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## Quantifying the impact of no-till on sediment yield in southern Brazil at the hillslope and catchment scales

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3 1 **Title:** Quantifying the impact of no-till on runoff in southern Brazil at hillslope and catchment  
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23 17 **Abstract:**

24 18 No-till (NT) is a conservation system that improves the hydrological regime of agricultural  
25 19 slopes by providing greater surface protection and benefits to the physical and hydrological  
26 20 properties of soils. However, the isolated use of NT is not enough to control runoff and its  
27 21 associated degradation processes. Therefore, this study aimed to evaluate the runoff of  
28 22 agricultural slopes under NT under different runoff control conditions by monitoring 63 rainfall  
29 23 events in two 2.4-ha zero-order catchments and 27 rainfall events in four 0.6-ha macroplots.  
30 24 The catchments are paired and similar in terms of the type of soil and relief, but different  
31 25 regarding the presence of terraces. The macroplots have different soil and crop management  
32 26 systems. By using monitoring techniques, the hyetographs and hydrographs revealed the  
33 27 influence of the different types of management on the catchments and macroplots and allowed  
34 28 rainfall characteristics, runoff volume, runoff coefficients, water infiltration, peak runoff,  
35 29 response times, and curve number to be analyzed. The terraces positively affected the NT and  
36 30 controlled runoff and related variables, in addition to infiltration significantly increasing and  
37 31 runoff reducing in the terraced catchment. All the hydrological information assessed pointed to  
38 32 the positive effects provided by the presence of the terraces. The results in the macroplots  
39 33 showed that high amounts of phytomass and/or chiseling do not control runoff and its correlated  
40 34 variables in medium and high magnitude events. The study concludes by underlining the need  
41 35 for additional measures to control runoff (terraces), even in areas under NT and with high  
42 36 phytomass production. Additionally, the study emphasizes the importance of monitoring at the  
43 37 catchment scale to better understand the hydrological behavior of agricultural areas and provide  
44 38 the necessary parameters to effectively control runoff.  
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54 41 **Keywords:** hydrological monitoring, soil management, soil conservation, curve number,  
55 42 infiltration, terraces, water losses.  
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60 45 **1. Introduction**

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4 47 Soil conservation in Brazil made a breakthrough in the 1990s with the spread of no-till  
5 48 (NT). This practice of soil conservation is based on several key principles, such as not tilling  
6 49 the soil, maintaining plant residues on the soil, and controlling runoff (Derpsch, Friedrich,  
7 50 Kassam, & Hongwen., 2010; Friedrich, Derpsch, & Kassam, 2012; Reicosky, 2015). Despite  
8 51 the widespread adoption of NT in Brazil, the quality of the system falls short in mitigating  
9 52 problems of conservation and environmental nature. Moreover, disregard is given to the full  
10 53 adoption of technological processes required by the conservation system (Didoné et al., 2014;  
11 54 Ribeiro et al., 2014; Le Gall et al., 2017; Londero et al., 2017; Tiecher et al., 2017a; Deuschle,  
12 55 Minella, Hörbe, Londero, & Schneider, 2019). Simplifying the system as a conservation  
13 56 strategy through the sole use of NT is not enough to maintain or improve soil quality and control  
14 57 runoff and erosion processes (Friedrich et al., 2012; Olley, Brooks, Spencer, Pietsch, &  
15 58 Borombovits, 2013; Reicosky, 2015), leading to negative repercussions in production, the  
16 59 environment, and society.

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21 60 Furthermore, overlooking soil conservation practices further aggravates problems  
22 61 caused by climate change and high volume and intensity rains, and this hydrological and erosive  
23 62 standard must be understood through a monitoring approach capable of reflecting the dominant  
24 63 hydrological processes. Therefore, studies on runoff formation and propagation on agricultural  
25 64 slopes and paired catchments are fundamental to define the best control strategy (Williams,  
26 65 Wuest, & Long, 2014; Merten, Araújo, Biscaia, Barbosa, & Conte, 2015; Sidle, 2018).  
27 66 Hydrological monitoring data is essential to better comprehend how agricultural activity affects  
28 67 water flow on the landscape (Merten et al., 2015; Londero et al., 2017; Deuschle et al., 2019).  
29 68 In addition, hydrological and sedimentological monitoring data serve as a basis for calibrating  
30 69 and validating mathematical models, which are useful to simulate conservation scenarios and  
31 70 their effects on soil and water resource degradation (de Vente et al., 2013). The spatial and  
32 71 temporal distribution of rainfall is significantly affected by climate change (IPCC, 2013;  
33 72 Delgado et al., 2011). In southern Brazil, more erosive rainfall is projected to occur (Almagro,  
34 73 Oliveira, Nearing, & Hagemann, 2017), which corresponds to a new standard of rainfall with  
35 74 higher frequency, intensity, and accumulated volume, in addition to longer and more severe  
36 75 droughts (IPCC, 2013). These factors negatively affect the agricultural activity and water  
37 76 resources, and small changes in rainfall patterns directly impact crop productivity and the  
38 77 geography of production, thus jeopardizing agricultural development and food security in  
39 78 numerous regions. Given this scenario, the agricultural system must adapt to this new rainfall  
40 79 pattern and conditions of water deficit or excess by maximizing infiltration and controlling  
41 80 runoff. Basche (2017) and Rockstrom et al. (2010) described the need to manage water in  
42 81 agricultural systems to minimize the economic and environmental effects of floods and  
43 82 droughts. Moreover, the demand for food will require a 60% increment in production in the  
44 83 following decades, increasing agricultural water consumption by 40% (FAO, 2015).  
45 84 Nevertheless, this rise in water use can be mitigated by avoiding waste due to runoff.

46 85 One commonly employed water management technique in agricultural areas is terracing,  
47 86 which consists of using strips of land mobilized at a level to intercept runoff and reduce its  
48 87 speed, increasing water infiltration into the soil (Arnáez, Lana-Renault, Lasanta, Ruiz-Flaño, &  
49 88 Castroviejo, 2015; Hussein, Amien, & Kariem, 2016). With the spread of NT and its benefits  
50 89 against the erosive action of the impact of raindrops, the terraces were removed under ill-

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6 90 founded justifications at the end of the 1990s (Caviglione et al., 2010). The abandonment of  
7 91 terracing occurred due to changes in the technological standards of grain production in Brazil  
8 92 (larger agricultural properties, genetic engineering, and developments in the agricultural  
9 93 machinery and equipment sector), erroneously implying this technique would be unnecessary  
10 94 and reduce the efficiency of agricultural operations. Allied to this, the excessive use of  
11 95 agricultural machinery in conditions that were often inadequate significantly increased the  
12 96 problems of soil compaction, including reduced soil water infiltration and storage (Alaoui,  
13 97 Rogger, Peth, & Blöschl, 2018, NRCS, 2004).

14 98 Estimating runoff is pivotal in soil and environment conservation practices, such as  
15 99 using the Curve Number method (CN) (Hawkins, Ward, Woodward, & Van Mullem, 2009;  
16 100 Mishra, Tyagi, Singh, & Singh, 2006). Runoff volume is estimated from rainfall volume and  
17 101 CN values, which must be obtained from a set of monitored events in which rainfall and runoff  
18 102 are considered. Despite the importance and versatility of the CN method, few studies have been  
19 103 conducted in Brazil (Oliveira et al., 2016; Pruski, Griebeler, & Silva, 2001; Tedela et al., 2013;  
20 104 Do Valle Junior, Rodrigues, & de Oliveira, 2019) to estimate CN values under Brazilian  
21 105 conditions, and the correct parameterization of the CN is essential for validating the method for  
22 106 application under different conditions. The surface and subsurface conditions of the NT carried  
23 107 out in Brazil are very particular that must be adapted in hydrological and erosive modeling  
24 108 (Huang, Gallichand, & Zhang, 2003; Polyakov et al., 2010).

25 109 The analysis of hydrological responses as a function of soil use and management can be  
26 110 performed by comparing hydrographs in paired catchments (Rinaldo, Vogel, Rigon, and  
27 111 Rodriguez-Iturbe, 1995; Nadal-Romero, Peña-Angulo, & Regüés, 2018; Williams et al., 2014;  
28 112 Solyom and Tucker, 2004). In NT, geomorphology control is crucial since erosive processes  
29 113 are concentrated in the thalweg, and there is a great demand for information on the effects of  
30 114 different conservationist management practices on controlling runoff at catchment scale. This  
31 115 data is essential for choosing the best set of practices, considering farmers' interests and need  
32 116 to protect water resources. In this context, this study aimed to evaluate the hydrological  
33 117 variables obtained through the hydrological monitoring of catchments and paired slopes under  
34 118 NT to evidence the effects of the farming practices on runoff. The objective was to generate  
35 119 information from hyetographs and hydrographs capable of quantitatively demonstrating the  
36 120 efficiency of the amount of biomass, chiseling, and terracing in reducing runoff.

## 37 121 38 122 39 123 **2. Materials and Methods**

40 124  
41 125 The study is based on the monitoring of rainfall and liquid discharge representing the  
42 126 volume of runoff in two zero-order catchments and four paired macroplots. These monitoring  
43 127 units represent different surface conditions in NT. The information extracted from the events  
44 128 was used to characterize the runoff in each of the studied conditions. Monitoring was performed  
45 129 between 2014 and 2018 in southern Brazil (29°13'39"S, 53°40'38"W) in a region belonging to  
46 130 the Southern Plateau, which was formed from successive volcanic spills with the formation of  
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3 131 extrusive volcanic rocks (Figure 1) and characterized by a smooth wavy relief and 5-13%  
4 132 slopes. The region has a Cfa climate (humid subtropical) with hot and humid summers and dry  
5 133 and cold winters, according to the Köppen classification (Alvares, Stape, Sentelhas, De Moraes  
6 134 Gonçalves, & Sparovek, 2013). The soil has >30% of clay content and is classified as Rhodic  
7 135 Nitisol (Dystric) (WRB, 2014). The average annual rainfall is 1678 mm, evenly distributed  
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9 136 throughout the year.  
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12 138 Figure 1. Location of the experimental area and six monitoring units.  
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15 140 The six monitoring units were placed side by side on a slope with similar soil and relief  
16 141 characteristics and representative of the physiographic conditions of the region. A previous  
17 142 physical and chemical soil characterization of the slope demonstrated the homogeneity of the  
18 143 area (Deuschle et al., 2019; Londero et al., 2016). A detailed topographic survey and analysis  
19 144 of topographic attributes of the slope, slope shape, accumulated runoff, and moisture content of  
20 145 the terrain were then performed using the digital elevation model (DEM). These indices were  
21 146 used to define the monitoring units. Different sizes, positions, and directions of the units were  
22 147 tested to seek the maximum similarity. Homogeneity was considered within the units and  
23 148 between them.

24 149 Two different scales were used considering the area of contribution and form. One of  
25 150 them was the hydrographic catchment with the largest contribution area and converging  
26 151 curvature in the plane and a length slope of ~200m to evaluate the runoff control management  
27 152 (broad-based terraces). The other scale explored was the slope scale with the smallest  
28 153 contribution area with rectilinear curvature in the plane and length slope of ~80m to assess the  
29 154 influence of soil and crop management.  
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## 34 158 **2.1 Zero-order catchments and macroplots**

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36 160 The two zero-order catchments are paired and have similar soil and relief characteristics.  
37 161 The catchments were named non-terraced catchment (NTC) and terraced catchment (TC) with  
38 162 2.43 and 2.35 ha, respectively, with approximately 200 m in length, converging curvature in  
39 163 the plane, and convex in the profile favoring the concentration and spread of runoff. Small  
40 164 ridges (40 cm high) were built to delimitate the experimental units and prevent runoff from  
41 165 coming in from outside of the catchment. Five medium-level infiltration terraces were built at  
42 166 the TC. The terraces were distributed and dimensioned according to the estimated runoff  
43 167 volume for a design rainfall of 110 mm based on a ten-year return period (RP) for 6 h of  
44 168 duration. The basic infiltration velocity is measured in concentric rings in the order of 20 mm  
45 169 h<sup>-1</sup>. The terraces are 40-70 cm high, have ~2 m<sup>2</sup> cross-sectional areas, and were built with their  
46 170 ends closed to prevent water from leaving the system and enable total runoff quantification  
47 171 (Figure 2).  
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51 174 Figure 2. The terraces controlling the runoff after a rainfall event.  
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6 174 The crops intended for grain production and soil cover were the same for both  
7 175 catchments in all monitoring years. In the first three years (2014-2016), a lower addition of  
8 176 phytomass was applied using soybean (*Glycine max*), wheat (*Triticum* spp.), and black oats  
9 177 (*Avena sativa* L.). In the following two years (2017-2018), there was a greater addition of  
10 178 phytomass using maize (*Zea mays* L.), black oats (*Avena sativa* L.), and forage turnip  
11 179 (*Raphanus raphanistrum* L.). The average production of phytomass was 3.0 t ha<sup>-1</sup> during the  
12 180 period of cropping the binomial soybean/wheat or soybean/black oats. In the period of the  
13 181 greatest phytomass addition, the forage turnip ensured approximately 4.0 t ha<sup>-1</sup> and maize  
14 182 approximately 12.0 t ha<sup>-1</sup>.

15 183 The four paired macroplots M1, M2, M3, and M4 have 0.59, 0.60, 0.63, and 0.63 ha,  
16 184 respectively, and 8.8, 9.0, 9.2, and 8.8% slopes with straight curvature in the plane and slightly  
17 185 convex in the profile. The average ramp length is 80 m and enough for runoff formation without  
18 186 forming an ephemeral channel, which is different from what happens in the zero-order  
19 187 catchments. Thus, the flow spreads in relatively parallel flow lines towards the monitoring  
20 188 section. Ridges prevent water from entering and leaving the macroplots. Soil (no-till and  
21 189 chiseling) and plant (crop rotation) management practices were carried out to assess their ability  
22 190 to control runoff without the need to adopt terraces. All macroplots were cultivated under NT,  
23 191 two (M1 and M3) with chiseling (C), and two (M2 and M4) without chiseling (NC). Chiseling  
24 192 was performed in the first year of monitoring after the summer harvesting.

25 193 Chiseling is a commonly used tillage process to increase infiltration and reduce runoff.  
26 194 The other treatment tested was the amount of phytomass added to the soil through the chosen  
27 195 crops. There was a low addition of phytomass (LF) with soybean, fallow, and wheat succession  
28 196 in M1 and M2 and a high addition of phytomass (HF) with soybean or corn, turnip, oats, vetch,  
29 197 or wheat succession in M3 and M4. Contour farming was carried out as a standard practice in  
30 198 all monitoring units. Table 1 shows the nomenclature of treatments adopted in both catchments  
31 199 and four macroplots.

32 200  
33 201 Table 1. Soil, plant, and water management systems (treatments) used in each catchment and  
34 202 macroplot.

## 35 203 36 204 **2.2 Monitoring and hydrological analysis**

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38 206 Hydrological monitoring of rainfall (P) and runoff (Q) was carried out from July 2014  
39 207 to April 2018 in the zero-order catchments and from July 2015 to April 2018 in the macroplots  
40 208 during rainfall-runoff events (runoff depth >0.1 mm). All monitored events were overseen by a  
41 209 field team that manually recorded water level height variations and collected water samples to  
42 210 assess water quality and suspended sediment concentration. Rainfall was monitored with a rain  
43 211 gauge programmed to record data at two-minute intervals and two rain gauges to quantify the  
44 212 daily accumulated rainfall. The rainfall gauge was installed in the outlet of NTC and flow data  
45 213 was obtained by monitoring the water level measured in H-flumes using a staff gauge and  
46 214 pressure transducer sensors (Campbell brand) with a precision of five millimeters and five-

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3 215 minute intervals. In addition, 3-meter long soothing channels were installed upstream of the H-  
4 216 flumes to ensure runoff flow linearity (Figure 3). The flumes were scaled based on the  
5 217 maximum runoff estimate using the rational method (Chevallier, 1991).  
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8 219 Figure 3. H-flume for monitoring the flow rates installed in the lower part of the catchments  
9 220 and macroplots.  
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11 222 The relationship between the elevation and flow is defined using a specific rating curve  
12 223 depending on the dimensions of the installed flumes (Brakenseik et al., 1979). The flumes in  
13 224 the zero-order catchments were 0.6096 m wide and 0.4572 m wide in the macroplots. Each  
14 225 event featured a specific condition (catchments or macroplots) and was unique in terms of  
15 226 climatic characteristics (rainfall and soil moisture) and surface conditions (crop development  
16 227 stage and management effects). Hydrologic characteristic variables were extracted from  
17 228 hyetographs and hydrographs for each event with the potential of reflecting the effects of these  
18 229 factors on runoff behavior (formation and propagation). The data were analyzed to characterize  
19 230 the differences between the management systems in each monitoring unit. Three  
20 231 complementary approaches were used to analyze data and indicate differences between  
21 232 monitoring units:  
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- 23 234 a) Characteristic variables derived from hydrographs and hyetographs such as runoff  
24 235 depth (mm), runoff coefficient (%), peak flow ( $L s^{-1}$ ), lag times (min), etc.;
- 25 236 b) Estimation of apparent infiltration based on instantaneous data of runoff and rainfall  
26 237 intensity; and  
27 238 c) Estimation and analysis of the “Curve Number” (CN) parameter integrating the main  
28 239 controlling factors.

29 240 **a) Hydrological characteristics**  
30 241

31 242 Hyetographs and hydrographs were analyzed to obtain characteristic variables  
32 243 sensitive to the influence of controlling factors (climate, crop management, and soil  
33 244 management). As the monitoring units are paired, each rainfall event generates a response  
34 245 capable of quantitatively indicating the efficiency of the management in controlling runoff  
35 246 by reducing its volume and peak flow ( $Q_{peak}$ ). Therefore, we sought information from the  
36 247 hyetograph and hydrograph that characterize the event and express the influence of the  
37 248 surface condition in each monitoring unit influenced by the imposed management and  
38 249 characteristics of the rainfall that occurred. The set of all variables analyzed are shown in  
39 250 Table 2 and divided into four categories: a) rainfall, b) runoff, c) rainfall-runoff  
40 251 relationship, and d) lag time. Information on lag time was obtained based on the method  
41 252 proposed by Dingman (2015). The values are presented using box plot graphs that show  
42 253 the median (middle line), first and quartile (box), maximum and minimum values  
43 254 (whiskers), and extreme values (points).  
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45 256 Table 2. Characteristic variables obtained in the hyetogram and hydrogram analysis.  
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258 Rainfall characterization is important to define the range of magnitude and patterns  
259 that the set of monitored events provided. The information obtained from the runoff data  
260 and its relationship with rainfall is essential to define the proportion of the rainfall that is  
261 converted into runoff, which has a high potential for degradation. The information related  
262 to lag times reflects the effects of the roughness generated by the different managements  
263 applied in runoff propagation time. The effects are due to terracing in the catchments and  
264 land surface roughness imposed by the amount of phytomass and/or chiseling in the  
265 macroplots. The results of each variable were analyzed using the paired t-test to compare  
266 the means of each monitoring unit. The mean of the variables of each unit is compared by  
267 considering that each event can be paired with the observations in the other unit. Statistical  
268 significance was expressed as a p-value, followed by a Student's t-distribution under the  
269 null hypothesis that there is no difference between treatments (Casella & Berger, 2010).

### 271 **b) Total apparent infiltration**

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273 The concept of apparent infiltration rate ( $I_{ap}$ , mm h<sup>-1</sup>) (Rose, 2004) was used to  
274 demonstrate the infiltration pattern as a function of rainfall intensity (mm h<sup>-1</sup>). Analysis of all  
275 instantaneous values led to Eq. 1, where  $I_{ap}$  is calculated by the difference between the  
276 instantaneous values of rainfall intensity ( $R$ , mm h<sup>-1</sup>) and runoff ( $Q$ , mm h<sup>-1</sup>).

$$277 \quad I_{ap} = R_i - Q_i \quad (1)$$

278  
279 The analysis was performed with the paired values of  $R$  and  $I_{ap}$  for all events to  
280 characterize each monitoring unit. The model obtained ( $I_{ap} = f(R, I_m)$ ) shows the infiltration  
281 rate behavior as a function of the rainfall intensity and an estimate of the maximum infiltration  
282 rate of the unit ( $I_m$ ). The model obtained in each unit and  $I_m$  values were compared to determine  
283 the influence of the controlling factors on infiltration in each unit.

### 284 285 **c) Curve number method (CN-SCS)**

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287 The CN model (NRCS, 2004) is a widely used method in hydrological models to  
288 estimate runoff generated in a rainfall event as a function of the rainfall ( $P$ ), initial abstractions  
289 ( $I_a$ ), and the estimate of the maximum water storage capacity of the soil ( $S$ ). The value of  $S$  is  
290 estimated according to an empirical parameter called CN. This dimensionless parameter varies  
291 between 0 and 100 and represents the soil characteristics regarding permeability, use, and soil  
292 management. The CN parameter was empirically derived from a network of experimental  
293 catchments in the USA to design conservation practices (Hawkins et al., 2009). In this study,  $S$   
294 and CN values were estimated for each event and the different monitoring units, considering  
295 the monitored values of rainfall (mm) and runoff (mm) using Eqs. 2 and 3:



$$S = 5 \left[ P + 2Q - \sqrt{(4Q^2 + 5PQ)} \right] \quad (2)$$

$$CN = \frac{25400}{(S + 254)} \quad (3)$$

### 3. Results

The El Niño climate phenomenon occurred from 2014 to 2015 and generated above-average rainfall, increasing high-magnitude rainfall events. In 2016, the La Niña climate phenomenon reduced the number of monitored events (NOAA, 2018). This time series favored the analysis of the hydrological behavior in the monitoring units in contrasting conditions (e.g., high soil moisture and low soil coverage). Moreover, runoff occurred in events of all magnitudes, from small rainfall events (14 mm) to the largest one (160 mm). The boxplot of Figure 4 shows the median (middle line), first and quartile (box), maximum and minimum values (whiskers), and extreme values (points) of the R monitored at three different durations (10, 30, and 60 min). The 30-min rainfall intensity ( $R_{30}$ ) reached the average magnitude of 25 mm h<sup>-1</sup> and several events with values >50 mm h<sup>-1</sup>.

Figure 4. Rainfall intensity for 10, 30, and 60-min intervals.

The main characteristics of the rainfall to represent its magnitude are shown in Table 3. Six events (9%) had a RP of rainfall between 1 and 10 years, five events (8%) between 11 and 70 years, and one event (1.6%) exceeded the 100-year RP.

Table 3. Major rainfall events classified by decreasing return periods.

#### 3.1 Zero-order catchments

##### a) Hydrological characteristics

The runoff in the study period, considering the 63 monitored events, is described in Figure 5. The terraces (TC) significantly reduced runoff (p-value = 0.038). The terraces overflowed in some events, especially in 2015, although there was a significant reduction in runoff volume during these events. On average, the terraces reduced runoff by 56%, despite the reduction tending to be greater in smaller events. It should be noted that 2015 was the year with the highest number of high magnitude events (1413 mm of total monitored rainfall), where the total runoff was 19% in the NTC and 10% in the TC. Furthermore, there was 781 mm of rainfall monitored in 2017, which provided 13% of runoff in the NTC and 6% in the TC.

Figure 5. Rainfall and total runoff volume in the NTC and TC during rainfall events.

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6 338 The terraces (TC) significantly reduced runoff coefficient (p-value = 0.001), and their  
7 339 efficiency is presented through the runoff coefficient (RC) considering similar periods in terms  
8 340 of rainfall regime (dry and wet years) (Figure 6). Approximately 45% of all monitored events  
9 341 in the NTC showed C values above 10%, with RC exceeding 50% in some events (Figure 6).

10 342  
11 343 Figure 6. Values of runoff coefficient (RC) in the NTC and TC.  
12 344

13 345  $Q_{\text{peak}}$  analysis also showed a significant difference (p-value = 0.024) between the NTC  
14 346 and TC (Figure 7). The terraces contributed to  $Q_{\text{peak}}$  reduction by lowering the volume in the  
15 347 events in which there was overflow. This can be seen in three major overflowing events (RP:  
16 348 43, 19, and 2 years) in 2015. The  $Q_{\text{peak}}$  values significantly decreased in the TC. In one of the  
17 349 largest monitored events in 2014 (07/23/2014), the values reported were  $117 \text{ L s}^{-1}$  for the NTC  
18 350 and  $34 \text{ L s}^{-1}$  for the TC when the terraces did not overflow.

19 351  
20 352 Figure 7. Differences in peak flow ( $Q_{\text{peak}}$ ) between the NTC and TC.  
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22 354  $Q_{\text{peak}}$  is affected by surface roughness and is mainly controlled by relief characteristics,  
23 355 including the slope, slope length, and slope shape. In this case, the terraces decreased the  
24 356 effective slope length by reducing  $Q_{\text{peak}}$  by runoff detention and delaying runoff propagation  
25 357 when there was overflow. Some of the delay variables (lag time) demonstrate the effects of  
26 358 terracing in propagating runoff more clearly and explicitly. Among them, we highlight the  
27 359 TLP (time between the beginning of rainfall and peak runoff), TLPC (time between the  
28 360 centroid of the hyetograph and the peak runoff), TLC (Time between the hyetogram centroid  
29 361 and the hydrogram centroid) indices that showed the differences between the catchments, and  
30 362 TLR (time between the beginning of the rainfall and the beginning of the runoff). The higher  
31 363 values of these lag times indicate the positive effect of these management measures on runoff  
32 364 behavior. The differences observed in four of the main lag time variables analyzed are shown  
33 365 in Figure 8.

34 366  
35 367 Figure 8. The behavior of three Lag Time variables (TLC, TLP, TLPC, and TLR) for the set of  
36 368 events monitored at NTC and TC.  
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38 370 As observed for  $Q_{\text{peak}}$ , the terraces reduced the runoff volume and increased its  
39 371 propagation time on the surface. The average of all events indicates that the terraces increased  
40 372 the TLR by 27% (p-value = 0.2323). By separating the events into two groups (low and high  
41 373 phytomass), the combined effects of terracing with the amount of phytomass was observed.  
42 374 Under the high coverage condition ( $\sim 11 \text{ t ha}^{-1} \text{ y}^{-1}$  of phytomass), the values were 65 and 75 min  
43 375 in the NTC and TC, respectively, while the values were 70 and 102 min at the NTC and TC,  
44 376 respectively, under low coverage ( $\sim 6 \text{ t ha}^{-1} \text{ y}^{-1}$  of phytomass). Analysis of the TLC values  
45 377 showed that the averages were similar and that the extreme values were affected by the terraces,  
46 378 thus further underlining their importance since their efficiency is mainly expected in high  
47 379 magnitude events. The average of all events indicates that the terraces increased the TLP by

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3 380 15% (p-value = 0.0391). The mean TLPC values were similar between NTC and TC, with no  
4 381 significant differences between them.

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6 383 b) Apparent infiltration

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8 385 The apparent total infiltration ( $I_{ap}$ ) was estimated using data pairs ( $I_{ap}$  and  $R$ ) and  
9 386 considering 30-min intervals (Figure 9). The distribution generates different regions in the  
10 387 graphs: a)  $R_{30} < 25 \text{ mm h}^{-1}$ , b)  $25 < R_{30} < 65 \text{ mm h}^{-1}$ , and  $R_{30} > 65 \text{ mm h}^{-1}$ . In the first section,  
11 388  $I_{ap} \approx R$  and practically all the rainfall infiltrates. In the intermediate section, there is high data  
12 389 dispersion due to the influence of soil moisture in the infiltration process (i.e., infiltration may  
13 390 be higher or lower depending on the initial soil moisture in similar  $R$  values). In the final section,  
14 391 there is a tendency to form an asymptote that expresses the maximum possible infiltration.

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16 393 Figure 9. Total apparent infiltration model for 30-min rainfall intensities at the NTC and TC.

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18 395 Equations 4 and 5 describe the apparent total infiltration model of each catchment. The  
19 396 values of 95 and 154  $\text{mm.h}^{-1}$ , in the NTC and TC, respectively, mathematically express the  
20 397 asymptote of the curve and physically express the maximum infiltration limit when the  
21 398 maximum area is saturated.

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$$I_{ap} = 95 * \left[ 1 - \exp\left(\frac{-R}{95}\right) \right] \quad (4)$$

$$I_{ap} = 154 * \left[ 1 - \exp\left(\frac{-R}{154}\right) \right] \quad (5)$$

23 400

24 401 c) Determination of the CN parameter

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26 403 The CN values determined in both catchments for all events are shown in Figure 10. The  
27 404 average CN values for the NTC and TC were 69 and 59, respectively, clearly showing the  
28 405 effects of terracing. The figure also shows the analysis of CN behavior as a function of rainfall.  
29 406 Moreover, there is a clear difference in the distribution of points between both catchments.

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31 408 Figure 10. CN values as a function of the rainfall that occurred during the monitoring period.

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33 410 The points are close to the curve that defines the  $CN_0$  value at the TC, while the points  
34 411 have greater dispersion and are farther from the  $CN_0$  curve at the NTC, showing the inefficiency  
35 412 of the system in controlling runoff. The  $CN_0$  curve represents the minimum runoff value for a  
36 413 given rainfall event (Soil Conservation Service Engineering Division, 1972).

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### 38 415 3.2 Macroplots

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6 417 The macroplots are cultivated under NT with different soil (chiseling *versus* no  
7 418 chiseling) and crop management systems (low *versus* high phytomass addition) without  
8 419 terracing. The results of this set of monitoring units reflect the efforts to control runoff without  
9 420 the terraces and by only covering the soil via crops in succession and rotation and chiseling.  
10 421 The monitoring includes 27 events with different climatic and land cover conditions. The total  
11 422 rainfall monitored during events that generated runoff was 1648 mm. The highest intensity  
12 423 rainfall for 30-min intervals occurred on 05/26/2017 with 115 mm h<sup>-1</sup> and 03/15/2018 with 84  
13 424 mm h<sup>-1</sup>.  
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18 425  
19 426 a) Characteristic variables  
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21 428 The different management practices applied in the macroplots led to small differences in  
22 429 the total amount of runoff monitored during events. Macroplots M1 and M2 have low  
23 430 phytomass addition (LF), M1 with chiseling (CLF) and M2 without chiseling (NC + LF). In  
24 431 M1, there were 14.9% of water losses due to runoff, and 21.1% in M2 (p-value= 0.35),  
25 432 considering the average for the whole period. For this condition of low phytomass supply,  
26 433 chiseling reduced runoff by approximately 6%. Macroplots M3 and M4 have high phytomass  
27 434 addition (HF) due to improved plant management through crop rotation, M3 scarified with  
28 435 chiseling (CHF), and M4 without chiseling (NCHF). There was 13.6% of water loss through  
29 436 runoff in M3 and 15.8% in M4 (p-value= 0.63), considering the average for the whole period.  
30 437 Chiseling was less efficient in reducing runoff (only 2%). Moreover, comparing the effects of  
31 438 phytomass input with chiseling (M1 *versus* M3) showed an insignificant difference (0.7%) (p-  
32 439 value= 0.97), while comparing the effects of phytomass without chiseling (M2 *versus* M4)  
33 440 revealed a difference of approximately 4% (p-value = 0.64). The results of the runoff coefficient  
34 441 over the years of monitoring are presented in Figure 11.  
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41 442  
42 443 Figure 11. Variation of the runoff coefficient in the macroplots.  
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44 445 The efficiency of soil (chiseling and no-till) and crop management (with and without  
45 446 crop rotation) in controlling runoff during rainfall-runoff events was low. The runoff  
46 447 coefficient (RC) was above 10% in 41% of the events, with CLF being the worst condition,  
47 448 where in addition to not having crop rotation, the soil was chiseled up to 30 cm in depth, thus  
48 449 emphasizes that chiseling without the additional biological effects does not effectively mitigate  
49 450 erosion processes. More than half of the rainfall volume monitored on 12/24/2015 was lost by  
50 451 runoff under the low biomass condition, being 55 and 62% in M1 and M2, respectively. The  
51 452 highest amount of phytomass generated runoff coefficients of 43 and 53% in M3 and M4,  
52 453 respectively, for the 12/24/2015 event. The small RC difference between phytomass additions  
53 454 demonstrates that runoff from the crops is significant in high magnitude events and that other  
54 455 runoff control measures are necessary. We emphasize events of great magnitude as these are  
55 456 responsible for the highest levels of degradation and water losses. The behavior of the  $Q_{\text{peak}}$   
56 457 monitored in each event is shown in Figure 12. The magnitude of  $Q_{\text{peak}}$  expresses the potential  
57 458 for soil degradation by runoff.  
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4 460 Figure 12. The difference of  $Q_{\text{peak}}$  on the events monitored in the four macroplots.  
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7 463 Despite the importance of phytomass production to improve soil structure, which occurs  
8 464 in the medium/long term, its effects on runoff control have been reduced. This  $Q_{\text{peak}}$  behavior  
9 465 can be visualized in three different representative events: 08/13/2017, 12/24/2015, and  
10 466 05/26/2017 (Figure 13). The 08/13/2017 event, for example, had an accumulated volume of 80  
11 467 mm rainfall, with a long duration and low intensity. In this condition, the macroplots showed a  
12 468 dense vegetation cover provided by the wheat (M1 and M2) and black oats (M3 and M4) and  
13 469 in the physiological stage of full flowering. Despite the dense ground cover, the systems  
14 470 responded directly to the increased rainfall intensity, with the greatest response in M2 (NCLF),  
15 471 even under low rainfall conditions. Despite good soil coverage by vegetation and low rainfall  
16 472 intensity, the soil and plant management systems could not control runoff.

17 473 Figure 13. Hyetograph and hydrograph characteristics in the macroplots.  
18 474

19 475 Most lag time parameters in the four macroplots had no significant differences,  
20 476 demonstrating the influence of surface characteristics and their potential to cause friction  
21 477 (Figure 14. ). The mean TLR values of the macroplots with low phytomass was 105 min in M1  
22 478 and 121 min in M2. In M3 and M4 (greater phytomass amount), the values were 125 and 132  
23 479 min, respectively.

24 480 The concentration time ( $T_c$ ) showed the most significant variation among the systems  
25 481 (Figure 14), despite the absence of statistical difference. The mean  $T_c$  values of the macroplots  
26 482 with low phytomass (LF) was approximately 122 min in M1 and 153 min in M2 ( $p$ -value =  
27 483 0.47). In M3 and M4, the  $T_c$  values were approximately 105 and 96 min, respectively ( $p$ -value  
28 484 = 0.81). When considering the upper quartile values in M3 and M4 compared with M2, there  
29 485 is a reduction of approximately 50 min. However, the reduction is approximately 100 min for  
30 486 the maximum values. The other variables tested (TLPC, TLC, and TLR) were similar in the  
31 487 four systems.

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33 489 Figure 14. Behavior of time lag variables for the set of events monitored in the macroplots.  
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#### 36 492 b) Apparent infiltration

37 493 The P and Q data for each event were used to calculate the apparent infiltration ( $I_{\text{ap}}$ ) and  
38 494 allowed the construction of the infiltration models for the four macroplots (Figure 15). As in  
39 495 the catchments, the different infiltration behavior for the three ranges of rain intensity is evident.  
40 496 For intensity ( $R_{30}$ ) below  $40 \text{ mm h}^{-1}$ , practically the entire rainfall precipitated layer infiltrates;  
41 497 b) for rain intensities between 40 and  $100 \text{ mm h}^{-1}$ , there is a strong influence of the antecedent  
42 498 humidity in the definition of infiltration or runoff formation; and c) for an intensity greater than  
43 499  $100 \text{ mm h}^{-1}$ , there is a tendency to form an asymptotic behavior that would indicate the  
44 500 maximum infiltration capacity in each macroplot.

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502 Figure 15. Relationship between the total apparent infiltration and maximum rainfall intensity  
503 of 30 min for the macroplots.

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505 The high phytomass addition system with chiseling provided better infiltration  
506 conditions. The influence of phytomass was more effective than chiseling in both soil cover  
507 conditions which demonstrates that the biological effects are more efficient than the mechanical  
508 effects on soil structure recovery. There was a higher infiltration rate with high coverage  
509 condition (M3: CHF and M4: NCHF) comparing with low coverage (CLF: M1 and NCLF:  
510 M2). Chiseling mitigated runoff losses for both soil cover condition.

511  
512 c) Determination of the CN parameter

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514 The CN values were sensitive to the influence of chiseling and phytomass input. The  
515 median CN values for M1, M2, M3, and M4 were 61, 66, 57, and 59, respectively (Figure 16).  
516 There is a greater discrepancy in the behavior of the M2 values compared to the other systems,  
517 showing that the simple adoption of no-till without chiseling and phytomass input increases  
518 runoff.

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520 Figure 16. The CN values estimated for the set of events monitored in the macroplots.

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522 The analysis of the dispersion of CN data as a function of rainfall is shown in Figure 17.  
523 Unlike what was found in the TC, all macroplots have CN values with high dispersion distant  
524 from the  $CN_0$  curve. Despite the difference in the median values in Figure 15, there is no clear  
525 breakdown of the effects of phytomass amount and chiseling on the set of points.

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527 Figure 17. Dispersion of CN values as a function of rainfall in the macroplots.

## 528 529 **4. Discussion**

### 530 531 **4.1 Runoff control**

532 Alternative farming practices, such as those providing high phytomass input through  
533 crop rotation and/or chiseling were not enough to control runoff ( $C > 10\%$ ). The monitoring  
534 results showed no reduction in  $Q$ ,  $Q_{peak}$ , and  $C$  values compared to the high phytomass amount  
535 in M3 and M4 in relation to M1 and M2 or the presence of chiseling in M1 and M3 regarding  
536 M2 and M4. Although the effects of both practices were not very significant, it is clear that the  
537 effects of soil cover density by vegetation were more efficient than chiseling in controlling  
538 runoff. Chiseling is commonly used to control runoff, although its effects are short-lived  
539 (Drescher, Eltz, Denardin, & Faganello, 2011; Drescher et al., 2016). Phytomass supply through  
540 crop rotation allows permanent coverage of soil surface with vegetation and contributes to  
541 improving the soil structure, increasing soil water infiltration and storage (Groff, 2015). The  
542 positive effects of higher phytomass input (M3 and M4) were observed in all magnitudes of  
543 events, but this was not enough to control the runoff completely. The runoff control during high

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3 544 magnitude rainfall events are extremely important in soil degradation processes even with a low  
4 545 frequency of occurrence, as demonstrated by Falloon and Betts (2010) and Rodriguez-Lloveras  
5 546 et al. (2015).

7 547 The results obtained in the macroplots show that the partial adoption of conservation  
8 548 practices is not enough to control the degradation processes associated with runoff. This  
9 549 observation was already reported by Didoné et al. (2014) and Tiecher et al. (2017) under similar  
11 550 soil use and management conditions in southern Brazil and at the catchment scale. The runoff  
12 551 formation during significant magnitude events also depends on complementary practices, such  
13 552 as terracing. Land management is the main runoff driving factor during extreme events. Unlike  
15 553 the effects of adding phytomass and chiseling, the significant reduction in volume,  $Q_{peak}$ , and  
16 554 runoff coefficient in the TC compared to the NTC strengthens the need to adopt terracing  
18 555 (Arnáez, Lana-Renault, Lasanta, Ruiz-Flaño, & Castroviejo, 2015; Merten et al., 2015; Pfister,  
19 556 Bayer, Koehler, & Hellweg, 2011).

20 557 The estimate of apparent infiltration ( $I_{ap}$ ) in the macroplots and paired catchments was  
21 558 also sensitive to the adopted management systems. According to Barros, Minella, Tassi,  
23 559 Dalbianco, and Ottonelli (2014), unlike traditional methods,  $I_{ap}$  incorporates other processes  
24 560 that act in the landscape to express the real infiltration and its relationship with runoff formation.  
26 561 The infiltration models showed that its magnitude to higher values of rainfall is different for the  
27 562 three management systems. The highest infiltration rates were found in the terraced condition,  
28 563 followed by the largest amount of phytomass and, finally, the effects of chiseling.

30 564 In the analysis of  $I_{ap}$  in the macroplots, the phytomass input efficiency was greater than  
31 565 the chiseling. Moreover, mechanical chiseling has ephemeral effects since the alteration of  
32 566 physical-hydraulic properties, which control water infiltration and indicate the structural state  
33 567 of the soil, may have a shorter duration than an agricultural harvest (Drescher et al., 2011,  
35 568 2016). Meanwhile, crop rotation carried out for long periods increases phytomass supply,  
36 569 maintains the soil surface permanently covered, presents a different root system, and improves  
37 570 the physical, chemical, and biological quality of the soil (Groff, 2015).

39 571 The analysis of the pattern of variation of the CN values between the NTC and TC  
40 572 demonstrated a significant difference imposed by the terraces. The CN values in the TC are  
41 573 close to those defined by the  $CN_0$  curve (Soil Conservation Service Engineering Division,  
43 574 1972), while the values in the NTC were higher and had a completely different behavior  
44 575 depending on the magnitude of rainfall. The determination of the  $CN = f(P)$  model is useful to  
46 576 develop conservation projects, as it allows the dimensioning of drainage control practices  
47 577 (Ajmal, Waseem, Kim, & Kim, 2020; Lian et al., 2020). Determining the CN values for local  
48 578 conditions of climate, use, and management are essential to efficiently determine the  
50 579 appropriate practices (Do Valle Junior et al., 2019). The CN values derived in this study, for  
51 580 the conditions with and without terracing under no-till, may improve soil and water  
52 581 conservation planning under conditions similar to the experiment in southern Brazil, as  
54 582 corroborated by Barros et al. (2014). The lower sensitivity of the characteristic variables and  
55 583 the CN in the macroplots compared to the catchments implies the roughness imposed by the  
57 584 amount of phytomass and chiseling is not enough to control runoff. Castro, Cogo, and Volk  
58 585 (2006) emphasized that NT reduces soil roughness, which may increase water losses. This was  
59 586 observed in the present study when comparing NT with chiseling. In addition, when sowing is

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6 587 carried out in the direction of the slope, preferential channels are formed that increase runoff  
7 588 speed. The monitored values of  $Q_{\text{peak}}$  in both the NTC and macroplots show the erosive potential  
8 589 of runoff in NT when the water management system (terracing) was not carried out. It is  
9 590 important to emphasize the importance of the relief as a runoff-controlling factor. Even under  
10 591 NT with intense soil cover and chiseling, there are places sensitive to runoff formation that may  
11 592 trigger erosion processes. Hence, topographic indices may help identify the most sensitive  
12 593 regions on the slopes, either due to the greater erosive capacity of the runoff or the presence of  
13 594 wet areas (Minella & Merten, 2012).

14 595 Roughness is a fundamental factor in increasing friction to runoff and reducing its speed  
15 596 (Hansen, Schjønning, & Sibbesen, 1999; Takken, Jetten, Govers, Nachtergaele, & Steegen,  
16 597 2001), increasing infiltration. In the analysis of the different lag times under contrasted farming  
17 598 practices, the greater coverage increased the roughness, although it was not enough to  
18 599 effectively control runoff speed during the events of greater magnitude. In contrast, the positive  
19 600 effects of terracing in the TC compared to the NTC in the lag times is evident. Reducing runoff  
20 601 speed is essential to increase energy dissipation that controls erosion processes (Giménez &  
21 602 Govers, 2008; Gómez & Nearing, 2005). Nonetheless, this is a challenge for the current  
22 603 agricultural systems, which need to adopt management systems that can contain the spread of  
23 604 runoff and reduce their kinetic energy. Despite the importance and need for soil cover for  
24 605 numerous soil functionalities, its efficiency is relatively small in controlling runoff during high  
25 606 magnitude events ( $RP > 1$  year) compared to terracing, which has proved to be an efficient  
26 607 alternative in mitigating conservation and environmental problems related to soil degradation.

27 608 The runoff control in the NT is one of the main challenges of this agricultural production  
28 609 system. It is important to emphasize that runoff dynamics and controlling erosion processes  
29 610 also regulate the processes of water contamination by the dissolved elements associated with  
30 611 the transported sediment load containing fertilizers and pesticides (Exterkoetter et al., 2019).  
31 612 Avoiding excess runoff is a way to reduce the risks of contaminating natural resources (Zuazo  
32 613 et al., 2011) and ensuring that water is stored in the plant's rooting zone and, thereby, increasing  
33 614 its efficiency for agricultural production (Lal, 2008). The impacts resulting from runoff in areas  
34 615 under NT and that do not adopt conservationist principles are recurrent. Thus, this soil  
35 616 management system increases the fragility of slopes under agricultural production,  
36 617 consequently accelerating erosion processes (Didoné et al., 2014; Kassam, Derpsch, &  
37 618 Friedrich, 2014; Merten et al., 2015).

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## 39 620 **5. Conclusions**

40 621 The information obtained allows us to conclude that the high phytomass input by crop  
41 622 rotation and/or chiseling was not enough to control runoff in medium and high rainfall events.  
42 623 In contrast, terracing significantly reduced runoff variables, demonstrating its importance as a  
43 624 complementary conservation practice for controlling runoff during high-magnitude events. The  
44 625 evaluation of catchments and macroplots allowed the quantification of the response of all units  
45 626 in the same rainfall event with contrasting water, soil, and plant management conditions. Even  
46 627 in a short period of monitoring, such as the one carried out in this study, it was possible to



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3 628 generate a set of relevant information. The runoff monitoring allowed the estimation of  
4 629 parameters necessary to quantify the apparent infiltration ( $I_{ap}$ ) and runoff (CN, C, and  $Q_{peak}$ ),  
5 630 which are fundamental to design conservation practices in NT at the catchment scale.

6 631 The high monitoring frequency associated with the monitoring of paired units optimized  
7 632 the results for a short monitoring period (5 years), which was essential to obtain additional  
8 633 information to compare different management effects. Furthermore, monitoring showed the  
9 634 importance of improving water management by reducing runoff and controlling erosion  
10 635 processes. This study also demonstrated the importance of monitoring projects for locally  
11 636 defining parameters and information for mathematical modeling. The quantification of runoff  
12 637 in extreme rainfall events (RP>20 years) was essential to assess the weak ability of no-till to  
13 638 resist the effects of runoff and the need to develop a more sustainable production system.  
14 639 Approaches based on mathematical modeling supported by catchment monitoring databases  
15 640 may help evaluate and recommend the best management practices.  
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Table 1. Soil, plant and water managements (treatments) used in each catchment and macroplot.

<b>Macroplots</b>	<b>Soil management</b>	<b>Crop management</b>	<b>Runoff management*</b>	<b>Abbreviation</b>
M1	With chisel	Low phytomass	Without	CLF
M2	Without chisel	Low phytomass	Without	NCLF
M3	With chisel	High phytomass	Without	CHF
M4	Without chisel	High phytomass	Without	NCHF
<b>Catchments</b>				
C1	Without chisel	Low phytomass	Without	NTC
C2	Without chisel	Low phytomass	With	TC

\*Broad-based terraces

Table 2. Characteristic variables obtained in the analysis of hyetograms and hydrograms.

<b>Abbreviation</b>	<b>Description</b>	<b>Unit</b>
P	Rainfall	mm
R <sub>10</sub> , R <sub>30</sub> e R <sub>60</sub>	Maximum rainfall intensity at 10, 30 and 60 minute intervals	mm h <sup>-1</sup>
RP	Return period	years
RC	Runoff coefficient	%
Q	Runoff	mm
Q <sub>peak</sub>	Peak flow	L s <sup>-1</sup>
TLP	Time between the beginning of rainfall and peak flow	min
TLPC	Time between the hyetogram centroid and the peak flow	min
TLC	Time between the hyetogram centroid and the hydrogram centroid	min
TLR	Time between the beginning of rainfall and start of runoff	min
T <sub>C</sub>	Time of concentration	min

Table 3. Major monitored rainfall events classified by decreasing return periods.

<b>Date</b>	<b>P (mm)</b>	<b>TDP (min)</b>	<b>RP (years)</b>
05/13/2017	105	102	115.38
02/10/2018	93	86	67.43
10/08/2015	160	774	43.66
11/19/2015	73	66	19.82
10/18/2016	111	306	16.07
03/15/2018	82	121	11.22
01/27/2018	61	69	4.34
06/07/2017	116	1012	2.1
12/23/2015	79	230	2.05
11/03/2014	51	56	1.86
08/13/2017	80	294	1.35
10/30/2014	69	192	1.04

Where: P is the total accumulated rainfall; TDP is the rainfall total duration; and RP is the return period.



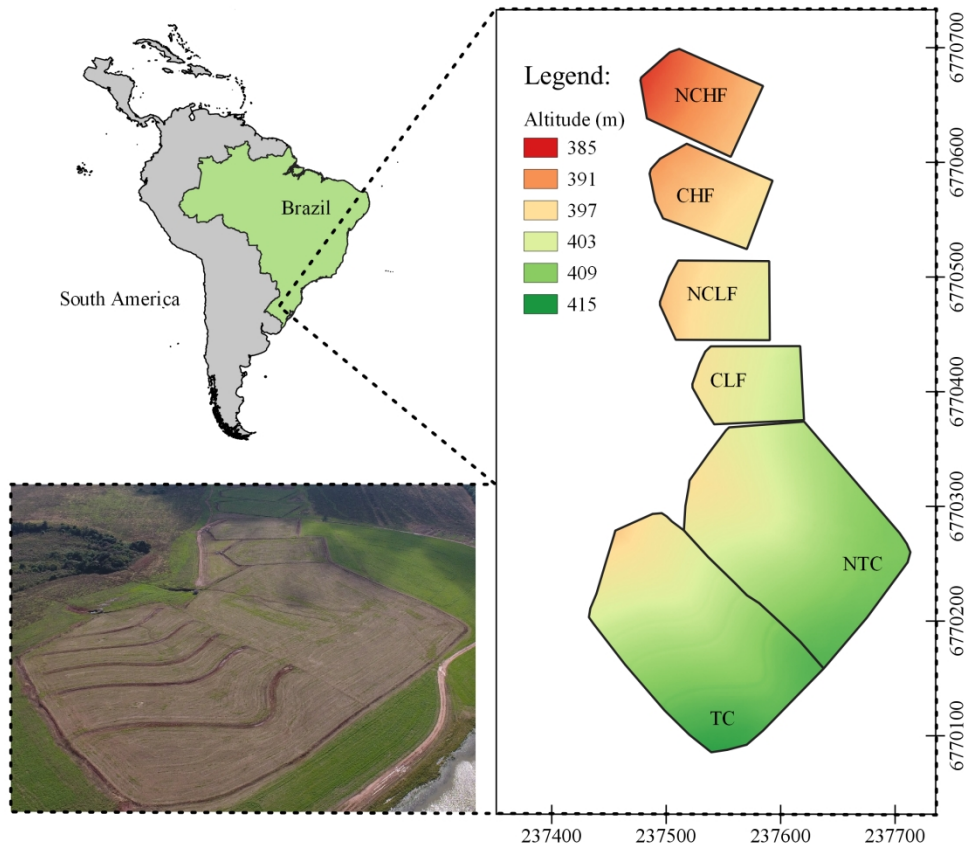


Figure 1. Location of the experimental area and six monitoring units.

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Figure 2. The terraces controlling the runoff after a rainfall event.



Figure 3. H-flume for monitoring the flow rates installed in the lower part of the catchments and macroplots.

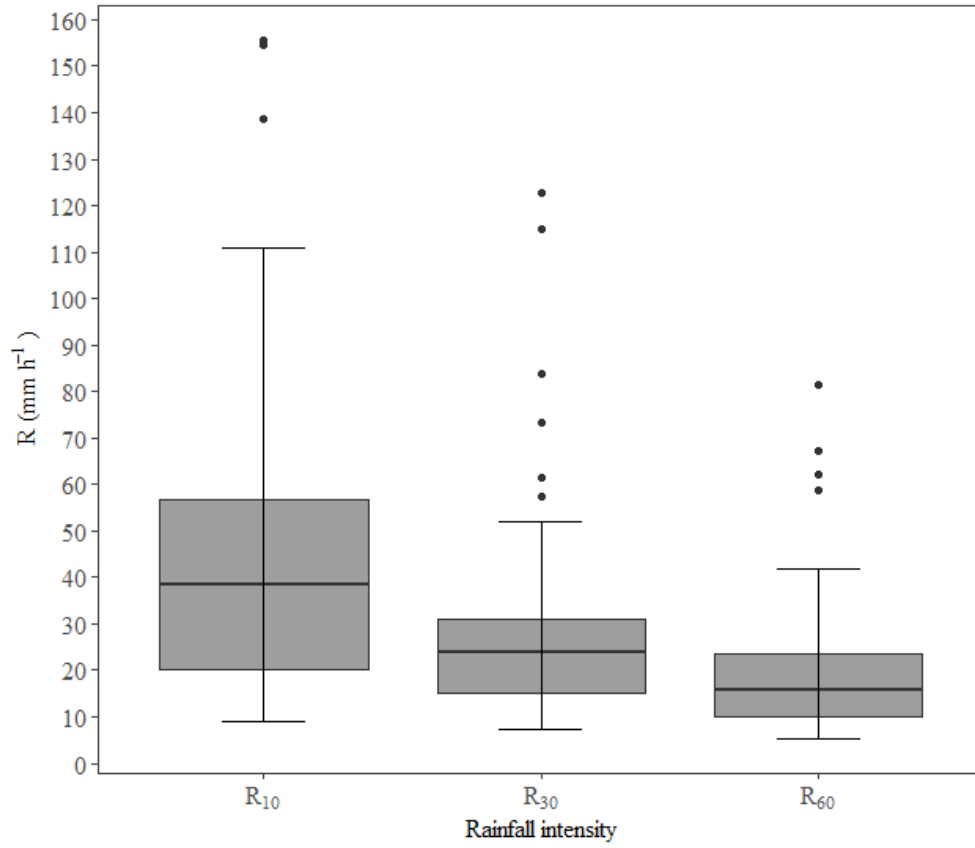


Figure 4. Rainfall intensity for 10, 30, and 60-min intervals.

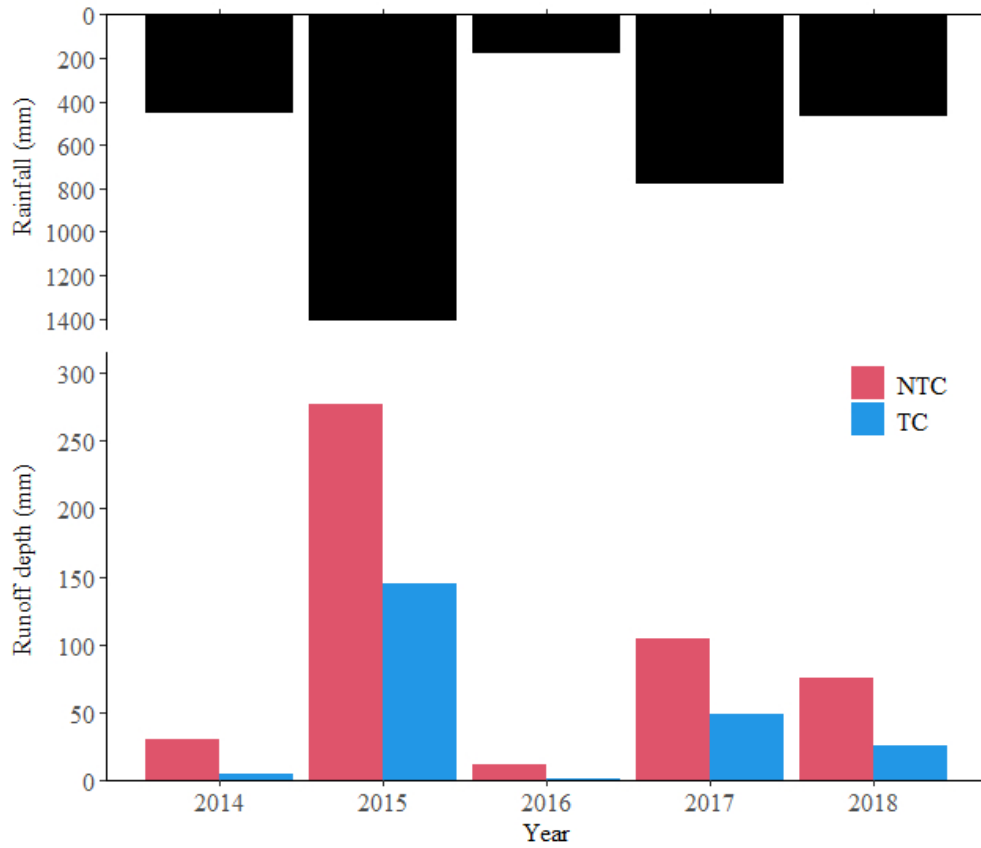


Figure 5. Rainfall and total runoff volume in the NTC and TC during rainfall events.

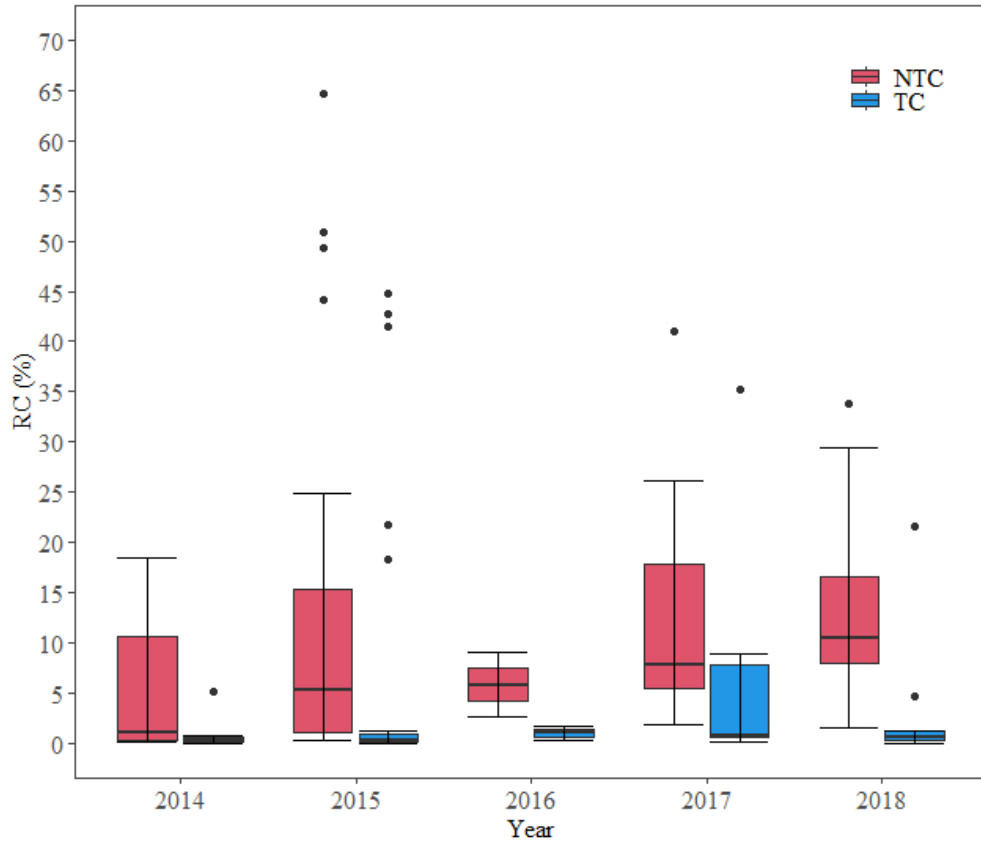


Figure 6. Values of runoff coefficient (RC) in the NTC and TC.

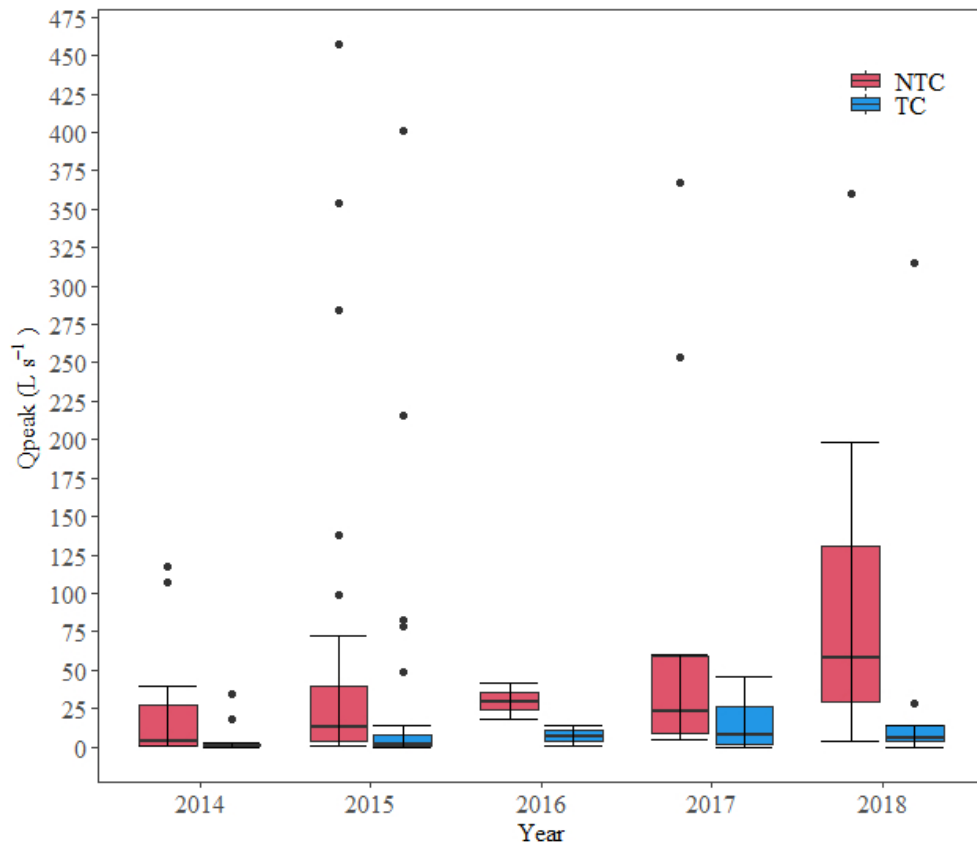


Figure 7. Differences in peak flow ( $Q_{peak}$ ) between the NTC and TC.

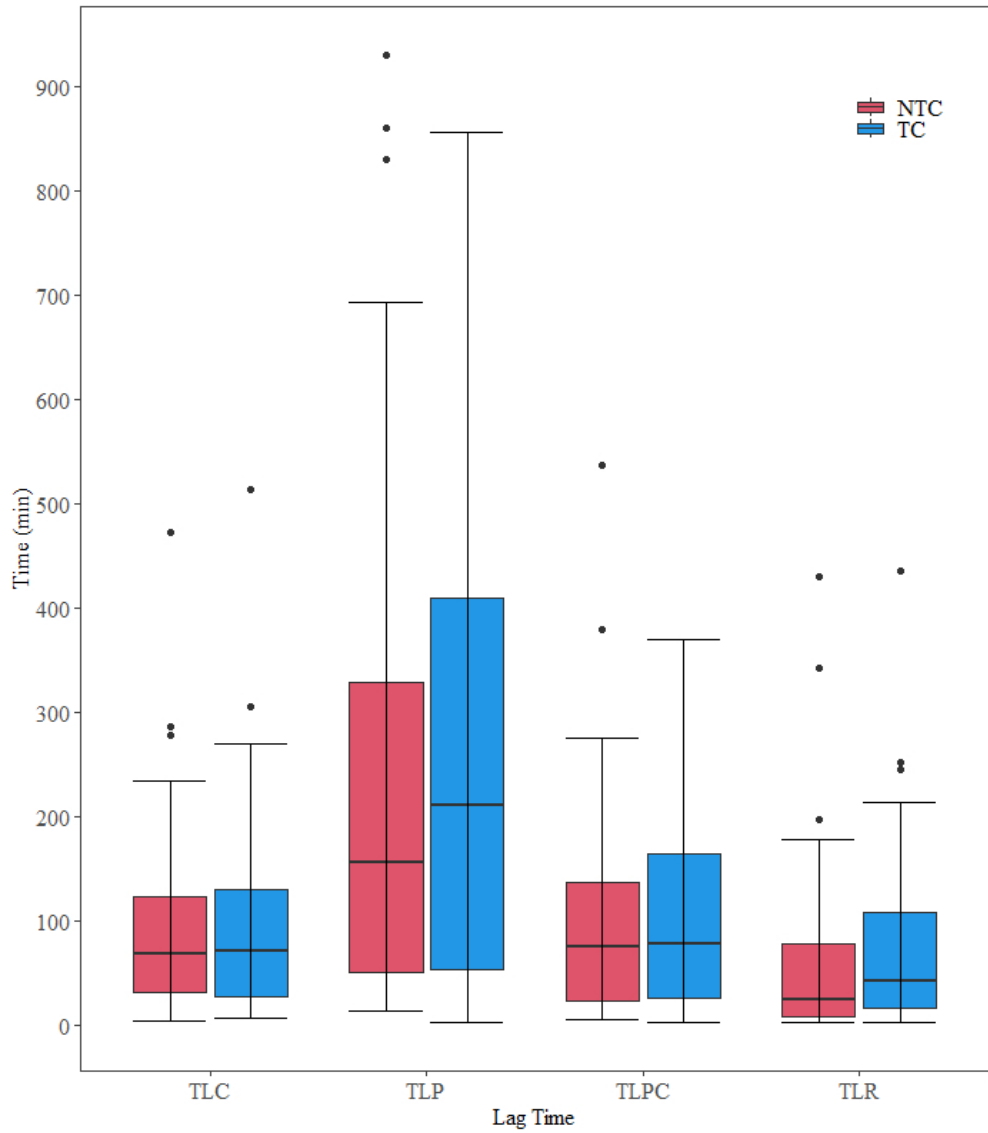


Figure 8. The behavior of three Lag Time variables (TLC, TLP, TLPC, and TLR) for the set of events monitored at NTC and TC.



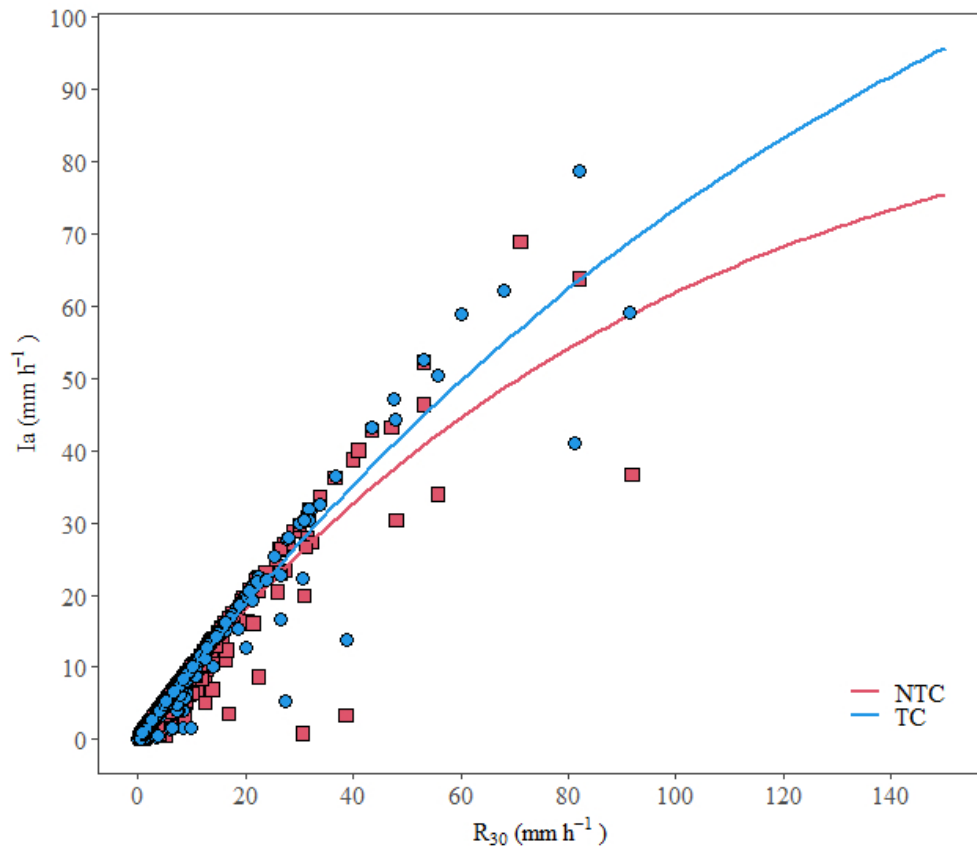


Figure 9. Total apparent infiltration model for 30-min rainfall intensities at the NTC and TC.

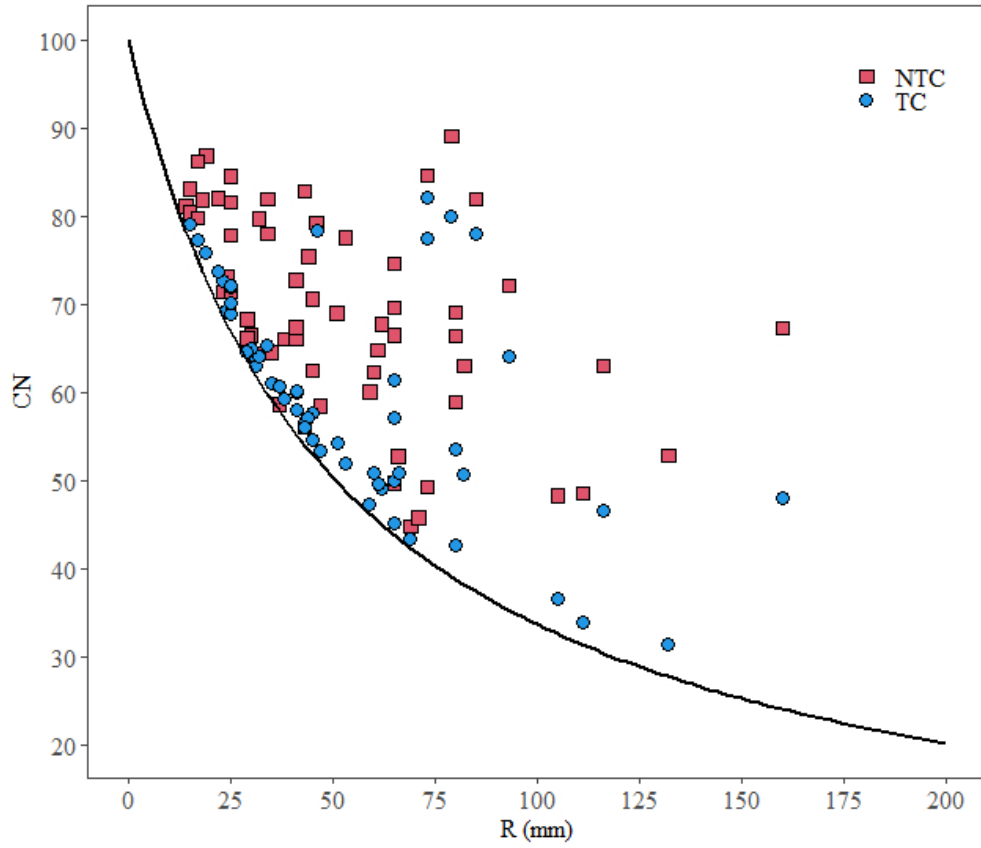


Figure 10. CN values as a function of the rainfall that occurred during the monitoring period.

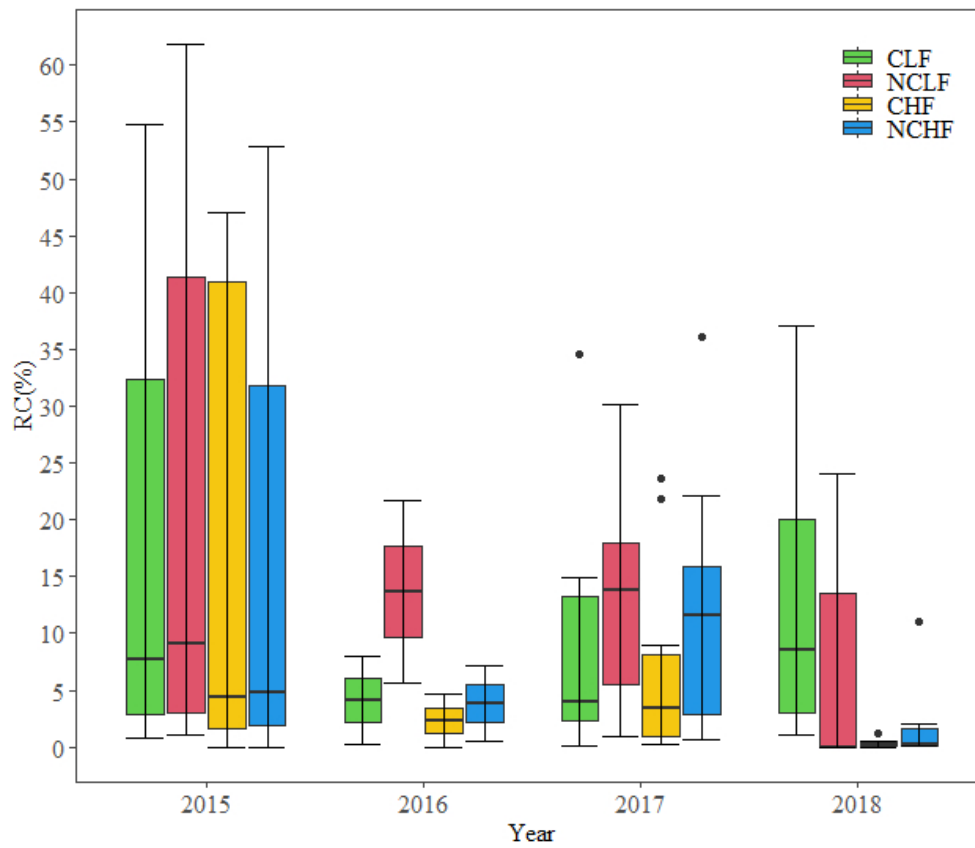


Figure 11. Variation of the runoff coefficient in the macroplots.

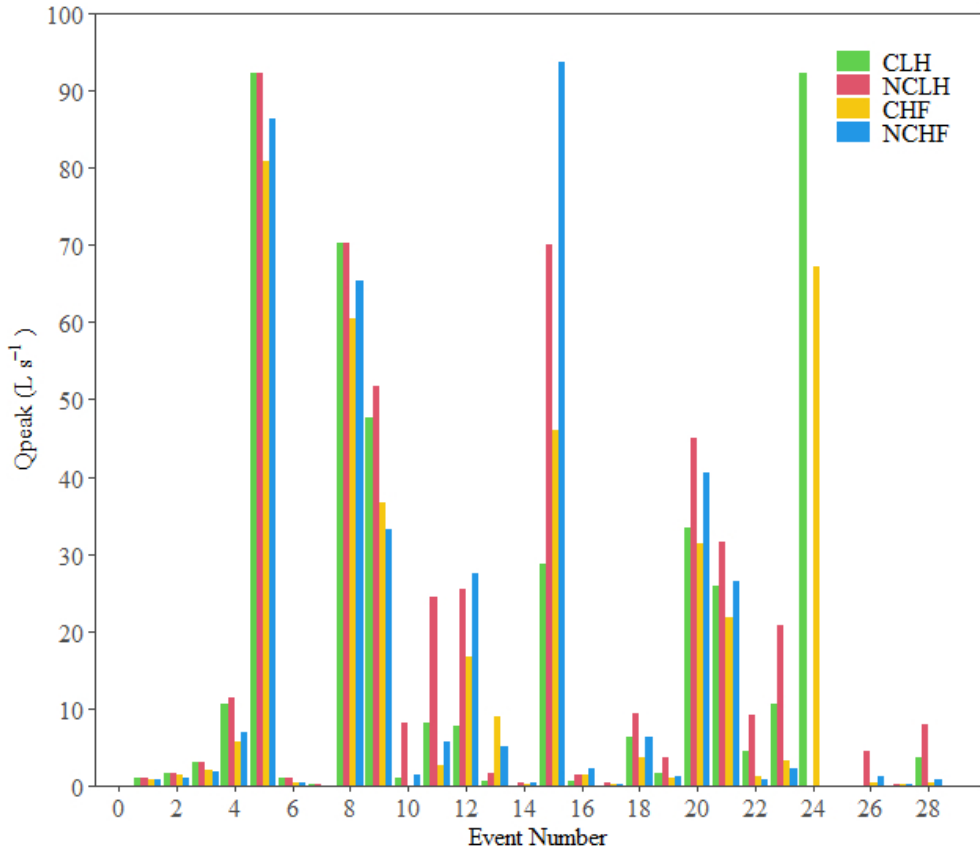


Figure 12. The difference of Qpeak on the events monitored in the four macroplots.

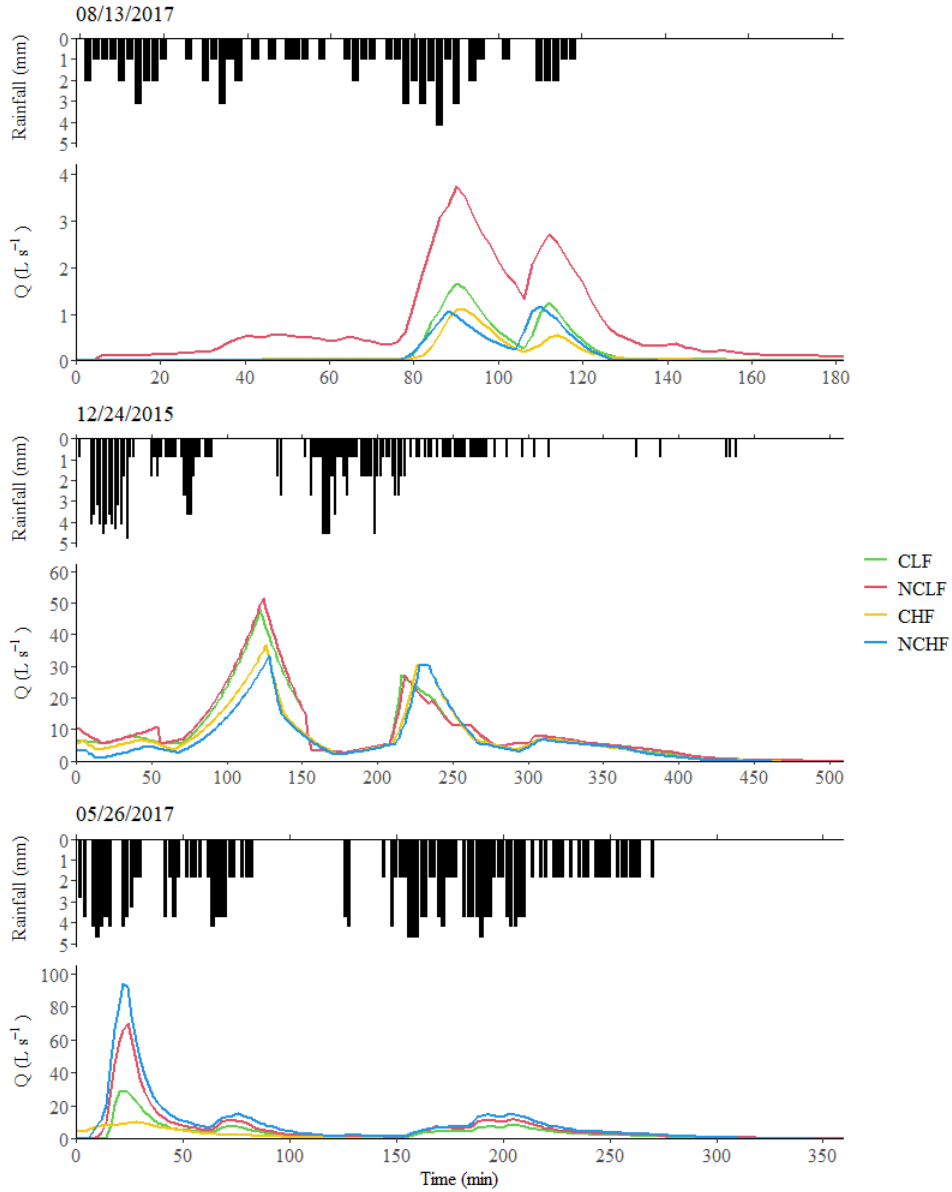


Figure 13. Hyetograph and hydrograph characteristics in the macroplots.

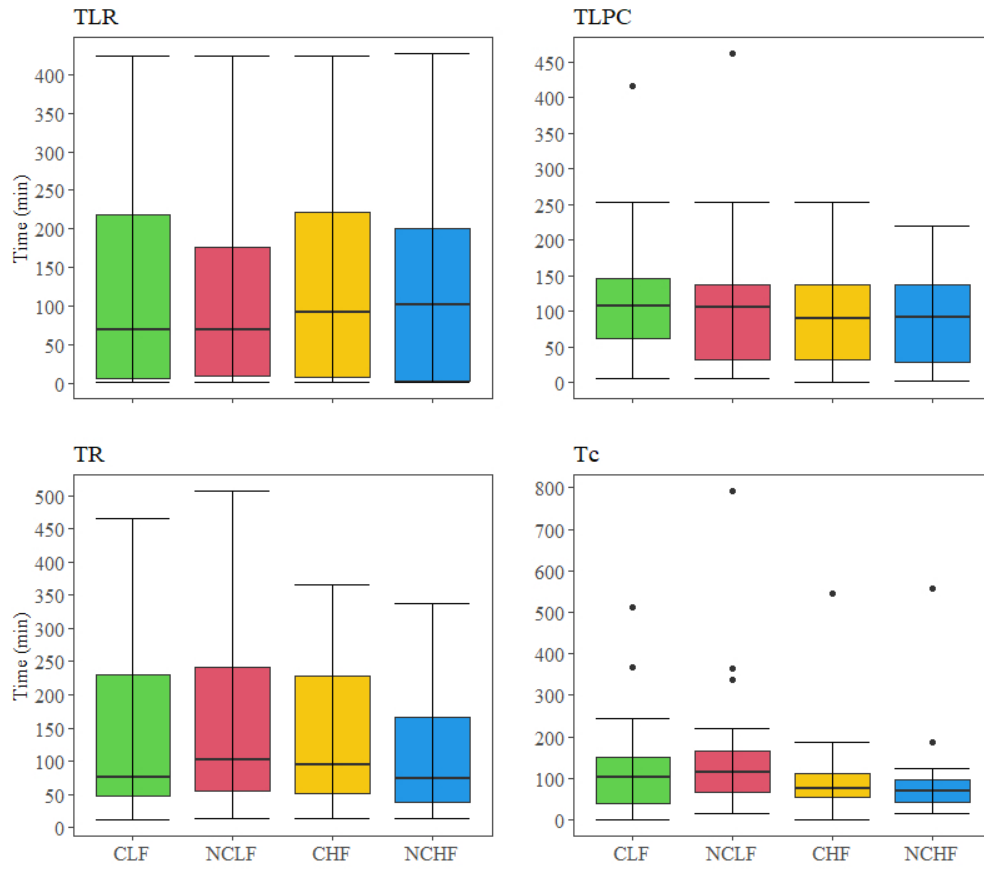


Figure 14. Behavior of time lag variables for the set of events monitored in the macroplots.

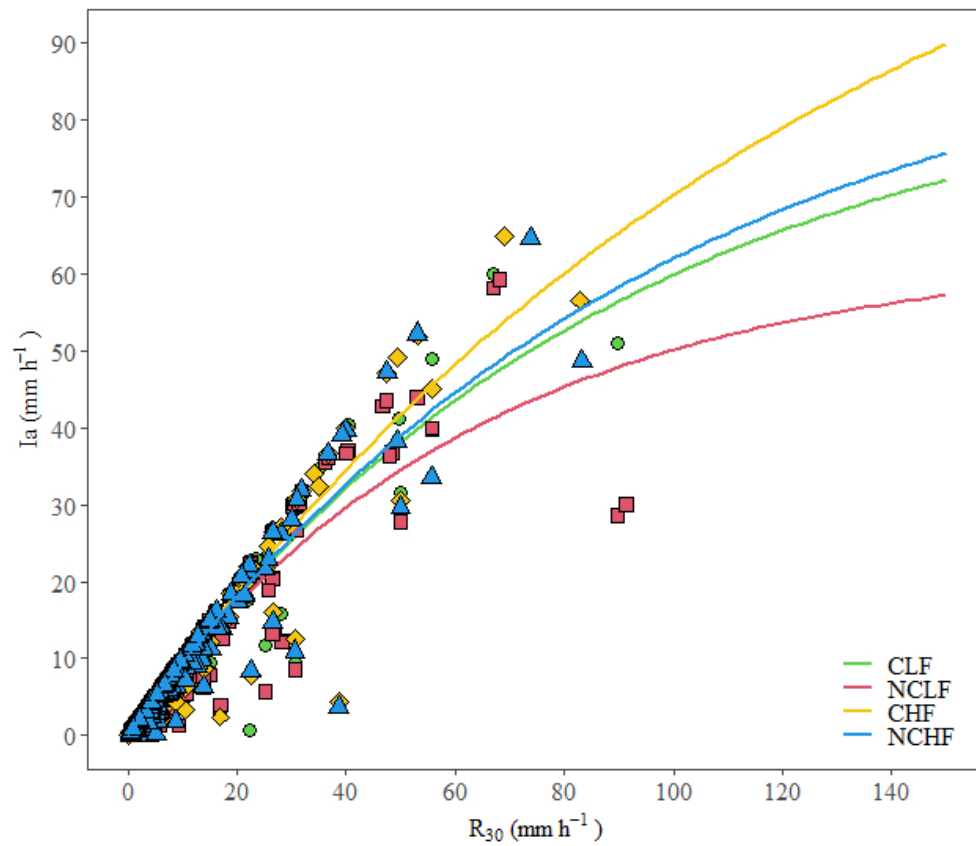


Figure 15. Relationship between the total apparent infiltration and maximum rainfall intensity of 30 min for the macroplots.

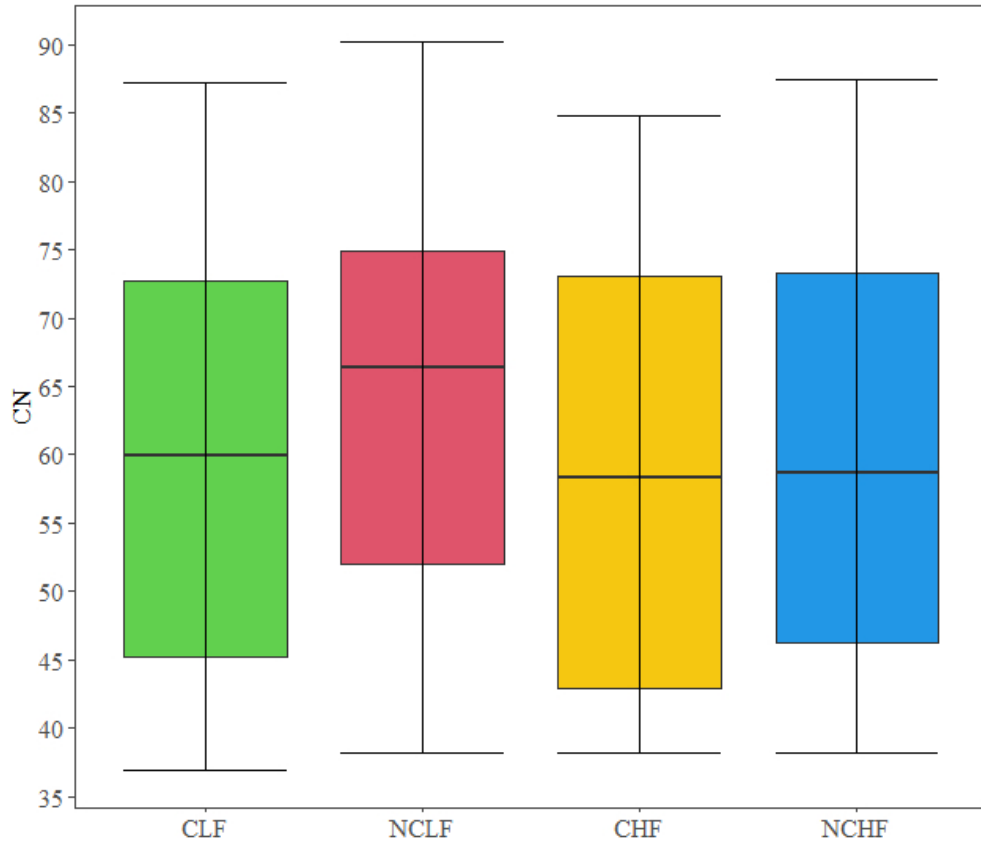


Figure 16. The CN values estimated for the set of events monitored in the macroplots.



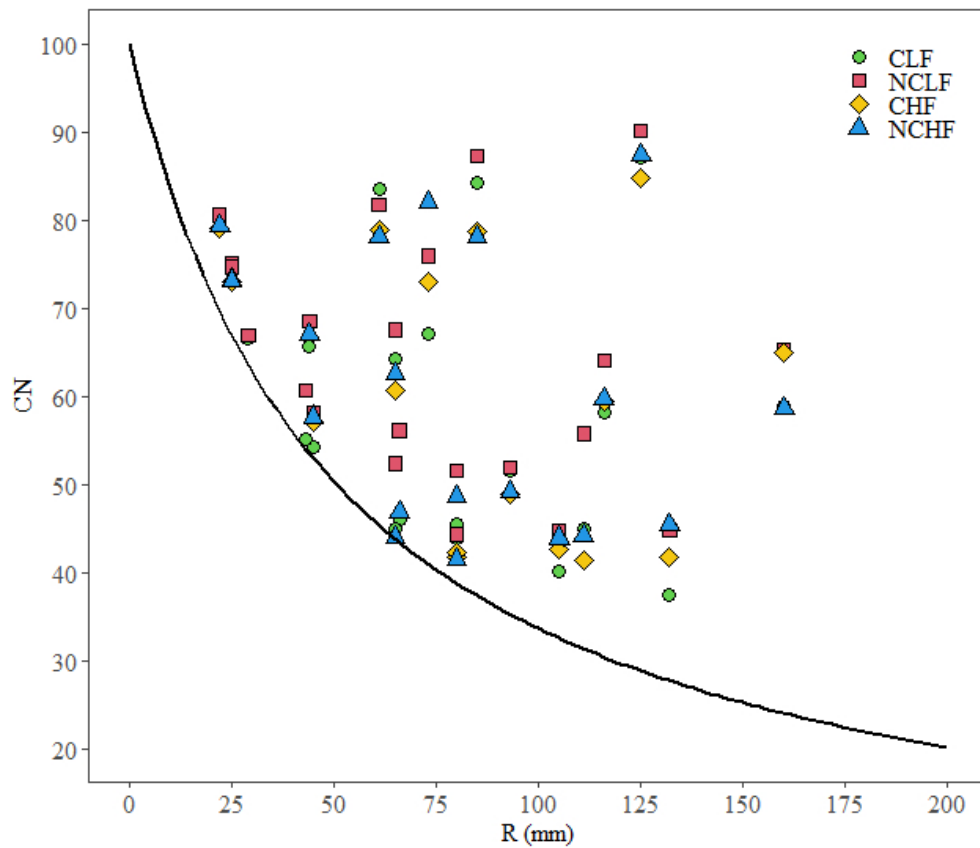


Figure 17. Dispersion of CN values as a function of rainfall in the macroplots.

Runoff under No-tillage at Catchment/Hillslope scale



Without terrace



With terrace



Low phytomass



High phytomass

Runoff management	Runoff coefficient*	Peak discharge*	Curve Number*
Without terrace	11.6 %	60 L s <sup>-1</sup>	69
With terrace	4.4 %	24 L s <sup>-1</sup>	60

\*Mean values of 63 events

Soil management	Crop management	Runoff coefficient*	Peak discharge*
With chisel (C)	Low phytomass (LF)	10%	13 L s <sup>-1</sup>
Without chisel (NC)	Low phytomass (LF)	14%	17 L s <sup>-1</sup>
With chisel (C)	High phytomass (HF)	8%	13 L s <sup>-1</sup>
Without chisel (NC)	High phytomass (HF)	10%	16 L s <sup>-1</sup>

\*Mean values of 27 events

