of bare soil by mechanical or chemical weeding, intense tractor traffic along fixed paths) (Corti et al., 2011). The adopted soil management strongly influences the temporal and spatial variations of the soil surface characteristics (soil cover, topsoil structure and soil crusting) (Pare et al., 2011) and soil hydrological characteristics (Whalley et al., 2012), which drive the partition of rainfall between

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runoff and infiltration at the field-scale. The use of grass cover in the inter-rows is one of the most common and effective soil management practices adopted in order to reduce runoff and soil erosion in vineyards (Blavet et al., 2009), however, especially on low-permeability soils, tillage is still used as a practice to remove grass in summer and improve water infiltration, particularly during autumn and winter time (Novara et al., 2011): growers are often worried that the grass cover could spoil and reduce soil resources, that is water and nutrients, reducing grape yield and quality (Ruiz- Colmenero et al., 2011).

This study presents the results of a 4 years experiment monitoring topsoil hydrological properties and recording runoff and soil erosion in two vineyard field-scale plots with two different inter-row soil management: conventional tillage (CT) and grass cover (GC). The objective was to evaluate the effects of soil management, at seasonal temporal scales, in relation to soil hydraulic conductivity, considering soil moisture and precipitation characteristics.

2. Materials and methods

2.1 Study site

The study was carried out at the “Tenuta Cannona Experimental Vine and Wine Centre of Regione Piemonte”, which is located in the Alto Monferrato hilly area of Piemonte, North-West Italy, at 296 m asl. The climate is sublitoranean, at the study site, the average annual precipitation in the period 2000–2016 was 848 mm, mainly concentrated in October, November and March. The driest month was July.

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. The soils derived from reworked Pleistocene alluvium, and they have a clay to clay-loam texture. Soil is classified as *Typic Ustorthents*, *fine-loamy, mixed, calcareous, mesic* (Soil Survey Staff, 2010). The experiment was conducted in two vineyard plots on a hillslope with SE aspect and average 15% slope. The soil has been managed with two different techniques since 2000: twice a year, in spring and autumn, either conventional tillage (CT, cultivated with chisel to a depth of about 0.25 m), or grass cover (GC, with spontaneous grass controlled with mulcher during the year) were carried out. Most of the farming operations in the vineyard were carried out using tracked or tyred tractors, with passages intensification from spring to the grape harvest time.

2.2 Measurements

The experiment was conducted from November 2012 to March 2016. A monitoring system provided continuous measurements of rainfall, runoff and topsoil water content for the two experimental plots. Periodic measurements were carried out to obtain values of saturated hydraulic conductivity (K_{fs}), and initial soil water content (SWC_i) in the two plots. They were performed in order to detect the temporal variability of the field-saturated soil hydraulic conductivity at the surface of the vineyard inter-rows, with different conditions depending on soil management. Measurements were carried out both in the no-track (indicated as NT) and in the track position (indicated as T), which is the portion of soil affected by the passage of tractor wheels or tracks.

2.2.1 Rainfall, runoff, and soil water content

Rainfall measurements were obtained from an automatic rainfall gauge, with 0.2 mm resolution. For each season, rainfall amount and duration, maximum rainfall intensity at 60 min intervals were computed, by means of RIST (Rainfall Intensity Summarization Tool) (ARS-USDA, 2015). Rainfall events were considered as significant when cumulative rainfall was higher than 12.7 mm, according to the RUSLE procedure.

Each plot was hydraulically bounded: a channel at the top of the plots collected upstream water. Runoff was collected by a channel, connected to a sedimentation trap and then to a tipping bucket device to measure the hourly volumes of runoff from each plot. Runoff has been summarized by calculating the seasonal mean.

Soil moisture 5 TM sensors (Decagon Devices) were gravimetrically calibrated and installed at 0.1 m depth in each plot in NT and T positions. Soil water content measurements were recorded every 60 min. Dataset were summarized by calculating for every season the mean and the associated standard deviation (SD), in the 12 hours before the event.

2.2.2. Infiltration tests

During the 4-year period of observations 110 infiltration tests were carried out, using the simplified falling head technique (SFH), proposed by Bagarello et al. (2004). To assure one-dimensional flow, a larger second ring was inserted concentric to the inner one. The two PVC cylinders had a height of 0.30 m, and inner diameters of 0.305 m and 0.486 m. They were inserted in the soil to a minimum depth of 0.06 m. The applied volumes of water were 7.0 L in the inner ring and 10.8 L in the external one. According to Bodhinayake et al. (2004) the slope of the experimental plots do not affect the measurements significantly. In winter soil temperature was checked to be sure that soil was not frozen.

Undisturbed soil cores (V = 100 cm^3), at the depth of 0–0.07 m, were collected (next to the investigated area and, after the water infiltration, inside the inner ring) in order to determine initial and saturated volumetric water content values (SWC_i and SWC_s). The K_{fs} dataset was divided by season (spring: 3, 4, 5; summer: 6, 7, 8; autumn: 9, 10, 11; winter: 12, 1, 2), before/after tillage, and track/no-track positions, then summarized by calculating the geometric mean and the standard deviation value for lognormal distributions (Lee et al., 1985) in order to compare the data obtained by the infiltration experiments. The statistical frequency distributions of the data were assumed to be log-normal. Differences between positions (track vs no-track) and among treatments (GC vs CT(BT), GC vs CT(AT), CT(BT) vs CT(AT)) were tested by using t-tests (P=0.05).

3. Results and Discussions

The field-saturated hydraulic conductivity ranged between 9 and 9119 mm h^{-1} in the tilled plot and between 4 and 1775 mm h^{-1} in the plot with grass cover. Initial soil water content (SWC_i) ranged between 0.146 and 0.378 m^3 m^{-3} in CT, and between 0.084 and 0.428 m^3 m^{-3} in GC. Initial soil water content was usually higher in GC than in CT, and higher in T than in NT in the two plots.

Figure 1 shows the field-saturated hydraulic conductivity (K_{fs}) measured in each season in the two positions (T and NT) of the two plots, versus initial soil water content (SWC_i). The Table 1 resumes the mean values of K_{fs} that were measured in each season along with the mean runoff coefficient for rainfall events. In spring and summer K_{fs} ranged between 10 and 1000 mm h^{-1}. Values obtained in the CT plot, T position, were generally lower than 100 mm h^{-1}. In spring hydraulic conductivity in the GC plot and in the no-track position of the CT plot was mainly higher than 100 mm h^{-1}, while in the track position of the CT plot it was lower. In summer, highest values of K_{fs} were obtained in CT, in the NT position. Measurements carried out during autumn showed the highest K_{fs} in CT, after tillage, whereas before tillage they were lower than 100 mm h^{-1}, especially in the T position. In winter, hydraulic conductivity was higher than 1000 mm h^{-1} in CT, and generally lower than 1000 mm h^{-1} in GC, with lowest values in T position. Similar values for hydraulic conductivity were obtained in Sicilian vineyards by Bagarello et al. (2014) and Bagarello and Sgroi (2007). They measured K_{fs} ranging between 838 mm h^{-1} and 7424 mm h^{-1}, and mean values ranging from 20 mm h^{-1} to 952 mm h^{-1}, in clay and sandy loam soil (previously tilled but then undisturbed over the 2 years of observation), respectively.

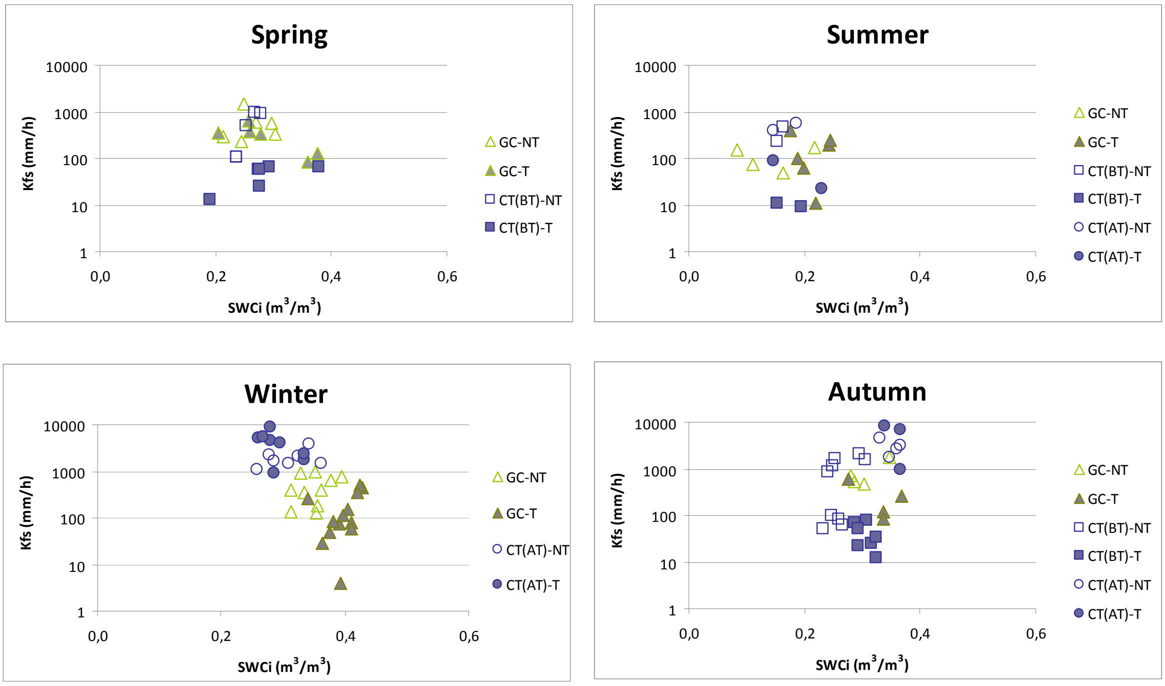

Figure 1: Field-saturated hydraulic conductivity (K_{fs}) measured in each season in the two positions (T and NT) of the two plots, versus initial soil water content (SWC_i).

Table 1: Seasonal mean and standard deviation (SD) of field-saturated hydraulic conductivity K_{fs} (mm h^{-1}), and runoff coefficient (RC), measured in the CT and GC treatments in track (T) and no-track (NT) positions. Geometric mean and the standard deviation value for lognormal distributions (Lee et al., 1985) was used for K_{fs}. Seasons in which SWC_i is higher than 0.250 m^3 m^{-3} are considered wet, otherwise if SWC_i is lower than 0.250 are considered dry (Biddoccu et al., 2017). Mean values in italic *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.*

Season	GC-T	GC-NT	CT(BT)-T	CT(BT)-NT	CT(AT)-T	CT(AT)-NT	RC_GC (%)	RC_CT (%)
SPRING (wet)	255.1 A	474.1 a	*38.8* B	*258.9* a	-	-	5.5	22.9
SD	2,1	1,9	2,0	3,4				
SUMMER (dry)	104.4 A	99.5 a	*10.0* A	*332.6* ab	44.7 A	486.9 b	4.4	13.3
SD	3,6	1,8	2,0	1,6	2,6	1,3		
AUTUMN (wet)	*197.6* A	*756.6* a	35.5 A	*373.5* a	3747.3 B	2886.2 b	5.2	12.4
SD	2,4	1,8	2,0	5,0	3,3	1,5		
WINTER (wet)	*95.6* A	*385.1* a	-	-	*3406.2* B	*1843.7* b	7.8	36.6
SD	3,7	2,2			0,0	1,5		

Mean values of K_{fs} (Table 1) show the different hydrologic behaviours of the two plots, considering different positions and soil conditions in each season. The track position before tillage, in the CT plot, had always the lowest field-saturated hydraulic conductivity because of the compaction due to the tractor traffic. Also in summer in CT(AT)-T, low values were due to tractor passages after the tillage operations.

The highest runoff coefficients were obtained both in CT and in GC in winter, even if in the CT plot the field-saturated hydraulic conductivity showed the highest values, as consequence of the autumn tillage. Thus, runoff that was generated in the freshly tilled soil was mainly consequence of soil saturation rather than hortonian runoff, as Biddoccu et al. (2017) observed during selected precipitation events. These data will allow to better investigate the processes by modeling as for border irrigation simulation (e.g., Canone et al., 2016), also allowing runoff scenarios simulations.

Years 2013 and 2014 had a higher precipitation (980 and 1210 mm), and 2015 and 2016 lower (612 and 713 mm) than the average annual precipitation in the period 2000–2016 (848 mm). During the period of study the yearly rain distribution was very variable (Figure 2): in 2013 more than 76% of the cumulative precipitation fell in spring and winter, whereas autumn and especially summer were drier than usual. In 2014 the 40% and 35% of annual precipitation were recorded in autumn and in winter, respectively (Biddoccu et al., 2016). In 2016 the summer was very dry, and 70% of precipitation fell in autumn and winter.

Table 2 presents the seasonal mean and the associated standard deviation of every single significant rainfall event during the years 2013 - 2016. Autumn and winter show very high variability, with events that present elevated rain and duration (more than 2 days), but little intensity. The events with the highest rainfall (222 mm) and the longest duration (181 h) were recorded in the winter season of 2013 and 2014 respectively. In summer storms are usually shorter and with less rainfall, but with higher intensity, than in other seasons. The event with the highest intensity (24.6 mm h^{-1}) was recorded in summer 2014.

Soil water content before events (mean of the previous 12 h) had a very low variability among seasons. During the 4 years it ranged from 0.161 m^3 m^{-3} to 0.358 m^3 m^{-3} in the GC plot, and from 0.120 m^3 m^{-3} to 0.446 m^3 m^{-3} in the CT plot. The no-track position of the CT plot presented the highest value of SWC during winter. The track position in GC plot presented the highest values of SWC during whole the year, however the no-track position was the driest.

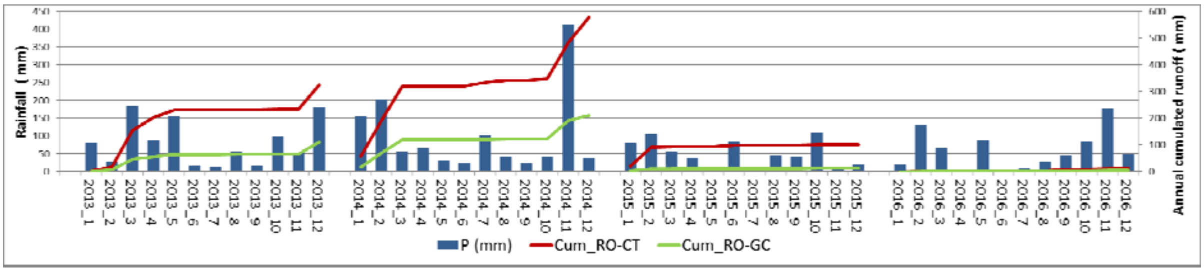

Figure 2: Precipitations (P) and cumulated runoff (Cum_RO) measured in each month in the two plots, during the years 2013 - 2016.

Table 2: Mean values and standard deviation (SD) of significant rainfall events for: precipitation (P), duration (P_Dur), intensity (P_Int), soil water content in the 12 hours before the event (SWC), runoff (RO), measured in the CT and GC treatments in track (T) and no-track (NT) positions during the years 2013 - 2016.

Season	P (mm)	P_Dur (h)	P_Int (mm h^{-1})	SWC_CT-T (m^3 m^{-3})	SWC_CT-NT (m^3 m^{-3})	SWC_GC-T (m^3 m^{-3})	SWC_GC-NT (m^3 m^{-3})	RO_CT (mm)	RO_GC (mm)
SPRING	30.2	33.4	4.4	0.305	0.300	0.302	0.259	9.52	2.59
SD	23.6	21.2	2.5	0.1	0.0	0.0	0.0	17.8	5.1
SUMMER	18.8	11.3	10.1	0.271	0.204	0.266	0.232	4.81	1.95
SD	11.8	12.9	6.2	0.0	0.0	0.0	0.0	17.4	9.0
AUTUMN	52.6	54.2	6.6	0.267	0.253	0.281	0.250	11.30	5.01
SD	46.3	43.9	5.0	0.1	0.1	0.0	0.0	24.5	11.6
WINTER	43.9	55.3	4.0	0.266	0.307	0.302	0.270	20.76	6.96
SD	48.2	38.1	2.7	0.1	0.1	0.0	0.0	35.4	15.3

The response of the plots to precipitation events, in terms of runoff varied considerably during the year (Figure 2). Generally, during most of the events, the runoff in the tilled plot resulted higher (up to nearly 20 times) than in the grassed one. In the period of observation yearly runoff was reduced between 54% and 88% by the grass cover. Other studies measured annual runoff reduction between 50% and 75%, due to use of different cover crops in the inter-rows, with respect to tillage (Novara et al., 2011; Ruiz- Colmenero et al., 2011). The grass cover was less effective on occasion of large precipitation events during autumn and winter, when grass cover is lower than in other months. The season with the highest mean of runoff was winter, but single events with high runoff were also measured in spring and summer in CT on occasion of storms with intensity greater than 8 mm h^{-1}. In winter and spring both the plots were generally already wet, thus in occasion of a rainfall, with high and long duration, or snowfall (that melts in the days following), this contributes to make easer soil saturation runoff occurrence.

4. Conclusions

Field-saturated hydraulic conductivity was investigated in grassed and tilled hillslope vineyard plots over a period of 4 years. The soil water content and the soil response to rainfall events, in terms of runoff, were also monitored. As it was expected, the tillage increased the field-saturated hydraulic conductivity with respect to the plot with permanent grass cover. However, infiltration tests showed that this effect was only temporary, since a decrease in field-saturated hydraulic conductivity was observed as a consequence of cumulative precipitation and tractor passages after the tillage operations. The field-saturated hydraulic conductivity varied within the plot in relation to the portion of the inter-row that was investigated (track or no-track), and among seasons, also in consideration of time elapsed from tillage. The response of the plots to precipitation events, in terms of runoff also varied considerably. Highest runoff was recorded in the tilled plot in winter, despite the highest hydraulic conductivities, due to wet soil conditions which make easy triggering of saturation runoff. High runoff was measured also during high-intensity spring and summer storms. During most of the events, the runoff in the tilled plot resulted higher than in the grassed one, also if the grass cover was less effective in reducing runoff during large precipitation events during autumn and winter than in other months.

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