Temporal variability of soil management effects on soil hydrological properties, runoff and erosion at the field scale in a hillslope vineyard, North-West Italy

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Abstract: Soil management in vineyard inter-rows has a great influence on soil hydraulic conductivity and bulk density, and, consequently, on runoff and soil erosion processes at the field scale. The maintenance of bare soil in vineyard inter-rows with tillage, as well as the tractor traffic, are known to expose the soil to compaction, reduction of soil water holding capacity and increase of runoff and erosion formation. The use of grass cover is one of the most common and effective practices in order to reduce such threats. It is therefore important to relate rainfall characteristics, soil properties and response in terms of runoff and soil erosion, from yearly to seasonal and to single event temporal scales.

The objective of this work is to quantify the temporal variability of the effects of two different kind of inter-row management on soil hydrological properties, runoff and erosion in vineyards. For this reason two vineyard field-scale plots in the Alto Monferrato vine-growing area (Piedmont, NW Italy) were monitored in two years. The inter-rows were managed with conventional tillage (CT) and grass cover (GC), respectively. Fifteen series of infiltration tests were carried out during a 2-year period of observation (October 2012 to November 2014). In order to take into account the effect of tractors traffic, the tests were done on the track, and outside the track. Furthermore, a dataset of 29 rainfall-runoff events covering a wide range of topsoil characteristics was collected in the two plots, along with soil water content and runoff discharge monitoring, and determination of sediment yield in case of erosive events. An optical disdrometer installed in the plots provided also 1-min rainfall intensity data. In summer, just one month after tillage, CT soil showed very low hydraulic conductivity, so storms were able to cause Hortonian runoff and soil losses up to 5.7 Mg ha-1. In autumn and winter very high saturation-excess runoff was observed in CT, that reached 83% of the precipitation. Runoff in the grass cover plot was mainly due to saturation of the topsoil, and the annual reduction of runoff in the GC plot was about 63%. Soil erosion up to 1.2 Mg ha-1 in a single event was observed in the GC vineyard in winter. In each year of observation, most of the erosion occurred during a single event, while the total annual erosion was up to 9 times higher in the CT treatment than in the GC.

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June 23th, 2016

Dear editorial board of Soil and Tillage Research,

Please find enclosed the new revised version of the manuscript entitled "Temporal and soil management effects on hydrological properties, runoff and erosion at field scale in a hillslope vineyard, North-West Italy", to be submitted as a research paper to Soil and Tillage Research for consideration of publication. We followed indications of editor in preparing this new version of the manuscript. All co-authors have seen and agree with the contents of the manuscript. We certify that the submission is original work and is not under review at any other publication.

In this manuscript, we reported the results of a research evaluating the temporal and soil management effects on soil hydrological properties in two vineyard field-scale plots (Piedmont, North-West Italy), which inter-rows were managed with grass cover and conventional tilled, respectively. Furthermore, the study was addressed to identify correlations between rainfall characteristics, soil properties and field-scale response in terms of runoff and soil erosion, at event temporal scale. During a 2-years period of observation, several series of infiltration tests were carried out, and a dataset of 29 rainfall-runoff events covering a wide range of topsoil characteristics was collected in the two plots, along with soil water content monitoring, measurements and sampling of runoff in order to determine the sediment yield.

The results highlighted the positive effect of grass cover in favoring water infiltration, reducing runoff and soil erosion throughout the year, compared with the conventional tillage management, with greatest effectiveness in summer. The annual reduction was greater than 63% and up to 90%, respectively for runoff and soil erosion. Only saturation-excess runoff was observed in the grassed vineyard. The highest runoff rates and soil losses were measured in the vineyard managed with conventional tillage even some weeks after the execution of tillage. In summer and early autumn, the tilled soil showed the lowest hydraulic conductivity, so summer storm were able to generate hortonian runoff and high soil losses, up to 5.7 Mg ha^{-1} soil erosion for a single event in the period of observation. In autumn and winter, the wettest seasons, despite the autumn tillage, very high saturation-excess runoff was observed, so the winter runoff reached 83% of the precipitation.

We believe that our research could be of interest to the readers of Soil and Tillage Research and we hope that the editorial board will agree on the interest of this paper.

Thank you for your consideration.

Sincerely yours,

Marcella Biddoccu

on behalf of the authors.

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***Revision Notes**

Click here to download Revision Notes: Rev_notes3.docx

June, 23th, 2016

Dear editor,
The authors thanks for your comments and suggestion to further improve the manuscript. We reviewed the manuscript taking in account them.
The conclusion section was revised and shortened to be more
Apart from the editorial comments, which were solved, the answers to the specific comments are described below.
Finally, the text was revised in English by a native speaker.

Reviewers' comments:

Line 4 should read: "… are known to expose …".

L. 6 should read: "practices".

L. 9: spelling of "scales".

L. 9: Somewhere here, the objective of this study should be provided before you tell what was done in the study.
Answer: the objective is now provided in L10-11

L. 16: spelling of "in".

L. 17 should read: "… just one month after tillage …".

L. 18: spelling of "Hortonian" as this is based on a name.

L. 27 should read: "… one of the land uses …".

L. 34-40: This sentence is grammatically incomplete.

L. 47 should read: "… and other land uses …".

L. 58 should read: "… at yearly or multi-annual scales …".

L. 59: Spelling of "Gómez".

L. 63 should read: "… runoff and infiltration at the field-scale …".

L. 71 should read: "… objectives …".

L. 92 should read: "The soil has been managed …".

L. 96 should read: "… on the soil surface."

L. 100: spelling of "Glyphosate".

L. 121 should read: "… recorded at 10-min intervals …".

L 123 should read: "… data have been obtained from …".

L. 132 should read: "To obtain the sediment yield from each erosive event …".

L. 135-136: How were the TM sensors calibrated?
Answer: The TM sensors were gravimetrically calibrated (L136)

L. 138 should read: "… in the 2-year period of observations, …".

L. 140 should read: "… on the same date …".

L. 149 should read: "… that slope does not affect the measurements significantly."

L. 161 should read: "Rainfall events occurring after August 2013 for which precipitation was recorded at 10-min intervals, were …".

L. 166 should read: "… were computed …".

L. 170-171: "Soil characteristics (Kfs, SWCs, BD) for NT and T positions, were associated at each event."
I do not understand this statement. What do you mean by "associated". Do not erase this statement, clarify it.
Answer: Each rainfall event was analyzed considering its characteristics and the "soil properties (Kfs, SWCs, BD) measured in T and NT position in the closest date (L172-173).

L. 174: spelling of "Hortonian".

L. 178-179:" the lower mean values between Kfs(T) and Kfs(NT) and between SWCs(T) and SWCs(NT) were chosen."
This statement is not clear. What do you mean by lower mean values, and were chosen for what?
Answer: The paragraph was modified, to clarify this point (L178-188). Each rainfall event was characterize by values of Kfs and SWCs measured in T and NT. The lower value between Kfs(T) and Kfs(NT) was chosen as reference Kfs to compare the time series of rainfall intensity during the event. The lower between SWCs(T) and SWCs(NT) was chosen as reference SWCs to compare the SWC time series, to complete the event analysis in order to detect runoff generation and the type of runoff.

L. 181 should read: "reached" and "remained".

L. 197: I can't make sense of "both in T than in NT position". Do you mean "both in T and in NT position"?
Answer: it was corrected throughout the text

L. 200 should read: "… for both treatments."

L. 202 should read: "… some days after tillage."

L. 212 sould be "cumulative" instead of "cumulated".

L. 216 should read: "The 40% and 35% of annual precipitation were recorded …".

L. 218 should read: "… in both plots."

L. 244 should read: "… 36 mm of rain fell with the highest …".

L. 246 should read: "5.6" (decimal point).

L. 252-253 should read: "… with a higher determination coefficient …".

L. 255 should read: "… at 7-day intervals …">

L. 264 should read: "… are displayed in Figs. 3 and 4."

L. 270-271: Similar as above, I can't make sense of "both from CT than from GC". Please clarify.

L. 271 should read: "… with a maximum 10-min rainfall intensity…".

L. 275 should read: "… did not overcome …".

L. 282 should read: "… thus runoff caused by infiltration excess …".

L. 284 should read: "… shows a rainfall occurring in autumn …".

L. 284 should read: "… the 10-minute rainfall intensity …".

L. 288 should read: "… near the 140 …".

L. 289-290: I could not grasp the sense of this sentence, but did you intend to say "Erosion detected in the two plots was nearly 40 times higher in CT than in GC."?
Answer: L295-296 "Erosion was detected in the two plots, and in CT it was nearly 40 times higher than in GC"

L. 294-205 should read: "Runoff appeared in the first hours of the event …".

L. 296 should read: "Within a few hours …".

L. 297: Replace "first" with "upper".

L. 304: Wghat do you mean by "this kind of saturation runoff events"? Clarify.

L. 307 "Hortonian".

L. 308-309 should read: "… and rainfall depth from 14 to 36 mm."

L. 311: "Hortonian".

L. 312 should read: "Runoff occurred for 50% of the observations …".

L. 317: "Hortonian".

L. 319 should read: "whereas 50% of the rainfall events produced Hortonian …".

L. 320 should read: "… were examined in the following."

L. 323 "Hortonian".

L. 324: "… runoff in CT, but no runoff in GC."

L. 324: "Hortonian".

L. 325 should read: "… with a depth ranging from …".

L. 326 should read: "… in both plots."

L. 329: "Hortonian".

L. 331: "Hortonian".

L. 332: "Hortonian".

L. 335 should read: "… in GC …".

L. 338 should read: "With a few exceptions …".

L. 338-339 should read: "… so soil water saturation was reached sooner than in the T position."

L. 344 should read: "vineyard."

L. 346-347 should read: "The coefficients of variation …".

L. 348 should read: "During most of the sampling dates …".

L. 349: Replace "exclusion" with "exception".

L. 357 should read: "during summer and autumn, a finding that was particularly evident …".

L. 364 should read: "In 2014, the CT topsoil showed higher sand content …".

L. 369-370 should read: "… could also be related to these differences …".

L. 371: There is no "role" on something. I suggest to say: "Impact of soil management, soil properties and rainfall on runoff".
Answer: the section title was changed (L381)

L. 372 should read: "… was usually 2 to 3.6 times higher …".

L. 374: should read: "… the highest runoff was observed during …".

L. 375: Do you mean "… both in CT and in GC."?

L. 375-376: "The highest differences in runoff between CT and GC occurred in …".

L. 376 should read: "… when the grass cover was higher."

L. 377 should read: "… and runoff coefficients were observed in winter …".

L. 378 should read: "… when snowfall was followed by rainfall."

L. 378-379 should read: "… whereas it was 28 % in GC."

L. 383: replace "have" with "had".

L. 385: I could not understand this statement. Instead of "which was originated" do you mean "that was generated"?
Answer: it was corrected (L395)

L. 387 should read: "… despite Kfs showing the highest mean values …".

L. 397: Do you mean "… at 7-day intervals."?

L. 400: This statement seems to be erroneous: "when the some precipitation was recorded in the previous 7 days". Do you mean "when the same precipitation" or "when some precipitation"?
Answer: it was corrected (L411) “when some precipitation was recorded in the previous 7 days”

L. 403 should read "rainfall-runoff event analysis".

L. 404 should read: "… runoff was caused by saturation of the topsoil …".

L. 407 should read: "… of a structural crust …".

L. 408: "cumulative" instead of "cumulated".

L. 409 should read: "factors".

L. 416: "Hortonian".

L. 421: Replace "Role" with "Impact".

L. 422 should read: "Sediment yields of …".

L. 423 should read: "… was close to 7.4 …".

L. 424: Replace "yearly" with "annual".

L. 435 should read: "… were due to the variability of rainfall …".

L. 441: Replace "where" with "when".

L. 446 should read: "These results …".

L. 446: Spelling of "Gómez".

L. 449: I was not sure what you meant with "and then with 7-days antecedent precipitation". Did you mean "… and is also related with the 7-day antecedent precipitation"?
Answer: it was corrected in "7-day antecedent precipitation" all over in the text

L. 458 should read "… was observed."

L. 462 should read: "… over a 5-minute period."

L. 464-466: This sentence is grammatically incomplete.

L. 469 should read: "… to those of Gómez et al. …".

L. 482: "Hortonian".

L. 483 should read: "Due to high compaction after grape harvest, the worst conditions for infiltration were found before tillage in CT and also in winter for GC.

L. 489: Replace "in case of" with "during".

Highlights

- Soil moisture, runoff, soil erosion were monitored in vineyard field-scale plots
- Temporal and soil management effects on soil hydrological properties were evaluated
- Summer storms caused hortonian runoff and high soil losses just a month after tillage
- Highest runoff rates were observed in late autumn and winter in tilled vineyard
- High runoff was due to soil saturation in the wet seasons

Title page

Title:

Temporal variability of soil management effects on soil hydrological properties, runoff and erosion at the field scale in a hillslope vineyard, North-West Italy

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Abstract

Soil management in vineyard inter-rows has a great influence on soil hydraulic conductivity and bulk density, and, consequently, on runoff and soil erosion processes at the field scale. The maintenance of bare soil in vineyard inter-rows with tillage, as well as the tractor traffic, are known to expose the soil to compaction, reduction of soil water holding capacity and increase of runoff and erosion formation. The use of grass cover is one of the most common and effective practices in order to reduce such threats. It is therefore important to relate rainfall characteristics, soil properties and response in terms of runoff and soil erosion, from yearly to seasonal and to single event temporal scales.

The objective of this work is to quantify the temporal variability of the effects of two different kind of inter-row management on soil hydrological properties, runoff and erosion in vineyards. For this reason two vineyard field-scale plots in the Alto Monferrato vine-growing area (Piedmont, NW Italy) were monitored in two years. The inter-rows were managed with conventional tillage (CT) and grass cover (GC), respectively. Fifteen series of infiltration tests were carried out during a 2-year period of observation (October 2012 to November 2014). In order to take into account the effect of tractors traffic, the tests were done on the track, and outside the track. Furthermore, a dataset of 29 rainfall-runoff events covering a wide range of topsoil characteristics was collected in the two plots, along with soil water content and runoff discharge monitoring, and determination of sediment yield in case of erosive events. An optical disdrometer installed in the plots provided also 1-min rainfall intensity data. In summer, just one month after tillage, CT soil showed very low hydraulic conductivity, so storms were able to cause Hortonian runoff and soil losses up to 5.7 Mg ha^{-1}. In autumn and winter very high saturation-excess runoff was observed in CT, that reached 83% of the precipitation. Runoff in the grass cover plot was mainly due to saturation of the topsoil, and the annual reduction of runoff in the GC plot was about 63%. Soil erosion up to 1.2 Mg ha^{-1} in a single event was observed in the GC vineyard in winter. In each year of observation, most of the

erosion occurred during a single event, while the total annual erosion was up to 9 times higher in the CT treatment than in the GC.

1. Introduction

Grapevine cultivation represents one of the land uses for which higher runoff rates and sediment losses are observed in Europe, especially in the Mediterranean area (Tropeano, 1983; Kosmas et al., 1997; Cerdà and Doerr, 2007; García-Ruiz, 2010; García-Ruiz et al., 2015). Analysis of data collected throughout Europe showed that in the Mediterranean region runoff higher than 9% of annual precipitation (Maetens et al., 2012) and the highest erosion rates (17.4 Mg ha^{-1} $year^{-1}$) are related to vineyard land use (Cerdan et al., 2010).

Some typical features of the vine-growing system, such as location on hillslopes and disposition of rows along the slope, make runoff and erosion stronger (Corti et al., 2011). Furthermore, some practices usually adopted in vineyards' installation (land levelling works and deep tillage) and vineyards' management (maintenance of bare soil by mechanical or chemical weeding, intense tractor traffic along fixed paths) are favoring runoff, erosion and further threats as compaction, nutrient losses and reduction of soil water holding capacity (Tropeano, 1984; Ramos and Martínez-Casasnovas, 2004; Ferrero et al., 2005; Ramos and Martínez-Casasnovas, 2007; Arnáez et al., 2007). The effects of the inter-rows soil management on runoff and soil erosion in vineyards of southern Europe was evaluated in several studies under natural rainfall, at different spatial scales (from plot to catchment) and from event to multi-year temporal scales (Tropeano, 1983; Kosmas et al., 1997; Arnaez et al., 2007; Brenot et al., 2008; Casalí et a., 2008; Raclot et al., 2009; Ruiz-Colmenero et al., 2011; Novara et al., 2011; Corti et al., 2011; Biddoccu et al., 2016). 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; Novara et al., 2011; Ruiz-Colmenero et al., 2011; Prosdocimi et al., 2016) and other land uses which are especially subjected to erosion as olive groves (Gómez et al., 2009). Under the indication of the

CAP agro-environmental requirements, some Rural Development Programmes (i.e., Regione Piemonte, NW-Italy) introduced during the period 2007-2013 specific subsidies to encourage the adoption of grass cover in vineyards and orchards in order to protect soil from degradation. However, tillage is still used in vineyards growing on low-permeability soils as a practice to remove grass in summer and improve water infiltration, particularly during autumn and winter time. In fact, growers are often worried that competition for soil resources, namely water and nutrients, between the grass cover and grapevines could affect grape yield and quality.

Most studies on runoff and erosion in vineyards consider topographic features, soil properties, rainfall characteristics, and soil management techniques in relation to the hydrological and erosive response of the vineyard at yearly or multi-annual scales (Prosdocimi et al., 2016). Nevertheless, annual runoff and soil losses could be strongly conditioned by few rainfall events (Gómez et al., 2014; González-Hidalgo et al., 2009). The adopted soil management influences strongly the temporal and spatial variations of the soil surface characteristics (soil cover, topsoil structure and soil crusting) and soil hydrological characteristics, which drive the partition of rainfall between runoff and infiltration at the field-scale (Leonard and Andrieux, 1998; Pare et al., 2011). There is still a gap in knowledge about the effect of the temporal variations of topsoil conditions on the triggering of runoff and soil water erosion throughout the year. A better understanding of the field response to rainfall events, taking into account the variability of the soil conditions during the year, could be useful for water balance and erosion modelling purposes (Celette et al., 2010) and to support soil management decisions in vineyards, in order to reduce runoff and erosion.

This study presents the results of a 2-year experiment monitoring topsoil hydrological properties and recording runoff and soil erosion in two vineyard field-scale plots with different inter-row soil management, conventional tillage and grass cover, respectively. The objectives were: (i) to evaluate the effects of soil management, at different temporal scales, namely at yearly, seasonal and single event ones; (ii) to identify in each event the prevalent runoff mechanism (either infiltration or saturation excess) in relation to soil management, soil hydraulic conductivity and bulk density, soil moisture and precipitation characteristics.

2. Materials and Methods

2.1 Study site

The study was carried out within the “Tenuta Cannona Experimental Vine and Wine Centre of Regione Piemonte” (44°40’ N, 8°37’ E, 296 m asl), which is located in the Alto Monferrato hilly area of Piemonte, North-West Italy . The climate is sublitoranean, (average annual precipitation of 965 mm at the Ovada station, in the period 1951-1990), mainly concentrated in October, November and March. The driest month was July. The mean annual temperature measured at Alessandria during the same period of observation was 12.6°C (Biancotti et al. 1998). At the study site, the average annual precipitation in the period 2000-2014 was 905 mm and the mean annual air temperature was 14.5°C. 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.

The experiment was conducted in two vineyard plots, which are part of a larger vineyard, lying on a hillslope with SE aspect and average 15% slope. Each plot is 1221 m^2 (74 m long and 16.5 m wide) and 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. The soil has been managed with different techniques since 2000. The first plot has been managed with conventional tillage (CT, cultivated with chisel to a depth of about 0.25 m), while in the second plot grass cover has been adopted (GC, with spontaneous grass controlled with mulcher during the year). The mulcher mows and chips the grass, and residues are left on the soil surface. Soil tillage (in CT) and grass mulching (in GC) were usually carried out twice a year, in spring and autumn. In autumn 2011, the inter-rows of the GC plot were tilled and a grass mixture was sown, to renew the grass cover. The grass mixture was composed of: *Lolium* *perenne* 20%, *Festuca rubra* 60%, *Poa nemoralis* 15%, *Poa trivialis* 5%. Weeds under the rows of the two plots were controlled with Glyphosate in spring, 0.6 m across the vine row. Most of the farming operations in the vineyard were carried out using tracked or tyred tractors, with intensification from spring to the grape harvest time. During the period of the present study, soil tillage (in CT) and grass mulching (in GC) were carried out five times (on: 24/10/2012, 05/06/2013, 11/11/2013, 16/05/2014, 24/10/2014). The soil is classified as *Typic Ustorthents, fine-loamy, mixed, calcareous, mesic* (Soil Survey Staff, 2010) or *Dystric Cambisols* (FAO/ISRIC/ISSS, 1998). Soil textural composition obtained from soil samples taken in 2014, at 0-10 cm depth, indicated a silty clay loam soil in the GC plot, with 15% sand, 53% silt and 32% clay content; and a silt loam soil in the CT plot, with 28% sand, 54% silt and 18% clay content.

2.2 Measurements

The experiment was conducted from October, 2012 to November, 2014. A monitoring system provided continuous measurements of rainfall, runoff and topsoil water content for the two experimental plots. Runoff samples were also collected to obtain sediment yield for erosive events. Periodic measurements were carried out to obtain values of saturated hydraulic conductivity (K_{fs}), bulk density (BD) and initial soil water content (SWC_i) in the two plots, 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.

Rainfall, runoff, erosion and soil water content

Rainfall measurements were obtained from an automatic rainfall gauge, with 0.2 mm resolution, at about 200 m from the plots. Rainfall data were recorded at 10-min intervals since August, 2013, whereas only hourly measurements were available for the previous period. Since June, 2014, 1-min rainfall intensity data have been obtained from an optical disdrometer installed near the plots (Laser Precipitation Monitor, Thies-Clima, Germany).

Each plot was hydraulically bounded: a channel at the top of the plots collected upstream water. Runoff and sediments were collected by a channel, connected to a sedimentation trap and then to a tipping bucket device to measure the discharge of runoff from each plot. A portion of the runoff-sediment mixture was sampled for each tip. The tipping bucket devices were calibrated to measure runoff with 0.1 mm resolution. In addition, hourly measurements of the runoff volumes were obtained from electro-magnetic counters. After each erosive event, a 1.5 L sample of runoff-sediment mixture was collected. Sediments deposited along drains and in the sedimentation traps were also collected and dry-weighed. To obtain the sediment yield from each erosive event, sediment concentration was multiplied by the runoff volume and added to the weight of deposited sediments. Four soil moisture 5 TM sensors (Decagon Devices) were gravimetrically calibrated and installed at 10 cm depth in each plot in NT and T positions. Soil water content measurements were recorded every 60 minutes.

Infiltration tests

Several series of infiltration tests were carried out in the 2-year period of observations, using the simplified falling head technique (SFH), proposed by Bagarello et al. (2004). Eight series of tests were done in the CT plot and seven series in the GC plot. The tests were conducted on the same date in the two plots, except from November to December 2012, when they were carried out with a delay of three weeks in GC. At each measurement date, four to eight SFH experiments were performed, with 2-4 measurements carried out in the no-track position of the inter-row and 2-4 in the track position. To assure one-dimensional flow, a 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 bigger cylinder. We kept a minimum height of 0.06 m of water on the sloping soil surface. Bodhinayake et al. (2004) have demonstrated that slope does not affect the measurements significantly. Before the execution of each test an undisturbed soil core (V= 100 cm^3) was collected next to the investigated area at depth of 0 to 0.07 m, to determine the soil bulk density. For the same purpose a sample was collected after the water infiltration inside the inner ring. Initial and saturated volumetric water contents (SWC$_i$ and SWC$_s$) were also obtained from the collected soil samples.

Each BD, SWC$_i$, K$_{fs}$, dataset was summarized by calculating the mean and the associated coefficient of variation (CV), in order to compare the data obtained by the infiltration experiments. The statistical frequency distributions of the data were assumed to be normal for the initial soil water content and the soil bulk density and log-normal for the field-saturated hydraulic conductivity (Warrick, 1998). Differences between positions (NT vs T) in the same plot, and differences between the two plots , were evaluated by using *t*-test at 0.05 probability level.

2.3 Rainfall-runoff events analysis

Rainfall events occurring after August 2013 for which precipitation was recorded at 10-min intervals, were analysed in order to evaluate the relationships among rainfall and soil hydrological characteristics and the runoff and erosion processes. For each event, rainfall amount and duration, maximum rainfall intensity at different time intervals (10, 30, and 60 minutes), and cumulative precipitation (during the previous 7, 15, 30, and 45 days) were obtained. Rainfall energy (Brown and Foster, 1987) and rainfall event erosivity (Renard et al., 1997) were computed, by means of RIST (Rainfall Intensity Summarization Tool) (ARS-USDA, 2015). Rainfall events were considered as significant when cumulative rainfall was larger than 12.7 mm, according to the RUSLE procedure. Only one smaller rainfall event (on 14/08/2013) was analysed, because of its high intensity (21.6 mm h^{-1} in 10 min). A total of 29 rainfall events were selected, each one with its own measured values of the following soil properties: K$_{fs}$, SWC$_s$, BD, for T and NT positions.

Firstly, Principal Component Analysis (PCA) was performed. Afterwards, stepwise multiple linear regression was applied. Finally, each of the significant rainfall events was analyzed in order to identify the surface runoff occurrence and its type (Hortonian or saturation of the soil surface horizon).

For this last purpose, the method of Dehotin et al. (2015) was applied, by comparing time series of rainfall intensities with K_{fs} values, and topsoil SWC with SWC_s values, respectively in order to detect either Hortonian or saturation excess runoff type. The measured values of K_{fs} and SWC_s in the CT and GC plots in the period of occurrence of each rainfall event were used as reference values. The lower mean values between K_{fs}(T) and K_{fs}(NT), and between SWC_s(T) and SWC_s(NT), respectively, were chosen as reference K_{fs} and SWC_s for the event. Hortonian runoff was detected if rainfall intensity values were higher than the K_{fs} reference value. The runoff occurrence due to saturation of the soil surface horizon was detected by comparing soil water content time series with the SWC_s reference for each event. It was assumed that if the soil water content time series reached the value of SWC_s and remained almost constant, the first horizon was saturated and additional rainfall was generating surface runoff.

Results

3.1. Soil hydrological properties

Table 1 summarizes the infiltration tests, which were conducted with initial soil water content ranging between 0.158 and 0.357 cm^3cm^{-3} in CT, and between 0.191 and 0.405 cm^3cm^{-3} in GC. On most dates, CV(SWC_i) was lower than 10% in CT. Higher variations were obtained in GC, especially in the NT position. Soil water content was usually higher in T than in NT in the two plots, with significant differences only in October, 2012, in CT and in December, 2012, and in July, 2013, in GC. For measurements carried out on the same date, soil water content was always higher in GC than in CT.

At the time of the execution of the infiltration tests, the bulk density varied between 1.19 and 1.55 g cm^{-3} in CT and between 1.24 and 1.47 g cm^{-3} in GC. The coefficient of variation of bulk density was generally < 10%, with some exceptions in GC. In the CT plot, bulk density differences between positions were significant in most of the sampling dates. Unexpectedly, in July 2013, about a month after tillage, bulk density was higher than before tillage (May, 2013), both in T and in NT position. Further increase in bulk density was recorded in the T position during the following months, up to 1.55 g cm^{-3} (October, 2013). A decrease of bulk density was usually observed between measurements done in autumn and in the following spring, for both treatments.

The K_{fs} was significantly lower in GC(T) than in CT(T) comparing mean values which were obtained in November and December, 2012, some days after tillage. For the remaining dates, the lowest hydraulic conductivity was always measured in CT(T), and the difference was statistically significant in May 2014 and October 2014. In NT, K_{fs} was higher in CT than in GC in most of the dates, being the difference statistically significant in autumn 2012, October 2013 and May 2014. Higher field-saturated hydraulic conductivity values in the less compacted portion of the GC inter-row could also relate to different texture of the topsoil.

3.2 Runoff and soil erosion seasonal distribution

Table 2 presents a summary of the annual precipitation, runoff and sediment yield during the years 2013 and 2014. During 2013 the annual precipitation was 971 mm, higher than the mean of the period 2000-2013 (849 mm) (Biddoccu et al., 2016). The rainiest seasons were spring and then winter, when more than 76% of the cumulative precipitation fell, whereas autumn and especially summer were drier than usual. The highest runoff coefficients were measured in spring (in CT) and winter (in GC). In CT sediment yield was much greater in winter than in other seasons, due to a single event (19-28/12/2013). Precipitation measured in 2014 was more than 40% greater than the above cited average. The 40% and 35% of annual precipitation were recorded in autumn and in winter, respectively. Highest runoff volumes and runoff coefficients were measured in winter in both plots.

3.3 Influence of rainfall and soil properties on runoff and sediment yield

Table 3 summarises the results of the PCA for the rainfall events and soil properties. More than 80% of the variance among events can be explained by four principal componets for CT (83%) and for GC (86%). The first principal component for CT represents 29% of the variance of the system and is a good indicator (loadings>0.90) of rainfall and runoff depth, and rainfall duration of the event. The intensity of the rainfall is highly correlated with the second principal component (26% of the variance). Sediment yield is also moderately correlated with this component. The antecedent precipitation (during the previous 7, 15 and 30 days) and the field-saturated hydraulic conductivity were the variables best correlated with the third and fourth component, respectively. The first principal component for the GC events (30% of the variance) is a good indicator of the rainfall and runoff depths, of rainfall duration and sediment yield. Initial soil water content and antecedent precipitation in the previous 30 and 15 days are moderately well-represented in the second principal component (21 % of the variance of the system). The PC3-GC component also represents 21% of the variance and it is well correlated with maximum rainfall intensity. The PC4-GC is highly correlated with field-saturated hydraulic conductivity and bulk density.

Figure 1 shows the rainfall events represented as individuals on the principal component plans, and classified by season. Fig.1a represents the events measured in the CT plot in the PC1_CT-PC2_CT plan. In the first quadrant larger rainfall events that produced highest runoff and sediment yield in CT are represented. They occurred in autumn and winter, when most precipitations greater than 100 mm and long duration (>60 hours) produced significant runoff and erosion, up to 4.9 Mg ha^{-1}. The highest runoff coefficients were recorded with rain causing snowmelt and also relevant erosion (29/1-13/2/2013 and 26/2-4/3/2013). Most of the high intensity and potentially erosive events (positive values of PC2_CT) occurred in summer and early autumn. In that period, runoff occurred when high intensity rainfall (Imax10>30 mm h^{-1}) was preceded by rainfall in the previous days. The storm event of 7-8/7/2014 occurred three days after another storm, which did not produce significant runoff. In the second event, 36 mm of rain fell with the highest 10-min intensity (59.15 mm h^{-1}) and produced 9.5 mm of runoff. This resulted in the highest erosion recorded during the period of observation (5.6 Mg ha^{-1}). Figure 1b shows events recorded in the GC plot in the PC1_GC-PC3_GC plan. Events represented in the first and fourth quadrant (PC1_GC>0) occurred in autumn and winter. Among them, events with P>90 mm produced high runoff (RC>20%) and erosion. Summer and spring events produced negligible runoff and erosion, even with high rainfall intensities.

Table 4 presents the summary of the multiple linear regression models for runoff and sediment yield variables. In predicting runoff, there is significant correlation with rainfall depth, with a higher determination coefficient for CT. The runoff model for GC included firstly the rainfall duration. The variables which were included in the following steps in the runoff model for CT were rainfall erosivity, maximum hourly intensity and 7-day antecedent precipitation. In predicting sediment yield there was a significant correlation with erosivity and rainfall depth. The second variable was the 7-day antecedent precipitation (lower determination coefficient for CT). Figure 2 shows the accuracy of the predictions with the best multiple linear regression models. The prediction models resulted in an overestimation of runoff and sediment yield. For the CT treatment this was particularly evident in autumn and winter events without snowfall.

3.4 Analysis of single events to identify the runoff occurrence and mechanism

Runoff was considered as *significant* when its depth was greater than 1 mm or greater than 2% of the rainfall depth: 14 and 9 rainfall events produced significant runoff in CT and GC, respectively. Some cases of surface runoff are shown in Figs.3 and 4. The orange lines represent the reference value of K_{fs} measured in the GC plot (discontinuous) and in the CT plot (continuous). In some cases K_{fs} reference values could not be represented in the graph, because of their greater order of magnitude, with respect to rainfall intensity. The blue lines represent the values of saturated soil water content for CT and GC. The grey band indicates the uncertainty range of sensors (3%). Green symbols indicate hourly mean values of soil water content measured by the sensors in the plots.

Fig. 3a represents a typical winter rainfall event which caused high runoff volumes both from CT and from GC. The rainfall event accounted for 216.2 mm of rainfall, with maximum 10-min rainfall intensity of 16.8 mm h^{-1}. Measured runoff coefficients and sediment yields accounted for 42% of rainfall depth and 4.9 Mg ha^{-1} in the CT plot, and 20% and 0.49 Mg ha^{-1} in the GC plot. Fig. 3b shows a spring event for which light runoff was measured, that caused little soil erosion. The rainfall intensity did not overcome K_{fs} in the plots, but soil water content increased to reach saturation of the soil surface and to generate light saturation-excess runoff in CT. The summer rainfall event in Fig. 3c accounted for 35.8 mm of rainfall. Although the rainfall intensity was the highest (59 mm h^{-1}), it did not overcome the K_{fs} minimum value in GC (106 mm h^{-1}). The fast increase of soil water content made the soil saturated in GC for most of the event duration, both in T than in NT, and little runoff (0.6 mm) was thus originated in this plot. An increase of the topsoil water content was also measured in CT, but saturation of the soil surface was not reached. Rainfall intensity overcame K_{fs} in CT, thus runoff caused by infiltration excess occurred (9.5 mm) in this plot. Sediment yield was very high in the tilled plot (5.6 Mg ha^{-1}) and negligible in the grassed vineyard.

Fig. 3d shows a rainfall occurring in autumn, before the execution of tillage. After the 10-minute rainfall intensity exceeded the K_{fs} measured in CT, 7.2 mm of runoff were recorded in this plot. Very low runoff (only 0.4 mm after the whole rainfall event) was measured in GC. For the same rainfall event 1-min rainfall intensity was also obtained from disdrometer records (Fig. 4a). The maximum 1-min rainfall intensity was near the 140 mm h^{-1} peak measured by the pluviometer of 34.8 mm h^{-1} (over 10-min interval). Erosion was detected in the two plots, and in CT it was nearly 40 times higher than in GC. Fig. 4b presents the 1-min rainfall intensity recorded during another event. The rainfall intensity peak did not exceed the K_{fs}: The soil in CT was tilled 20 days before the rainfall event, so its conductivity was assumed to be greater than 2800 mm h^{-1} and the mean K_{fs} measured in GC ranged between 395 mm h^{-1} and 967 mm h^{-1}. However, soil water content was close to the saturation level, due to the 236 mm of rainfall in the previous two weeks. Runoff appeared in the first hours of the event, when 1-min rainfall intensity was higher than 10 mm h^{-1} and soil was saturated in CT. Thus, runoff was due to saturation of the soil surface in CT. Within a few hours high rainfall intensity induced saturation of the upper horizon also in GC. When soil saturation was reached, both in CT and in CG, runoff depth increased in consequence of higher rainfall intensities. Sediment yield measured in the two plot was nearly 1.4 Mg ha^{-1} and 0.5 Mg ha^{-1} in CT and GC, respectively.

The rainfall depth of autumn and winter events which caused runoff due to saturation in CT ranged between 36 and 216 mm and the 10-min maximum rainfall intensity varied between 5 to 17 mm h^{-1}. The soil was wet, with soil water content between 0.267 and 0.382 cm^3cm^{-3} and it was characterized by K_{fs} greater than 1000 mm h^{-1} and bulk density of about 1.41 g cm^{-3}. The mean runoff coefficient which was observed in the CT plot for saturation runoff events occurring in autumn and winter was 79%. A light saturation-excess runoff was also detected in spring, with a very low rainfall depth (P=19.60 mm, Imax10 = 4.8 mm h^{-1}) and field-saturated hydraulic conductivity (minimum K_{fs} = 18.5 mm h^{-1}), and wet soil (SWC_{max} = 0.373 cm^3cm^{-3}). Rainfall events that caused Hortonian runoff in CT were characterized by 10-min maximum rainfall intensity ranging between 37 and 59 mm h^{-1} and rainfall depth from 14 to 36 mm. Although the K_{fs} values which were measured in autumn and winter in GC were the lowest (ranging between 41 mm h^{-1} and 85 mm h^{-1}), rainfall intensities in this period (maximum 10-min rainfall intensity ranging between 4 and 35 mm h^{-1}) did not cause Hortonian runoff.

Runoff occurred for 50% of the observations in CT and 20% in GC (Fig. 5a). Relationships between surface runoff type and the season of rainfall event occurrence was firstly examined, after identification of runoff occurrence on single events (Fig. 5b). Only saturation excess runoff was found during winter, both in CT and in GC. In spring runoff was detected only in CT, for 20% of the events. In autumn runoff was detected during 40% and 20% of the events, for CT and GC, respectively. Half of the runoff events which occurred in autumn in CT were due to Hortonian runoff. In summer less than 20% of the rainfall events caused saturation excess runoff in GC, whereas 50 % of the rainfall events produced Hortonian runoff in CT. Relationships between surface runoff frequency and some rainfall characteristics were examined in the following. Fig. 5c shows that surface runoff by infiltration excess was detected only in CT for 10-min maximum rainfall intensity higher than 20 mm h^{-1} and it occurred for 60% of rainfall events. In relation to the rainfall depth (Fig. 5d), rainfall events whose depth was lower than 20 mm, produced some Hortonian and saturation-excess runoff in CT, but no runoff in GC. Most of the Hortonian runoff events were induced in CT for rainfall events with a depth ranging from 20 to 40 mm. Every analyzed rainfall event greater than 40 mm produced surface runoff due to saturation excess in both plots. Finally, relationships are shown between surface runoff and soil water content at the rainfall occurrence (Fig. 5e) and field-saturated hydraulic conductivity (Fig. 5f). When soil water content was lower than 0.250 cm^3 cm^{-3}, no runoff was measured and detected in GC, and only Hortonian runoff appeared in CT. Both in CT and in GC, the frequency of saturation excess runoff increased as initial SWC_i was higher. In CT some cases of Hortonian runoff were detected with initial SWC_i greater than 0.250 cm^3cm^{-3}. In relation to the field-saturated hydraulic conductivity of the soil, the frequency of events that caused Hortonian runoff was about 30% for K_{fs}<100 mm h^{-1} in CT, whereas more than 70% of the rainfall events produced runoff due to saturation excess when K_{fs} >1000. On the contrary, most of the runoff events occurred in GC soil when K_{fs} was lower than 100 mm h^{-1}.

3. Discussions

4.1. Temporal and management effects on soil hydrological properties

With a few exception, soil water content was higher in the T position than in NT, so soil water saturation was reached sooner in the T position. The topsoil water content was always higher in GC than in CT, in both T and NT positions.

In both treatments, from late autumn and winter to spring, a decrease of bulk density was observed. Differences between T and NT were significant in CT, except for one month after autumn tillage.

Bagarello et al. (2014) measured K_{fs} of 838 mm h^{-1} and 7424 mm h^{-1}, in the clay soil of a Sicilian vineyard. In a sandy loam soil, previously tilled but then undisturbed over the 2 years of observation, Bagarello & Sgroi (2007) obtained mean values ranging from 20 mm h^{-1} to 952 mm h^{-1}, a range that was very similar to that the one obtained in the GC plot in the present study. The coefficients of variation obtained in this study were also comparable to those in Bagarello & Sgroi (2007).

During most of the sampling dates the mean values of K_{fs} in NT position were higher in CT than in GC. On the contrary, with the only exception of measurements carried out after the autumn tillage, the lowest mean values in the T position were observed in CT. In the T portion of the inter-row the increase in water infiltration with respect to GC was evident only within few weeks after the autumn tillage, whereas tillage was effective in increasing the hydraulic conductivity in the central portion of the inter-row for a longer period. From spring to autumn, hydraulic conductivity tended to be higher in CT than in GC in the central part of the inter-row, but it was lower in the T portion , showing mean K_{fs} values lower than 75 mm h^{-1}.

Both in CT and in GC, during summer and autumn, bulk density showed an increasing trend, and hydraulic conductivity a decreasing one, that was particularly evident in the T position. Such tendency was likely the effect of compaction, due to rainfall and especially to intense tractors traffic during farming and harvesting operations which were carried out in summer and early autumn. After harvest, mean hydraulic conductivity lower than 100 mm h^{-1} was observed in the GC plot and the lowest K_{fs} value (40.5 mm h^{-1}) was obtained in winter in the T position. The topsoil showed higher compaction and lower hydraulic conductivity after the productive season, especially after grape harvest. Indeed, worst conditions for water infiltration were observed during autumn (before tillage in CT) and also in winter for GC. In 2014 the CT topsoil showed higher sand content than in GC, whereas the clay content was the highest in GC. Since soil erosion by overland flow is a selective process (Alberts et al., 1980), the more intense erosion which was observed in CT rather than in GC in the period 2000-2013 (Biddoccu et al., 2016) may have caused the loss of the finest particles of soil in CT. Differences in field-saturated hydraulic conductivity, namely the higher values which were observed in the less compacted portion of the inter-row of the GC plot with respect to the CT plot, could also be related to these differences in the texture of the surface soil.

4.2. Impact of soil management, soil properties and rainfall on runoff

The seasonal and annual runoff amount was usually 2 to 3.6 times higher in CT than in GC. During summer 2013, which was relatively dry, no runoff was measured, whereas in summer 2014 the CT runoff was 38% higher than in GC. In 2013 the highest runoff was observed during spring, the most rainy season, both in CT and in GC. The highest differences in runoff between CT and GC occurred in summer and spring, when grass cover was higher.

In 2014, the highest runoff volumes and runoff coefficients were observed in winter, especially when snowfall was followed by rainfall. The seasonal runoff coefficient in CT was 83%, whereas it was 28% in GC. In CT, the winter season showed the highest runoff coefficient also during the previous decade (Biddoccu et al., 2014; Biddoccu et al., 2016).

Winter precipitation events had also the greatest values on the PC1 axis in Fig.1. Despite the autumn tillage, runoff was much more abundant in CT than in GC, if one or more rainfall events had already occurred after the execution of tillage. In CT the runoff response to autumn and winter relevant rainfall events was confirmed by the single event analysis, carried out to identify the type of runoff that was originated. Among the events for which runoff was identified, all the winter precipitation events and 20% of the autumn events caused runoff due to topsoil saturation. In both

CT and GC the highest runoff coefficients were observed during events when precipitation included snowfall. Saturation excess runoff was mainly observed after tillage, in late autumn, despite K_{fs} showing the highest mean values. The water infiltration could be limited at greater depth, because of the subsoil compaction. In tilled vineyards van Dijk & van Asch (2002) measured in the subsoil higher bulk density and penetration resistance than in the topsoil, due to the effect of compaction of wheel load in tilled vineyards. In autumn and winter the grass cover was less effective in reducing runoff than in other seasons, however runoff measured in GC was at least more than 50% lower than in CT.

The multiple linear model showed the variable response of the CT plot to rainfall characteristics, in relation to the main mechanism that generated runoff. Runoff was mainly correlated with precipitation amount, and also moderately correlated with EI30, maximum hourly rainfall intensity and 7-day antecedent precipitation. In CT, runoff was generated by infiltration excess during rainfall events characterized by short duration and low depth, and relevant rainfall intensities and erosivity, that typically occurred in summer and early autumn (before the execution of tillage), especially when some precipitation was recorded in the previous 7 days.

On the contrary, only duration and depth of the precipitation event were correlated with runoff in GC, which occurred mainly during large events, because of the saturation-excess effect. Indeed, infiltration-excess runoff was not identified by the rainfall-runoff event analysis in GC, even in summer. Despite the low hydraulic conductivity, runoff was caused by saturation of topsoil, as shown by the fast increase of soil water content up to the saturation level.

In summer, the very low hydraulic conductivity of the topsoil in the CT plot was likely due also to the presence of a structural crust, which was observed after first rainfall events following the late-spring tillage. As Pare et al. (2011) reported in tilled vineyards, cumulative rainfall and kinetic energy are the main predicting factors of soil reconsolidation, especially from the fresh tillage to crusting. During summer the gradual increase of crusting and compaction due to the tractors traffic made the runoff larger in CT than in GC.

The analysis of runoff occurrence of each single event was carried out by comparing soil water content time series with the saturated values obtained in T and NT positions. Similarly the rainfall intensity time series were compared with K_{fs}. During most of the events, the value which was overcome determining the runoff occurrence, was the value of saturated water content (in case of saturation-excess runoff) or K_{fs} (in case of Hortonian runoff), in the T position. This effect was especially evident in summer, when infiltration-excess runoff occurred in CT and not in GC, in consequence of the lower K_{fs} in the T position. The winter rainfall-runoff events represented the most frequent exception to this, because the differences between values of K_{fs} and SWC_s were not significant between the two positions.

4.3. Impact of soil management and rainfall characteristics on sediment yield

Sediment yields of 5.3 and 9.3 Mg ha^{-1} were measured during the two years, respectively, in the CT plot. The average value was close to 7.4 Mg ha^{-1} year^{-1}, of the period 2000-2012 for the same plot (Biddoccu et al., 2016). Tropeano (1984) reported annual soil loss of 47.4 Mg ha^{-1} in a tilled vineyard in Piedmont and annual sediment yields of 31.4 and 88.71 Mg ha^{-1} were measured in 2 years of observation in a tilled vineyard in Sicily (Novara et al., 2011). In 2013 erosion was higher in CT than in GC in each season. During the most erosive winter event, erosion in CT was 10 times greater than in GC. Also in 2014 seasonal erosion was greater in CT than in GC. In GC annual soil erosion was 1.5 Mg ha^{-1} in 2013, and 1.0 Mg ha^{-1}, in 2014, lower than the mean observed in 2000-2012, of 1.8 Mg ha^{-1} year^{-1}. Annual sediment yield in GC was 72 and 89% less than in CT. The difference between CT and GC was greater than in other studies. Novara et al. (2011) observed that the use of different cover crops in the inter-row reduced soil losses by 56%. Ruiz-Colmenero et al. (2011), in a 2-year study at plot scale, observed that vineyards with a cover crop lost between 50% and 75% less soil than with tilled soil.

Differences among seasonal amounts of sediment yields were due to the variability of rainfall during the years. Seasonal distribution of rainfall, runoff and soil erosion in 2014 was similar to the period 2000-2013 (Biddoccu et al., 2016). Nevertheless in both years just a single event per year had a great influence in determining the annual sediment yield. In 2013 the rainfall event which occurred in the period 19-28/12/2013 was the largest (216.2 mm). It was the most erosive event observed in GC during the study, and the second most erosive event measured in CT, where it caused 93% of the annual erosion. In 2014, the highest erosion occurred during the summer storm on 7-8/7/2014, when the rainfall of highest intensity (59 mm h^{-1} over 10 minutes) caused more than 5.6 Mg ha^{-1} of sediment yield in CT, whereas in GC only 9 kg ha^{-1}. Those two extreme events, with the highest precipitation depth and 10-min maximum intensity, respectively, caused the highest erosion. These results confirmed the observation of Gómez et al. (2014) and Gonzàlez-Hidalgo et al. (2009). The multiple linear model predicting sediment yield in CT showed the highest correlation with erosivity, which depends on the 30-min rainfall intensity and on the energy of precipitation, and then with the 7-day antecedent precipitation. Hortonian runoff was mainly observed in summer and early autumn, for rainfall events with 10-min maximum intensity greater than 20 mm h^{-1}, and with significant the 7-day antecedent rainfall. In those cases, although runoff coefficients were limited (average value of 7%), sediment yield ranged between 289 kg ha^{-1} and 5658 kg ha^{-1}. Apart from the first precipitation event after tillage, most of the events in autumn and winter generated saturation-excess runoff in CT, whose rates were greater than 42%, and caused sediment yield up to 4.9 Mg ha^{-1}.

The high correlation between sediment yield and erosivity for CT was related to the absence of soil protection and low hydraulic conductivity in summer and early autumn, when most intense and erosive rainfall was observed. Nevertheless, high erosivity is also related to the rainfall energy, that is high for large precipitation events in autumn and winter. Similarly to this study, Raclot et al. (2009), in tilled vineyards, at event temporal scale and at field spatial scale, found significant correlation between total suspended sediment and rainfall depth and between erosion and maximum rainfall intensity over a 5-min period.

In GC in summer and early-autumn negligible erosion was observed. The protective role of grass was little effective when saturation-excess runoff was generated by large precipitation events. In autumn and winter, when grass is sparse and soil is more compacted and less conductive than in summer (runoff coefficients and erosion up to 53% and 1181 kg ha^{-1}). The multiple linear model showed sediment yield mainly correlated with precipitation depth, and, secondly, to rainfall in the previous 7 days. The sediment yield during single events, in any case, was lower than in CT. The results obtained in the GC plot were similar to those of Gómez et al. (2014) in a grassed olive orchard, with higher correlation between sediment yield and rainfall depth than with rainfall erosivity and short term intensity. They also observed the largest erosive events in GC in late autumn and winter, when grass cover is scarce and soil compacted after the productive season.

4. Conclusions

The soil management effects on soil hydraulic conductivity, bulk density, soil moisture, runoff and water erosion were evaluated in a two-year period in two vineyard field-scale plots, where inter-rows were managed with conventional tillage and grass cover, respectively. Eighty infiltration tests were carried out and a dataset of 29 rainfall-runoff events was collected, covering a wide range of topsoil characteristics.

The results highlighted how the tillage increased field-saturated hydraulic conductivity only for a short period. It tended to be higher in CT than in GC in the central part of the inter-row, but in track it quickly decreased to such low values that Hortonian runoff was produced during intense summer storms. Sediment yield in the tilled plot was up to 9 times higher than in the grass cover plot. Due to high compaction after grape harvest, the worst condition for infiltration were found before autumn tillage in CT and in autumn and winter for GC. The main runoff events were related to the saturation-excess mechanism, which was the only one observed in the GC plot and that was frequently observed in the tilled one, particularly in late autumn and in long-duration winter precipitation events. Despite the autumn tillage, in CT the winter 2014 runoff reached 83% of the precipitation amount and was nearly 4 times greater than in the grassed plot. The largest runoff occurred in case of snowfall events followed by rainfall. Very high sediment yield in the tilled plot was mainly related to rainfall intensity (during summer storm) and rainfall depth (in autumn and winter). The annual reduction of runoff in the grassed plot was 63% in comparison with the tilled plot. In autumn and winter the grass cover was less effective in reducing runoff than in summer. Erosion was relevant in winter when large saturation-excess runoff was generated by long-lasting rainfall and snowfall. However, the grass cover was effective in reducing annual soil losses (up to 90%) and especially during most erosive events that occurred in summer and early-autumn.

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Table 1 – Mean values and coefficient of variation (CV, %) of the bulk density (BD), initial soil water content (SWC_i) and field-saturated hydraulic conductivity(K_{fs}) measured with the SFH techniques on each sampling date in the CT and GC treatments in track (T) and no-track (NT) positions. Geometric mean was used for K_{fs}. Bold values are different between positions according to t-test at p=0.05 level. Different letters indicate significant differences between treatments according to t-test at p=0.05 level.

CT		From Tillage Days	P (mm)	BD (g cm^{-3})		SWCi (cm^{3}cm^{-3})		K_{fs} (mm^{-1})		GC		From Tillage Days	R (mm)	BD (g cm^{-3})		SWCi (cm^{3}cm^{-3})		K_{fs} (mm h^{-1})	
				NT	T	NT	T	NT	T					NT	T	NT	T	NT	T
Oct-12	Mean	158	141.2	**1.30**	**1.50**	**0.251**	**0.300**	**71.0**	**31.3**										
	CV (%)			6.2	7.3	6.1	4.3	29.9	53.0										
Nov-12	Mean	21	139.2	1.34	1.41	0.351	0.357	2886.2 **a**	3747.3 a	Dec-12	Mean	42	259.0	1.35	1.41	**0.332**	**0.405**	251.1 **b**	40.5 **b**
	CV (%)			8.2	5.5	4.5	4.4	39.1	102.1		CV (%)			2.98	9.79	6.3	2.1	186.4	154.4
May-13	Mean	202	698.6	**1.19**	**1.38**	0.267	0.315	**770.1 a**	**63.6 a**	May-13	Mean	202	698.6	1.18	1.29	0.270	0.314	427.5 **a**	153.6 **a**
	CV (%)			2.1	7.2	4.5	17.4	34.8	8.6		CV (%)			5.82	11.47	9.8	30.4	45.9	93.6
Jul-13	Mean	34	16.2	1.32	1.41	0.167	0.188	486.87 **a**	44.69 a	Jul-13	Mean	37	16.2	1.31	1.48	**0.098**	**0.187**	105.6 **a**	156.7 **a**
	CV (%)			7.0	3.0	17.4	31.6	25.4	102.0		CV (%)			8.22	6.22	19.8	9.3	55.5	152.0
Sep-13	Mean	93	88.2	**1.25**	**1.45**	0.158	0.174	**332.6 a**	**10.0 a**	Sep-13	Mean	92	88.2	1.27	1.42	0.191	0.224	93.7 **a**	85.2 **a**
	CV (%)			1.1	2.0	4.9	17.1	49.5	11.0		CV (%)			0.74	9.71	20.4	11.6	95.1	120.5
Oct-13	Mean	133	137.4	**1.31**	**1.55**	0.270	0.297	**1456.3 a**	**74.4 a**	Oct-13	Mean	134	137.4	1.34	1.42	0.291	0.336	**591.8 b**	**99.0 a**
	CV (%)			1.2	2.7	11.7	5.2	17.2	12.2		CV (%)			5.35	2.97	5.7	0.0	27.8	25.2
May-14	Mean	184	740.6	**1.28**	**1.51**	0.249	0.233	**87.1 a**	**18.5 a**	May-14	Mean	183	740.6	1.24	1.37	0.255	0.265	525.8 **b**	423.9 **b**
	CV (%)			5.8	2.8	8.8	26.1	31.9	45.7		CV (%)			12.88	7.60	17.8	4.5	126.8	37.2
Oct-14	Mean	156	246.2	1.25	1.47	0.267	0.324	**1343.5 a**	**20.5 a**	Oct-14	Mean	157	246.2	1.24	1.37	0.317	0.323	967.4 **a**	394.7 **b**
	CV (%)			6.2	0.5	14.3	0.4	63.1	75.6		CV (%)			6.42	4.76	13.8	20.1	91.3	63.1

Table 2 – Seasonal and annual records from the experimental vineyard plots (conventional tillage, CT; grass cover, GC) in 2013 and 2014: Precipitation (including snowfall in winter), runoff (RO), runoff coefficient (RC), sediment yield (SY).

			CT						GC					
	Precipitation (mm)		RO (mm)		RC (%)		SY (kg ha^{-1})		RO (mm)		RC (%)		SY (kg ha^{-1})	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Winter	323.2	433.4	108.2	358.4	33	83	4982	1806	51.0	123.4	16	28	498	440
Spring	421.0	125.0	214.1	2.0	51	2	222	2	58.1	0.8	14	1	996	1
Summer	66.8	171.8	0.0	21.4	0	12	0	5657	0.0	1.6	0	1	0	9
Autumn	159.8	480.0	3.1	196.7	2	41	107	1911	1.4	86.0	1	18	6	593
Total	970.8	1210.2	325.5	578.5	34	48	5311	9377	110.5	211.9	11	18	1501	1043

Table 3 – Results of factor analysis of the rainfall events variables and soil variables measured in the two plots, for the extraction of principal components. Values in *italic* and **bold** indicated the moderately high (>0.70) and high (>0.90) loadings. (CT = conventional tilled, GC = grass cover, I max X min = maximum intensity in X min, EI30 = erosivity, RO = runoff, RC = runoff coefficient, SY = sediment yield, Ant. Prec. Y days = antecedent precipitattion in previous Y days, SWC = soil water content, K_{fs} = field-saturated hydraulic conductivity, BD = bulk density).

CT	PC1-CT	PC2-CT	PC3-CT	PC4-CT	GC	PC1-GC	PC2-GC	PC3-CT	PC4-CT
Precipitation	**0.971**	0.096	-0.018	-0.001	Precipitation	**0.966**	0.117	0.058	-0.103
Precip. duration	**0.925**	-0.201	0.035	-0.112	Precip. duration	**0.904**	0.161	-0.206	0.106
I max 10 min	-0.235	**0.870**	-0.208	0.021	I max 10 min	-0.173	-0.207	**0.914**	0.005
I max 30 min	-0.220	**0.909**	-0.194	0.058	I max 30 min	-0.112	-0.190	**0.960**	-0.039
I max 60 min	-0.089	**0.950**	-0.141	0.113	I max 60 min	0.039	-0.112	**0.957**	-0.082
EI30	0.275	**0.915**	-0.109	0.015	EI30	0.677	-0.069	0.641	-0.144
RO CT	**0.964**	0.011	0.037	-0.045	RO GC	**0.930**	0.166	-0.090	0.150
RC CT	*0.899*	0.066	0.287	-0.033	RC GC	*0.798*	0.383	-0.156	0.234
SY_CT	0.111	*0.787*	0.251	-0.077	SY_GC	**0.915**	-0.116	0.034	0.091
Ant. Prec. 7 days	-0.148	0.002	*0.780*	0.003	Ant. Prec. 7 days	-0.001	*0.708*	0.023	-0.386
Ant. Prec. 15 days	0.159	-0.223	*0.703*	0.002	Ant. Prec. 15 days	-0.041	**0.824**	-0.191	-0.062
Ant. Prec.30 days	0.460	-0.220	*0.719*	-0.218	Ant. Prec.30 days	0.124	**0.826**	-0.247	0.302
Ant. Prec. 45 days	*0.709*	-0.250	0.521	-0.209	Ant. Prec. 45 days	0.324	*0.701*	-0.322	0.381
SWC CT	0.141	0.130	0.605	0.448	SWC GC	0.226	**0.830**	-0.070	0.017
K_{fs} CT	-0.102	-0.014	0.031	**0.964**	K_{fs} GC	-0.013	0.089	0.019	**-0.921**
BD CT	0.368	-0.086	0.504	-0.513	BD GC	0.179	0.132	-0.084	**0.906**
Eigenvalues	4.661	4.181	2.773	1.522	Eigenvalues	4.797	3.389	3.377	2.195
Accumulated variance	29.134	26.130	17.330	9.514	Accumulated variance	29.982	21.183	21.106	13.716

Table 4 – Summary of the stepwise multiple linear regression model for runoff and sediment yield in the two plots (R^2_{adj} = adjusted coefficient of determination, EI30 = erosivity, I max 60 min = maximum intensity in 60 min, Ant. Prec.7 days = antecedent rainfall in previous 7 days).

Runoff Conventional Tillage

Variable	Step	Value	R^2_{adj}	Increase in R^2_{adj}	Sign.
Intercept		-40.939			
Precipitation	1	1.366	0.899	0.899	
EI30	2	-0.387	0.918	0.019	0.000
I max 60 min	3	3.488	0.947	0.029	0.000
Ant. Prec.7 days	4	0.337	0.957	0.010	0.000

Runoff Grass Cover

	Step	Value	R^2_{adj}	Increase in R^2_{adj}	Sign.
Intercept		-6.798			
Precipitation duration	1	0.230	0.769	0.769	0.000
Precipitation	2	0.129	0.810	0.041	0.000

Sediment Yield Conventional Tillage

Variable	Step	Value	R^2_{adj}	Increase in R^2_{adj}	Sign.
Intercept		-855.559			
EI30	1	13.696	0.507	0.507	0.000
Ant. Prec. 7 days	2	32.758	0.585	0.078	0.000

Sediment Yield Grass Cover

	Step	Value	R^2_{adj}	Increase in R^2_{adj}	Sign.
Intercept		-33.434			
Precipitation	1	1.882	0.753	0.753	0.000
Ant. Prec.7 days	2	-1.335	0.819	0.066	0.000

Figure captions

Fig.1 – Representation of events as individuals on the principal component plan, classified by season. (a) Rainfall events associated with runoff-erosion and soil characteristics measured in the CT plot represented in the PC1_CT-PC2_CT plan and (b) Rainfall events associated with runoff-erosion and soil characteristics measured in the GC plot represented in the PC1_GC-PC3_GC plan. Different symbols indicate season of rainfall occurrence.

Fig.2 – Comparison of values observed and predicted by the multiple linear regression models for (a) runoff in the CT plot, (b) sediment yield in the CT plot, (c) runoff in the GC plot, (b) sediment yield in the GC plot.

Fig.3 – Examples of runoff detection graphs with pluviometer data (10 minutes step) for some rainfall events. R= rain intensity at 10 min step, SWC = measured volumetric soil water content (1 hour step), SWCs = reference value of saturated water content, K_{fs} = reference value of field-saturated hydraulic conductivity, RO cum = cumulated measured runoff, P = total event precipitation, I10 = maximum rain intensity at 10 min step, P7 = antecedent precipitation at 7-day step, RO= measured runoff , SY = measured sediment yield.

Fig.4 – Examples of runoff detection graphs with disdrometer data (1 minutes step) for some rainfall events. TotalPIntensity_1min= rain intensity at 1 min step, SWC = measured volumetric soil water content (1 hour step) in the plot, SWCs = reference value of saturated water content, K_{fs} = reference value of field-saturated hydraulic conductivity, RO cum = cumulated measured runoff, P = total event precipitation, I1 = maximum rain intensity at 1 min step, P7 = antecedent precipitation at 7-day step, RO = measured runoff plot, SY= measured sediment yield, T = track position, NT = no track position.

Fig.5 – Influence of soil management (a), season (b), rainfall maximum intensity (c), rainfall depth (d), initial soil water content (e) and field-saturated hydraulic conductivity (f) on the surface runoff occurrence and type of runoff. Each bar represents the totality of analyzed events for each category, and among those events they indicate the fractions of: (i) events without runoff occurrence (No runoff, blue bars), (ii) events for which hortonian runoff was detected (red bars), (iii) events for which saturation-excess runoff was identified (green bars).

Figure1

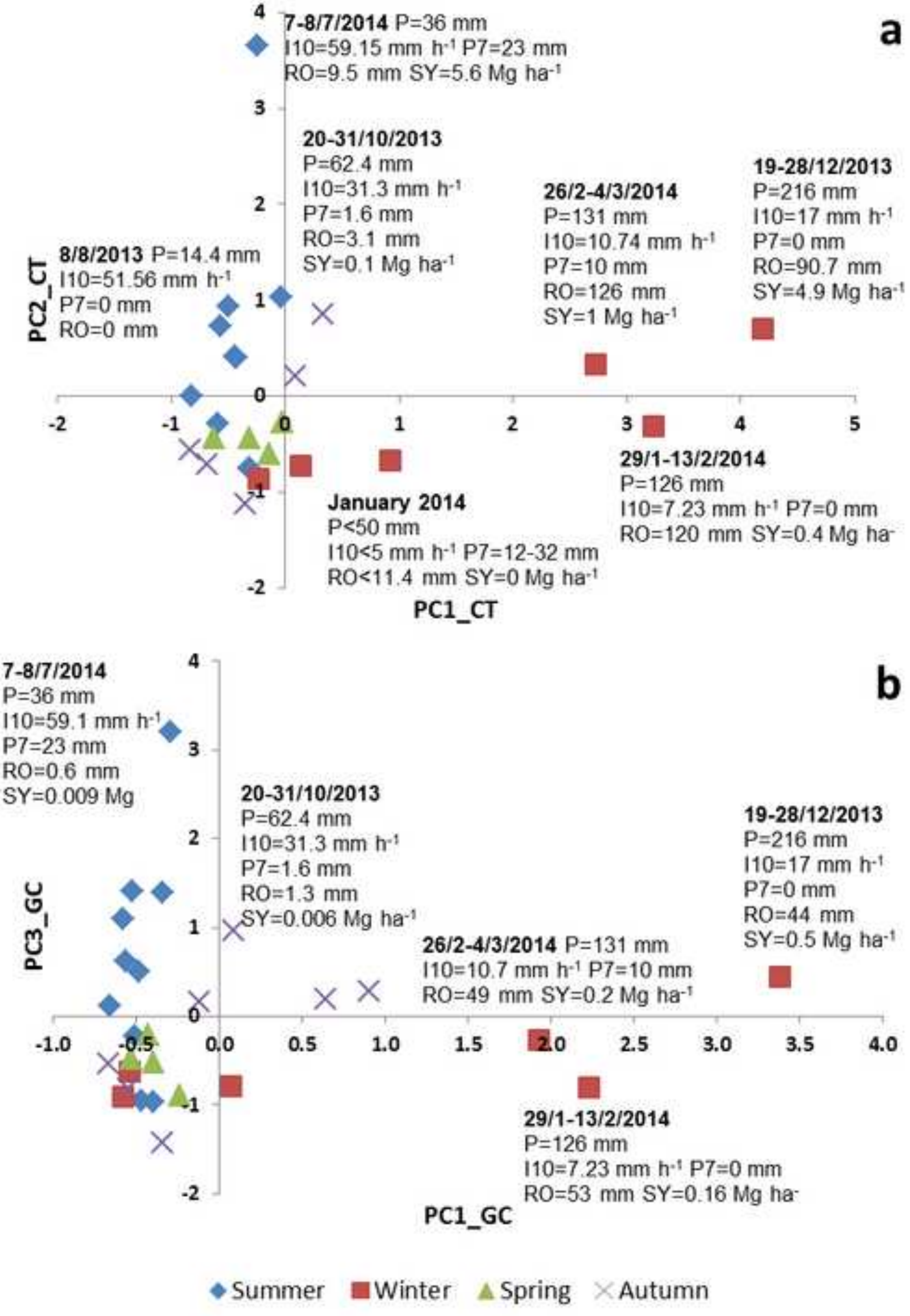

a
7-8/7/2014 P=36 mm
I10=59.15 mm h-1 P7=23 mm
RO=9.5 mm SY=5.6 Mg ha-1
20-31/10/2013
P=62.4 mm
I10=31.3 mm h-1
P7=1.6 mm
RO=3.1 mm
SY=0.1 Mg ha-1
26/2-4/3/2014
P=131 mm
I10=10.74 mm h-1
P7=10 mm
RO=126 mm
SY=1 Mg ha-1
19-28/12/2013
P=216 mm
I10=17 mm h-1
P7=0 mm
RO=90.7 mm
SY=4.9 Mg ha-1
8/8/2013 P=14.4 mm
I10=51.56 mm h-1
P7=0 mm
RO=0 mm
29/1-13/2/2014
P=126 mm
I10=7.23 mm h-1 P7=0 mm
RO=120 mm SY=0.4 Mg ha-
January 2014
P<50 mm
I10<5 mm h-1 P7=12-32 mm
RO<11.4 mm SY=0 Mg ha-1
PC2_CT
PC1_CT
4
3
2
1
0
-1
-2
-2
-1
0
1
2
3
4
5
b
7-8/7/2014
P=36 mm
I10=59.1 mm h-1
P7=23 mm
RO=0.6 mm
SY=0.009 Mg
20-31/10/2013
P=62.4 mm
I10=31.3 mm h-1
P7=1.6 mm
RO=1.3 mm
SY=0.006 Mg ha-1
19-28/12/2013
P=216 mm
I10=17 mm h-1
P7=0 mm
RO=44 mm
SY=0.5 Mg ha-1
26/2-4/3/2014 P=131 mm
I10=10.7 mm h-1 P7=10 mm
RO=49 mm SY=0.2 Mg ha-1
29/1-13/2/2014
P=126 mm
I10=7.23 mm h-1 P7=0 mm
RO=53 mm SY=0.16 Mg ha-
PC3_GC
PC1_GC
4
3
2
1
0
-1
-2
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
◆ Summer
■ Winter
▲ Spring
✕ Autumn

Figure2

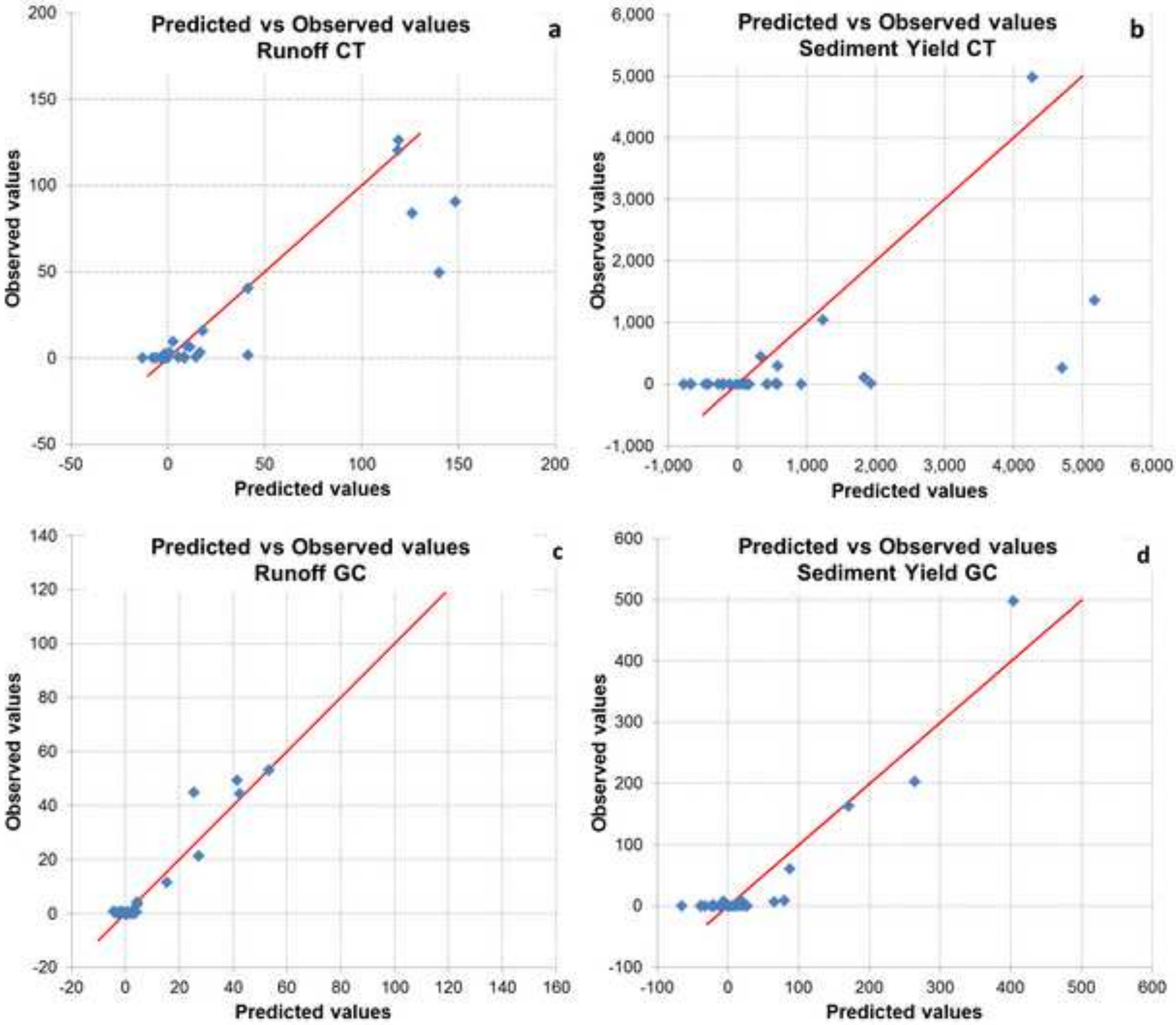

Predicted vs Observed values
Runoff CT
a
Observed values
Predicted values
200
150
100
50
0
-50
-50
0
50
100
150
200
Predicted vs Observed values
Sediment Yield CT
b
Observed values
Predicted values
6,000
5,000
4,000
3,000
2,000
1,000
0
-1,000
-1,000
0
1,000
2,000
3,000
4,000
5,000
6,000
Predicted vs Observed values
Runoff GC
c
Observed values
Predicted values
140
120
100
80
60
40
20
0
-20
-20
0
20
40
60
80
100
120
140
160
Predicted vs Observed values
Sediment Yield GC
d
Observed values
Predicted values
600
500
400
300
200
100
0
-100
-100
0
100
200
300
400
500
600

Figure3a

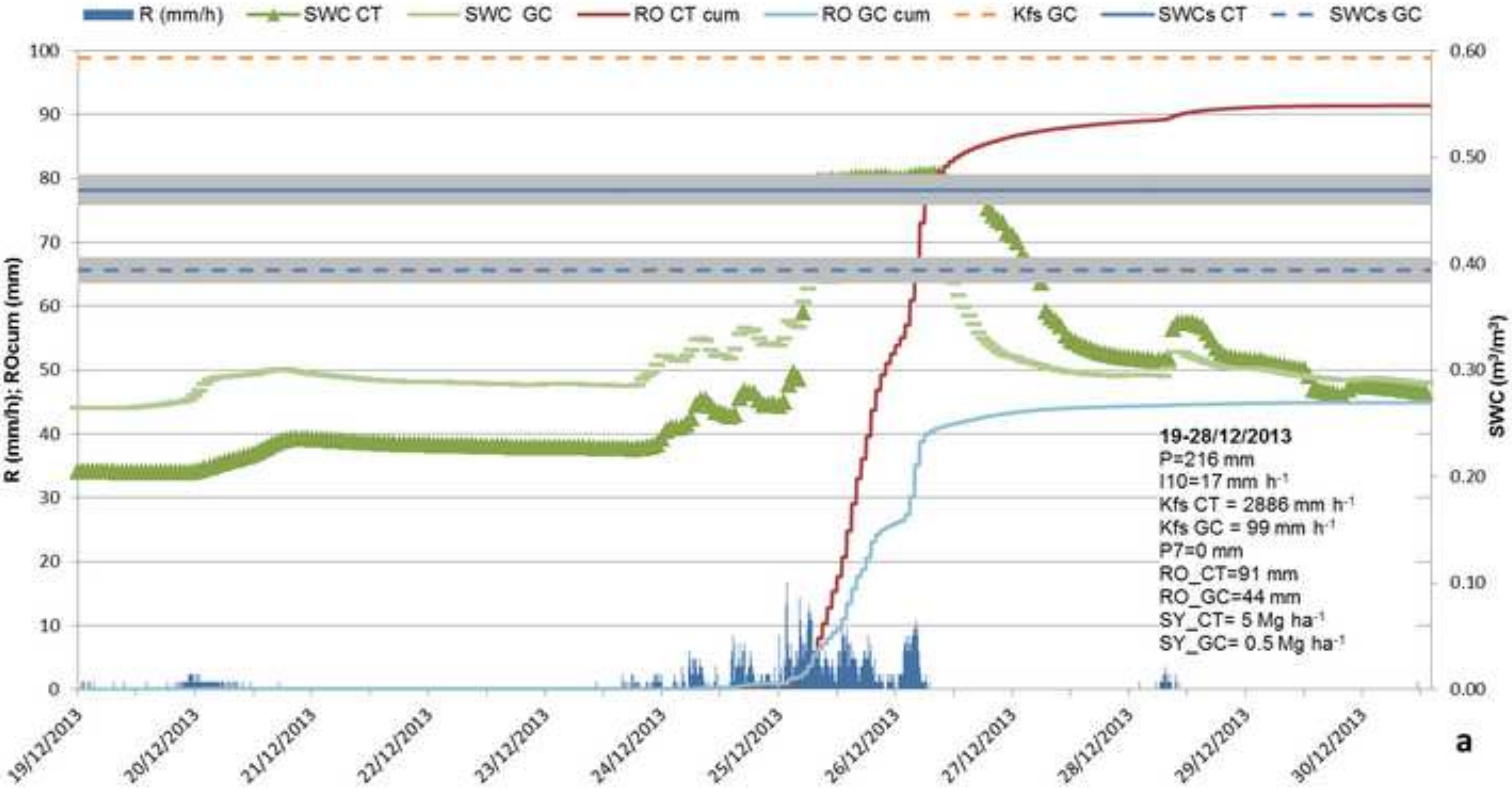
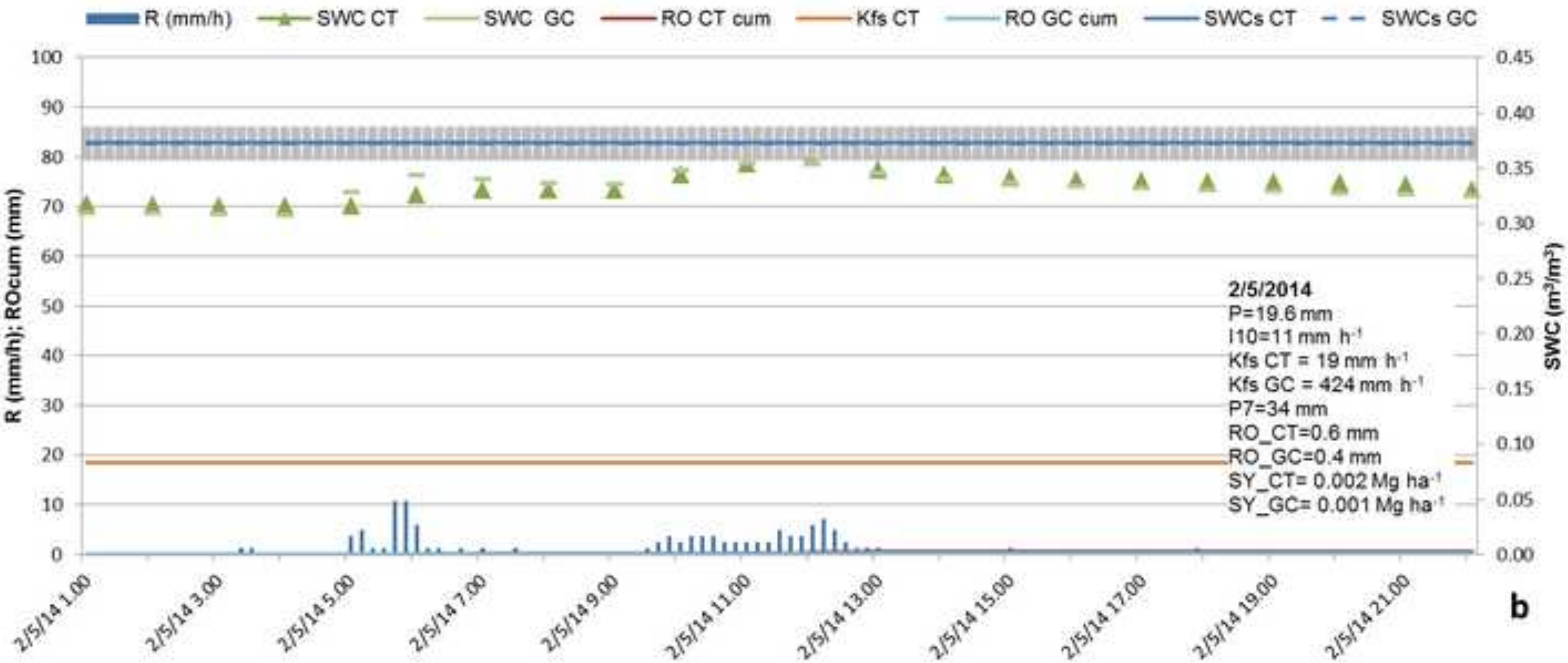

R (mm/h)
SWC CT
SWC GC
RO CT cum
RO GC cum
Kfs GC
SWCs CT
SWCs GC
R (mm/h); ROcum (mm)
SWC (m^3/m^3)
100
90
80
70
60
50
40
30
20
10
0
0.60
0.50
0.40
0.30
0.20
0.10
0.00
19/12/2013
20/12/2013
21/12/2013
22/12/2013
23/12/2013
24/12/2013
25/12/2013
26/12/2013
27/12/2013
28/12/2013
29/12/2013
30/12/2013
19-28/12/2013
P=216 mm
I10=17 mm h^{-1}
Kfs CT = 2886 mm h^{-1}
Kfs GC = 99 mm h^{-1}
P7=0 mm
RO_CT=91 mm
RO_GC=44 mm
SY_CT= 5 Mg ha^{-1}
SY_GC= 0.5 Mg ha^{-1}
a

Figure3b



2/5/2014
P=19.6 mm
I10=11 mm h^{-1}
Kfs CT = 19 mm h^{-1}
Kfs GC = 424 mm h^{-1}
P7=34 mm
RO_CT=0.6 mm
RO_GC=0.4 mm
SY_CT= 0.002 Mg ha^{-1}
SY_GC= 0.001 Mg ha^{-1}

Figure3c

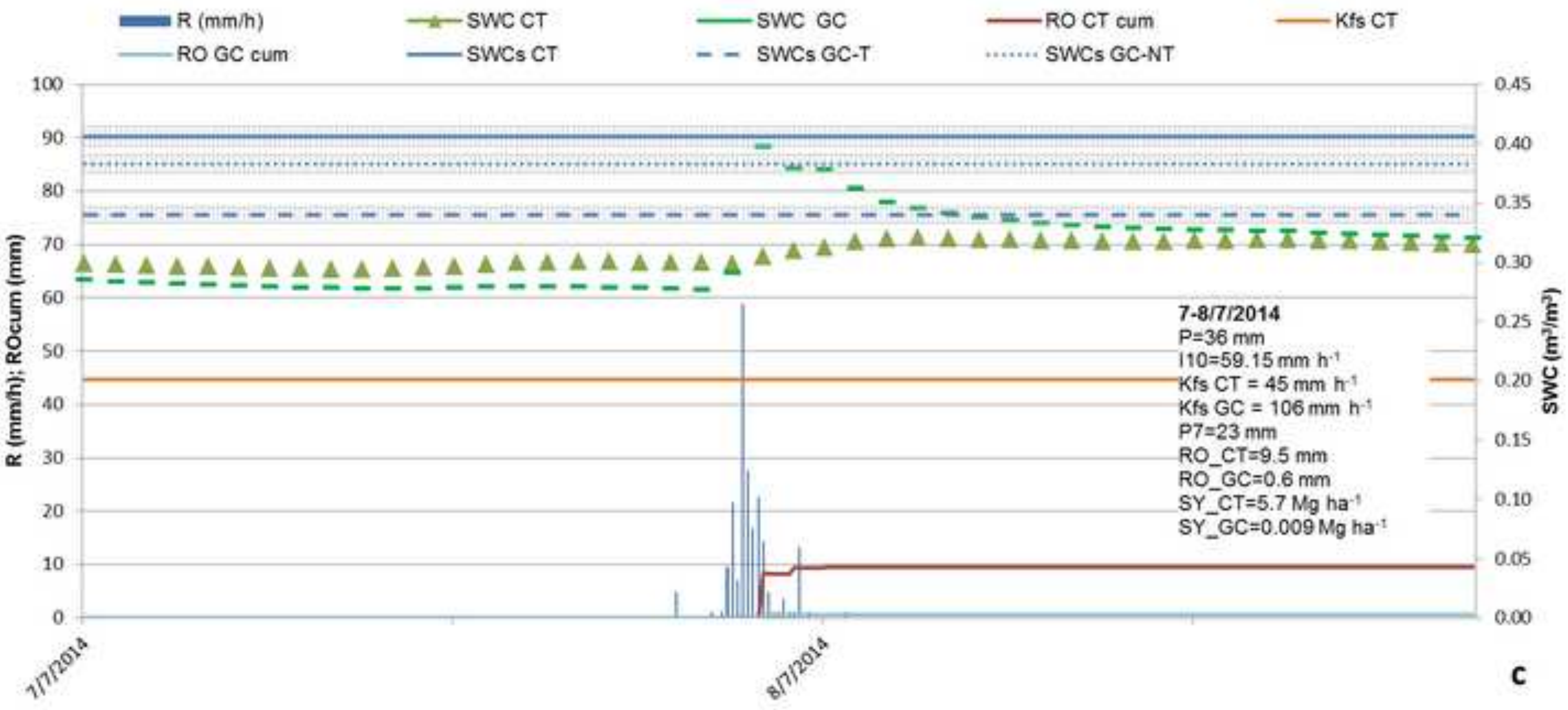
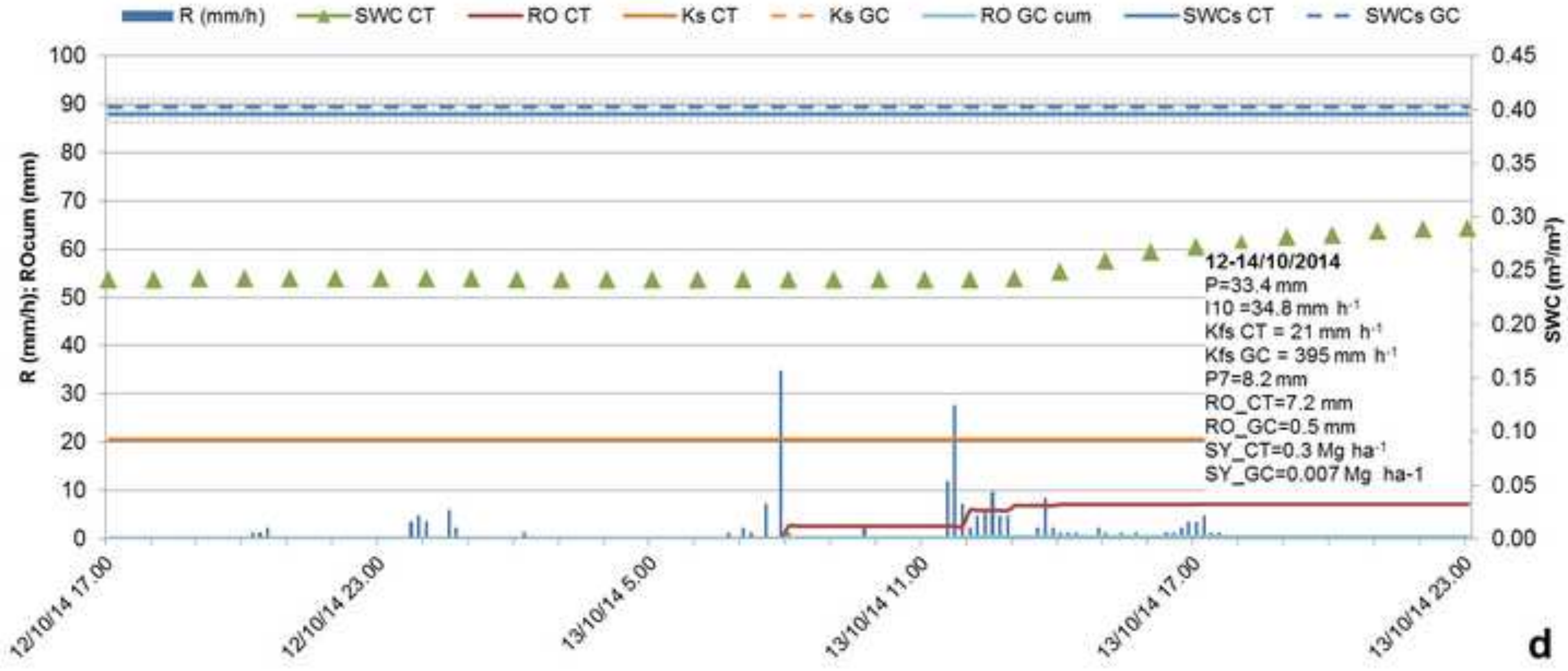
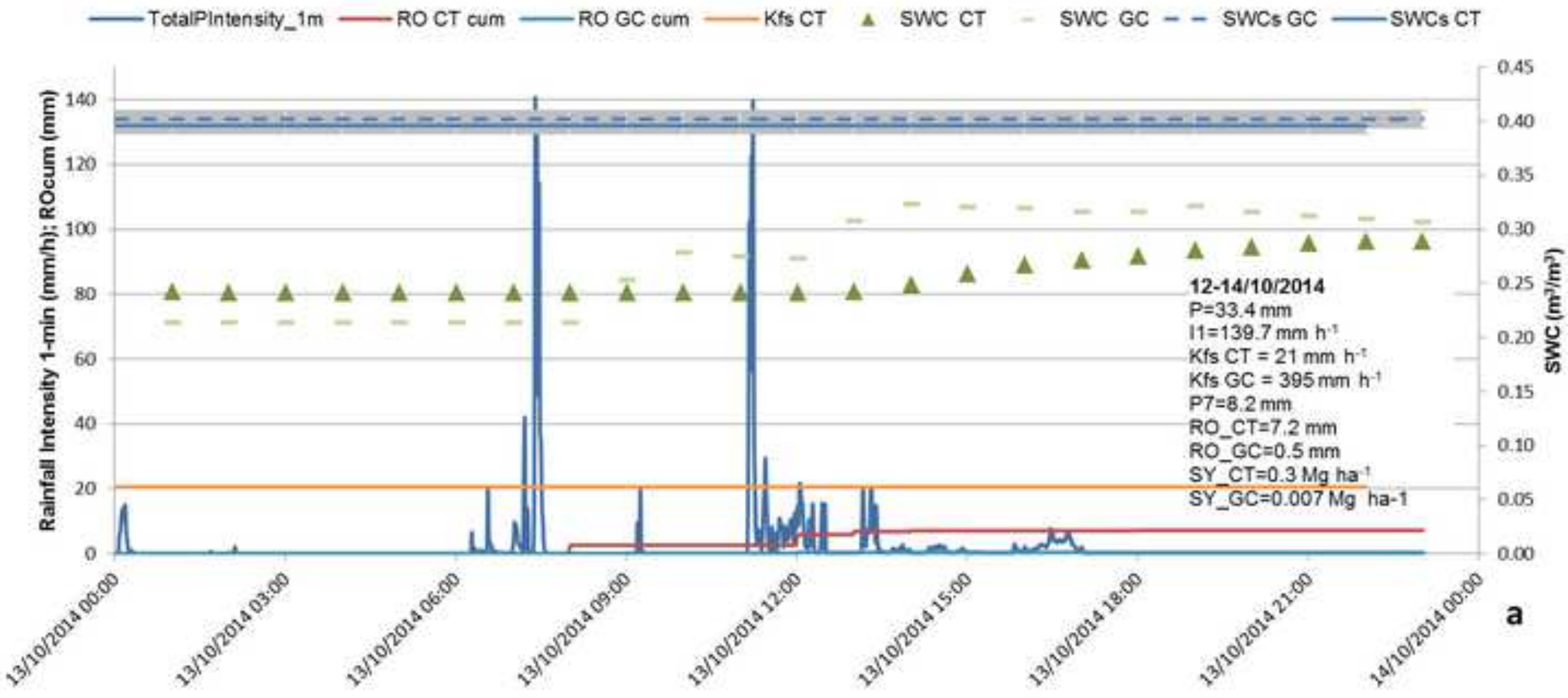

R (mm/h)
SWC CT
SWC GC
RO CT cum
Kfs CT
RO GC cum
SWCs CT
SWCs GC-T
SWCs GC-NT
R (mm/h); ROcum (mm)
100
90
80
70
60
50
40
30
20
10
0
SWC (m^3/m^3)
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
7/7/2014
8/7/2014
7-8/7/2014
P=36 mm
I10=59.15 mm h^{-1}
Kfs CT = 45 mm h^{-1}
Kfs GC = 106 mm h^{-1}
P7=23 mm
RO_CT=9.5 mm
RO_GC=0.6 mm
SY_CT=5.7 Mg ha^{-1}
SY_GC=0.009 Mg ha^{-1}
c

Figure3d



12-14/10/2014
P=33.4 mm
I10 =34.8 mm h^{-1}
Kfs CT = 21 mm h^{-1}
Kfs GC = 395 mm h^{-1}
P7=8.2 mm
RO_CT=7.2 mm
RO_GC=0.5 mm
SY_CT=0.3 Mg ha^{-1}
SY_GC=0.007 Mg ha-1

Figure4a



12-14/10/2014
P=33.4 mm
I1=139.7 mm h^{-1}
Kfs CT = 21 mm h^{-1}
Kfs GC = 395 mm h^{-1}
P7=8.2 mm
RO_CT=7.2 mm
RO_GC=0.5 mm
SY_CT=0.3 Mg ha^{-1}
SY_GC=0.007 Mg ha-1

Figure4b

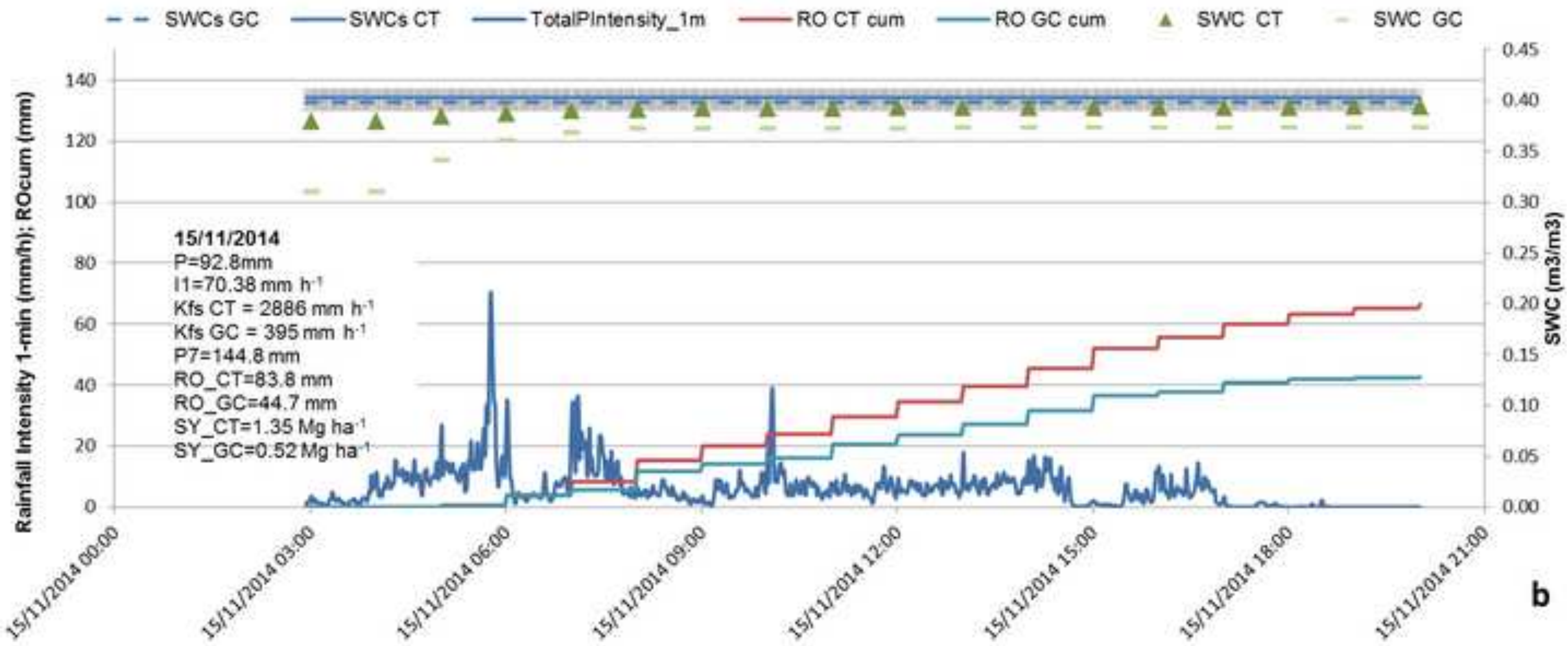

SWCs GC
SWCs CT
TotalPIntensity_1m
RO CT cum
RO GC cum
SWC CT
SWC GC
Rainfall Intensity 1-min (mm/h); ROcum (mm)
0
20
40
60
80
100
120
140
SWC (m3/m3)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
15/11/2014
P=92.8mm
I1=70.38 mm h-1
Kfs CT = 2886 mm h-1
Kfs GC = 395 mm h-1
P7=144.8 mm
RO_CT=83.8 mm
RO_GC=44.7 mm
SY_CT=1.35 Mg ha-1
SY_GC=0.52 Mg ha-1
15/11/2014 00:00
15/11/2014 03:00
15/11/2014 06:00
15/11/2014 09:00
15/11/2014 12:00
15/11/2014 15:00
15/11/2014 18:00
15/11/2014 21:00
b

Figure5

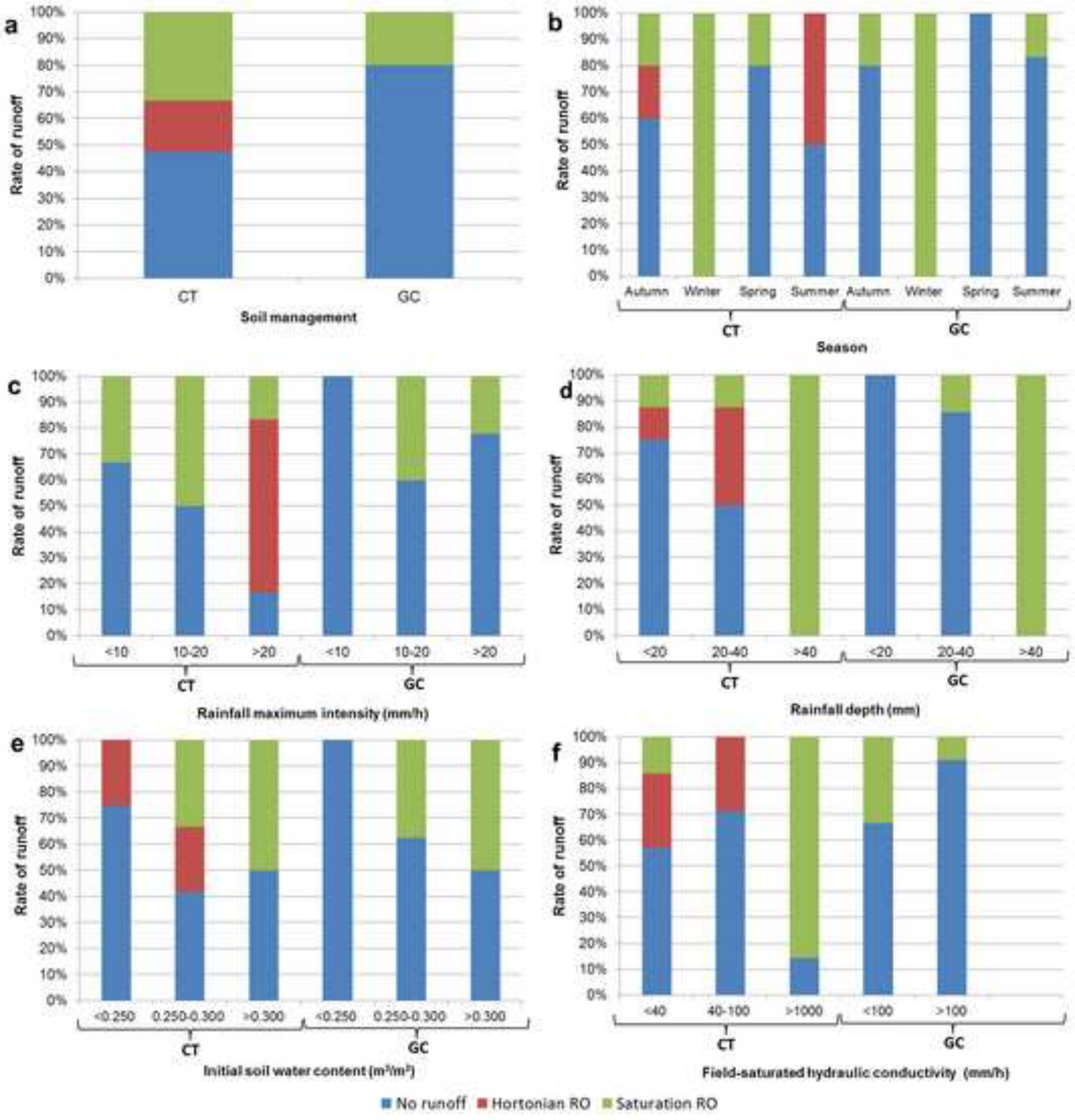
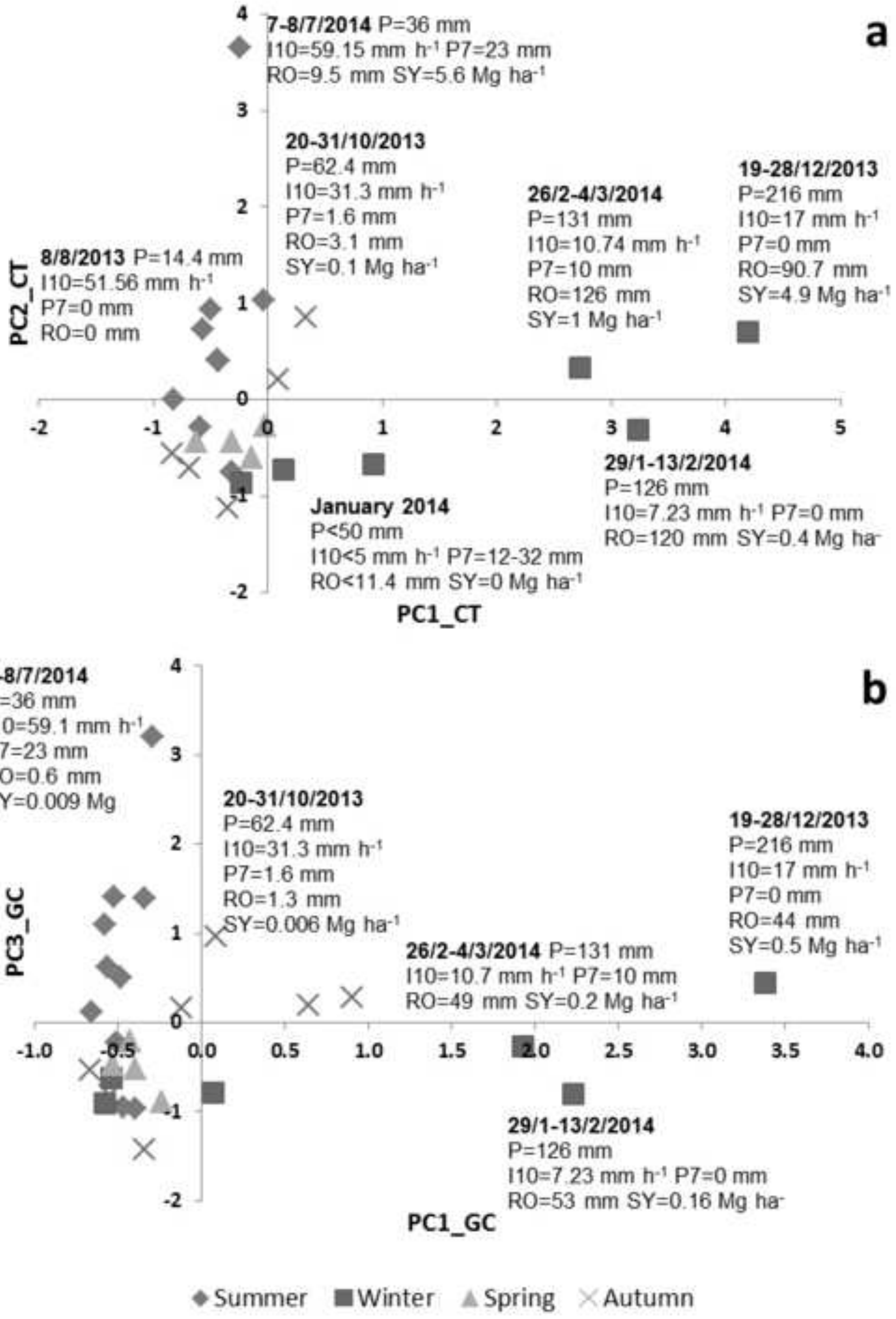

a
Rate of runoff
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
CT
GC
Soil management
b
Autumn
Winter
Spring
Summer
CT
GC
Season
c
<10
10-20
>20
Rainfall maximum intensity (mm/h)
d
<20
20-40
>40
Rainfall depth (mm)
e
<0.250
0.250-0.300
>0.300
Initial soil water content (m³/m³)
f
<40
40-100
>1000
<100
>100
Field-saturated hydraulic conductivity (mm/h)
No runoff
Hortonian RO
Saturation RO

Figure1_gray



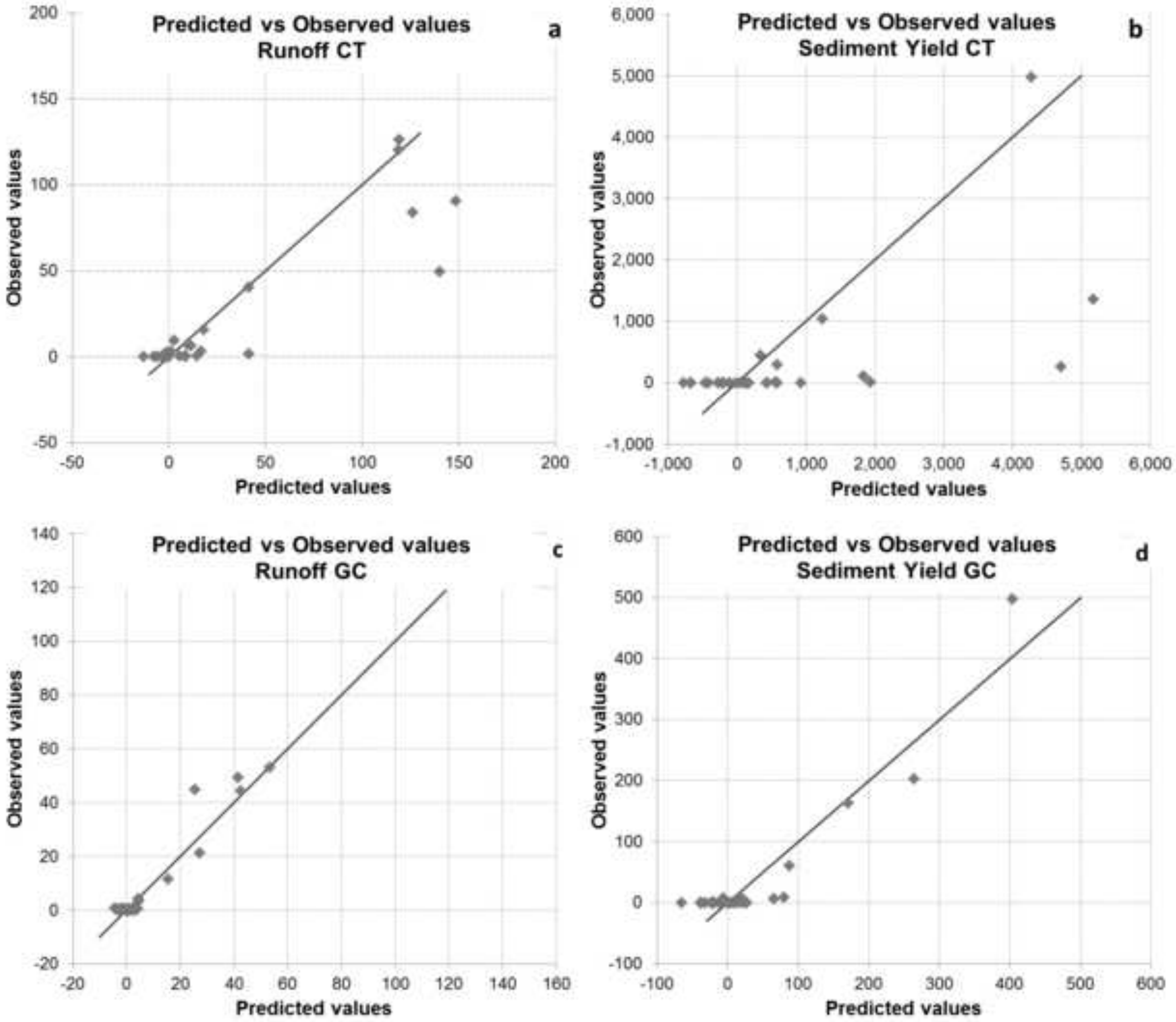
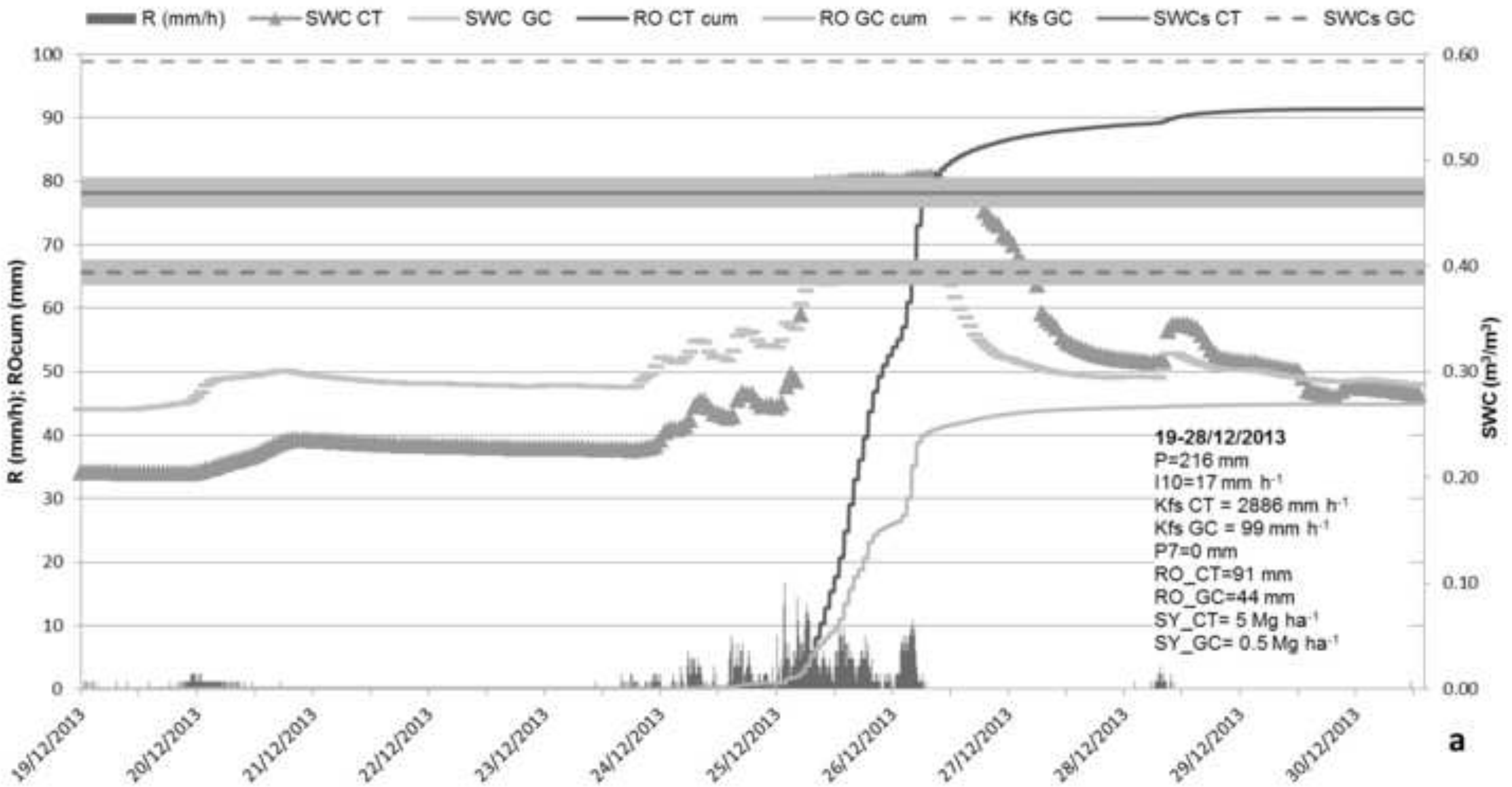
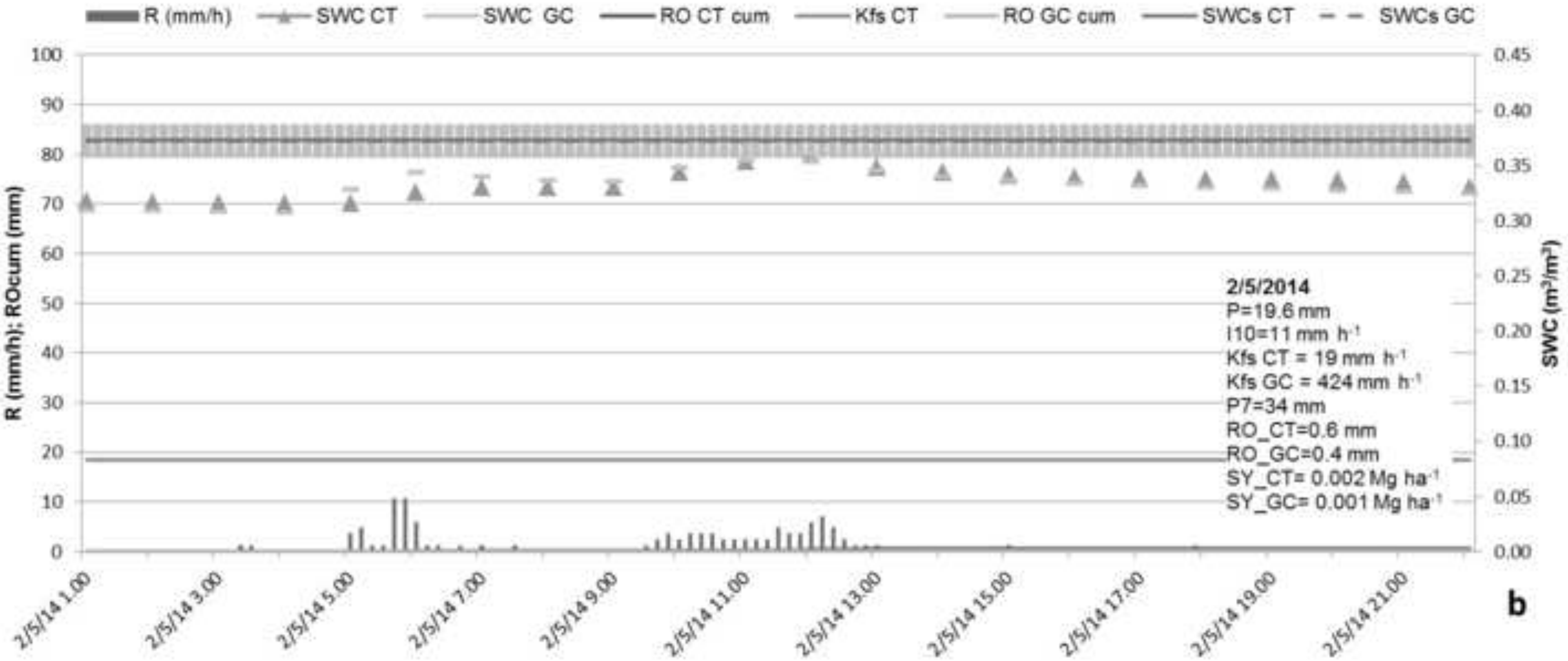

Predicted vs Observed values
Runoff CT
a
Observed values
Predicted values
200
150
100
50
0
-50
-50
0
50
100
150
200
Predicted vs Observed values
Sediment Yield CT
b
Observed values
Predicted values
6,000
5,000
4,000
3,000
2,000
1,000
0
-1,000
-1,000
0
1,000
2,000
3,000
4,000
5,000
6,000
Predicted vs Observed values
Runoff GC
c
Observed values
Predicted values
140
120
100
80
60
40
20
0
-20
-20
0
20
40
60
80
100
120
140
160
Predicted vs Observed values
Sediment Yield GC
d
Observed values
Predicted values
600
500
400
300
200
100
0
-100
-100
0
100
200
300
400
500
600

Figure3a_gray

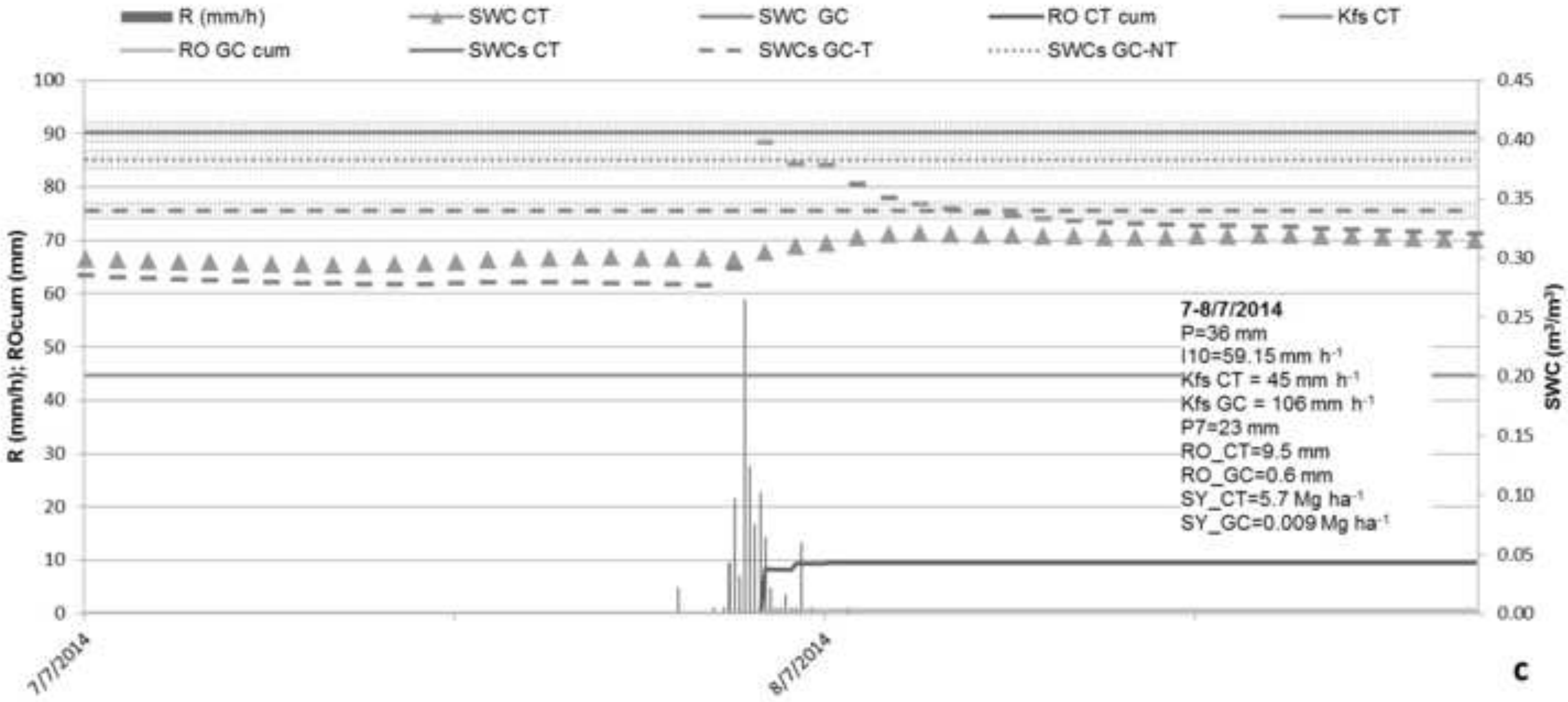


19-28/12/2013
P=216 mm
I10=17 mm h^{-1}
Kfs CT = 2886 mm h^{-1}
Kfs GC = 99 mm h^{-1}
P7=0 mm
RO_CT=91 mm
RO_GC=44 mm
SY_CT= 5 Mg ha^{-1}
SY_GC= 0.5 Mg ha^{-1}

Figure3b_gray



2/5/2014
P=19.6 mm
I10=11 mm h^{-1}
Kfs CT = 19 mm h^{-1}
Kfs GC = 424 mm h^{-1}
P7=34 mm
RO_CT=0.6 mm
RO_GC=0.4 mm
SY_CT= 0.002 Mg ha^{-1}
SY_GC= 0.001 Mg ha^{-1}



7-8/7/2014
P=36 mm
I10=59.15 mm h^{-1}
Kfs CT = 45 mm h^{-1}
Kfs GC = 106 mm h^{-1}
P7=23 mm
RO_CT=9.5 mm
RO_GC=0.6 mm
SY_CT=5.7 Mg ha^{-1}
SY_GC=0.009 Mg ha^{-1}

Figure3d_gray

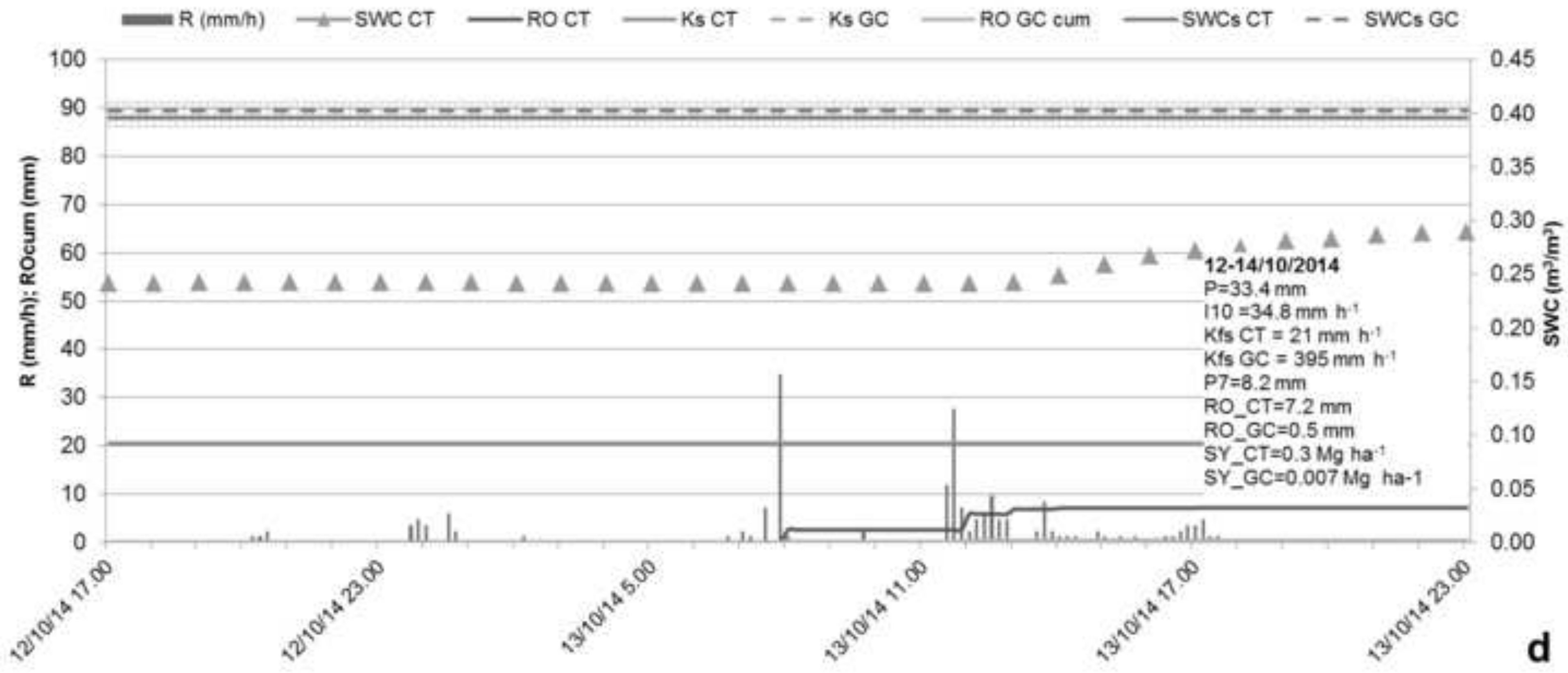


Figure4a_gray

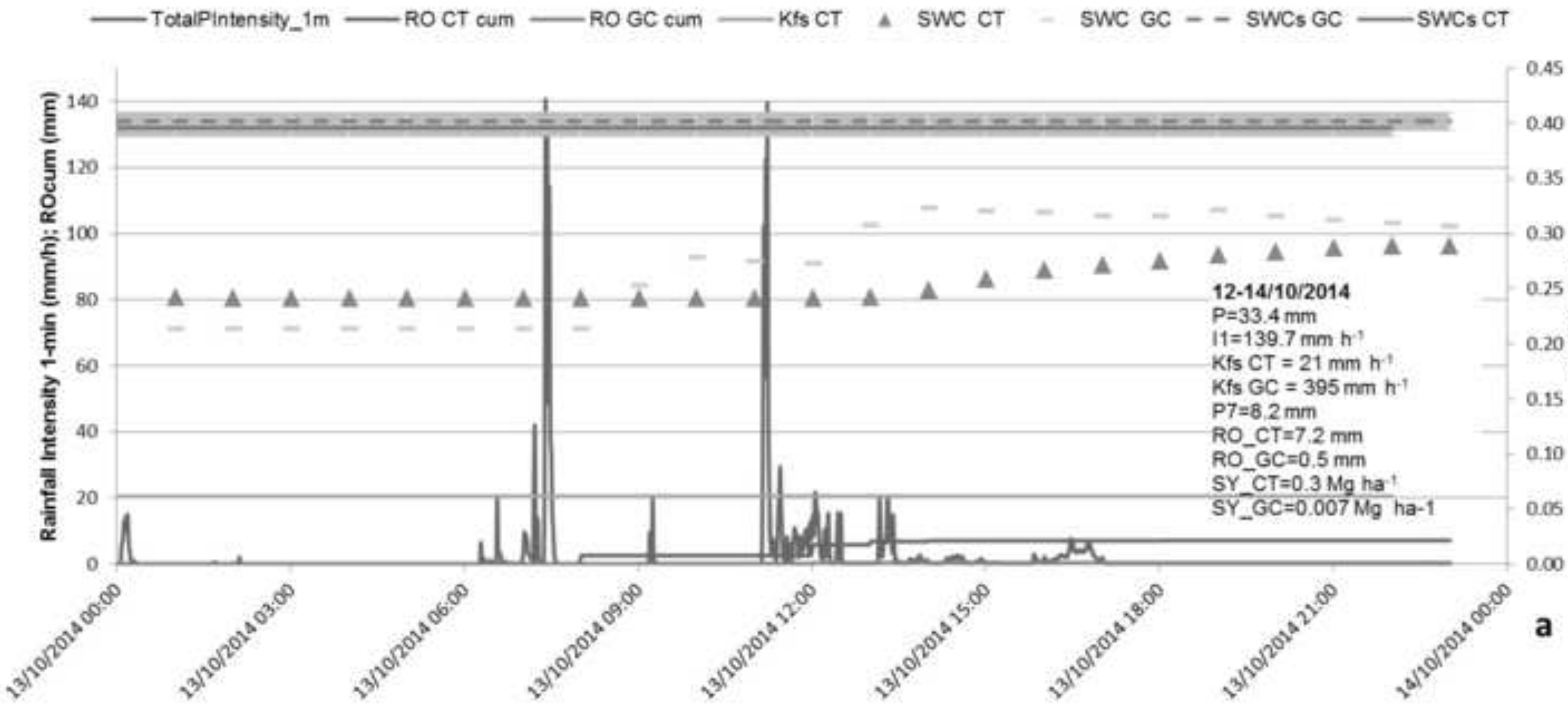


Figure4b_gray

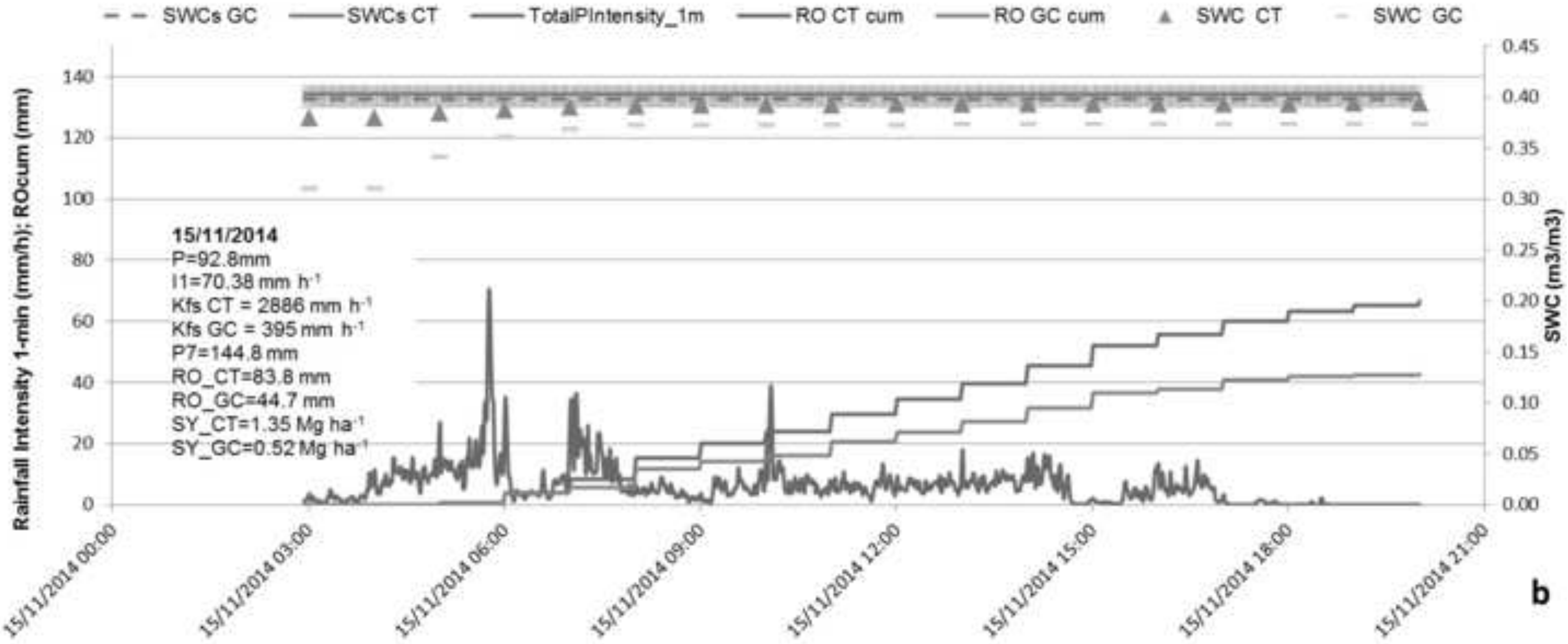


Figure5_gray