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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.

Consiglio Nazionale delle Ricerche



Istituto per le Macchine Agricole e Movimento Terra

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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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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 characterized 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 should 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: What 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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1 **Abstract**

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

10 The objective of this work is to quantify the temporal variability of the effects of two different kind
11 of inter-row management on soil hydrological properties, runoff and erosion in vineyards. For this
12 reason two vineyard field-scale plots in the Alto Monferrato vine-growing area (Piedmont, NW
13 Italy) were monitored in two years. The inter-rows were managed with conventional tillage (CT)
14 and grass cover (GC), respectively. Fifteen series of infiltration tests were carried out during a 2-
15 year period of observation (October 2012 to November 2014). In order to take into account the
16 effect of tractors traffic, the tests were done on the track, and outside the track. Furthermore, a
17 dataset of 29 rainfall-runoff events covering a wide range of topsoil characteristics was collected in
18 the two plots, along with soil water content and runoff discharge monitoring, and determination of
19 sediment yield in case of erosive events. An optical disdrometer installed in the plots provided also
20 1-min rainfall intensity data. In summer, just one month after tillage, CT soil showed very low
21 hydraulic conductivity, so storms were able to cause Hortonian runoff and soil losses up to 5.7 Mg
22 ha⁻¹. In autumn and winter very high saturation-excess runoff was observed in CT, that reached
23 83% of the precipitation. Runoff in the grass cover plot was mainly due to saturation of the topsoil,
24 and the annual reduction of runoff in the GC plot was about 63%. Soil erosion up to 1.2 Mg ha⁻¹ in
25 a single event was observed in the GC vineyard in winter. In each year of observation, most of the

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

28 **1. Introduction**

29 Grapevine cultivation represents one of the land uses for which higher runoff rates and sediment
30 losses are observed in Europe, especially in the Mediterranean area (Tropeano, 1983; Kosmas et al.,
31 1997; Cerdà and Doerr, 2007; García-Ruiz, 2010; García-Ruiz et al., 2015). Analysis of data
32 collected throughout Europe showed that in the Mediterranean region runoff higher than 9% of
33 annual precipitation (Maetens et al., 2012) and the highest erosion rates ($17.4 \text{ Mg ha}^{-1} \text{ year}^{-1}$) are
34 related to vineyard land use (Cerdan et al., 2010).

35 Some typical features of the vine-growing system, such as location on hillslopes and disposition of
36 rows along the slope, make runoff and erosion stronger (Corti et al., 2011). Furthermore, some
37 practices usually adopted in vineyards' installation (land levelling works and deep tillage) and
38 vineyards' management (maintenance of bare soil by mechanical or chemical weeding, intense
39 tractor traffic along fixed paths) are favoring runoff, erosion and further threats as compaction,
40 nutrient losses and reduction of soil water holding capacity (Tropeano, 1984; Ramos and Martínez-
41 Casasnovas, 2004; Ferrero et al., 2005; Ramos and Martínez-Casasnovas, 2007; Arnáez et al.,
42 2007). The effects of the inter-rows soil management on runoff and soil erosion in vineyards of
43 southern Europe was evaluated in several studies under natural rainfall, at different spatial scales
44 (from plot to catchment) and from event to multi-year temporal scales (Tropeano, 1983; Kosmas et
45 al., 1997; Arnaez et al., 2007; Brenot et al., 2008; Casalí et a., 2008; Raclot et al., 2009; Ruiz-
46 Colmenero et al., 2011; Novara et al., 2011; Corti et al., 2011; Biddoccu et al., 2016). The use of
47 grass cover in the inter-rows is one of the most common and effective soil management practices
48 adopted in order to reduce runoff and soil erosion in vineyards (Blavet et al., 2009; Novara et al.,
49 2011; Ruiz-Colmenero et al., 2011; Prosdocimi et al., 2016) and other land uses which are
50 especially subjected to erosion as olive groves (Gómez et al., 2009). Under the indication of the

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

58 Most studies on runoff and erosion in vineyards consider topographic features, soil properties,
59 rainfall characteristics, and soil management techniques in relation to the hydrological and erosive
60 response of the vineyard at yearly or multi-annual scales (Prosdocimi et al., 2016). Nevertheless,
61 annual runoff and soil losses could be strongly conditioned by few rainfall events (Gómez et al.,
62 2014; González-Hidalgo et al., 2009). The adopted soil management influences strongly the
63 temporal and spatial variations of the soil surface characteristics (soil cover, topsoil structure and
64 soil crusting) and soil hydrological characteristics, which drive the partition of rainfall between
65 runoff and infiltration at the field-scale (Leonard and Andrieux, 1998; Pare et al., 2011). There is
66 still a gap in knowledge about the effect of the temporal variations of topsoil conditions on the
67 triggering of runoff and soil water erosion throughout the year. A better understanding of the field
68 response to rainfall events, taking into account the variability of the soil conditions during the year,
69 could be useful for water balance and erosion modelling purposes (Celette et al., 2010) and to
70 support soil management decisions in vineyards, in order to reduce runoff and erosion.

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

76 saturation excess) in relation to soil management, soil hydraulic conductivity and bulk density, soil
77 moisture and precipitation characteristics.

78 **2. Materials and Methods**

79 **2.1 Study site**

80 The study was carried out within the “Tenuta Cannona Experimental Vine and Wine Centre of
81 Regione Piemonte” (44°40’ N, 8°37’ E, 296 m asl), which is located in the Alto Monferrato hilly
82 area of Piemonte, North-West Italy . The climate is sublitoranean, (average annual precipitation of
83 965 mm at the Ovada station, in the period 1951-1990), mainly concentrated in October, November
84 and March. The driest month was July. The mean annual temperature measured at Alessandria
85 during the same period of observation was 12.6°C (Biancotti et al. 1998). At the study site, the
86 average annual precipitation in the period 2000-2014 was 905 mm and the mean annual air
87 temperature was 14.5°C. The Cannona vineyards lie on Pleistocenic fluvial terraces in the Tertiary
88 Piedmont Basin, including highly altered gravel, sand and silty-clay deposits, with red alteration
89 products. The soils derived from reworked Pleistocene alluvium, and they have a clay to clay-loam
90 texture.

91 The experiment was conducted in two vineyard plots, which are part of a larger vineyard, lying on a
92 hillslope with SE aspect and average 15% slope. Each plot is 1221 m² (74 m long and 16.5 m wide)
93 and includes 7 vine rows aligned along the slope, where the vines are spaced 1.0 m along the row
94 and 2.75 m between the rows. The soil has been managed with different techniques since 2000. The
95 first plot has been managed with conventional tillage (CT, cultivated with chisel to a depth of about
96 0.25 m), while in the second plot grass cover has been adopted (GC, with spontaneous grass
97 controlled with mulcher during the year). The mulcher mows and chips the grass, and residues are
98 left on the soil surface. Soil tillage (in CT) and grass mulching (in GC) were usually carried out
99 twice a year, in spring and autumn. In autumn 2011, the inter-rows of the GC plot were tilled and a
100 grass mixture was sown, to renew the grass cover. The grass mixture was composed of: *Lolium*

101 *perenne* 20%, *Festuca rubra* 60%, *Poa nemoralis* 15%, *Poa trivialis* 5%. Weeds under the rows of
102 the two plots were controlled with Glyphosate in spring, 0.6 m across the vine row. Most of the
103 farming operations in the vineyard were carried out using tracked or tyred tractors, with
104 intensification from spring to the grape harvest time. During the period of the present study, soil
105 tillage (in CT) and grass mulching (in GC) were carried out five times (on: 24/10/2012, 05/06/2013,
106 11/11/2013, 16/05/2014, 24/10/2014). The soil is classified as *Typic Ustorthents, fine-loamy, mixed,*
107 *calcareous, mesic* (Soil Survey Staff, 2010) or *Dystric Cambisols* (FAO/ISRIC/ISSS, 1998). Soil
108 textural composition obtained from soil samples taken in 2014, at 0-10 cm depth, indicated a silty
109 clay loam soil in the GC plot, with 15% sand, 53% silt and 32% clay content; and a silt loam soil in
110 the CT plot, with 28% sand, 54% silt and 18% clay content.

111 **2.2 Measurements**

112 The experiment was conducted from October, 2012 to November, 2014. A monitoring system
113 provided continuous measurements of rainfall, runoff and topsoil water content for the two
114 experimental plots. Runoff samples were also collected to obtain sediment yield for erosive events.
115 Periodic measurements were carried out to obtain values of saturated hydraulic conductivity (K_{fs}),
116 bulk density (BD) and initial soil water content (SWC_i) in the two plots, in order to detect the
117 temporal variability of the field-saturated soil hydraulic conductivity at the surface of the vineyard
118 inter-rows, with different conditions depending on soil management. Measurements were carried
119 out both in the no-track (indicated as NT) and in the track position (indicated as T), which is the
120 portion of soil affected by the passage of tractor wheels or tracks.

121 ***Rainfall, runoff, erosion and soil water content***

122 Rainfall measurements were obtained from an automatic rainfall gauge, with 0.2 mm resolution, at
123 about 200 m from the plots. Rainfall data were recorded at 10-min intervals since August, 2013,
124 whereas only hourly measurements were available for the previous period. Since June, 2014, 1-min

125 rainfall intensity data have been obtained from an optical disdrometer installed near the plots (Laser
126 Precipitation Monitor, Thies-Clima, Germany).

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

139 *Infiltration tests*

140 Several series of infiltration tests were carried out in the 2-year period of observations, using the
141 simplified falling head technique (SFH), proposed by Bagarello et al. (2004). Eight series of tests
142 were done in the CT plot and seven series in the GC plot. The tests were conducted on the same
143 date in the two plots, except from November to December 2012, when they were carried out with a
144 delay of three weeks in GC. At each measurement date, four to eight SFH experiments were
145 performed, with 2-4 measurements carried out in the no-track position of the inter-row and 2-4 in
146 the track position. To assure one-dimensional flow, a second ring was inserted concentric to the
147 inner one. The two PVC cylinders had a height of 0.30 m, and inner diameters of 0.305 m and 0.486
148 m. They were inserted in the soil to a minimum depth of 0.06 m. The applied volumes of water
149 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

150 of water on the sloping soil surface. Bodhinayake et al. (2004) have demonstrated that slope does
151 not affect the measurements significantly. Before the execution of each test an undisturbed soil core
152 ($V= 100 \text{ cm}^3$) was collected next to the investigated area at depth of 0 to 0.07 m, to determine the
153 soil bulk density. For the same purpose a sample was collected after the water infiltration inside the
154 inner ring. Initial and saturated volumetric water contents (SWC_i and SWC_s) were also obtained
155 from the collected soil samples.

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

162 **2.3 Rainfall-runoff events analysis**

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

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

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

189 **Results**

190 **3.1. Soil hydrological properties**

191 Table 1 summarizes the infiltration tests, which were conducted with initial soil water content
192 ranging between 0.158 and 0.357 $\text{cm}^3\text{cm}^{-3}$ in CT, and between 0.191 and 0.405 $\text{cm}^3\text{cm}^{-3}$ in GC. On
193 most dates, $CV(SWC_i)$ was lower than 10% in CT. Higher variations were obtained in GC,
194 especially in the NT position. Soil water content was usually higher in T than in NT in the two
195 plots, with significant differences only in October, 2012, in CT and in December, 2012, and in July,
196 2013, in GC. For measurements carried out on the same date, soil water content was always higher
197 in GC than in CT.

198 At the time of the execution of the infiltration tests, the bulk density varied between 1.19 and 1.55 g
199 cm^{-3} in CT and between 1.24 and 1.47 g cm^{-3} in GC. The coefficient of variation of bulk density
200 was generally $< 10\%$, with some exceptions in GC. In the CT plot, bulk density differences between
201 positions were significant in most of the sampling dates. Unexpectedly, in July 2013, about a month
202 after tillage, bulk density was higher than before tillage (May, 2013), both in T and in NT position.
203 Further increase in bulk density was recorded in the T position during the following months, up to
204 1.55 g cm^{-3} (October, 2013). A decrease of bulk density was usually observed between
205 measurements done in autumn and in the following spring, for both treatments.

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

213 **3.2 Runoff and soil erosion seasonal distribution**

214 Table 2 presents a summary of the annual precipitation, runoff and sediment yield during the years
215 2013 and 2014. During 2013 the annual precipitation was 971 mm, higher than the mean of the
216 period 2000-2013 (849 mm) (Biddoccu et al., 2016). The rainiest seasons were spring and then
217 winter, when more than 76% of the cumulative precipitation fell, whereas autumn and especially
218 summer were drier than usual. The highest runoff coefficients were measured in spring (in CT) and
219 winter (in GC). In CT sediment yield was much greater in winter than in other seasons, due to a
220 single event (19-28/12/2013). Precipitation measured in 2014 was more than 40% greater than the
221 above cited average. The 40% and 35% of annual precipitation were recorded in autumn and in

222 winter, respectively. Highest runoff volumes and runoff coefficients were measured in winter in
223 both plots.

224 **3.3 Influence of rainfall and soil properties on runoff and sediment yield**

225 Table 3 summarises the results of the PCA for the rainfall events and soil properties. More than
226 80% of the variance among events can be explained by four principal components for CT (83%) and
227 for GC (86%). The first principal component for CT represents 29% of the variance of the system
228 and is a good indicator (loadings>0.90) of rainfall and runoff depth, and rainfall duration of the
229 event. The intensity of the rainfall is highly correlated with the second principal component (26% of
230 the variance). Sediment yield is also moderately correlated with this component. The antecedent
231 precipitation (during the previous 7, 15 and 30 days) and the field-saturated hydraulic conductivity
232 were the variables best correlated with the third and fourth component, respectively. The first
233 principal component for the GC events (30% of the variance) is a good indicator of the rainfall and
234 runoff depths, of rainfall duration and sediment yield. Initial soil water content and antecedent
235 precipitation in the previous 30 and 15 days are moderately well-represented in the second principal
236 component (21 % of the variance of the system). The PC3-GC component also represents 21% of
237 the variance and it is well correlated with maximum rainfall intensity. The PC4-GC is highly
238 correlated with field-saturated hydraulic conductivity and bulk density.

239 Figure 1 shows the rainfall events represented as individuals on the principal component plans, and
240 classified by season. Fig.1a represents the events measured in the CT plot in the PC1_CT-PC2_CT
241 plan. In the first quadrant larger rainfall events that produced highest runoff and sediment yield in
242 CT are represented. They occurred in autumn and winter, when most precipitations greater than 100
243 mm and long duration (>60 hours) produced significant runoff and erosion, up to 4.9 Mg ha⁻¹. The
244 highest runoff coefficients were recorded with rain causing snowmelt and also relevant erosion
245 (29/1-13/2/2013 and 26/2-4/3/2013). Most of the high intensity and potentially erosive events
246 (positive values of PC2_CT) occurred in summer and early autumn. In that period, runoff occurred

247 when high intensity rainfall ($I_{max10} > 30 \text{ mm h}^{-1}$) was preceded by rainfall in the previous days. The
248 storm event of 7-8/7/2014 occurred three days after another storm, which did not produce
249 significant runoff. In the second event, 36 mm of rain fell with the highest 10-min intensity (59.15
250 mm h^{-1}) and produced 9.5 mm of runoff. This resulted in the highest erosion recorded during the
251 period of observation (5.6 Mg ha^{-1}). Figure 1b shows events recorded in the GC plot in the
252 PC1_GC-PC3_GC plan. Events represented in the first and fourth quadrant ($PC1_GC > 0$) occurred
253 in autumn and winter. Among them, events with $P > 90 \text{ mm}$ produced high runoff ($RC > 20\%$) and
254 erosion. Summer and spring events produced negligible runoff and erosion, even with high rainfall
255 intensities.

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

266 **3.4 Analysis of single events to identify the runoff occurrence and mechanism**

267 Runoff was considered as *significant* when its depth was greater than 1 mm or greater than 2% of
268 the rainfall depth: 14 and 9 rainfall events produced significant runoff in CT and GC, respectively.
269 Some cases of surface runoff are shown in Figs.3 and 4. The orange lines represent the reference
270 value of K_{fs} measured in the GC plot (discontinuous) and in the CT plot (continuous). In some cases
271 K_{fs} reference values could not be represented in the graph, because of their greater order of

272 magnitude, with respect to rainfall intensity. The blue lines represent the values of saturated soil
273 water content for CT and GC. The grey band indicates the uncertainty range of sensors (3%). Green
274 symbols indicate hourly mean values of soil water content measured by the sensors in the plots.

275 Fig. 3a represents a typical winter rainfall event which caused high runoff volumes both from CT
276 and from GC. The rainfall event accounted for 216.2 mm of rainfall, with maximum 10-min rainfall
277 intensity of 16.8 mm h⁻¹. Measured runoff coefficients and sediment yields accounted for 42% of
278 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
279 shows a spring event for which light runoff was measured, that caused little soil erosion. The
280 rainfall intensity did not overcome K_{fs} in the plots, but soil water content increased to reach
281 saturation of the soil surface and to generate light saturation-excess runoff in CT. The summer
282 rainfall event in Fig. 3c accounted for 35.8 mm of rainfall. Although the rainfall intensity was the
283 highest (59 mm h⁻¹), it did not overcome the K_{fs} minimum value in GC (106 mm h⁻¹). The fast
284 increase of soil water content made the soil saturated in GC for most of the event duration, both in T
285 than in NT, and little runoff (0.6 mm) was thus originated in this plot. An increase of the topsoil
286 water content was also measured in CT, but saturation of the soil surface was not reached. Rainfall
287 intensity overcame K_{fs} in CT, thus runoff caused by infiltration excess occurred (9.5 mm) in this
288 plot. Sediment yield was very high in the tilled plot (5.6 Mg ha⁻¹) and negligible in the grassed
289 vineyard.

290 Fig. 3d shows a rainfall occurring in autumn, before the execution of tillage. After the 10-minute
291 rainfall intensity exceeded the K_{fs} measured in CT, 7.2 mm of runoff were recorded in this plot.
292 Very low runoff (only 0.4 mm after the whole rainfall event) was measured in GC. For the same
293 rainfall event 1-min rainfall intensity was also obtained from disdrometer records (Fig. 4a). The
294 maximum 1-min rainfall intensity was near the 140 mm h⁻¹ peak measured by the pluviometer of
295 34.8 mm h⁻¹ (over 10-min interval). Erosion was detected in the two plots, and in CT it was nearly
296 40 times higher than in GC. Fig. 4b presents the 1-min rainfall intensity recorded during another

297 event. The rainfall intensity peak did not exceed the K_{fs} : The soil in CT was tilled 20 days before
298 the rainfall event, so its conductivity was assumed to be greater than 2800 mm h^{-1} and the mean K_{fs}
299 measured in GC ranged between 395 mm h^{-1} and 967 mm h^{-1} . However, soil water content was
300 close to the saturation level, due to the 236 mm of rainfall in the previous two weeks. Runoff
301 appeared in the first hours of the event, when 1-min rainfall intensity was higher than 10 mm h^{-1}
302 and soil was saturated in CT. Thus, runoff was due to saturation of the soil surface in CT. Within a
303 few hours high rainfall intensity induced saturation of the upper horizon also in GC. When soil
304 saturation was reached, both in CT and in CG, runoff depth increased in consequence of higher
305 rainfall intensities. Sediment yield measured in the two plot was nearly 1.4 Mg ha^{-1} and 0.5 Mg ha^{-1}
306 in CT and GC, respectively.

307 The rainfall depth of autumn and winter events which caused runoff due to saturation in CT ranged
308 between 36 and 216 mm and the 10-min maximum rainfall intensity varied between 5 to 17 mm h^{-1} .
309 The soil was wet, with soil water content between 0.267 and $0.382 \text{ cm}^3\text{cm}^{-3}$ and it was characterized
310 by K_{fs} greater than 1000 mm h^{-1} and bulk density of about 1.41 g cm^{-3} . The mean runoff coefficient
311 which was observed in the CT plot for saturation runoff events occurring in autumn and winter was
312 79%. A light saturation-excess runoff was also detected in spring, with a very low rainfall depth
313 ($P=19.60 \text{ mm}$, $I_{\max 10} = 4.8 \text{ mm h}^{-1}$) and field-saturated hydraulic conductivity (minimum $K_{fs} =$
314 18.5 mm h^{-1}), and wet soil ($\text{SWC}_{\max} = 0.373 \text{ cm}^3\text{cm}^{-3}$). Rainfall events that caused Hortonian runoff
315 in CT were characterized by 10-min maximum rainfall intensity ranging between 37 and 59 mm h^{-1}
316 and rainfall depth from 14 to 36 mm. Although the K_{fs} values which were measured in autumn and
317 winter in GC were the lowest (ranging between 41 mm h^{-1} and 85 mm h^{-1}), rainfall intensities in this
318 period (maximum 10-min rainfall intensity ranging between 4 and 35 mm h^{-1}) did not cause
319 Hortonian runoff.

320 Runoff occurred for 50% of the observations in CT and 20% in GC (Fig. 5a). Relationships between
321 surface runoff type and the season of rainfall event occurrence was firstly examined, after

322 identification of runoff occurrence on single events (Fig. 5b). Only saturation excess runoff was
323 found during winter, both in CT and in GC. In spring runoff was detected only in CT, for 20% of
324 the events. In autumn runoff was detected during 40% and 20% of the events, for CT and GC,
325 respectively. Half of the runoff events which occurred in autumn in CT were due to Hortonian
326 runoff. In summer less than 20% of the rainfall events caused saturation excess runoff in GC,
327 whereas 50 % of the rainfall events produced Hortonian runoff in CT. Relationships between
328 surface runoff frequency and some rainfall characteristics were examined in the following. Fig. 5c
329 shows that surface runoff by infiltration excess was detected only in CT for 10-min maximum
330 rainfall intensity higher than 20 mm h^{-1} and it occurred for 60% of rainfall events. In relation to the
331 rainfall depth (Fig. 5d), rainfall events whose depth was lower than 20 mm, produced some
332 Hortonian and saturation-excess runoff in CT, but no runoff in GC. Most of the Hortonian runoff
333 events were induced in CT for rainfall events with a depth ranging from 20 to 40 mm. Every
334 analyzed rainfall event greater than 40 mm produced surface runoff due to saturation excess in both
335 plots. Finally, relationships are shown between surface runoff and soil water content at the rainfall
336 occurrence (Fig. 5e) and field-saturated hydraulic conductivity (Fig. 5f). When soil water content
337 was lower than $0.250 \text{ cm}^3 \text{ cm}^{-3}$, no runoff was measured and detected in GC, and only Hortonian
338 runoff appeared in CT. Both in CT and in GC, the frequency of saturation excess runoff increased
339 as initial SWC_i was higher. In CT some cases of Hortonian runoff were detected with initial SWC_i
340 greater than $0.250 \text{ cm}^3 \text{ cm}^{-3}$. In relation to the field-saturated hydraulic conductivity of the soil, the
341 frequency of events that caused Hortonian runoff was about 30% for $K_{fs} < 100 \text{ mm h}^{-1}$ in CT,
342 whereas more than 70% of the rainfall events produced runoff due to saturation excess when K_{fs}
343 > 1000 . On the contrary, most of the runoff events occurred in GC soil when K_{fs} was lower than 100
344 mm h^{-1} .

345 **3. Discussions**

346 **4.1. Temporal and management effects on soil hydrological properties**

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

350 In both treatments, from late autumn and winter to spring, a decrease of bulk density was observed.
351 Differences between T and NT were significant in CT, except for one month after autumn tillage.
352 Bagarello et al. (2014) measured K_{fs} of 838 mm h⁻¹ and 7424 mm h⁻¹, in the clay soil of a Sicilian
353 vineyard. In a sandy loam soil, previously tilled but then undisturbed over the 2 years of
354 observation, Bagarello & Sgroi (2007) obtained mean values ranging from 20 mm h⁻¹ to 952 mm h⁻¹,
355 a range that was very similar to that the one obtained in the GC plot in the present study. The
356 coefficients of variation obtained in this study were also comparable to those in Bagarello & Sgroi
357 (2007).

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

366 Both in CT and in GC, during summer and autumn, bulk density showed an increasing trend, and
367 hydraulic conductivity a decreasing one, that was particularly evident in the T position. Such
368 tendency was likely the effect of compaction, due to rainfall and especially to intense tractors traffic
369 during farming and harvesting operations which were carried out in summer and early autumn.
370 After harvest, mean hydraulic conductivity lower than 100 mm h⁻¹ was observed in the GC plot and
371 the lowest K_{fs} value (40.5 mm h⁻¹) was obtained in winter in the T position. The topsoil showed

372 higher compaction and lower hydraulic conductivity after the productive season, especially after
373 grape harvest. Indeed, worst conditions for water infiltration were observed during autumn (before
374 tillage in CT) and also in winter for GC. In 2014 the CT topsoil showed higher sand content than in
375 GC, whereas the clay content was the highest in GC. Since soil erosion by overland flow is a
376 selective process (Alberts et al., 1980), the more intense erosion which was observed in CT rather
377 than in GC in the period 2000-2013 (Biddoccu et al., 2016) may have caused the loss of the finest
378 particles of soil in CT. Differences in field-saturated hydraulic conductivity, namely the higher
379 values which were observed in the less compacted portion of the inter-row of the GC plot with
380 respect to the CT plot, could also be related to these differences in the texture of the surface soil.

381 **4.2. Impact of soil management, soil properties and rainfall on runoff**

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

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

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

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

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

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

417 In summer, the very low hydraulic conductivity of the topsoil in the CT plot was likely due also to
418 the presence of a structural crust, which was observed after first rainfall events following the late-
419 spring tillage. As Pare et al. (2011) reported in tilled vineyards, cumulative rainfall and kinetic
420 energy are the main predicting factors of soil reconsolidation, especially from the fresh tillage to

421 crusting. During summer the gradual increase of crusting and compaction due to the tractors traffic
422 made the runoff larger in CT than in GC.
423 The analysis of runoff occurrence of each single event was carried out by comparing soil water
424 content time series with the saturated values obtained in T and NT positions. Similarly the rainfall
425 intensity time series were compared with K_{fs} . During most of the events, the value which was
426 overcome determining the runoff occurrence, was the value of saturated water content (in case of
427 saturation-excess runoff) or K_{fs} (in case of Hortonian runoff), in the T position. This effect was
428 especially evident in summer, when infiltration-excess runoff occurred in CT and not in GC, in
429 consequence of the lower K_{fs} in the T position. The winter rainfall-runoff events represented the
430 most frequent exception to this, because the differences between values of K_{fs} and SWC_s were not
431 significant between the two positions.

432 **4.3. Impact of soil management and rainfall characteristics on sediment yield**

433 Sediment yields of 5.3 and 9.3 Mg ha⁻¹ were measured during the two years, respectively, in the CT
434 plot. The average value was close to 7.4 Mg ha⁻¹ year⁻¹, of the period 2000-2012 for the same plot
435 (Biddoccu et al., 2016). Tropeano (1984) reported annual soil loss of 47.4 Mg ha⁻¹ in a tilled
436 vineyard in Piedmont and annual sediment yields of 31.4 and 88.71 Mg ha⁻¹ were measured in 2
437 years of observation in a tilled vineyard in Sicily (Novara et al., 2011). In 2013 erosion was higher
438 in CT than in GC in each season. During the most erosive winter event, erosion in CT was 10 times
439 greater than in GC. Also in 2014 seasonal erosion was greater in CT than in GC. In GC annual soil
440 erosion was 1.5 Mg ha⁻¹ in 2013, and 1.0 Mg ha⁻¹, in 2014, lower than the mean observed in 2000-
441 2012, of 1.8 Mg ha⁻¹ year⁻¹. Annual sediment yield in GC was 72 and 89% less than in CT. The
442 difference between CT and GC was greater than in other studies. Novara et al. (2011) observed that
443 the use of different cover crops in the inter-row reduced soil losses by 56%. Ruiz-Colmenero et al.
444 (2011), in a 2-year study at plot scale, observed that vineyards with a cover crop lost between 50%
445 and 75% less soil than with tilled soil.

446 Differences among seasonal amounts of sediment yields were due to the variability of rainfall
447 during the years. Seasonal distribution of rainfall, runoff and soil erosion in 2014 was similar to the
448 period 2000-2013 (Biddoccu et al., 2016). Nevertheless in both years just a single event per year
449 had a great influence in determining the annual sediment yield. In 2013 the rainfall event which
450 occurred in the period 19-28/12/2013 was the largest (216.2 mm). It was the most erosive event
451 observed in GC during the study, and the second most erosive event measured in CT, where it
452 caused 93% of the annual erosion. In 2014, the highest erosion occurred during the summer storm
453 on 7-8/7/2014, when the rainfall of highest intensity (59 mm h⁻¹ over 10 minutes) caused more than
454 5.6 Mg ha⁻¹ of sediment yield in CT, whereas in GC only 9 kg ha⁻¹. Those two extreme events, with
455 the highest precipitation depth and 10-min maximum intensity, respectively, caused the highest
456 erosion. These results confirmed the observation of Gómez et al. (2014) and González-Hidalgo et
457 al. (2009). The multiple linear model predicting sediment yield in CT showed the highest
458 correlation with erosivity, which depends on the 30-min rainfall intensity and on the energy of
459 precipitation, and then with the 7-day antecedent precipitation. Hortonian runoff was mainly
460 observed in summer and early autumn, for rainfall events with 10-min maximum intensity greater
461 than 20 mm h⁻¹, and with significant the 7-day antecedent rainfall. In those cases, although runoff
462 coefficients were limited (average value of 7%), sediment yield ranged between 289 kg ha⁻¹ and
463 5658 kg ha⁻¹. Apart from the first precipitation event after tillage, most of the events in autumn and
464 winter generated saturation-excess runoff in CT, whose rates were greater than 42%, and caused
465 sediment yield up to 4.9 Mg ha⁻¹.

466 The high correlation between sediment yield and erosivity for CT was related to the absence of soil
467 protection and low hydraulic conductivity in summer and early autumn, when most intense and
468 erosive rainfall was observed. Nevertheless, high erosivity is also related to the rainfall energy, that
469 is high for large precipitation events in autumn and winter. Similarly to this study, Raclot et al.
470 (2009), in tilled vineyards, at event temporal scale and at field spatial scale, found significant

471 correlation between total suspended sediment and rainfall depth and between erosion and maximum
472 rainfall intensity over a 5-min period.

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

483 **4. Conclusions**

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

489 The results highlighted how the tillage increased field-saturated hydraulic conductivity only for a
490 short period. It tended to be higher in CT than in GC in the central part of the inter-row, but in track
491 it quickly decreased to such low values that Hortonian runoff was produced during intense summer
492 storms. Sediment yield in the tilled plot was up to 9 times higher than in the grass cover plot. Due to
493 high compaction after grape harvest, the worst condition for infiltration were found before autumn
494 tillage in CT and in autumn and winter for GC. The main runoff events were related to the
495 saturation-excess mechanism, which was the only one observed in the GC plot and that was

496 frequently observed in the tilled one, particularly in late autumn and in long-duration winter
497 precipitation events. Despite the autumn tillage, in CT the winter 2014 runoff reached 83% of the
498 precipitation amount and was nearly 4 times greater than in the grassed plot. The largest runoff
499 occurred in case of snowfall events followed by rainfall. Very high sediment yield in the tilled plot
500 was mainly related to rainfall intensity (during summer storm) and rainfall depth (in autumn and
501 winter). The annual reduction of runoff in the grassed plot was 63% in comparison with the tilled
502 plot. In autumn and winter the grass cover was less effective in reducing runoff than in summer.
503 Erosion was relevant in winter when large saturation-excess runoff was generated by long-lasting
504 rainfall and snowfall. However, the grass cover was effective in reducing annual soil losses (up to
505 90%) and especially during most erosive events that occurred in summer and early-autumn.

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517

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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)		SWC _i (cm ³ cm ⁻³)		K _{fs} (mm h ⁻¹)		GC		From Tillage Days		R (mm)		BD (g cm ⁻³)		SWC _i (cm ³ cm ⁻³)		K _{fs} (mm h ⁻¹)	
		NT	T	NT	T	NT	T	NT	T	NT	T			NT	T	NT	T	NT	T	NT	T		
Oct-12	Mean	158	141.	1.3	0	1.50	1	0	71.0	31.3													
	CV (%)		2	6.2	7.3	6.1	4.3	29.9	53.0														
Nov-12	Mean	21	139.	1.3	1.41	0.35	0.35	2886.2	3747.3			Dec-12	Mean	42	259.	1.35	1.41	0.33	0.40	251.	40.5		
	CV (%)		2	8.2	5.5	4.5	4.4	39.1	102.1				CV (%)			2.98	9.79	6.3	2.1	186.	154.		
May-13	Mean	202	698.	1.1	1.38	0.26	0.31	770.1	63.6 a			May-13	Mean	202	698.	1.18	1.29	0.27	0.31	427.	153.		
	CV (%)		6	2.1	7.2	4.5	17.4	34.8	8.6				CV (%)			5.82	11.4	9.8	30.4	45.9	93.6		
Jul-13	Mean	3	16.2	1.3	1.41	0.16	0.18	486.87	44.69			Jul-13	Mean	37	16.2	1.31	1.48	0.09	0.18	105.	156.		
	CV (%)		4	7.0	3.0	17.4	31.6	25.4	102.0				CV (%)			8.22	6.22	19.8	9.3	55.5	152.		
Sep-13	Mean	93	88.2	1.2	1.45	0.15	0.17	332.6	10.0 a			Sep-13	Mean	92	88.2	1.27	1.42	0.19	0.22	93.7	85.2		
	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.		
Oct-13	Mean	133	137.	1.3	1.55	0.27	0.29	1456.3	74.4 a			Oct-13	Mean	134	137.	1.34	1.42	0.29	0.33	591.	99.0		
	CV (%)		4	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.	1.2	1.51	0.24	0.23	87.1 a	18.5 a			May-14	Mean	183	740.	1.24	1.37	0.25	0.26	525.	423.		
	CV (%)		6	5.8	2.8	8.8	26.1	31.9	45.7				CV (%)			12.8	7.60	17.8	4.5	126.	37.2		
Oct-14	Mean	156	246.	1.2	1.47	0.26	0.32	1343.5	20.5 a			Oct-14	Mean	157	246.	1.24	1.37	0.31	0.32	967.	394.		
	CV (%)		2	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).

	Precipitation (mm)		CT						GC					
	2013	2014	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
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 precipitation 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-GC	PC4-GC
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	<i>0.899</i>	0.066	0.287	-0.033	RC GC	<i>0.798</i>	0.383	-0.156	0.234
SY_CT	0.111	<i>0.787</i>	0.251	-0.077	SY_GC	0.915	-0.116	0.034	0.091
Ant. Prec. 7 days	-0.148	0.002	<i>0.780</i>	0.003	Ant. Prec. 7 days	-0.001	<i>0.708</i>	0.023	-0.386
Ant. Prec. 15 days	0.159	-0.223	<i>0.703</i>	0.002	Ant. Prec. 15 days	-0.041	0.824	-0.191	-0.062
Ant. Prec.30 days	0.460	-0.220	<i>0.719</i>	-0.218	Ant. Prec.30 days	0.124	0.826	-0.247	0.302
Ant. Prec. 45 days	<i>0.709</i>	-0.250	0.521	-0.209	Ant. Prec. 45 days	0.324	<i>0.701</i>	-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						Runoff Grass Cover					
Variable	Step	Value	R^2_{adj}	Increase in R^2_{adj}	Sign.		Step	Value	R^2_{adj}	Increase in R^2_{adj}	Sign.
Intercept		-40.939				Intercept		-6.798			
Precipitation	1	1.366	0.899	0.899		Precipitation duration	1	0.230	0.769	0.769	0.000
EI30	2	-0.387	0.918	0.019	0.000	Precipitation	2	0.129	0.810	0.041	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						
Sediment Yield Conventional Tillage						Sediment Yield Grass Cover					
Variable	Step	Value	R^2_{adj}	Increase in R^2_{adj}	Sign.		Step	Value	R^2_{adj}	Increase in R^2_{adj}	Sign.
Intercept		-855.559				Intercept		-33.434			
EI30	1	13.696	0.507	0.507	0.000	Precipitation	1	1.882	0.753	0.753	0.000
Ant. Prec. 7 days	2	32.758	0.585	0.078	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.

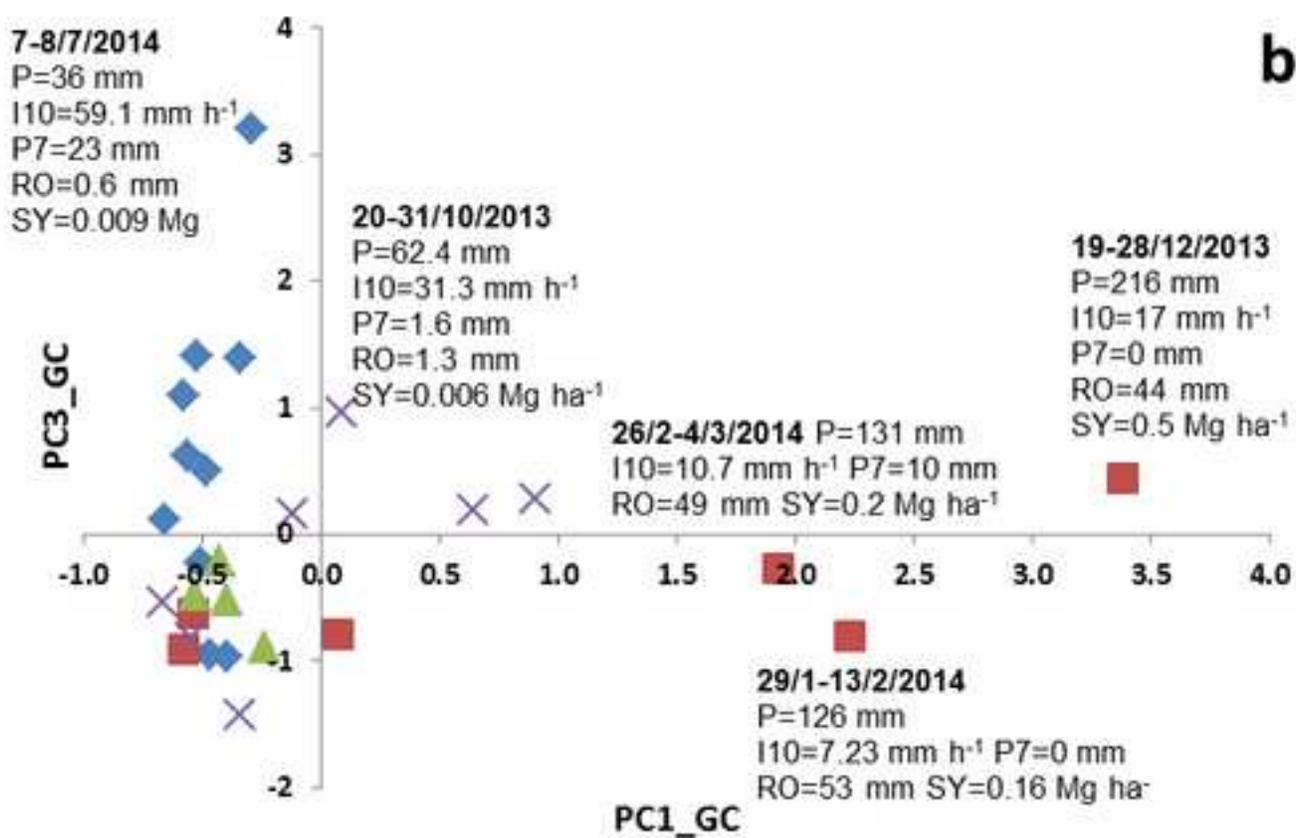
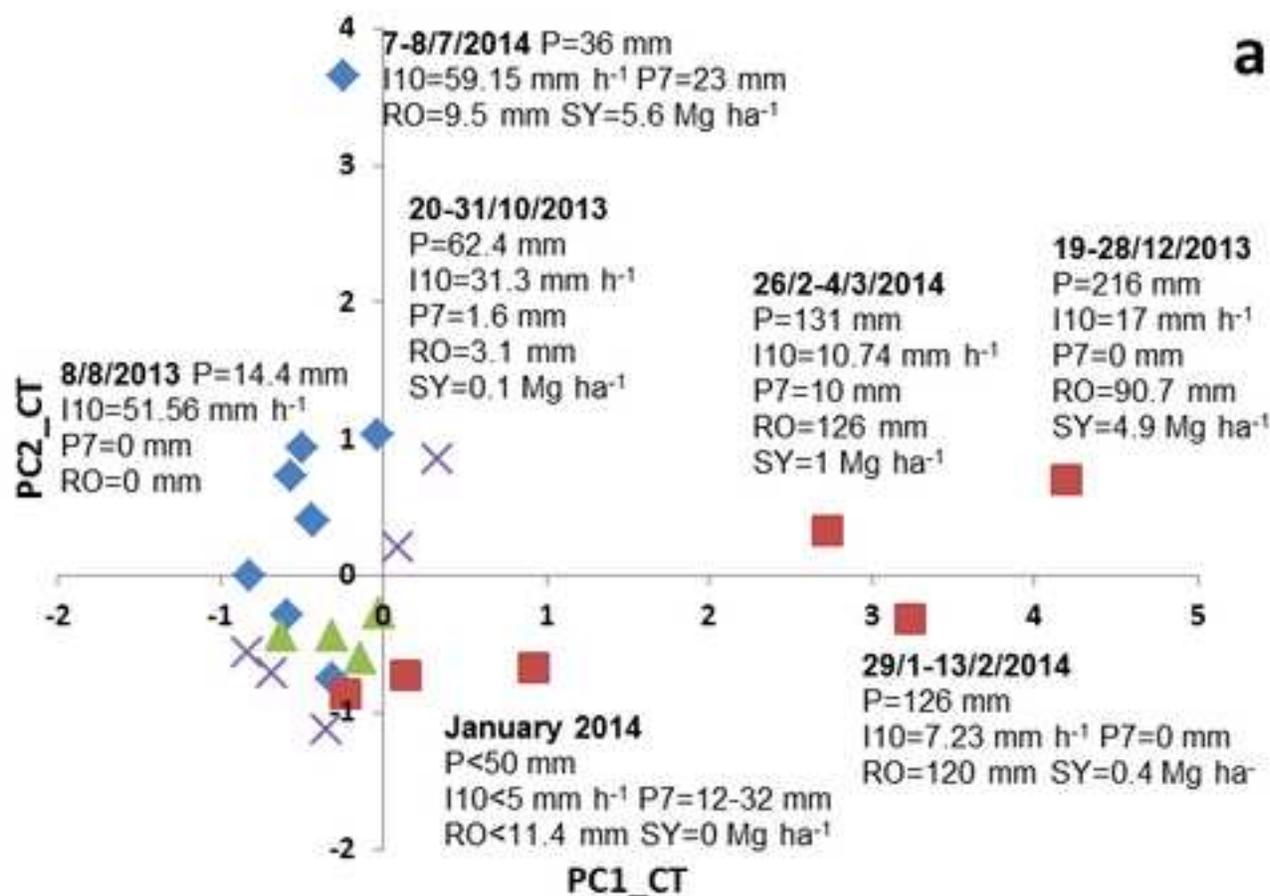
Fig.3 – Examples of runoff detection graphs with pluviometer data (10 minutes step) for some rainfall events. R= rain intensity at 10 min step, SWC = measured volumetric soil water content (1 hour step), SWCs = reference value of saturated water content, K_{fs} = reference value of field-saturated hydraulic 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

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◆ Summer ■ Winter ▲ Spring × Autumn

Figure2

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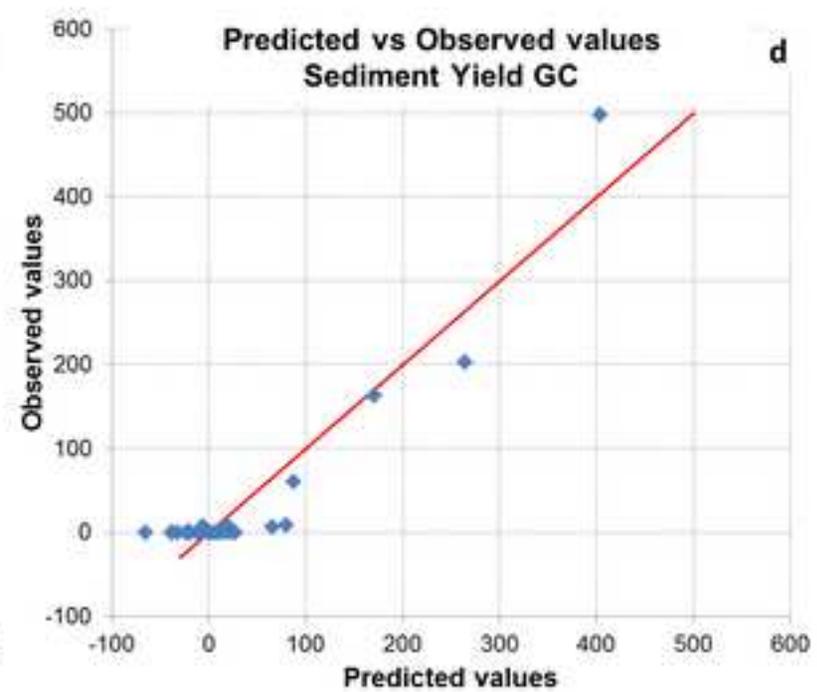
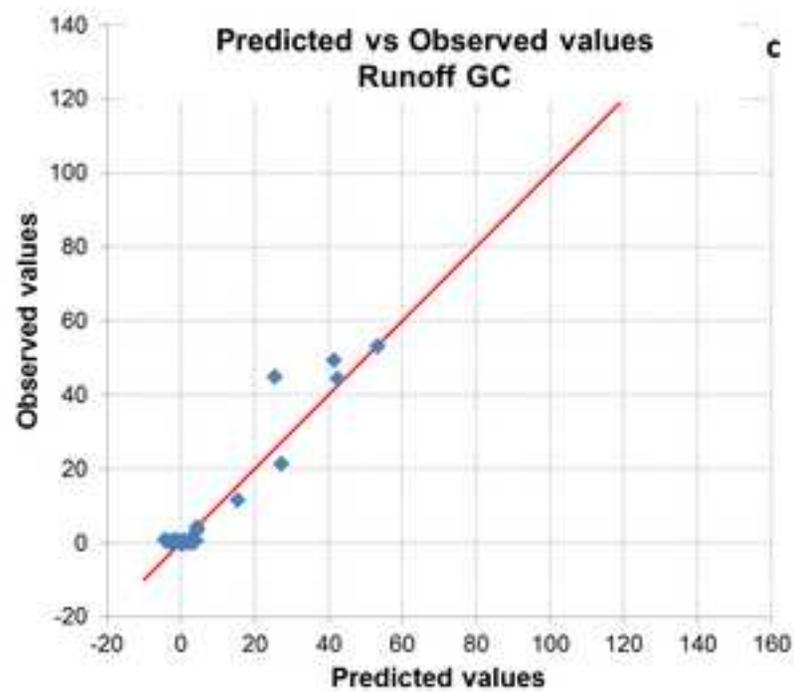
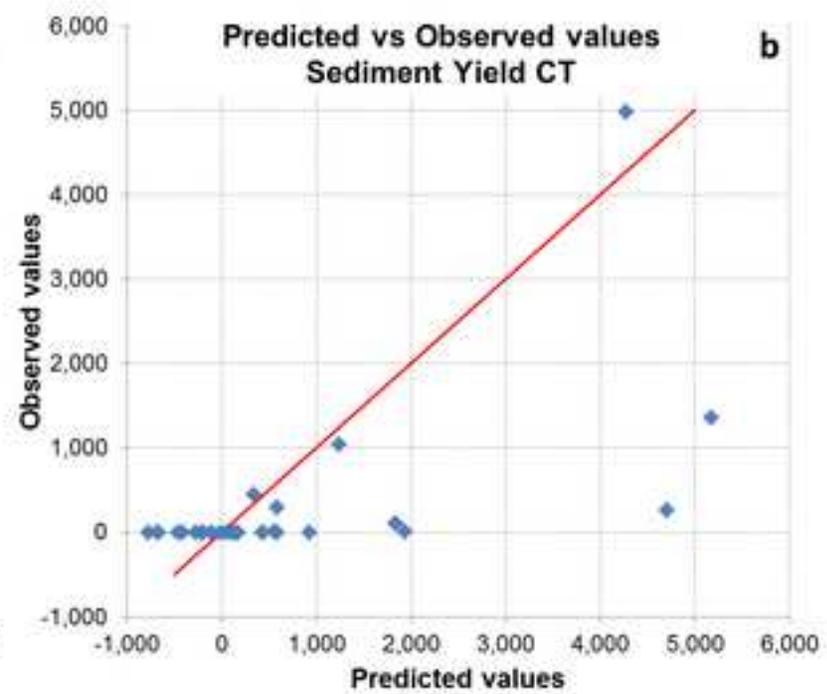
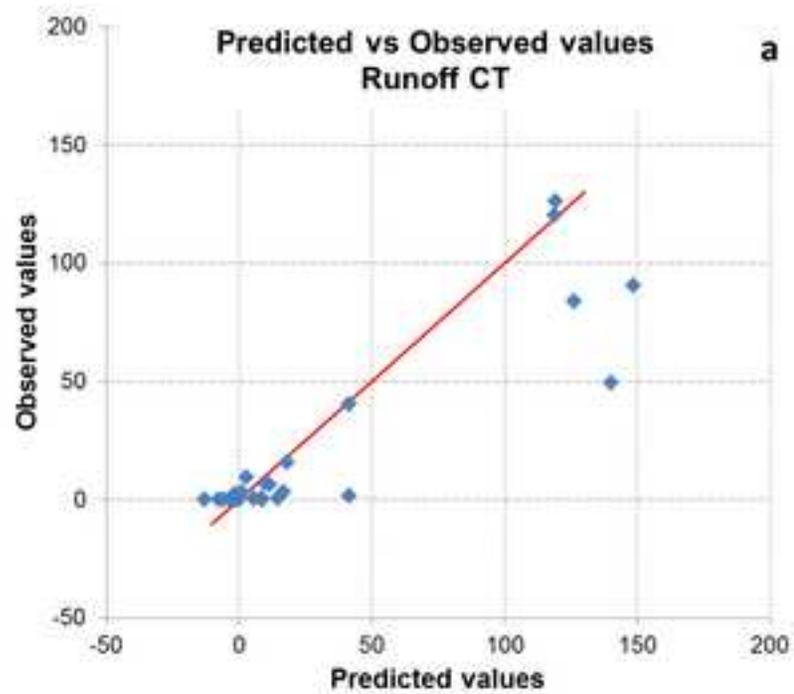
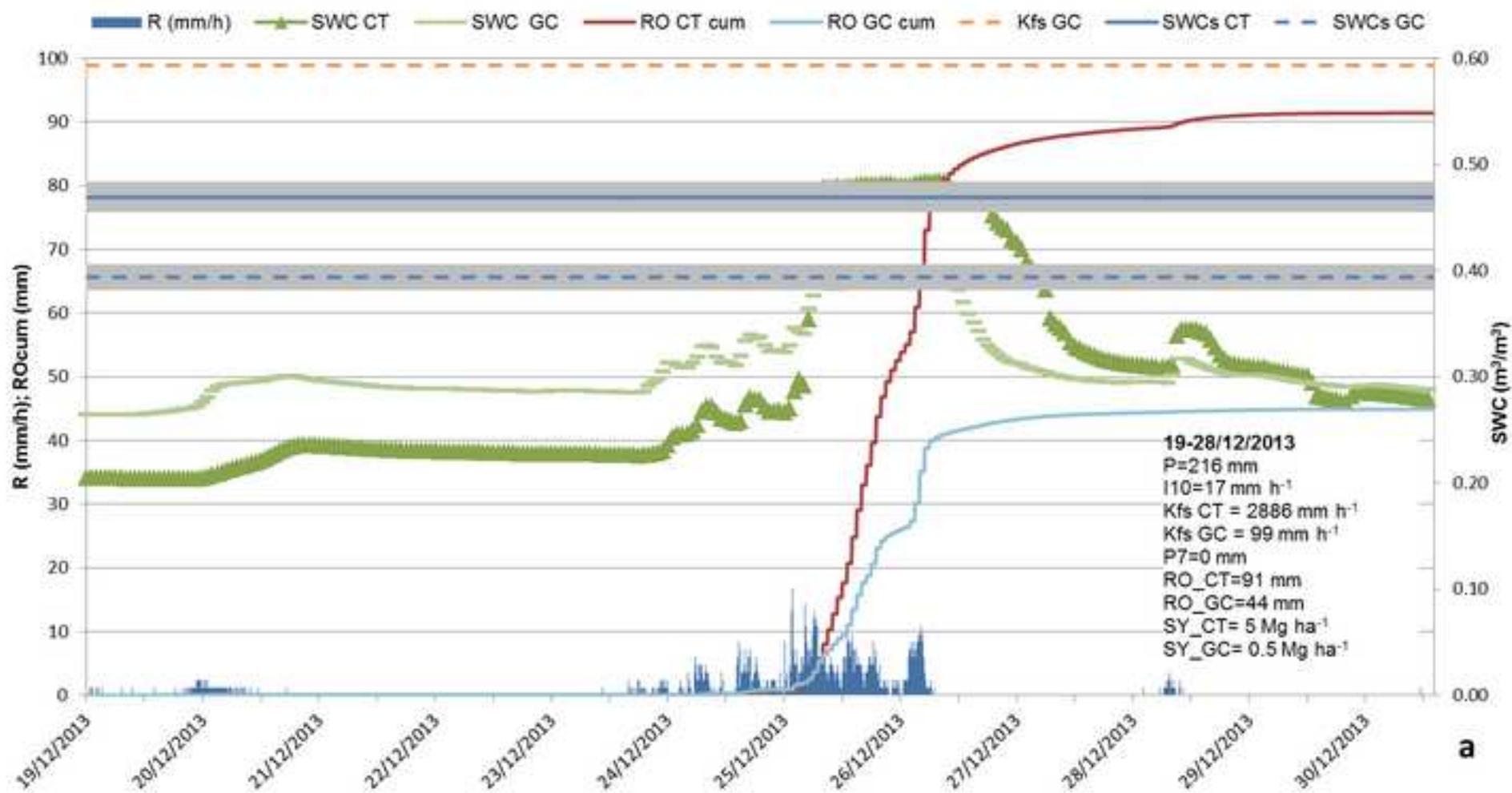


Figure3a

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a

Figure3b

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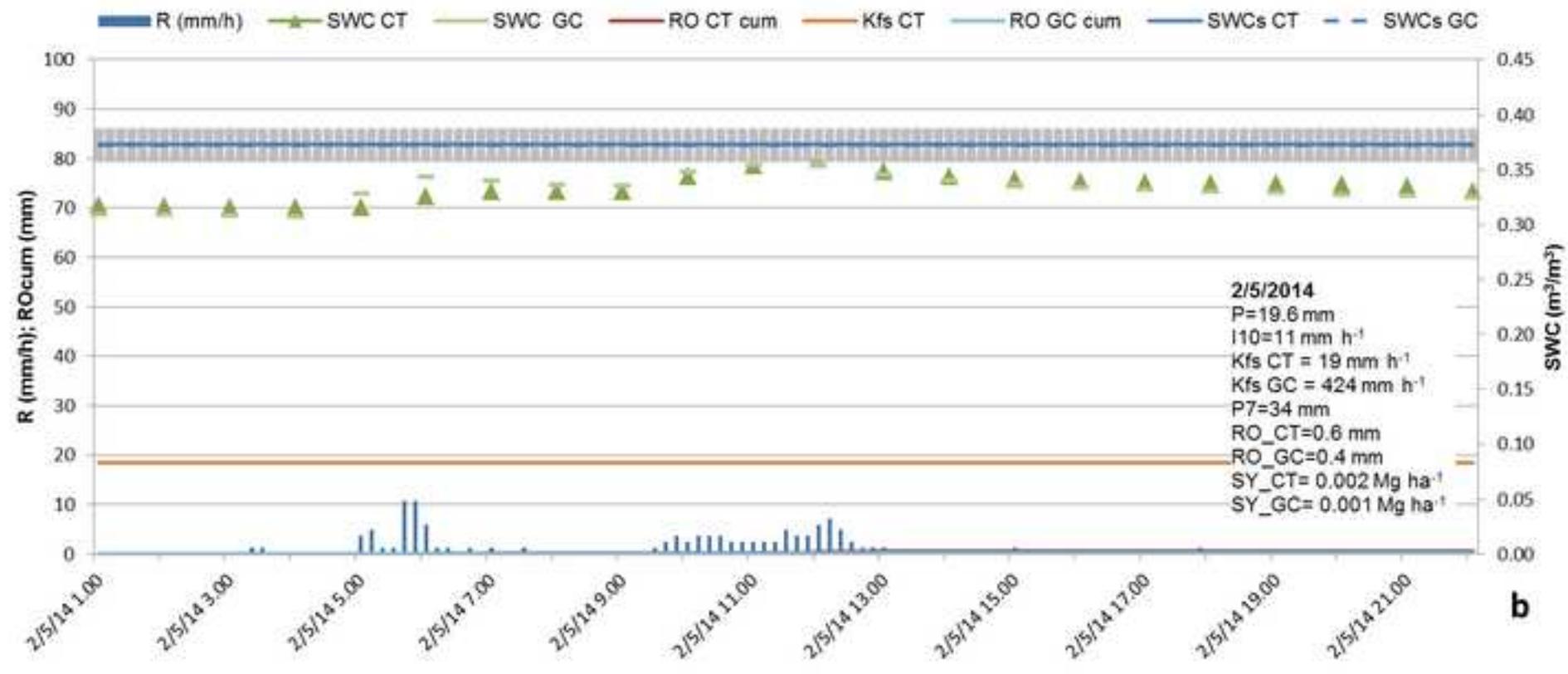
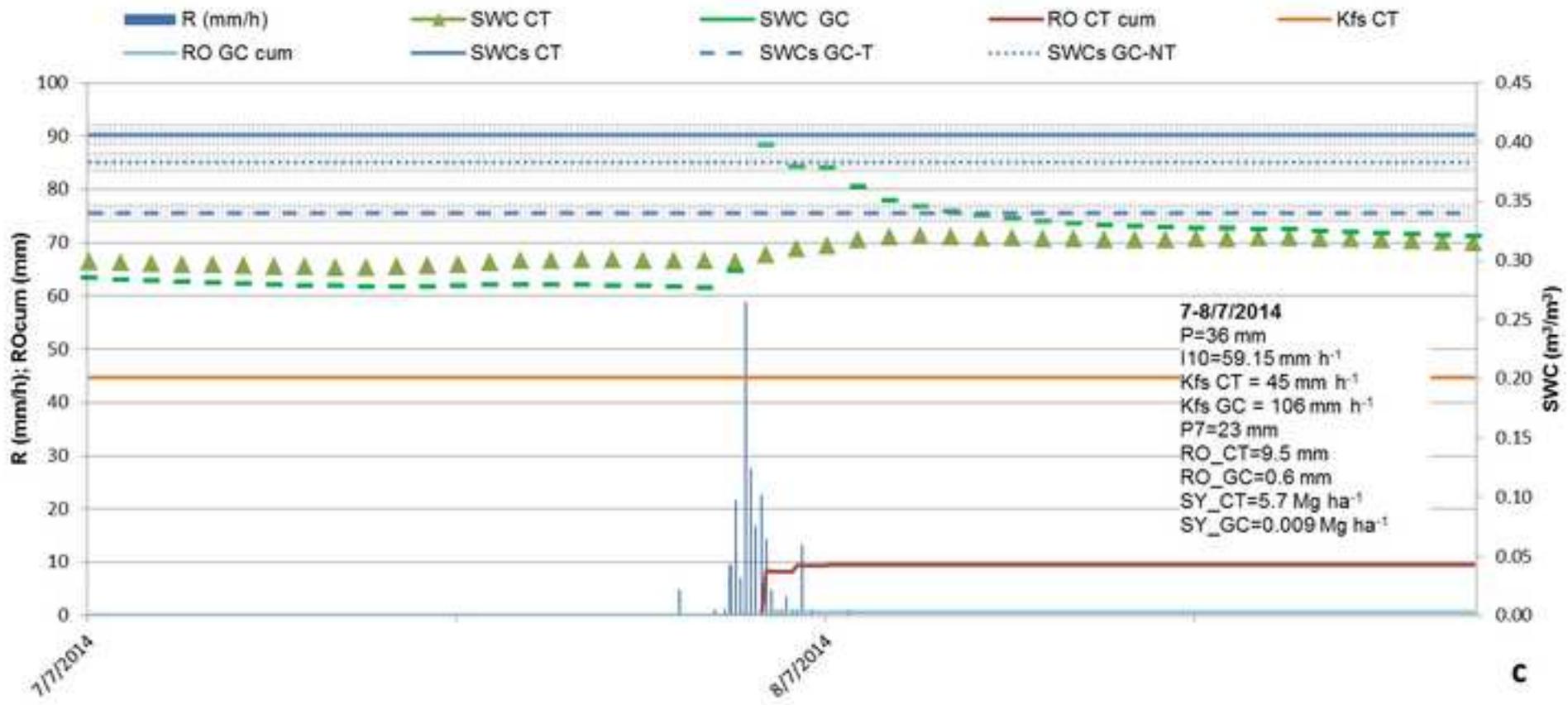


Figure3c

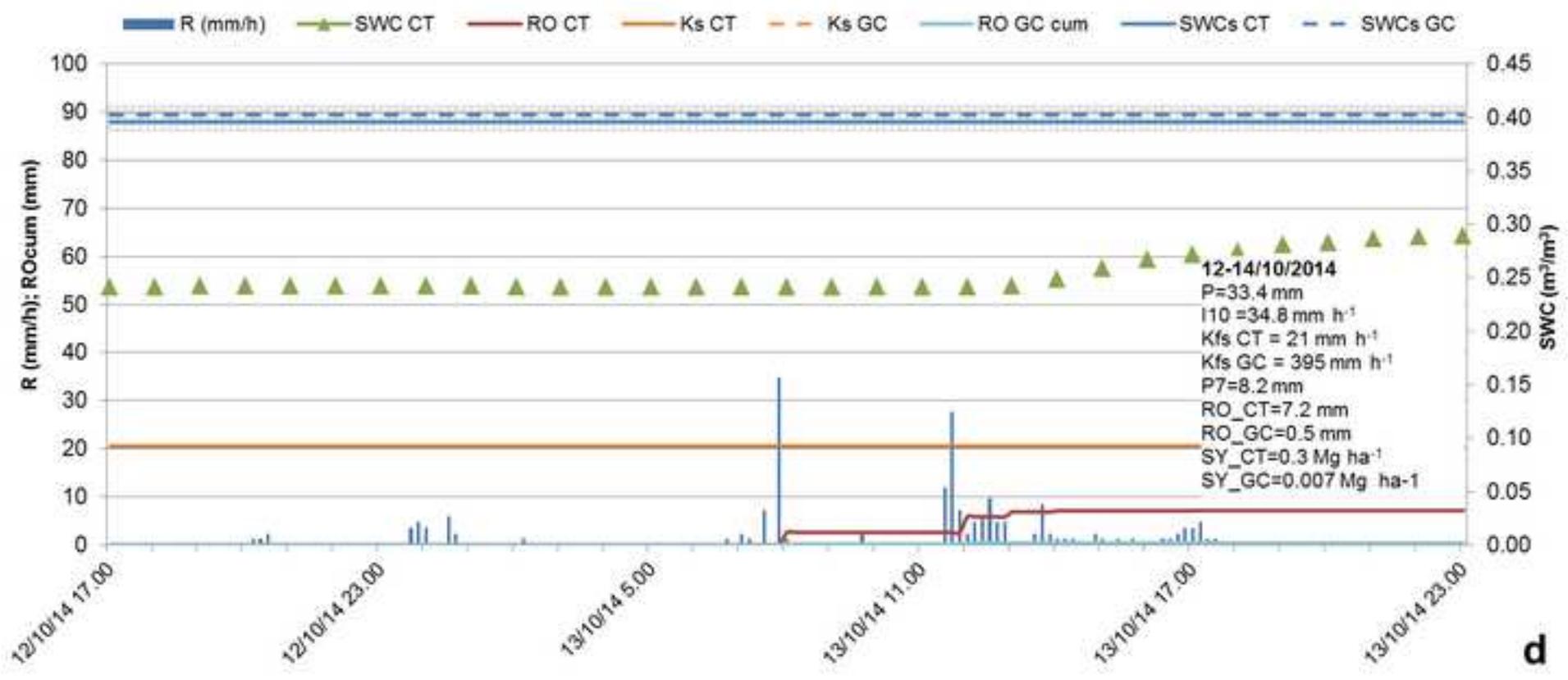
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C

Figure3d

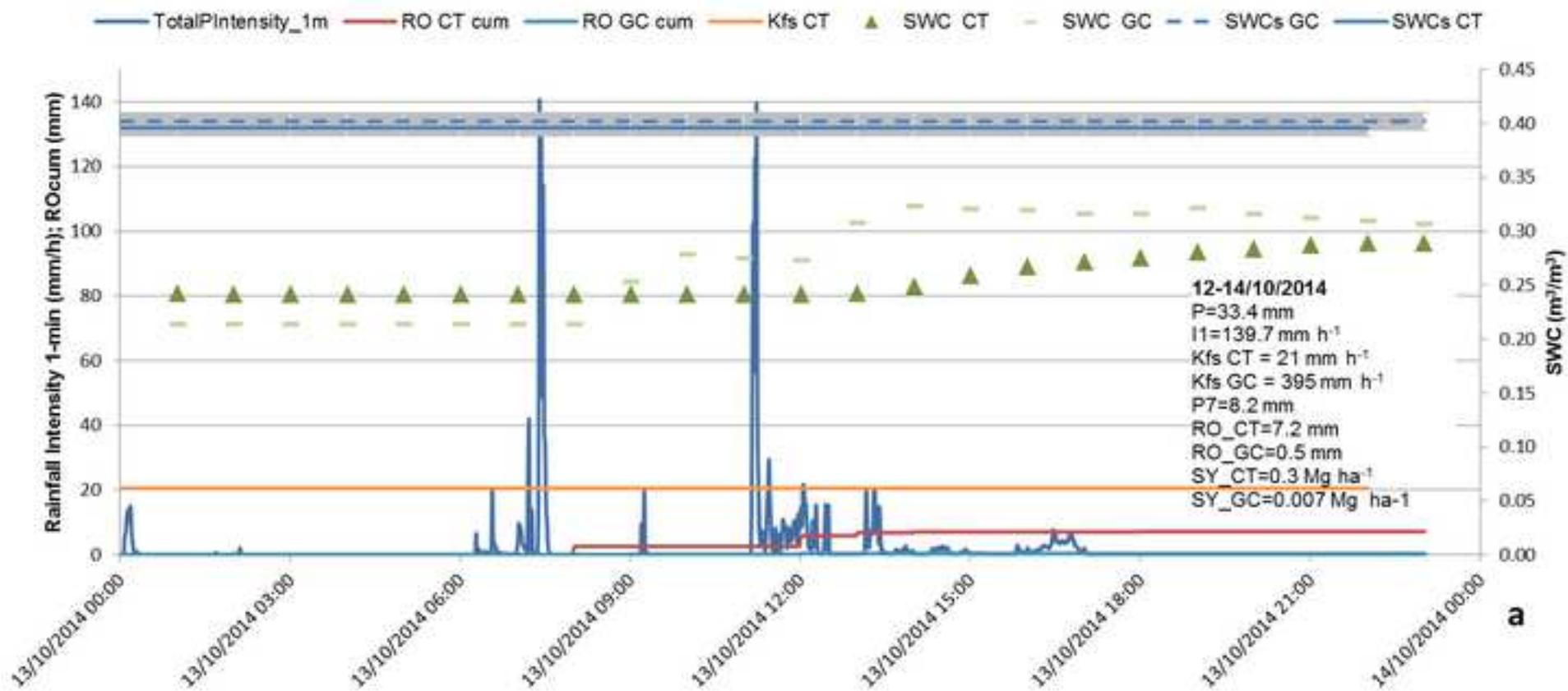
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d

Figure4a

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a

Figure4b

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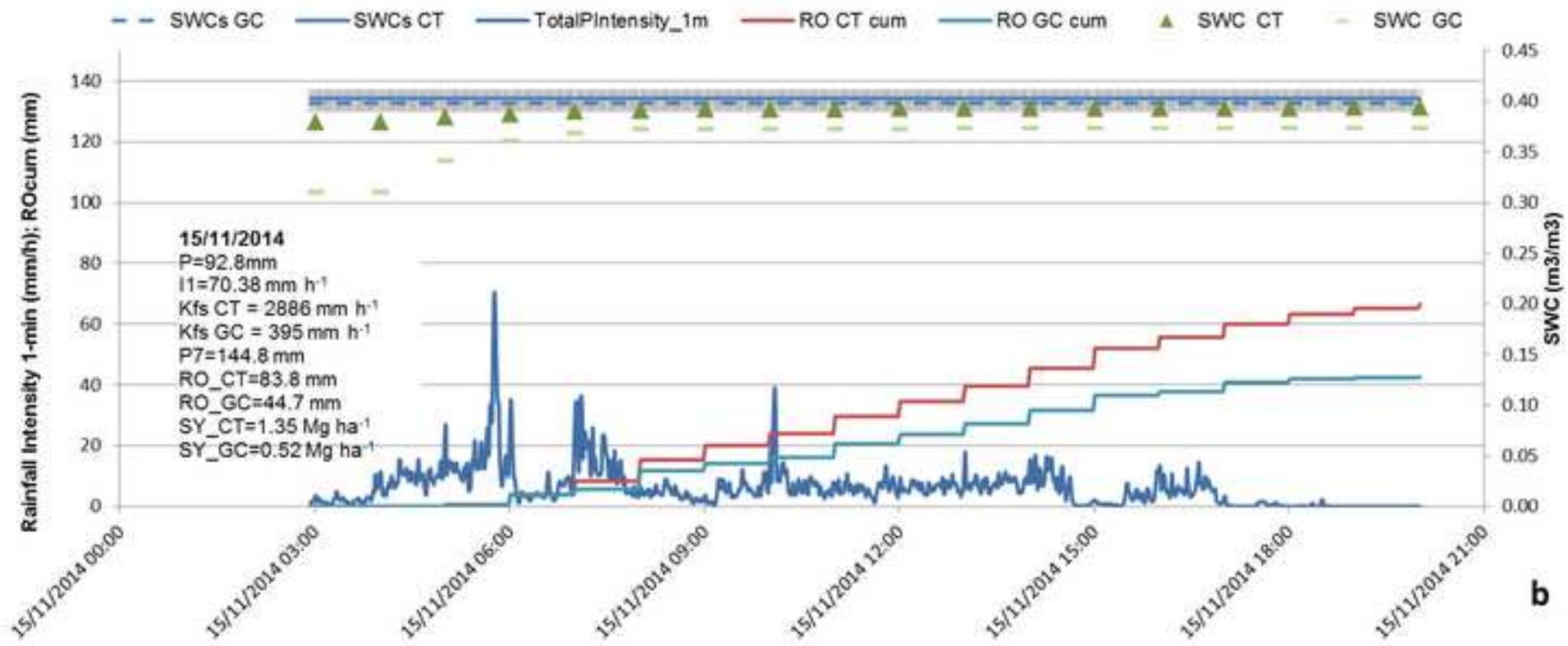


Figure 5

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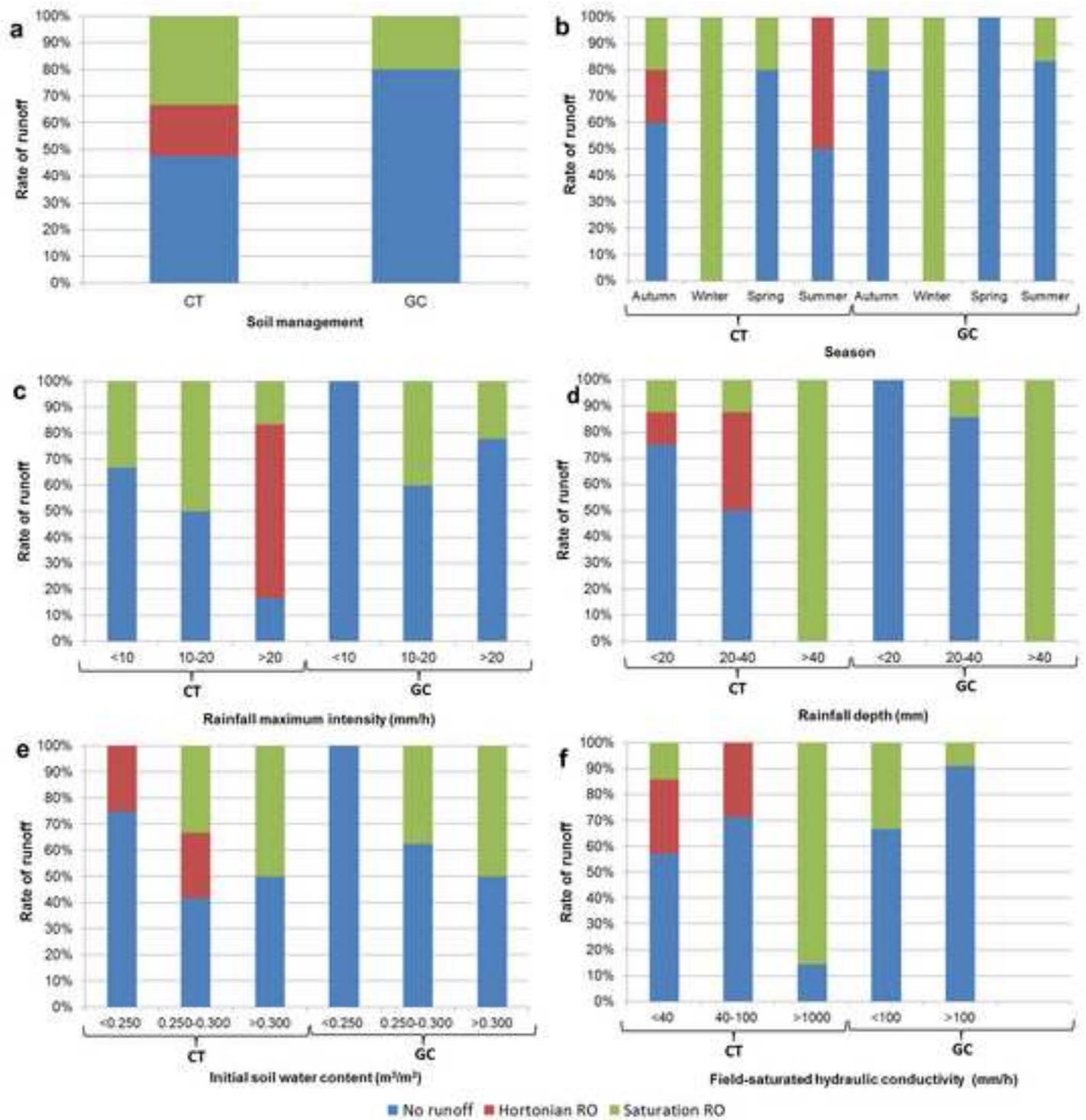
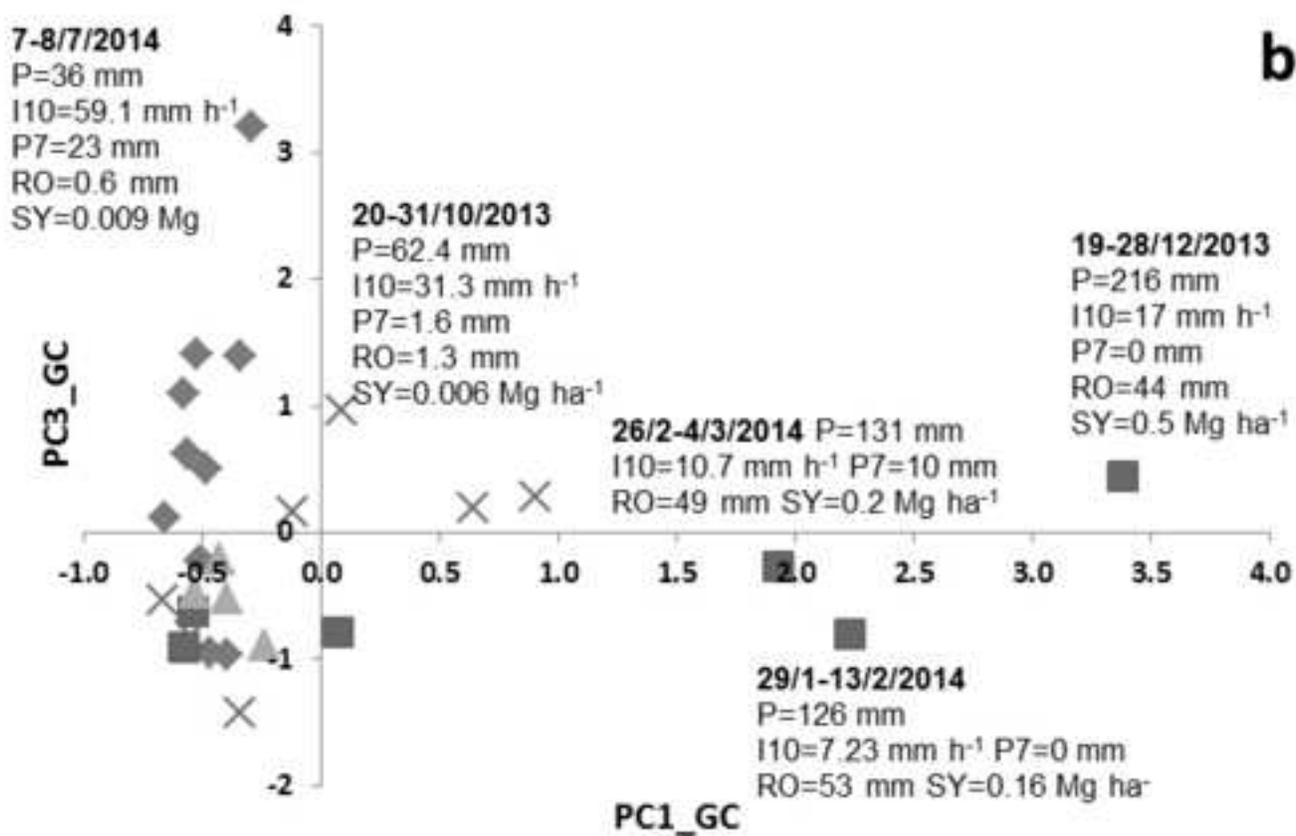
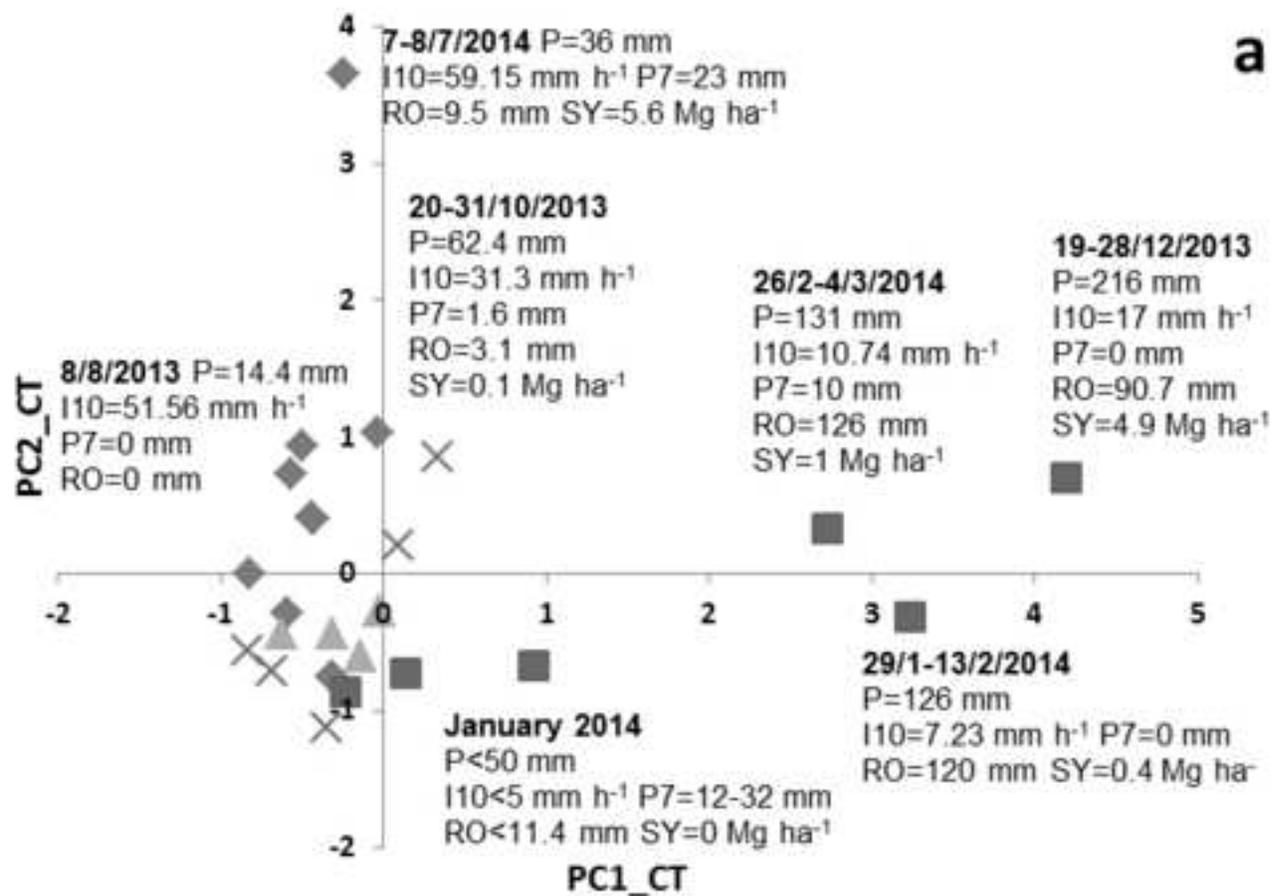


Figure1_gray

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◆ Summer ■ Winter ▲ Spring × Autumn

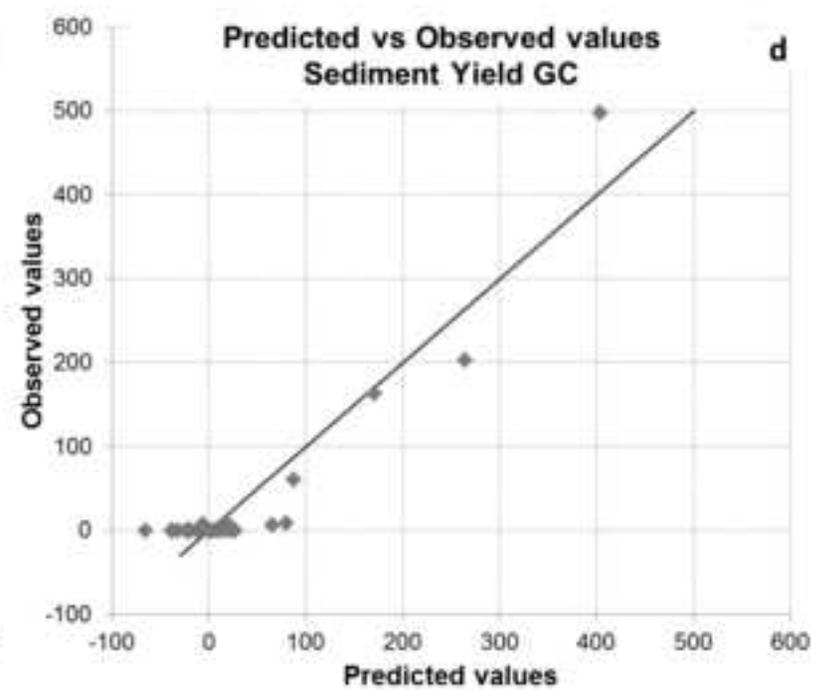
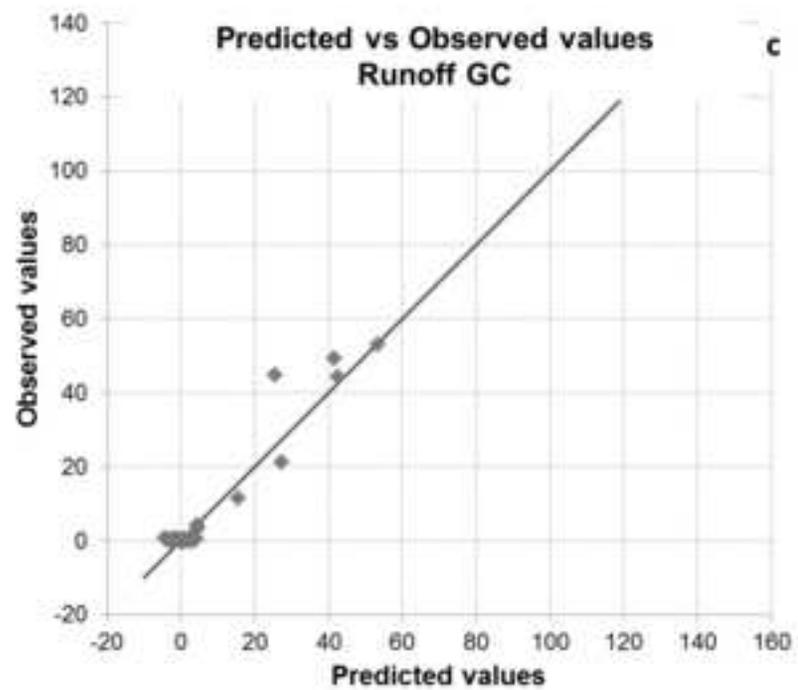
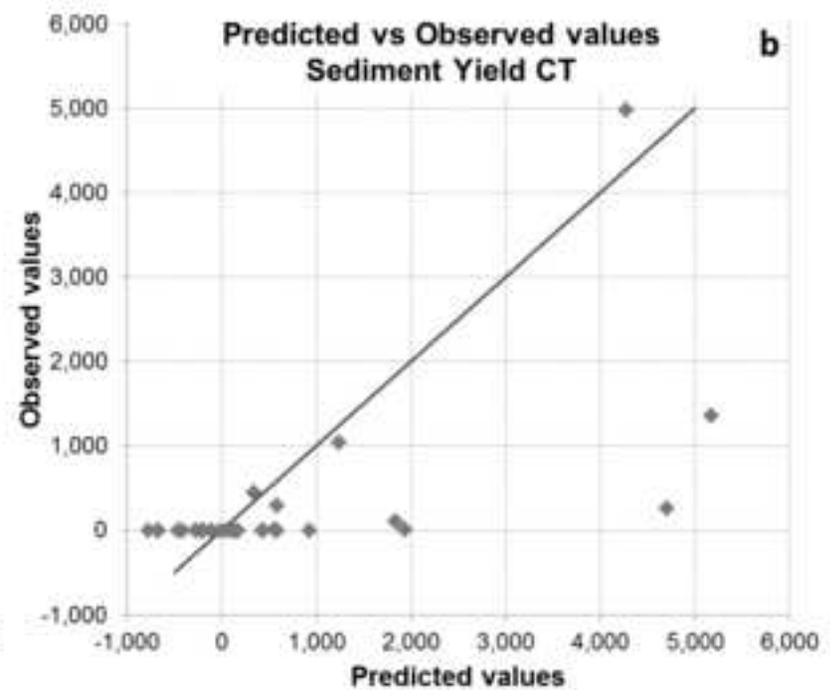
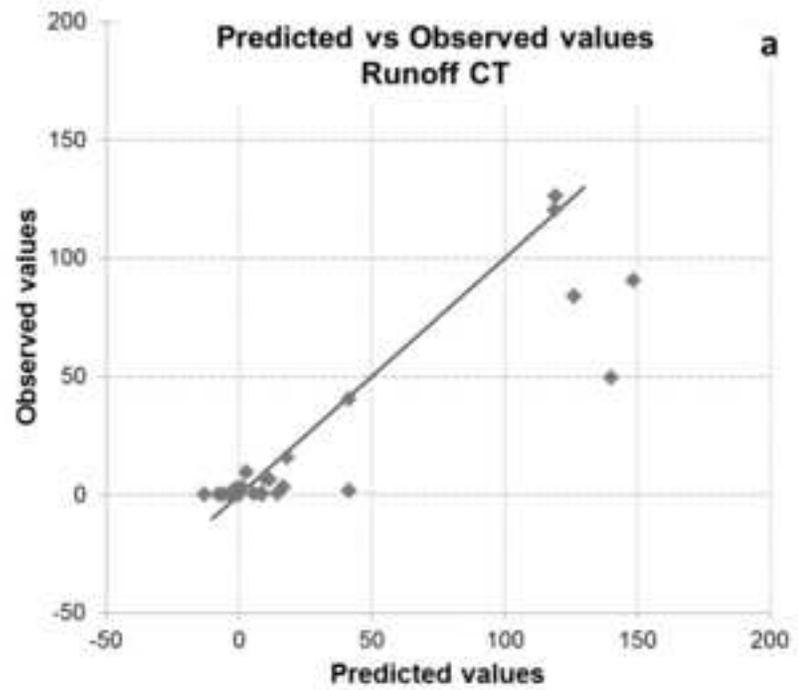
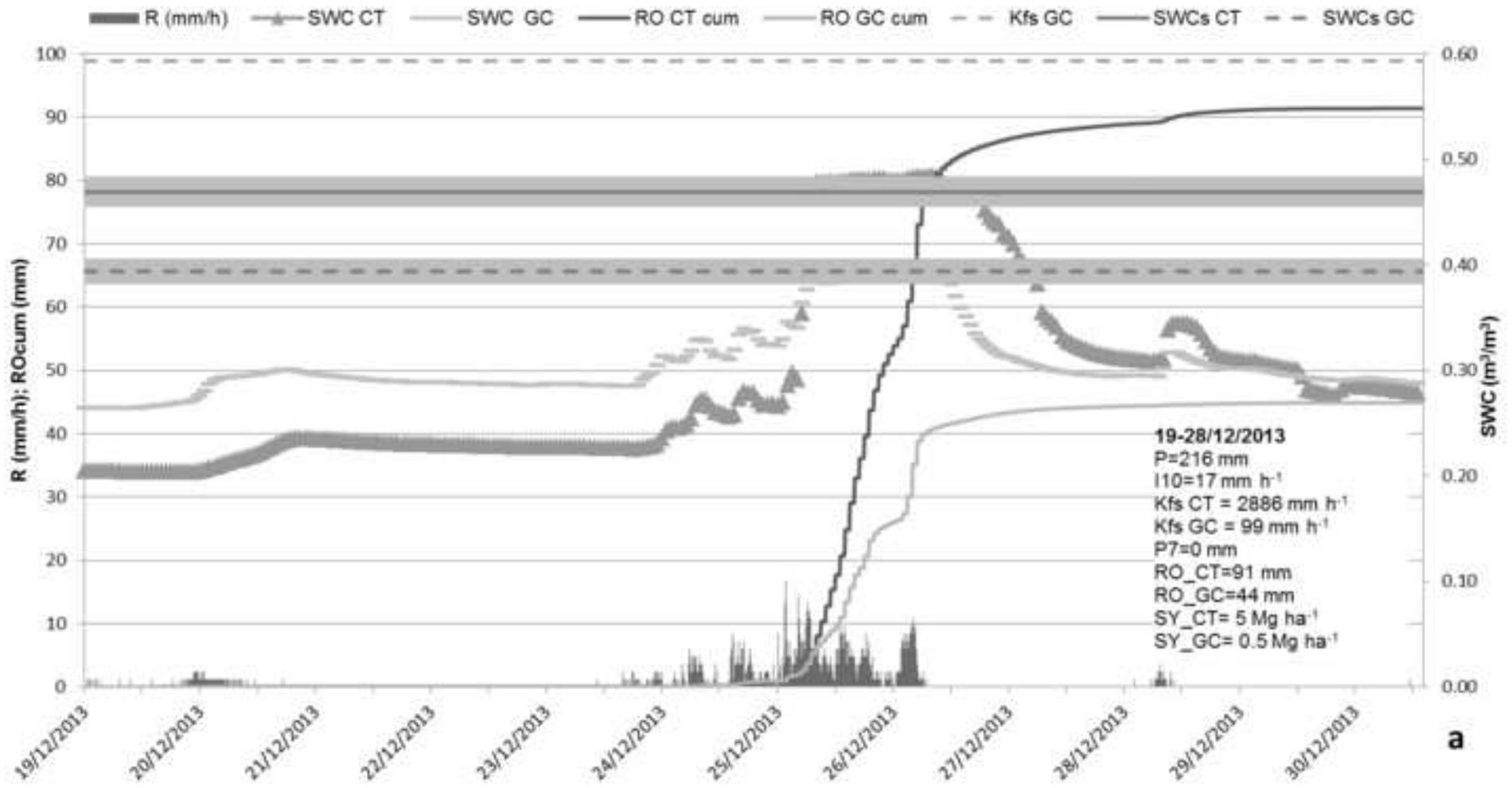


Figure3a_gray
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a

Figure3b_gray
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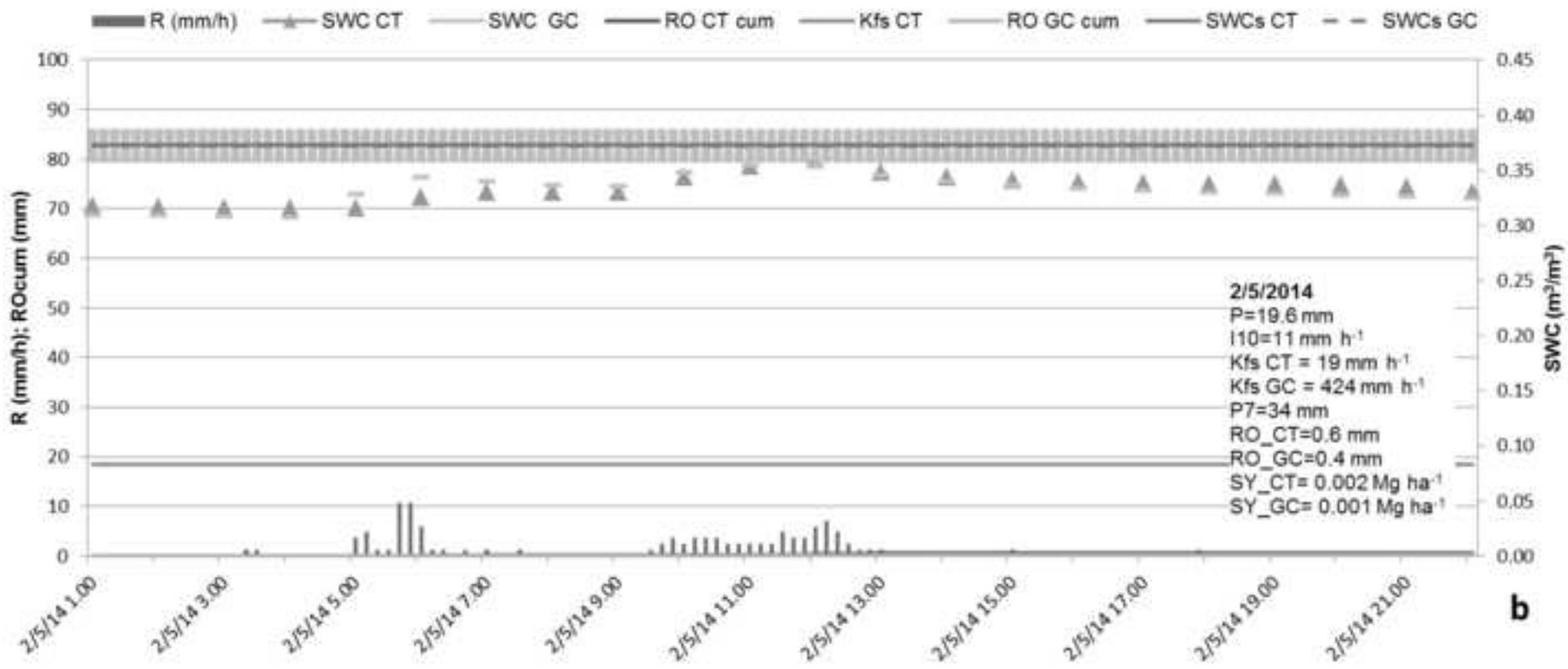


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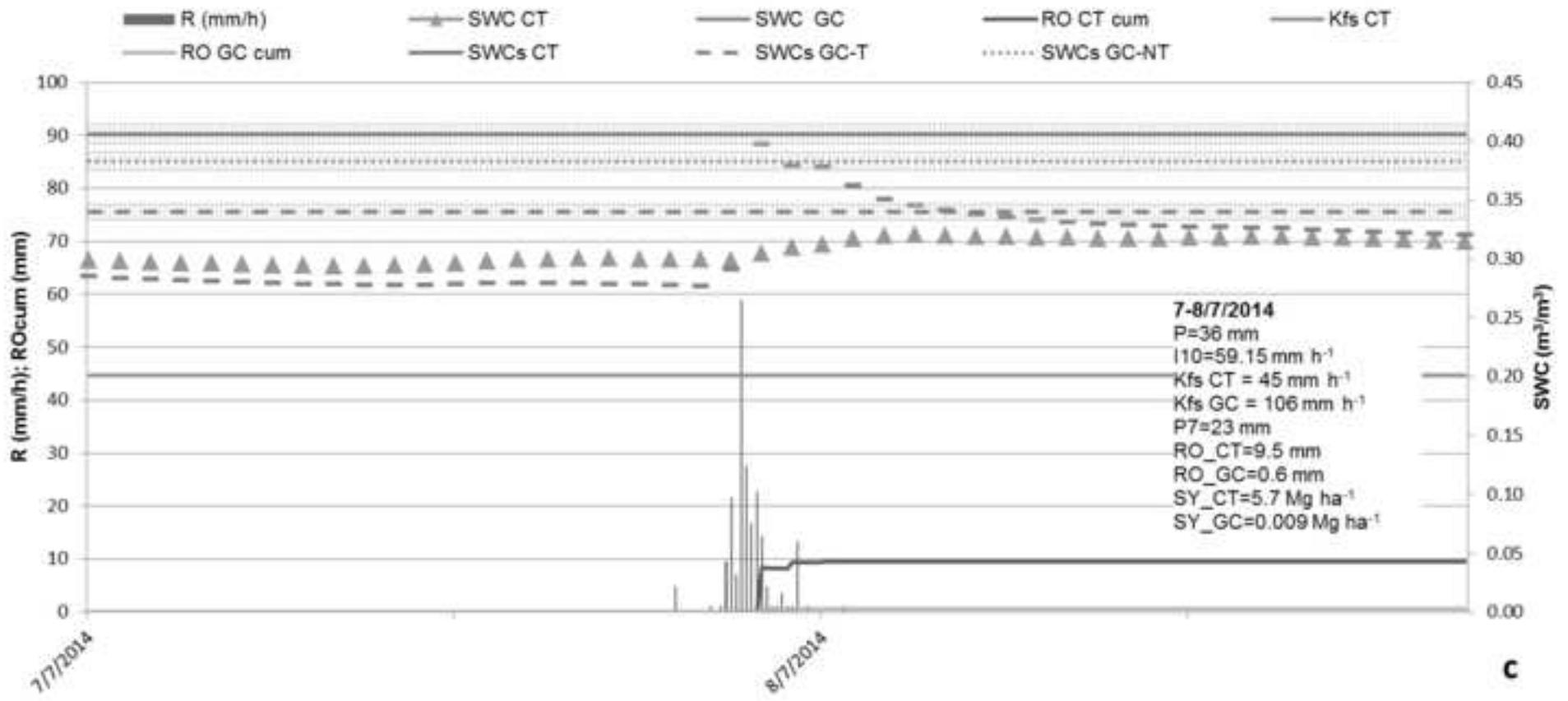


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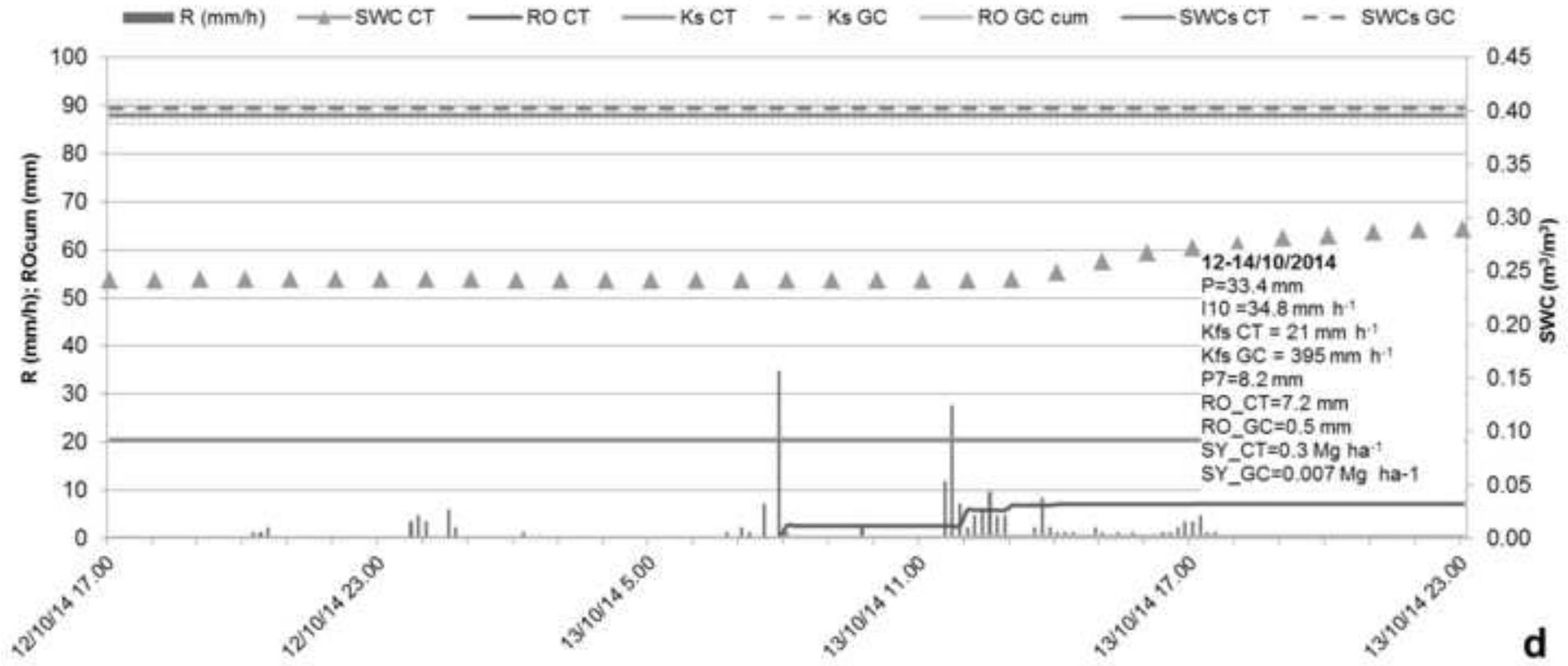
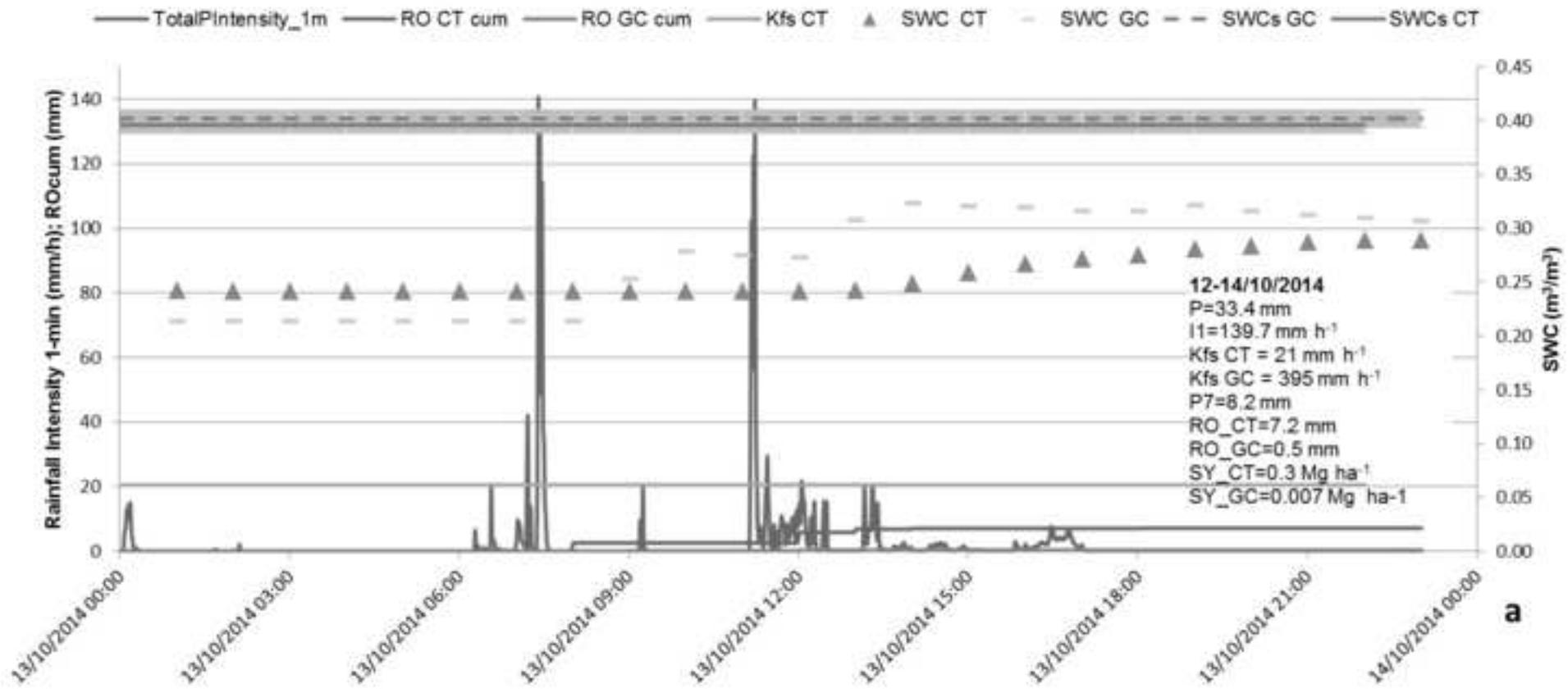


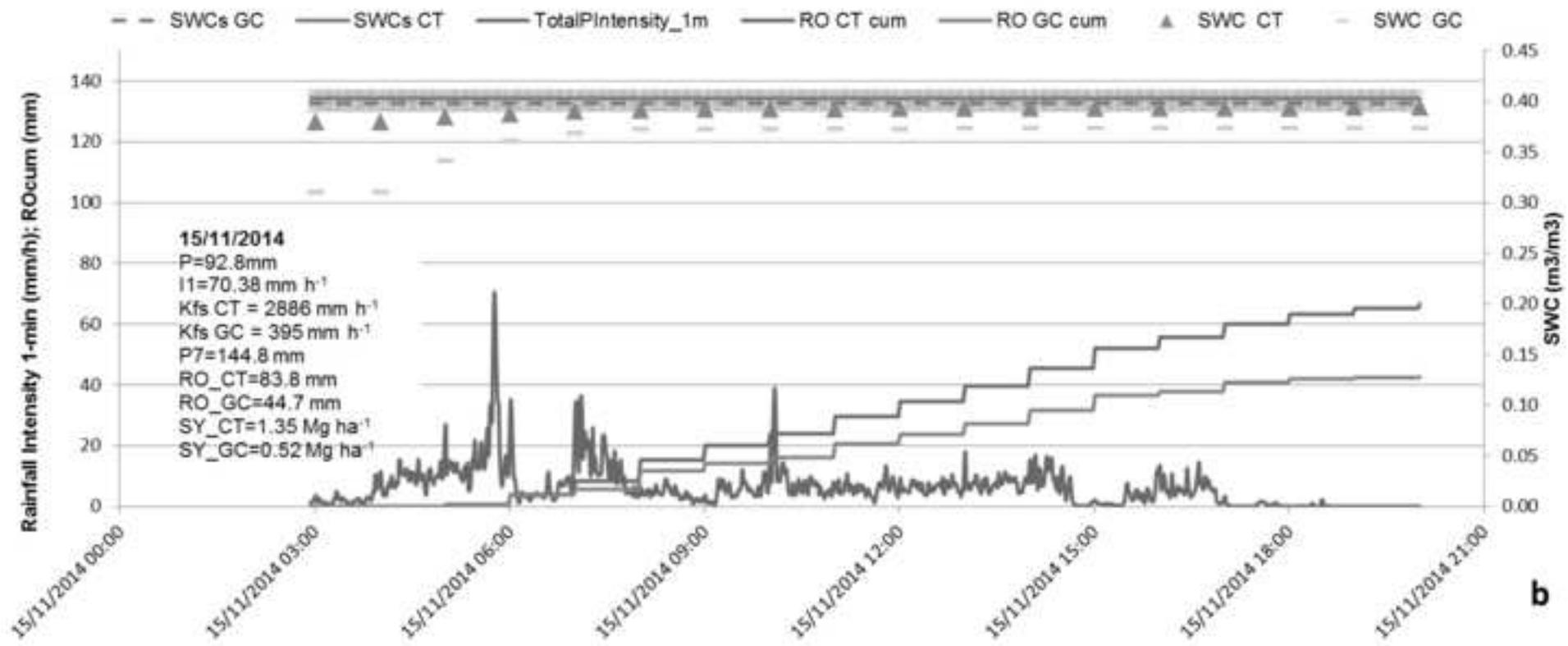
Figure4a_gray

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a

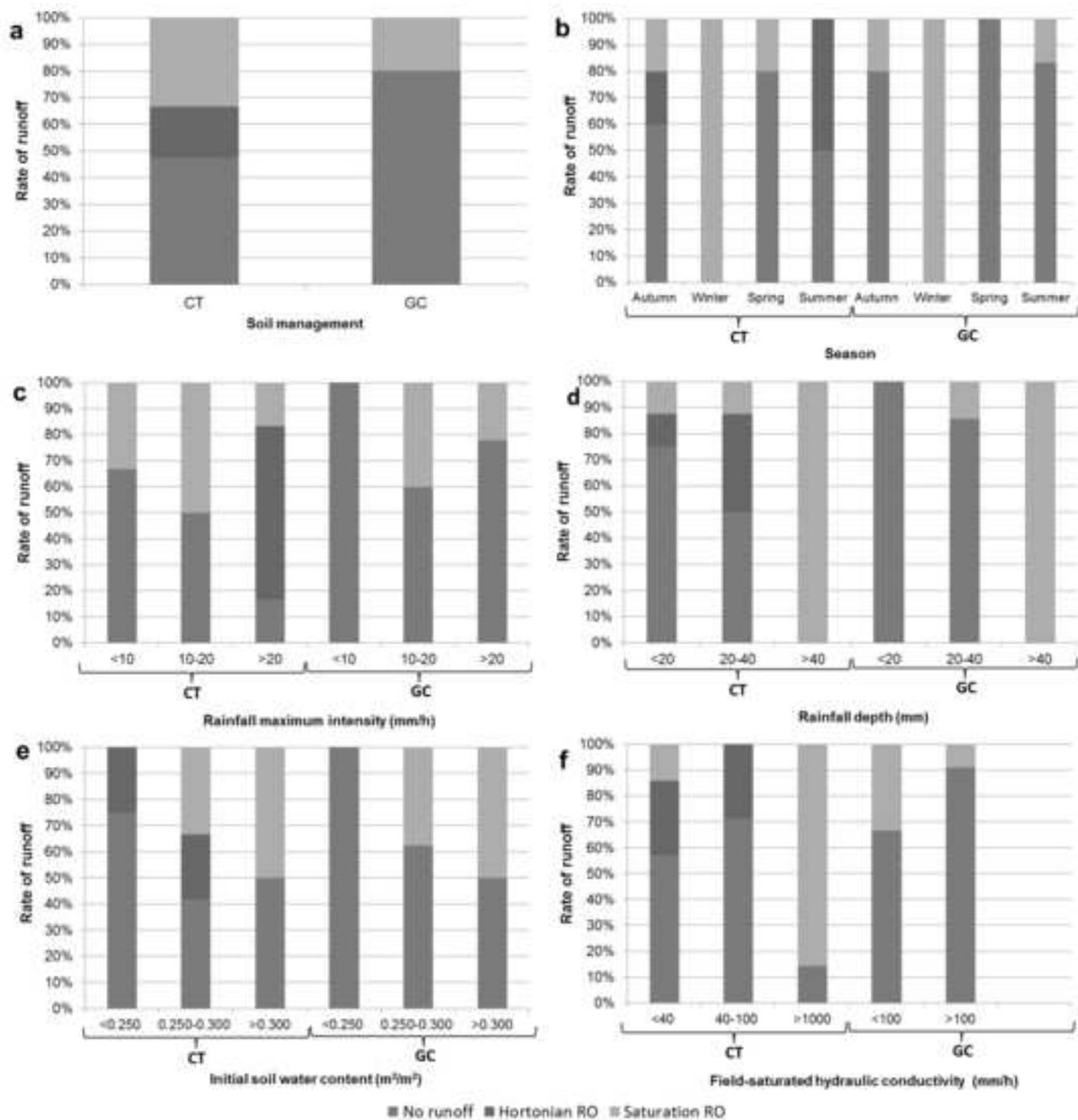
Figure4b_gray
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b

Figure5_gray

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