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► **To cite this version:**

Elizeu Jonas Didoné, Jean Paolo Gomes Minella, O. Evrard. Measuring and modelling soil erosion and sediment yields in a large cultivated catchment under no-till of Southern Brazil. *Soil and Tillage Research*, 2017, 174, pp.24 - 33. 10.1016/j.still.2017.05.011 . hal-01584132

HAL Id: hal-01584132

<https://hal.science/hal-01584132>

Submitted on 26 May 2020

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Measuring and modelling soil erosion and sediment yields in a large cultivated catchment under no-till of Southern Brazil

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Abstract

1 Erosion processes can be exacerbated when inappropriate soil conservation
2 practices are implemented. In Brazil, very few measurements are available to quantify the
3 impact of conservation practices on erosion processes in agricultural catchments. The
4 objective of this study is to quantify the impact of different conservation measures on soil
5 erosion and sediment dynamics in an agricultural catchment under no-till of southern
6 Brazil, and to simulate conservation scenarios using a model calibrated with sediment data
7 measured at the catchment outlet. Monitoring was carried out in a large agricultural
8 catchment (800 km²) of southern Brazil affected by extensive soil erosion and runoff
9 despite the widespread use of no-till. Rainfall, river water discharges and suspended
10 sediment concentrations were monitored during a five-year period (2011–2015). The
11 WaTEM/SEDEM model was then calibrated. Then, four scenarios including a Business-

12 As-Usual (BAU) scenario and the implementation of alternative conservation strategies
13 were simulated, and their impact on erosion, sediment deposition and sediment yield was
14 quantified. All four scenarios were simulated twice, using either rainfall measured during a
15 dry year or during a humid year. All the scenarios including alternative conservation
16 measures drastically reduced erosion and sediment yields, with reductions reaching up to
17 400% when compared to the BAU scenario. The implementation of mechanical
18 conservation measures such as crop levelling and terracing had the highest impact on soil
19 erosion, and the most effective scenario included the implementation of crop rotation, crop
20 levelling, terracing and the creation of forest protected areas. Model simulations indicated
21 that no-till alone has a low impact on erosion processes and that additional measures
22 increasing the vegetation cover/density of the soil are necessary to significantly reduce
23 sediment transfers in these agricultural areas. The simulations also demonstrate that during
24 wet years, erosion processes increase on average by 33.9% for all scenarios. This study
25 demonstrates that soil losses due to erosion processes remain significant and unsustainable
26 in agricultural catchments of southern Brazil. Soil erosion is exacerbated by the lack of
27 information provided to the farmers and the use of isolated conservation measures without
28 coordination at the catchment scale. Farmers' and local communities' awareness should be
29 raised to reduce soil degradation and sediment transfer to river systems.

30 **Key words:** Soil Conservation; No-till; Connectivity; Sediment yield; WaTEM/SEDEM
31 model; Terraces.

32 **1. Introduction**

33 According to Montgomery (2007), soil erosion remains the main mechanism of soil
34 degradation, which threatens the global sustainability of the food production systems (Lal
35 et al., 2012). In tropical and subtropical regions, soil erosion has often been accelerated by
36 improper agricultural practices, and particularly by the failure to implement appropriate

37 soil conservation measures, such as crop rotation, runoff control and contour farming.
38 Several studies showed that soil degradation generates the loss of basic soil properties
39 relevant to the farming system and/or an increase of the production costs (Derpsch et al.,
40 2014; Lal, 2007; Reicosky, 2015).

41 In southern Brazil, farmers have often reduced conservation agriculture to the use
42 of no-till alone (Reicosky, 2015). However, minimum tillage is not sufficient to control
43 runoff production (Gómez et al., 2003) To be efficient, it should be associated with other
44 measures such as contour farming and terracing to avoid an increase in surface runoff and
45 the occurrence of erosive processes when runoff concentrates (Bertol et al., 2007; Bolliger
46 et al., 2006; Denardin et al., 2008). In addition, the low residue cover of the soil, due to the
47 absence of crop rotation, is insufficient to protect the soil surface against the direct impact
48 of rainfall (Souza *et al.*, 2012).

49 Few studies have documented the impacts of no-till farming on runoff and erosion
50 at the catchment scale. However, there is a need to better understand the impact of
51 conservation agriculture on the spatial and temporal dynamics of soil degradation and to
52 identify the combination of control measures that would be the most efficient for
53 controlling losses and transfers of water, soil, nutrients and agrochemicals.

54 Accordingly, catchment monitoring and modelling should be combined to design
55 effective strategies to reduce the deleterious impacts of intensive farming. In large
56 catchments (Boix-Fayos et al., 2008), the flow response and sediment concentrations can
57 be monitored and related to rainfall and physiographic characteristics (relief, soil, use and
58 management) in order to identify the main factors controlling runoff and sediment
59 generation and their transfer across the landscape. Models can also be used to simulate the
60 spatial and temporal dynamics of hydrological and erosive processes. They can be either
61 deterministic (Knapen et al., 2007; Nearing et al., 1999; Okoro and Ibearugbulem, 2013) or

62 empirical (Foster et al., 2003; Kinnell, 2010) and their performance will depend on the
63 quality of the monitoring data and the availability of the input parameters (Horowitz et al.,
64 2014; Merten et al., 2006). Once they have been calibrated, these models can also be used
65 to simulate the impact of climate change (Nearing et al., 2004), or the effectiveness of
66 various scenarios of conservation practices (Fu et al., 2005; Terranova et al., 2009; Wang
67 et al., 2009) on sediment yields.

68 Empirical mathematical models based on the Universal Soil Loss Equation
69 (Alatorre et al., 2012; Bezak et al., 2015; Van Oost et al., 2000; Van Rompaey et al., 2001;
70 Verstraeten et al., 2002) and incorporating a transport capacity equation, such as
71 WaTEM/SEDEM (Van Rompaey et al., 2001) provide powerful tools to simulate erosion
72 and sediment transport at the catchment scale (de Vente et al., 2008; Poesen, 2011).
73 Studies with WaTEM/SEDEM model have generated satisfactory estimations of soil
74 redistribution on hillslopes (de Moor and Verstraeten, 2008; Notebaert et al., 2011;
75 Verstraeten et al., 2009) and sediment yields from catchments (Haregeweyn et al., 2013;
76 Rompaey et al., 2005). The model has been widely used in different topographic, climatic
77 and soil use conditions (Keesstra et al., 2009; Quiñonero-Rubio et al., 2014; Rompaey et
78 al., 2005). However, to the best of our knowledge, this model has never been applied in
79 large catchments of Brazil despite the very high erosion rates occurring in this region of
80 the world.

81 The objective of the current research is to quantify the impact of conservation
82 measures on spatial variations of runoff and soil erosion in an agricultural catchment under
83 no-till of southern Brazil. Accordingly, the impact of different conservation scenarios will
84 be assessed through the use of a model calibrated based on 5-yrs monitoring data. The need
85 to combine monitoring and modelling will then be discussed to propose the optimal set of

86 conservation measures for a sustainable soil and water management in this region of the
87 world.

88 **2. Material and methods**

89 **2.1 Study area**

90 The Conceição catchment is located in the northwest of the southernmost State of
91 Brazil (Rio Grande do Sul). It drains a surface area of 800 km², and the monitoring station
92 is located at the outlet (coordinates: 28°27'22"S and 53°58'24" W). According to Köppen's
93 classification, the climate is of Cfa type, i.e. subtropical humid without dry season, with an
94 average annual rainfall comprised between 1750 and 2000 mm and an average temperature
95 of 18.6 °C. The geological bedrock is basaltic, and it is overlaid with deep and highly
96 weathered soils (Oxisols, Ultisols, and Alfisols), with the Oxisols being the dominant soil
97 class in the catchment. These soils are enriched in iron oxides and kaolinite. The landscape
98 is characterized by gentle slopes (6–9 %) on the top and on the hillsides, whereas steeper
99 slopes (10–14 %) are found near the drainage channels. The main crops are soybean
100 (*Glycine max*) during summer and wheat (*Triticum spp.*), oats (*Avena strigosa*), and
101 ryegrass (*Lolium multiflorum*) during winter. The two latter crops provide straw for
102 mulching during summer and these fields may also be used as pasture for dairy cattle. No-
103 tillage is applied on >80 % of the cropland, without the implementation of additional
104 erosion control measures such as terraces, strip cropping, vegetated ridges, or contour-
105 farming. Other land uses including forests, wetlands, and urban areas cover less than 15%
106 of the total catchment surface area.

107 **Figure 1 - Location of the Conceição river catchment**

108 The riparian areas found along the permanent river network are narrow (<10 m
109 wide) and affected by cattle trampling, which prevents them from providing effective traps
110 to stop sediment originating from upper parts of the catchment. The current land cover

111 distribution in the catchment was used to define a business-as-usual (BAU) scenario
112 representative of the conditions found in areas dedicated to intensive grain farming in
113 southern Brazil.

114 **2.2 Hydro-sedimentary monitoring**

115 River monitoring was conducted during a 5-year period, from January 2011 to
116 December 2015. Rainfall (R), river discharge (Q) and suspended sediment concentrations
117 (SSC) were measured automatically at the catchment outlet every 10-minutes. In addition,
118 manual measurements were made every 30–60 minutes during flood events.

119 River discharge (Q) was estimated from water level measurements using a
120 limnigraph at the outlet station, through the conversion of pressure values into flow using
121 the appropriate discharge rating curve calculated for the monitoring section. Consistence of
122 this continuous monitoring data was compared to the daily measurements made by a local
123 observer. SSC data were acquired in 10-minute intervals indirectly using a turbidimeter.
124 Signals (mV) were converted into NTU by using Polymer bead calibration solutions and
125 the NTU was converted into SSC by using the SSC equation obtained from daily manual
126 samples using a DH-48 sampler (USGS).

127 Samples collected during flood events were brought back to the Sedimentology
128 Laboratory at the Federal University of Santa Maria, Brazil, to determine SSC after
129 evaporation and filtration of the samples (Shreve and Downs, 2005). In addition to the
130 traditional sampling methods, a turbidity meter was used to increase the frequency of
131 measurements. It was calibrated using SSC data acquired simultaneously, following the
132 method described by (Merten et al., 2006; Minella et al., 2008).

133 Suspended solid discharge SSD ($\text{kg}\cdot\text{s}^{-1}$) was estimated by multiplying instantaneous
134 Q ($\text{L}\cdot\text{s}^{-1}$) and SSC ($\text{g}\cdot\text{L}^{-1}$) data. SSD was then used to calculate sediment yield (SY; $\text{t}\cdot\text{year}^{-1}$),
135 (Porterfield, 1977).

136 **2.3 Modelling erosion processes**

137 Erosion processes were simulated using the spatially-distributed WaTEM-2000
138 model (Van Rompaey et al., 2001) developed to estimate water and tillage erosion,
139 sediment deposition and to quantify sediment supply to the river channels. The model is
140 divided into three modules: (I) assessment of annual soil loss using the Revised Universal
141 Soil Loss Equation (RUSLE) (Renard et al, 1997); (II) evaluation of the annual sediment
142 transport capacity (Van Rompaey et al., 2001; Verstraeten et al., 2002), and (III)
143 simulation of the sediment transfer pathway. The annual average of the gross soil erosion
144 (E ; $\text{kg m}^{-2} \text{ year}^{-1}$) is calculated for each pixel using Eq. (1):

$$145 \quad \mathbf{E = R * K * LS_{2D} * C * P} \quad (1)$$

146 Where R is the rainfall erosivity factor ($\text{MJ mm m}^{-2} \text{ h}^{-1} \text{ yr}^{-1}$), K is the soil erodibility factor
147 ($\text{kg h MJ}^{-1} \text{ mm}^{-1}$), LS_{2D} is a parameter reflecting the slope steepness and length based on
148 the algorithms of Desmet and Govers (1996), and the slope factor LS_{2D} is adjusted using a
149 two-dimensional routing algorithm (Van Oost et al., 2000) to account for rill, inter-rill and
150 gully erosion (Desmet et al., 1999), C is soil coverage factor (including biomass and mulch
151 depending on soil use and management; (Renard et al, 1997), and P the (optional) soil
152 conservation factor.

153 Two rainfall monitoring stations from the Water National Agency (ANA) located
154 within the catchment (Fig. 1) with 50-yr records were used to estimate the R factor.
155 Erosivity was calculated with an equation using monthly and annual rainfall developed by
156 Cassol et al., (2007) for Southern Brazil.
157 Erodibility (factor K) was calculated using equations developed by Roloff & Denardin
158 (1994) for Brazilian soils. The physical and chemical parameters required to apply the
159 equations were measured in the different soil classes, and their spatial distribution was
160 estimated from the soil map. Acrisols showed the highest susceptibility to erosion with a K

161 value of 0.03756, followed by Nitosols with a K of 0.01752. Oxisols, which cover
162 approximately 80% of the catchment surface area, were associated with values ranging
163 from 0.01155 to 0.01590. This demonstrates that most soils of the catchment show a very
164 high aggregate stability. The physical parameters used to calculate the K factor were the
165 soil texture, considering the grain size (0.02 mm), silt (0.02 - 0.005 mm) and fine sand (0.2
166 - 0.005 mm $g\ g^{-1}$) as well as the percentage of permeability of each soil type ($mm\ h^{-1}$). As
167 for the chemical parameters, the iron (Fe_2O_3) and aluminum (Al_2O_3) oxides ($g\ kg^{-1}$) were
168 used for each soil class; temporal variability in the K factor values was not considered,
169 because the parameters involved in determining the K-factor had not been altered. In
170 order to calculate the topographic factor (LS_{2D}), the Digital Elevation Model (DEM) was
171 created by interpolating between the contour lines of digital topographic maps with a 20-m
172 resolution. The LS_{2D} factor was calculated based on the algorithm proposed by Desmet and
173 Govers (1996). Considers that gully erosion is not dominant in the Conceição catchment.
174 Only few ephemeral gullies occur in the area. Gully erosion can be found in some
175 locations, but we still do not know how much it contributes to total sediment yield (SY).
176 Aiming to represent such processes, the Watem Sedem model uses the LS factor to
177 represent the sediment transport capacity.

178 In order to represent the transport capacity the model uses the logarithm of Desmet
179 et al. (1999) and Desmet and Govers (1996), which describes the LS factor and associates
180 the gullies process. The model incorporates different criteria and uses topographic
181 attributes to indicate the location of the gullies' starting points, flow direction,
182 characteristics of soil surface, vegetation cover, slope gradient and length.

183 Accordingly, the original transport capacity equation was used (Van Rompaey et
184 al., 2001), which allows the model to represent the connections directly through channels
185 with flow concentration preferential pathways (thalwegs) connecting water and sediment

186 flows on hillslopes with the rivers (Verstraeten et al., 2006) and / or interrupt the flows
187 with either natural or mechanical barriers. The C-factor was determined using the
188 methodology described by (Renard et al., 1997). Crop rotation (C-factor) aims to reduce
189 the direct impact of rainfall events on the soil surface. Annual values of C-factor were
190 attributed according to the land use (cropland, pasture and forest). The spatial distribution
191 of the C-factor for the catchment fields was based on of the analysis of satellite images and
192 field surveys (Table 1). In addition to the BAU conditions (C_{high}), an alternative scenario
193 (C_{low}) was constructed including an increase of crop rotations, with the planting of turnip
194 (winter) and maize (summer) in addition to the traditional soybean and wheat crops. This
195 study seeks to understand the effect of current conservation measures adopted by farmers,
196 and the impact of crop rotation on soil loss and the connectivity of sediments to
197 rivers. **Table 1 - Values for the soil cover factor (C) simulated for the Conceição River**
198 **Catchment.**

199 * **Business-as-usual; C : Factor C, Cs : Soil Cover, Cc : Cover by canopy, PU : Prior**
200 **land use, Rs : surface roughness.**

201 The P factor corresponds to the efficiency of conservation measures implemented
202 in the catchment. A value of 1 represents the worst case scenario with the least efficiency
203 (tillage). Currently, no-tillage is the only conservation measure implemented in the
204 catchment. Accordingly, a mean value of 0.8, which corresponds to a 20% water retention
205 efficiency, was attributed to the P factor for the entire catchment. In the study area, crops
206 are usually sown in the direction parallel to the longest field boundary (i.e. typically
207 perpendicular to the contour lines). In order to quantify the potential impact of crop
208 levelling in the catchment, the angle between the contour lines and the sowing rows was
209 measured (mean angle of 45°). According to the equation provided by (Renard et al, 1997),

210 the sowing efficiency was estimated to 0.20, which will affect the value of P for each pixel
211 depending on the local slope.

212 Eq. (1) estimates the amount of sediment generated, and consequently, transferred
213 to lower sections of the hillslope until it reaches the permanent drainage network. The
214 amount of sediments transported by surface flow depends on the soil transport capacity
215 (Tc) (Eq. 2), which is controlled by the physiographic factors of the cell considered (Van
216 Rompaey et al., 2001). Tc is the maximum amount of soil that can be transported from a
217 given pixel per length unit to the adjacent pixel, assuming that the transport capacity is
218 proportional to the potential of gully erosion.

$$219 \quad Tc = ktc * R * K * (LS_{2D} - 4.12 * S_g^{0.8}) \quad (2)$$

220 Where: Tc is the transport capacity expressed as ($kg\ m^{-1}\ yr^{-1}$), ktc is the coefficient of
221 transport capacity, expressed in m; R, K and LS_{2D} are RUSLE factors (Renard et al, 1997),
222 and S_g is the steepness of the slope ($m\ m^{-1}$).

223 The transport capacity coefficient Ktc (m) describes the proportionality between the
224 potential for rill erosion and the transport capacity. It can be interpreted as the theoretical
225 upslope distance that is needed to produce sufficient sediment to reach the transport
226 capacity of the cell considered, assuming a uniform slope and runoff discharge
227 (Verstraeten et al., 2006).

228 WATEM/SEDEM employs a routing algorithm to transfer the eroded sediment
229 from the source to the river network (Desmet and Govers, 1996; Van Oost et al., 2000).
230 This algorithm was improved by (Haregeweyn et al., 2013). The distribution between soil
231 erosion, transport and deposition processes is controlled by the values of E (Erosion) and
232 Tc (transport capacity): when $E > Tc$, deposition will occur, whereas there will be sediment
233 transfer when $E < Tc$.

234 **2.4 Model calibration and scenarios**

235 The model was calibrated based on sediment yields measured from 2011 to 2015.
236 The calibration parameters were the transport coefficients K_{tLow} and K_{tHigh} obtained by
237 minimizing the difference between simulated and measured values. The parameters of plot
238 efficiency (P_{tef}) in cropland, forests and pastures were 20, 90 and 60, respectively. The
239 parcel connectivity parameter (PC) was set to 20 for cropland and to 60 for forest and
240 pasture. The method described by (Moriassi et al., 2007) was used to quantify the statistical
241 efficiency of the WaTEM/SEDEM model to simulate the sediment yield.

242 Following the calibration of the model for the BAU conditions (factor P with 20%
243 efficiency), four alternative scenarios including different combinations of conservation
244 measures were modelled, with two sets of rainfall conditions (a dry year [R_{low}] with 1458
245 mm, corresponding to the situation observed in 2013; vs. a wet year [R_{high}] with 2251 mm,
246 corresponding to 2014) to quantify their respective impact on erosion, deposition and
247 sediment yield.

248 Two physical criteria were used to design the conservation scenarios: they had not
249 to be implemented yet by the farmers in the catchment and they had to limit sediment
250 connectivity within the catchment. The selected scenarios incorporate the vegetative and
251 mechanical practices for erosion control. The chosen vegetative practices (different
252 rotations) involve economic criteria, since that is the criteria most often used when
253 farmers implement parcial conservation measures. With this criteria in mind, there are
254 more effective practices that could be implemented maintaining their medium to long-term
255 financial expectations. The mechanical practices (terraces, areas of permanent forest
256 preservation) were chosen considering their ability to control surface runoff and increase
257 soil surface friction, thus, reducing the speed of the water flow. since such measures are
258 currently not present in the selected catchment. Five scenarios were modelled including a

259 business-as-usual (BAU) scenario representing current land use and management
260 conditions and four alternative soil conservation scenarios (Table 2):

261 **Table 2: Scenarios modelled in the Conceição River catchment.**

262 **(BAU) business-as-usual scenario: Chigh; Scenario I: Clow; Scenario II: Clow + CL +**
263 **T; Scenario III: Clow + CL + T + APP; Scenario IV: Clow + APP. Where: CL : crop**
264 **levelling; T: terracing; APP : areas of permanent forest preservation.**

265 It should be noted that the Brazilian Forestry Code legislation determines that
266 certain zones in the catchment should be considered as areas of permanent forest
267 preservation (APP) because of their importance for protecting the environment and the
268 quality of water resources. These include areas adjacent to rivers or natural and artificial
269 reservoirs, and hillslope sections with slope angles steeper than 45°. Removal of the
270 vegetation in these areas is only allowed in certain occasions (e.g. social interest), provided
271 previous authorization is obtained from the appropriate environmental agencies.

272 **3. Results**

273 **3.1 Hydrology and sediment yield**

274 Figure 2 shows the rainfall variability and erosivity from 2011 to 2015. The
275 monitoring period was heterogeneous, with long periods of drought in 2012 and periods of
276 concentrated rainfall in 2011, 2014 and 2015. In contrast, 2013 was characterized by a
277 rainfall amount close to the long-term average, despite the occurrence of rainfall events of
278 low-to-medium intensity and storms of extreme magnitude. The high intensity rainfall
279 observed in November and December 2015 is attributed to the El Niño phenomenon
280 (Marengo et al., 2009). This rainfall distribution affected the hydrological conditions in the
281 river and the resulting sediment fluxes. The highest sediment fluxes were observed during
282 the years characterized by the highest water discharges (Table 3).

283 **Figure 2 - Monthly rainfall and erosivity data of the Conceição River catchment for**
284 **the monitoring period (2011to 2015).**

285 **Table 3 - Representation of hydro-sedimentological variables of the Conceição River**
286 **catchment for the monitoring period (2011to 2015).**

287 **R: rainfall (mm); SSD: suspended sediment discharge; Q: Flow rate ($\text{m}^3 \text{s}^{-1}$), SY:**
288 **Sediment yield (t. km^{-2})); EI_{30} ($\text{MJ mm ha}^{-1} \text{ h}^{-1}$).**

289 In addition to this inter-annual variability, water flow (Q) and sediment yields (SY)
290 exhibited large seasonal variations controlled by rainfall distribution (R) and agricultural
291 practices affecting the sensitivity of soils to runoff and erosion (Figure 3).

292 The large impact of rainfall events occurring in spring on the increase of water
293 discharges, runoff and sediment yield is demonstrated.

294 **Figure 3 - Monthly averages (2011-2015) of sediment yield (SY), Flow (Q), rainfall (R)**
295 **for the Conceição River catchment.**

296 **3.2 Model efficiency analysis**

297 The model and the transport capacity coefficient (K_{tc}) were initially calibrated
298 considering the entire dataset covering the five years of monitoring (SY_A - Table 4). The
299 performance of the model measured by the efficiency index (SE- Statistical Efficiency)
300 was 40%. When excluding 2015 from the calibration data (SY_B – Table 4), the efficiency
301 of the model increased by 20%, to 60%. This is likely due to the atypical climate
302 conditions observed in 2015, with the occurrence of several extreme events that likely
303 modified the transport capacity and mobilized distinct sediment sources (e.g. channel
304 banks, roads).

305 The correspondence between the measured and the simulated mean annual SY
306 ($\text{t.km}^{-2} \text{ year}^{-1}$) for a 5-year period using the WaTEM/SEDEM model is shown in Figure 4.

307 Figure 4 - Performance of the WaTEM / SEDEM model in predicting sediment
308 yield (SY) for Conceição River.

309 When restricting the calibration period to 2011–2014, the optimized PC and
310 KTc_{Low} values were 60 and 0.12 for forests and pastures, and 20 and 0.36 for cropland,
311 respectively. The results of the simulations performed after the calibration are presented in
312 Table 4.

313 **Table 4 - Representation of calibration from sediment yield at the monitoring station**
314 **and efficiency of the model.**

315 **Where: EI_{30} : Erosivity ($MJ\ mm\ ha^{-1}h^{-1}$), SY : Sediment yield ($t.km^{-2}$): Sub index**
316 **A:four year database (from 2011 to 2014) and B : five year database (from 2011 to**
317 **2015).**

318 **3.3 Modelling alternative soil conservation scenarios**

319 Sediment yields were simulated for the BAU conditions and the four alternative
320 land cover scenarios (Table 5). Scenario I simulating the implementation of crop rotation
321 with plants providing higher biomass densities to protect the soils reduced only erosion by
322 0.6% and sediment yield by 1% compared to the BAU scenario. Scenario II included crop
323 rotation as well as crop levelling and terracing, and reduced erosion by 358%, deposition
324 by 316% and sediment yield by 400%. Scenario III combined the conservation measures
325 implemented in scenario II and areas of permanent forest preservation. It was the most
326 effective, with a reduction of soil erosion by 378%, a decrease of sediment deposition by
327 274% and of sediment yield by 541%. Scenario IV combined the introduction of crop
328 rotation and permanent forest preservation areas and led to a decrease of only 6.8% in
329 erosion and of approximately 38% in sediment yield. Furthermore, this was the only
330 scenario associated with an increase of sediment deposition rates (14%).

331 **Table 5 - Results of erosion, sediment deposition and sediment yield estimated by the**
332 **WaTEM-SEDEM model for the different scenarios.**

333 ***data set from 2013, representative of a dry year with cumulative rainfall lower than**
334 **the long-term average (1458 mm);**

335 ****data set from 2014, representative of a wet year with cumulative rainfall above the**
336 **long-term average (2251 mm).**

337 Overall, all simulated processes (erosion, deposition and sediment yield) were
338 33.9% higher under wet conditions (R_{high}) than under dry conditions (R_{low} ; Figure 5).

339 **Figure 5 - Results of erosion, sediment deposition and sediment yield estimated**
340 **by the WaTEM-SEDEM model for the different scenarios simulated for R_{low} and**
341 **R_{high} .**

342 Figure 6 shows the spatial pattern of soil losses within the Conceição catchment,
343 illustrating the important role played by topography (including slope length, steepness and
344 curvature) to explain spatial variations of erosion. The interactions of the LS factor with
345 the other RUSLE parameters are determined automatically by the WaTEM/SEDEM
346 model. The topographic attributes (LS) also consider the interactions of the soil surface and
347 the vegetation cover (C-factor), as well as the flow direction, which can be altered and/or
348 controlled through the mechanical practices (P-factor). Based on criterion such as
349 interventions in C factor values with increased plant biomass as well as factor P. Values for
350 both C and P factors were used to verify the responses of the different levels of
351 intervention on the values of soil losses and river connectivity.

352 Large volumes of runoff and sediment may accumulate on the long convex
353 hillslopes of the catchment and concentrate when reaching the river system, which exposes
354 the lower third section of the slopes to higher erosion rates.**Figure 6 - Spatial**
355 **representation of the erosion of the Conceição River catchment, according to the**

356 **proposed scenarios: a):BAU: C_{high}; B) Scenario I: C_{low}; C) Scenario II: C_{low} + CL + T;**
357 **D) Scenario III: C_{low} + CL + T + APP; E) Scenario IV: C_{low} + APP. Where: CL: crop**
358 **levelling; T: terracing; APP: areas of permanent forest preservation.**

359 **4. Discussion**

360 **4.1 Effectiveness of land cover scenarios to control soil erosion and sediment yield**

361 A comparison of the results of all scenarios for both dry (R_{low}) and wet (R_{high})
362 conditions shows that scenario III is the most efficient in reducing the intensity of erosion
363 and sediment transfer processes. Among the measures included in this scenario, the
364 mechanical conservation measures (simulated in both scenarios II and III) are likely the
365 most effective as they lead to a three-fold decrease of soil loss and sediment yields. In
366 contrast, the introduction of a crop rotation alone (scenario I) does not provide significant
367 erosion control. Results comparable to those obtained for scenario II are simulated for
368 scenario III, including the implementation of APPs. The contribution of APPs alone,
369 without the association with mechanical measures, is simulated in scenario IV. The model
370 indicates the relatively low efficiency of this scenario to control erosion processes,
371 although it is the single set of conditions leading to a 14% increase in sediment deposition.
372 This result illustrates the reduction of sediment velocity and the greater retention of
373 sediment in the APPs. Previous studies demonstrated that riparian vegetation leads to a
374 drastic decrease of sediment delivery (Cooper et al., 1987; Verstraeten et al., 2006).
375 However, when applied without the implementation of additional measures to control
376 sediment production at the source, this strategy is found not to be efficient in controlling
377 erosion (less than 10% reduction when compared to the BAU scenario), as cropland was
378 shown to provide the main source of sediment in this catchment (Tiecher et al., 2014).

379 **4.2 Impact of land cover scenarios on sediment connectivity**

380 Several scenarios have a clear impact on sediment connectivity, by affecting the
381 link between the sediment produced on the hillslopes and the material transiting the river
382 (Croke et al., 2005). In particular, the implementation of forest preservation areas in zones
383 of flow convergence or in the alluvial plains decreases sediment connectivity (Quiñonero-
384 Rubio et al., 2014). For instance, a change in land use in targeted zones through the
385 reforestation in fragile areas (Rompaey and Govers, 2002) may have an immediate impact
386 and reduce gross erosion and sediment connectivity (Alatorre et al., 2012). When
387 implementing APPs in the catchment, the model simulated a 38% reduction in sediment
388 yield and a 14% increase in sediment deposits (fig. 5), although it had limited impact on
389 gross erosion. The large heterogeneities in sediment connectivity simulated in the
390 catchment may reflect the spatial pattern of the conservation measures implemented in the
391 region (e.g. location of terraces; Fig. -6) or the intensity of rainfall events. Sediment
392 connectivity varies according to the intensity of the monthly and annual rainfall events.
393 Accordingly, sediment flows are heterogeneous over time. As found in other regions of
394 the world, the highest sediment connectivity between hillslopes and rivers is achieved
395 during the most intense events (e.g. during typhoons in Asia) (Chartin et al., 2016). The
396 lower efficiency of the WaTEM/SEDEM model during the most intense events may be
397 explained by the fact that roads and channels were not taken into account by the model,
398 and their inclusion in the future should improve the quality of the model results during
399 these intense storms.

400 **4.3 Improvement of soil conservation in Southern Brazil**

401 The scenario simulations demonstrated that there is a need to combine erosion
402 control measures on the cultivated fields (e.g. implementation of crop rotations, increase of
403 the vegetation cover of the soils) to reduce soil loss at the source, with additional measures
404 reducing sediment connectivity between hillslopes and rivers. The catchment is

405 characterized by the intensive soybean/wheat monoculture, which limits the diversity of
406 crops characterized by contrasting growing stages. In Europe, the variety of crops found on
407 a hillslope may create heterogeneous landscape mosaics, with bare soils producing
408 runoff/sediment and zones densely covered by vegetation that may infiltrate runoff and
409 trap sediment (Evrard et al., 2007; Souchère et al., 2005). The main soil characteristics
410 controlling runoff and sediment production at the field scale (i.e., soil cover by vegetation,
411 soil roughness, crusting stage) generally vary throughout the year, as a result of plant
412 growth, weather conditions and farming practices (Cerdan et al., 2002; Evrard et al.,
413 2008a). In southern Brazil, the most sensitive periods for runoff and erosion are winter and
414 spring, during the plant initial growth stage or after the harvest, when rainfall is the most
415 abundant (Figure 3). The modelled scenarios showed that soil cover by vegetation is not
416 sufficient during these periods to control erosion (Figure 5; Table 5), and it should be
417 increased to better protect the soils and further limit runoff/sediment production (Reicosky,
418 2015).

419 In addition, measures aimed to reducing sediment connectivity will act as a
420 physical barrier and prevent the sediment from reaching the water bodies when they are
421 located on the main runoff/sediment flow pathways (Boix-Fayos et al., 2008). Specific
422 plantation patterns (e.g. crop levelling, contour ploughing) can reduce sediment
423 connectivity (Karlen et al., 2009). Species such as elephant (*Pennisetum purpureum*),
424 vetiver (*Chrysopogon zizanioides*) and lemon grasses (*Cymbopogon citratus*) were shown
425 to provide effective sediment retention traps when planted in thalwegs or in concentrated
426 flow areas (Fiener and Auerswald, 2003; Verstraeten et al., 2002). An alternative to the
427 planting of specific vegetation species could be the installation of small earthen dams in
428 the thalwegs in order to slow down runoff and trap sediment. In Europe, these
429 measurements were shown to reduce sediment yield by 90% (Evrard et al., 2008a; Evrard

430 et al., 2008b). Importantly, there is a need to coordinate the implementation of these
431 control measures, both at the source and on the main flow pathways, at the catchment scale
432 in order to increase their effectiveness, as it was illustrated in regions of Northwestern
433 Europe where this type of measures was monitored in pilot areas (Evrard et al., 2010).

434 **4.4 Perspectives for future research**

435 Despite the widespread use of no-till in Southern Brazil, soil erosion and sediment
436 transfer remain excessive. Additional measures should be taken to improve this situation,
437 through the implementation of mechanical conservation measures, the increase of biomass
438 cover density of the soil, and the decrease of traffic of agricultural machinery to increase
439 the soil infiltration rates and sediment trapping (Denardin et al., 2008).

440 A previous modelling study compared the impact of applying conventional tillage
441 vs. no-till in a 20-km² catchment of Southern Brazil characterized by similar soil
442 characteristics, relief and land use as the study site investigated by the current research
443 (Castro et al., 1999). These authors showed that the runoff coefficient was higher when
444 applying no-till alone (7.7%) than when combining the use of conventional tillage and
445 terraces (5.8%). Other studies used the sediment fingerprinting technique to quantify the
446 sources supplying sediment to river systems of Southern Brazil. They showed that soils
447 found in lower parts of the catchment, cultivated with conventional practices on steep
448 slopes, were the main source of sediment to the Guaporé River network (Le Gall et al.,
449 2017). In contrast, soils found in upper parts of the catchment, cultivated with soybean
450 under direct sowing, deposited in ponds or in riparian areas before reaching the outlet. This
451 demonstrates the effectiveness of a strategy combining measures at the source and physical
452 barriers along the main flow pathways in the catchment.

453 Although models can provide powerful helping-decision tools for environmental
454 management, their use depends on the availability of large input datasets for calibration

455 (Tab.4). In the future, other soil erosion models such as STREAM (Cerdan et al., 2002),
456 APEX (Williams et al., 2008), or SWAT (Williams and Arnold, 1997) could be used to
457 investigate the impact of climate change on the effectiveness of conservation measures.
458 The magnitude and the frequency of heavy storms are expected to increase, which should
459 modify the production and the transfer of sediment across the landscape. The analysis of
460 sediment (dis)connectivity impact by these changes in interaction with the implementation
461 of contrasted conservation scenarios could usefully be tested in order to protect soil and
462 water resources and to allow their sustainable use for agriculture production.

463 **5 Conclusions**

464 Sediment fluxes were monitored from 2011 to 2015 in the Conceição catchment,
465 representative of cultivated environments under no-till in Southern Brazil. Very high
466 sediment yields, characterized by strong inter-annual variations ($37\text{--}259\text{ t km}^{-2}\text{ yr}^{-1}$), were
467 measured at the catchment outlet. These results illustrate that the use of no-tillage alone is
468 not sufficient to control soil erosion in this region. The WaTEM/SEDEM erosion model
469 was calibrated and validated with the unique dataset obtained in Conceição, and was
470 subsequently used to simulate contrasted land cover scenarios in order to propose a
471 sustainable use of soil resources in this intensively cultivated region.

472 The combination of direct sowing with measures recommended by the conservation
473 agriculture principles (e.g. increase in biomass cover of the soil, crop rotation, physical
474 barriers) was shown to lead to a 3-to-5 fold reduction of soil loss and sediment yields in
475 this region. Model simulations demonstrated in particular the need to implement
476 mechanical measures and to preserve riparian forests to slow down runoff and trap
477 sediment. This integrated soil conservation strategy should be tested in these environments
478 of Southern Brazil, in order to promote sustainable farming practices and to prevent the
479 further degradation of water quality.

480 **Acknowledgements**

481 The research benefited from the support of the CAPES-COFECUB project no
482 Te870-15.

483 **6 References**

484 Alatorre, L.C., Beguería, S., Lana-Renault, N., Navas, A., García-Ruiz, J.M., 2012. Soil
485 erosion and sediment delivery in a mountain catchment under scenarios of land use
486 change using a spatially distributed numerical model. *Hydrol. Earth Syst. Sci.* 16,
487 1321–1334. doi:10.5194/hess-16-1321-2012

488 Bertol, I., Cogo, N.P., Schick, J., Gudagnin, J.C., Amaral, A.J., 2007. Aspectos financeiros
489 relacionados às perdas de nutrientes por erosão hídrica em diferentes sistemas de
490 manejo do solo. *Rev. Bras. Ciência do Solo* 31, 133–142. doi:10.1590/S0100-
491 06832007000100014

492 Bezak, N., Rusjan, S., Petan, S., Sodnik, J., Mikoš, M., 2015. Estimation of soil loss by the
493 WATEM/SEDEM model using an automatic parameter estimation procedure.
494 *Environ. Earth Sci.* doi:10.1007/s12665-015-4534-0

495 Boix-Fayos, C., De Vente, J., Martínez-Mena, M., Barberá, G.G., Castillo, V., 2008. The
496 impact of land use change and check-dams on catchment sediment yield 22, 4922–
497 4935. doi:10.1002/hyp.7115

498 Bolliger, A., Magid, J., Amado, J.C.T., Skóra Neto, F., Ribeiro, M. de F. dos S., Calegari,
499 A., Ralisch, R., de Neergaard, A., 2006. Taking Stock of the Brazilian “Zero-Till
500 Revolution”: A Review of Landmark Research and Farmers’ Practice. *Adv. Agron.*
501 91, 47–110. doi:10.1016/S0065-2113(06)91002-5

502 Cassol, E.A., Martins, D., Luiz, F., Eltz, F., Lima, V.S. De, 2007. Erosividade e padrões
503 hidrologicos das chuvas de Ijuí (RS) no período de 1963 a 1993 Erosivity and
504 hydrological patterns of Ijuí (RS , Brazil) rainfalls in the period of 1963 to 1993.

505 Rev. Bras. Agrometeorol. 15, 220–231.

506 Castro, N.M.D.R., Auzet, A.-V., Chevallier, P., Leprun, J.-C., 1999. Land use change
507 effects on runoff and erosion from plot to catchment scale on the basaltic plateau of
508 Southern Brazil. *Hydrol. Process.* 13, 1621–1628.

509 Cerdan, O., Souchère, V., Lecomte, V., Couturier, A., Le Bissonnais, Y., 2002.
510 Incorporating soil surface crusting processes in an expert-based runoff model: Sealing
511 and Transfer by Runoff and Erosion related to Agricultural Management. *CATENA*
512 46, 189–205. doi:10.1016/S0341-8162(01)00166-7

513 Chartin, C., Evrard, O., Laceby, J.P., Onda, Y., Otlé, C., Lefèvre, I., Cerdan, O., 2016.
514 The impact of typhoons on sediment connectivity: Lessons learnt from contaminated
515 coastal catchments of Fukushima Prefecture (Japan). *Earth Surface Processes and*
516 *Landforms.* DOI: 10.1002/esp.4056.

517 Cooper, J.R., Gilliam, J.W., Daniels, R.B., Robarge, W.P., 1987. Riparian areas as filters
518 for agricultural sediment. *Soil Sci. Soc. Am. J.*

519 Croke, J., Mockler, S., Fogarty, P., Takken, I., 2005. Sediment concentration changes in
520 runoff pathways from a forest road network and the resultant spatial pattern of
521 catchment connectivity 68, 257–268. doi:10.1016/j.geomorph.2004.11.020

522 de Moor, J.J.W., Verstraeten, G., 2008. Alluvial and colluvial sediment storage in the Geul
523 River catchment (The Netherlands) — Combining field and modelling data to
524 construct a Late Holocene sediment budget. *Geomorphology* 95, 487–503.
525 doi:10.1016/j.geomorph.2007.07.012

526 Denardin, J.E., Kochhann, R.A., Faganello, A., Sattler, A., Manhago, D.D., 2008. “Vertical
527 mulching” como prática conservacionista para manejo de enxurrada em sistema
528 plantio direto. *Rev. Bras. Ciência do Solo* 32, 2847–2852. doi:10.1590/S0100-
529 06832008000700031

530 Derpsch, R., Franzluebbbers, A.J., Duiker, S.W., Reicosky, D.C., Koeller, K., Friedrich, T.,
531 Sturny, W.G., Sá, J.C.M., Weiss, K., 2014. Why do we need to standardize no-tillage
532 research? *Soil Tillage Res.* doi:10.1016/j.still.2013.10.002

533 Desmet, P.J.J., Govers, G., 1996. A GIS procedure for automatically calculating the USLE
534 LS factor on topographically complex landscape units. *J. Soil Water Conserv.* 51,
535 427–433.

536 Desmet, P.J.J., Poesen, J., Govers, G., Vandaele, K., 1999. Importance of slope gradient
537 and contributing area for optimal prediction of the initiation and trajectory of
538 ephemeral gullies.

539 Evrard, O., Heitz, C., Liégeois, M., Boardman, J., Vandaele, K., Auzet, A.-V., van
540 Wesemael, B., 2010. A comparison of management approaches to control muddy
541 floods in central Belgium, northern France and southern England. *L. Degrad. Dev.* 21,
542 322–335. doi:10.1002/ldr.1006

543 Evrard, O., Persoons, E., Vandaele, K., Wesemael, B. Van, 2007. Effectiveness of erosion
544 mitigation measures to prevent muddy floods : A case study in the Belgian loam belt
545 118, 149–158. doi:10.1016/j.agee.2006.02.019

546 Evrard, O., Vandaele, K., van Wesemael, B., Biielders, C.L., 2008a. A grassed waterway
547 and earthen dams to control muddy floods from a cultivated catchment of the Belgian
548 loess belt. *Geomorphology* 100, 419–428. doi:10.1016/j.geomorph.2008.01.010

549 Evrard, O., Vandaele, K., Wesemael, B. Van, Biielders, C.L., 2008b. A grassed waterway
550 and earthen dams to control muddy floods from a cultivated catchment of the Belgian
551 loess belt 100, 419–428. doi:10.1016/j.geomorph.2008.01.010

552 Fiener, P., Auerswald, K., 2003. Effectiveness of Grassed Waterways in Reducing Runoff
553 and Sediment Delivery from Agricultural Watersheds. *J. Environ. Qual.* 32, 927.
554 doi:10.2134/jeq2003.9270

555 Foster, G.R., Toy, T.E., Renard, K.G., 2003. Comparison of the USLE, RUSLE1.06c, and
556 RUSLE2 for Application to Highly Disturbed Lands. USDA-ARS 154–160.

557 Fu, B.J., Zhao, W.W., Chen, L.D., Zhang, Q.J., Lü, Y.H., Gulinck, H., Poesen, J., 2005.
558 Assessment of soil erosion at large watershed scale using RUSLE and GIS: A case
559 study in the Loess Plateau of China. *L. Degrad. Dev.* doi:10.1002/ldr.646

560 Le Gall, M., Evrard, O., Dapoigny, A., Tiecher, T., Zafar, M., Paolo, J., Minella, G.,
561 Laceby, J.P., Ayrault, S., 2017. Tracing sediment sources in a subtropical agricultural
562 catchment of southern Brazil cultivated with conventional and conservation farming
563 practices. *L. Degrad. Dev.* DOI: 10.1002/ldr.2662

564 Gómez, J.A., Battany, M., Renschler, C.S., Fereres, E., 2003. Evaluating the impact of soil
565 management on soil loss in olive orchards. *Soil Use Manag.* 19, 127–134.
566 doi:10.1111/j.1475-2743.2003.tb00292.x

567 Haregeweyn, N., Poesen, J., Verstraeten, G., Govers, G., Vente, J.D.E., Nyssen, J.,
568 Deckers, J., Moeyersons, J., 2013. Assessing the performance of a spatially
569 distributed soil erosion and sediment delivery model (WaTEM / SEDEM) IN 204,
570 188–204.

571 Horowitz, A.J., Elrick, K.A., Smith, J.J., Stephens, V.C., 2014. The effects of Hurricane
572 Irene and Tropical Storm Lee on the bed sediment geochemistry of U.S. Atlantic
573 coastal rivers. *Hydrol. Process.* 28, 1250–1259. doi:10.1002/hyp.9635

574 Karlen, D.L., Dinnes, D.L., Tomer, M.D., Meek, D.W., Cambardella, C.A., Moorman,
575 T.B., 2009. Is No-Tillage Enough ? A Field-Scale Watershed Assessment of
576 Conservation Effects 7, 1–24.

577 Keesstra, S.D., van Dam, O., Verstraeten, G., van Huissteden, J., 2009. Changing sediment
578 dynamics due to natural reforestation in the Dragonja catchment, SW Slovenia.
579 *CATENA* 78, 60–71. doi:10.1016/j.catena.2009.02.021

580 Kinnell, P.I.A., 2010. Event soil loss, runoff and the Universal Soil Loss Equation family
581 of models: A review. *J. Hydrol.* 385, 384–397. doi:10.1016/j.jhydrol.2010.01.024

582 Knapen, A., Poesen, J., Govers, G., Gyssels, G., Nachtergaele, J., 2007. Resistance of soils
583 to concentrated flow erosion: A review. *Earth-Science Rev.* 80, 75–109.
584 doi:10.1016/j.earscirev.2006.08.001

585 Lal, R., 2007. Constraints to adopting no-till farming in developing countries. *Soil Tillage
586 Res.* 94, 1–3. doi:10.1016/j.still.2007.02.002

587 Lal, R., Delgado, J.A., Gulliford, J., Nielsen, D., Rice, C.W., Pelt, R.S. Van, 2012. extreme
588 events 67, 162–166. doi:10.2489/jswc.67.6.162A

589 Marengo, J.A., Jones, R., Alves, L.M., Valverde, M.C., 2009. Future change of
590 temperature and precipitation extremes in South America as derived from the PRECIS
591 regional climate modeling system 2255, 2241–2255. doi:10.1002/joc

592 Merten, G.H., Horowitz, A., Clarke, R., Minella, J., Pickbrenner, K., Pinto, M., 2006.
593 Considerações sobre a utilização da curva-chave para determinação de fluxo de
594 sedimentos - Quantificação das incertezas nas estimativas do fluxo de sedimentos em
595 suspensão, gerados a partir de uma curva-chave.

596 Minella, J.P.G., Merten, G.H., Reichert, J.M., Clarke, R.T., 2008. Estimating suspended
597 sediment concentrations from turbidity measurements and the calibration problem.
598 *Hydrol. Process.* 22, 1819–1830. doi:10.1002/hyp.6763

599 Montgomery, D.R., 2007. Soil erosion and agricultural sustainability. *Proc. Natl. Acad.
600 Sci. U. S. A.* 104, 13268–72. doi:10.1073/pnas.0611508104

601 Moriasi, D.N., Arnold, J.G., Liew, M.W. Van, Bingner, R.L., Harmel, R.D., Veith, T.L.,
602 2007. *M e g s q a w s* 50, 885–900.

603 Nearing, M.A., Govers, G., Norton, L.D., 1999. Variability in Soil Erosion Data from
604 Replicated Plots. *Soil Sci. Soc. Am. J.* 63, 1829. doi:10.2136/sssaj1999.6361829x

605 Nearing, M., Pruski, F.F., O'Neal, M.R., 2004. Expected climate change impacts on soil
606 erosion rates: A review. *J. Soil Water Conserv.* 59, 43–50.

607 Notebaert, B., Verstraeten, G., Ward, P., Renssen, H., Rompaey, A. Van, 2011.
608 Geomorphology Modeling the sensitivity of sediment and water runoff dynamics to
609 Holocene climate and land use changes at the catchment scale 126, 18–31.
610 doi:10.1016/j.geomorph.2010.08.016

611 Okoro, B.C., Ibearugbulem, 2013. Gully Erosion Control along NWORIE River in Owerri,
612 \nImo State-A Deterministic Model Approach. *Ijmer* 3, 1774–1782.

613 Poesen, J., 2011. Challenges in gully erosion research 17, 5–9.

614 Porterfield, 1977. Computation of fluvial-sediment discharge.

615 Quiñonero-Rubio, J.M., Nadeu, E., Boix-Fayos, C., de Vente, J., 2014. Evaluation of the
616 Effectiveness of Forest Restoration and Check-Dams to Reduce Catchment Sediment
617 Yield. *L. Degrad. Dev.* 27, 1018–1031. doi:10.1002/ldr.2331

618 Reicosky, D.C., 2015. Conservation tillage is not conservation agriculture. *J. Soil Water*
619 *Conserv.* 70, 103A–108A. doi:10.2489/jswc.70.5.103A

620 Renard et al, 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning
621 with the Revised Universal Soil Loss Equation (RUSLE), 703rd ed. Washington, DC.

622 Roloff, G & Denardin, JE (1994). Estimativa simplificada da erodibilidade do solo. In.
623 Reunião Brasileira de Manejo e Conservação do Solo e da Água, Florianópolis. 10º,
624 Anais. Florianópolis: Sociedade Brasileira de Ciência do Solo. p.150-151.

625 Rompaey, A. Van, Bazzoffi, P., Jones, R.J.A., Montanarella, L., 2005. Modeling sediment
626 yields in Italian catchments. *Geomorphology* 65, 157–169.
627 doi:10.1016/j.geomorph.2004.08.006

628 Rompaey, A.J.J. Van, Govers, G., n.d. Data quality and model complexity for regional
629 scale soil erosion prediction. *Int. J. Geogr. Inf. Sci.* 16, 663–680.

- 630 Shreve, E.A., Downs, A.C., 2005. Quality-Assurance Plan for the Analysis of Fluvial
631 Sediment by the U.S. Geological Survey Kentucky Water Science Center Sediment
632 Laboratory.
- 633 Souza, C.M. de; Pires, F.R.; Partelli, F.L.; Assis, R.L. de Adubação verde e rotação de
634 culturas. Viçosa: Ed. UFV, 2012.108p.
- 635 Souchère, V., Cerdan, O., Dubreuil, N., Le Bissonnais, Y., King, C., 2005. Modelling the
636 impact of agri-environmental scenarios on runoff in a cultivated catchment
637 (Normandy, France). CATENA 61, 229–240. doi:10.1016/j.catena.2005.03.010
- 638 Terranova, O., Antronico, L., Coscarelli, R., Iaquina, P., 2009. Soil erosion risk scenarios
639 in the Mediterranean environment using RUSLE and GIS: An application model for
640 Calabria (southern Italy). Geomorphology 112, 228–245.
641 doi:10.1016/j.geomorph.2009.06.009
- 642 Tiecher, T., Paolo, J., Minella, G., Miguel, P., Rasche, J.W., Pellegrini, A., Capoane, V.,
643 Ciotti, L.H., Luiz, G., 2014. Contribuição das fontes de sedimentos em uma bacia
644 hidrográfica agrícola sob plantio direto. 639–649.
- 645 Van Oost, K., Govers, G., Desmet, P., 2000. Evaluating the effects of changes in landscape
646 structure on soil erosion by water and tillage. Landsc. Ecol.
647 doi:10.1023/A:1008198215674
- 648 Van Rompaey, A.J.J., Verstraeten, G., Van Oost, K., Govers, G., Poesen, J., 2001.
649 Modelling mean annual sediment yield using a distributed approach. Earth Surf.
650 Process. Landforms. doi:10.1002/esp.275
- 651 Vente, J. De, Poesen, J., Verstraeten, G., 2008. Spatially distributed modelling of soil
652 erosion and sediment yield at regional scales in Spain 60, 393–415.
653 doi:10.1016/j.gloplacha.2007.05.002
- 654 Verstraeten, G., Oost, K. Van, Rompaey, A. Van, Poesen, J., Govers, G., 2002. Evaluating

655 an integrated approach to catchment management to reduce soil loss and sediment
656 pollution through modelling. *Soil Use Manag.* 19, 386–394.
657 doi:10.1079/SUM2002150

658 Verstraeten, G., Poesen, J., Gillijns, K., Govers, G., 2006. The use of riparian vegetated
659 filter strips to reduce river sediment loads : an overestimated control measure ? 4267,
660 4259–4267. doi:10.1002/hyp.6155

661 Verstraeten, G., Rommens, T., Peeters, I., Poesen, J., Govers, G., Lang, A., 2009. A
662 temporarily changing Holocene sediment budget for a loess-covered catchment
663 (central Belgium). *Geomorphology* 108, 24–34. doi:10.1016/j.geomorph.2007.03.022

664 Wang, G., Hapuarachchi, P., Ishidaira, H., Kiem, A.S., Takeuchi, K., 2009. Estimation of
665 Soil Erosion and Sediment Yield During Individual Rainstorms at Catchment Scale.
666 *Water Resour. Manag.* 23, 1447–1465. doi:10.1007/s11269-008-9335-8

667 Williams, J.R., Arnold, J.G., 1997. A system of erosion-sediment yield models 11, 43–55.

668 Williams, J.R., Arnold, J.G., Kiniry, J.R., Gasaman, P.W., Green, C.H., 2008. History of
669 model development at Temple, Texas. *Hydrol. Sci. J.* 53, 948–960.
670 doi:10.1623/hysj.53.5.948

Table 1[Click here to download Table: Table 1_Didone.docx](#)

Table 1 - Values for the soil cover factor (C) simulated for the Conceição River Catchment.

	C	Cs	Cc	PU	Rs
C _{high} : Soybean/Fallow/Wheat/Soybean*	0.01794	0.122	0.576	0.236	0.980
C _{low} : Soybean/Turnip/Corn/Wheat	0.01260	0.106	0.529	0.170	0.969

* Business-as-usual; C = Factor C, Cs = Soil Cover, Cc = Cover by canopy, PU = Prior land use, Rs = surface roughness.

Table 2: Scenarios modelled in the Conceição River catchment.

Scenarios	Factor C	Additional conservation measure		
BAU	C_{high}	-	-	-
Scenario I	C_{low}	-	-	-
Scenario II	C_{low}	CL	T	-
Scenario III	C_{low}	CL	T	APP
Scenario IV	C_{low}	APP	-	-

(BAU) business-as-usual scenario: C_{high} ; Scenario I: C_{low} ; Scenario II: $C_{low} + CL + T$;
 Scenario III: $C_{low} + CL + T + APP$; Scenario IV: $C_{low} + APP$. Where: CL: crop leveling;
 T: terracing; APP: areas of permanent forest preservation.

Table 3[Click here to download Table: Table 3_Didone.docx](#)**Table 3** - Representation of hydrossedimentological variables of the Conceição River catchment for the monitoring period (2011 to 2015).

Year	R	EI ₃₀	SSD(kg s ⁻¹)		Q (m ³ s ⁻¹)		SY
			Mean	Maximum	Mean	Maximum	
2011	2135	11222	2.58	423.5	24.2	998.3	119.5
2012	1632	9476	1.53	264.7	13.4	541.2	73.6
2013	1458	8164	0.73	57.5	18.6	488	36.8
2014	2251	12129	1.72	365.3	31.6	1442.8	154.4
2015	2470	12368	2.14	457.39	35.9	1051.7	259.1

R: rainfall (mm); SSD: suspended sediment discharge; Q: Flow rate (m³ s⁻¹), SY:

Sediment yield (t. km⁻²); EI₃₀ (MJ mm ha⁻¹ h⁻¹).

Table 4 - Representation of calibration from sediment yield at the monitoring station and efficiency of the model.

		SY _A (t. km ⁻² yr ⁻¹)		SY _B (t. km ⁻² yr ⁻¹)
		NS=0.57		NS=0.40
Year	EI ₃₀	Measured	Simulated	Simulated
2011	11222	119.5	107.5	120.6
2012	9476	73.6	87.5	98.1
2013	8164	36.8	37.9	84.5
2014	12129	154.4	114.1	127.9
2015	12368	259.1	119.5	134.1

Where: EI₃₀ : Erosivity (MJ mm ha⁻¹h⁻¹), SY : Sediment yield (t.km⁻²): Sub index A:four year database (from 2011 to 2014) and B : five year database (from 2011 to 2015).

Table 5[Click here to download Table: Table 5_Didone.docx](#)

Table 5 - Results of erosion, sediment deposition and sediment yield estimated by the WaTEM-SEDEM model for the different scenarios.

R_{Low} *		t. km⁻² year⁻¹		
Model	Conservation measures	Erosion	Deposition	Sediment Yield
BAU	C _{high}	135.1	65.2	69.9
Scenario I	C _{low}	134.3 (-0.5 %)	65.2 (0 %)	69.2 (-1%)
Scenario II	C _{low} +CL+T	29.6 (-356.4 %)	15.7 (-315.2%)	13.9 (-402.8)
Scenario III	C _{low} +CL+T+APP	28.3 (-377.3%)	17.4 (-274.7%)	10.9 (-541.2%)
Scenario IV	C _{low} +APP	126.5 (-6.7%)	75.8 (13.78%)	50.7 (-37.8%)
R_{High} **		t. km⁻² year⁻¹		
Model	Conservation measures	Erosion	Deposition	Sediment Yield
BAU	C _{high}	204.6	98.8	105.8
Scenario I	C _{low}	203.4 (-0.6 %)	98.7 (-0.10%)	104.7 (-1.05 %)
Scenario II	C _{low} +CL+T	44.7 (-358 %)	23.7 (-316.8%)	21.0 (-403 %)
Scenario III	C _{low} +CL+T+APP	42.8 (-378 %)	26.4 (-274.2%)	16.5 (-541 %)
Scenario IV	C _{low} +APP	191.5 (-6.8%)	114.8 (13.9%)	76.7 (-37.9%)

*data set from 2013, representative of a dry year with cumulative rainfall lower than the long-term average (1458 mm);

**data set from 2014, representative of a wet year with cumulative rainfall above the long-term average (2251 mm).

Figure Captions

Figure 1 - Location of the Conceição river catchment in Brazil.

Figure 2 - Monthly precipitation and rainfall erosivity in the Conceicao River catchment for the monitoring period (2011–2015).

Figure 3 - Monthly averages (2011–2015) of sediment yield (SY), river water discharge (Q), rainfall (R) for the Conceição River catchment.

Figure 4 - Performance the WaTEM/SEDEM model in predicting sediment yield (SY) for Conceição River.

Figure 5 - Results of erosion, sediment deposition and sediment yield estimated by the WaTEM-SEDEM model for the different scenarios simulated including those with high and low rainfall.

Figure 6 - Spatial pattern of soil erosion within the Conceição River catchment, according to thescenarios simulated with the WATEM-SEDEM model: A): Business-as-usual (BAU) scenario: C_{high} ; B) Scenario I: C_{low} ; C) Scenario II: $C_{low} + CL + T$; D) Scenario III: $C_{low} + CL + T + APP$; E) Scenario IV: $C_{low} + APP$. Where: CL: Crop Leveling; T: Terracing; APP: Areas of permanent forest preservation.

Figure 1
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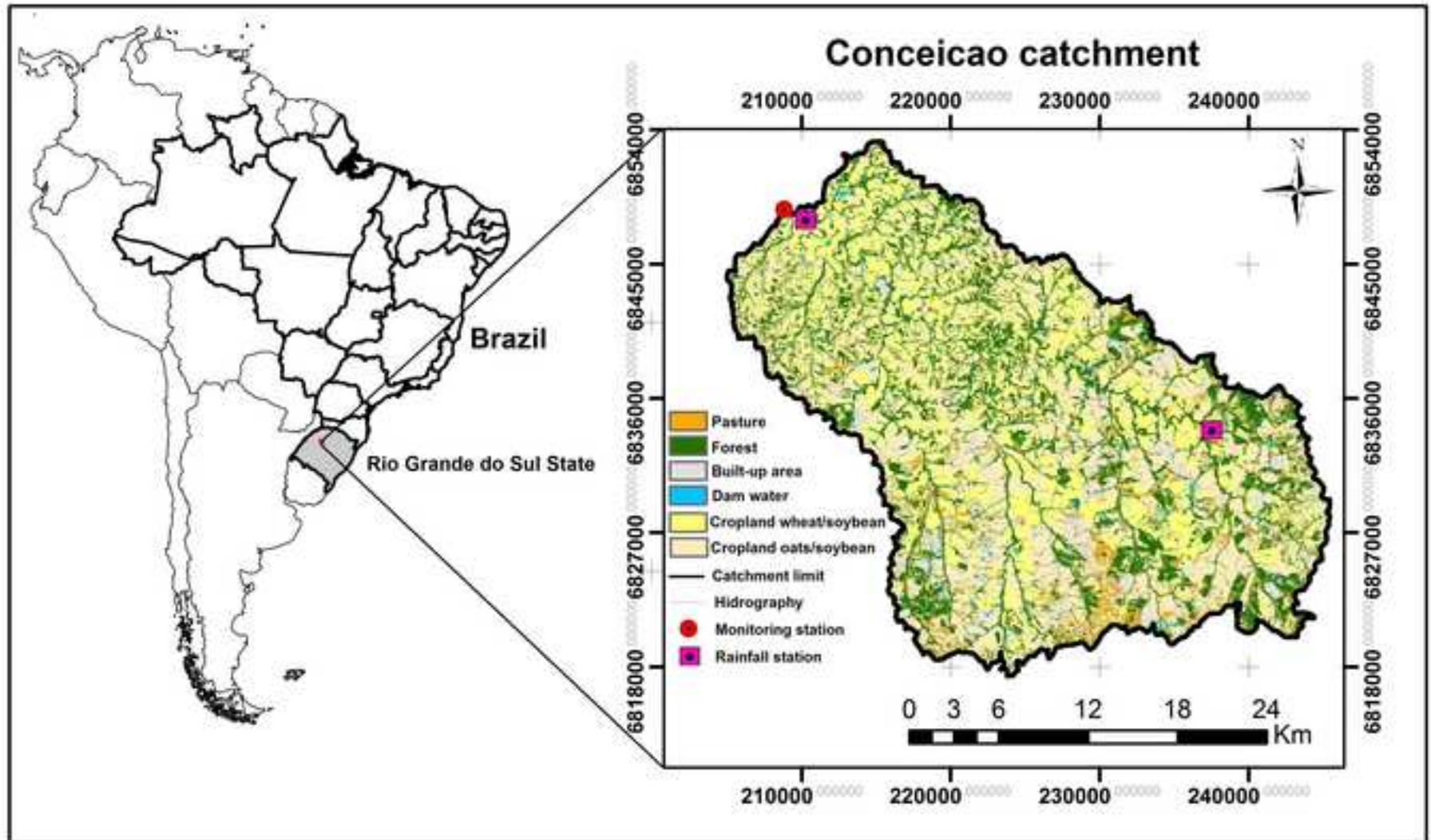


Figure 2

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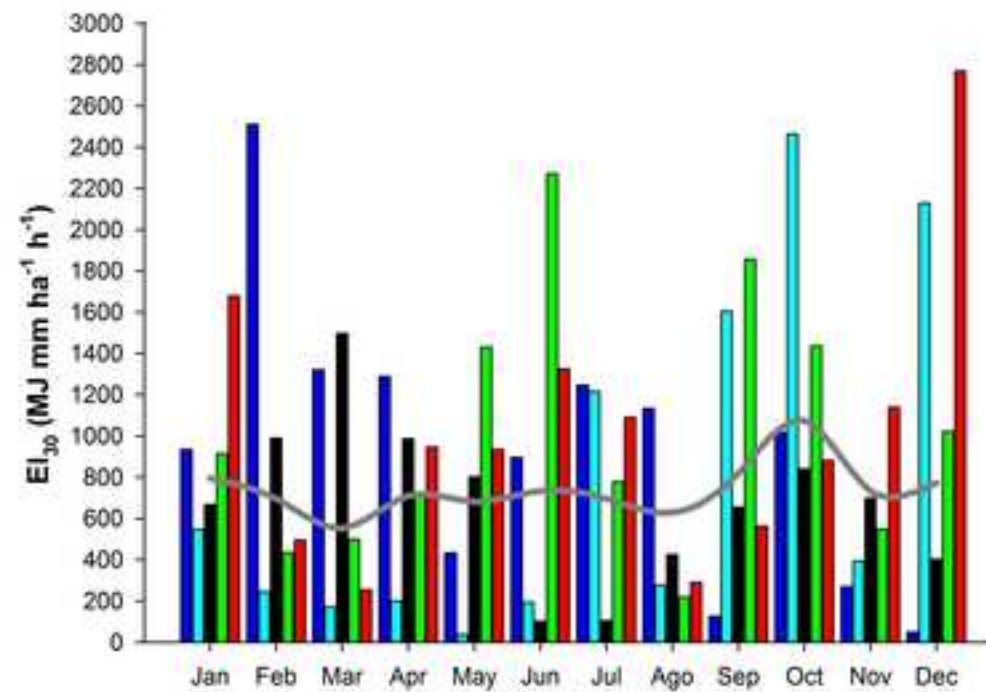
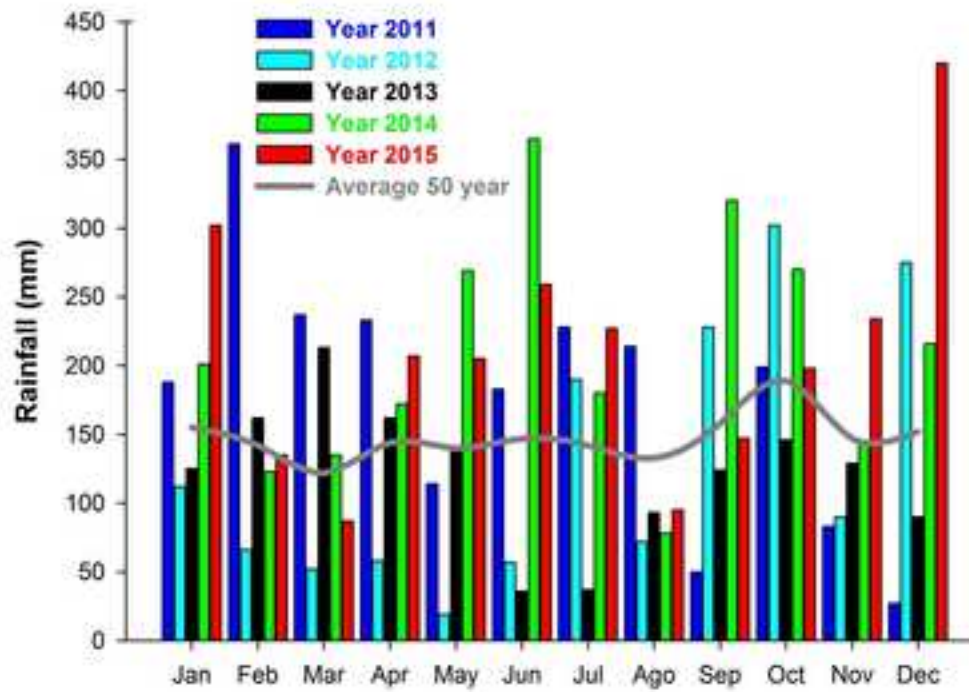


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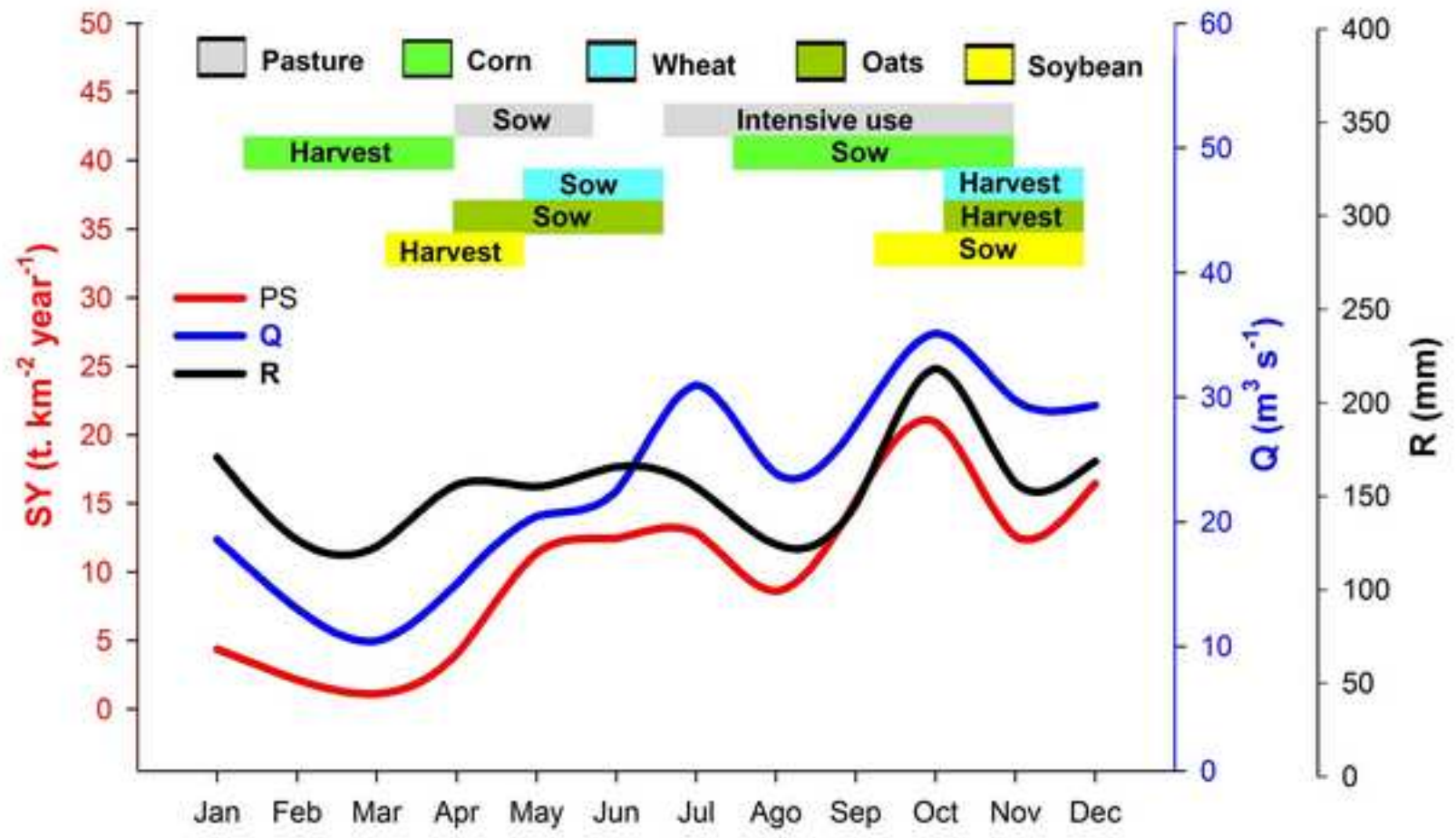


Figure 4
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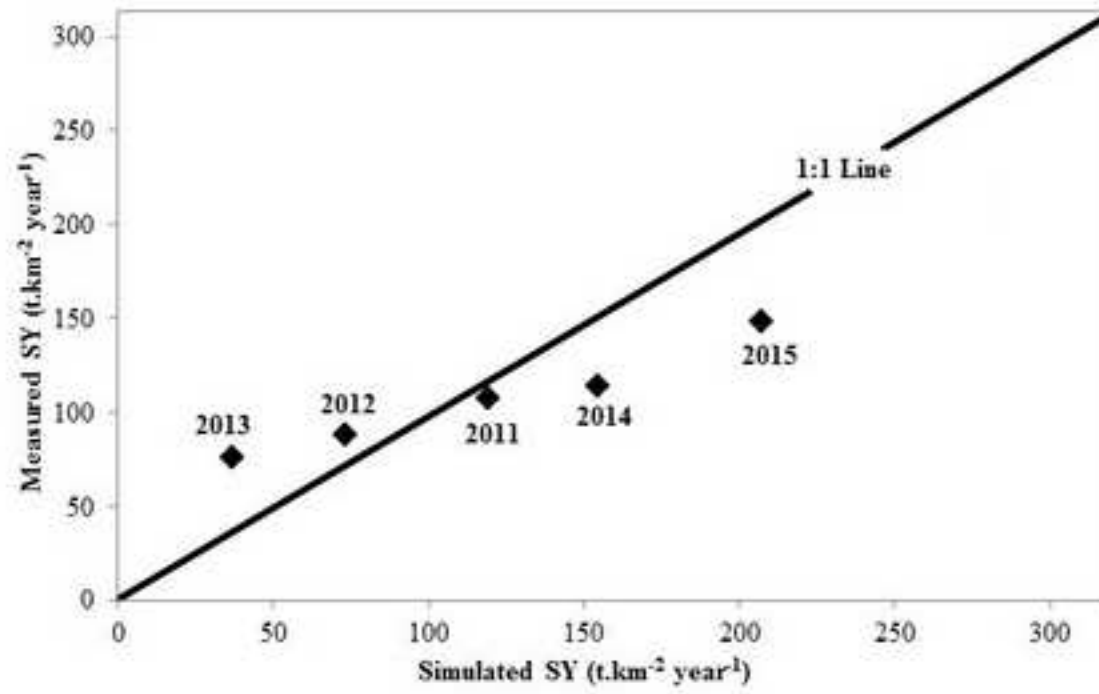


Figure 5
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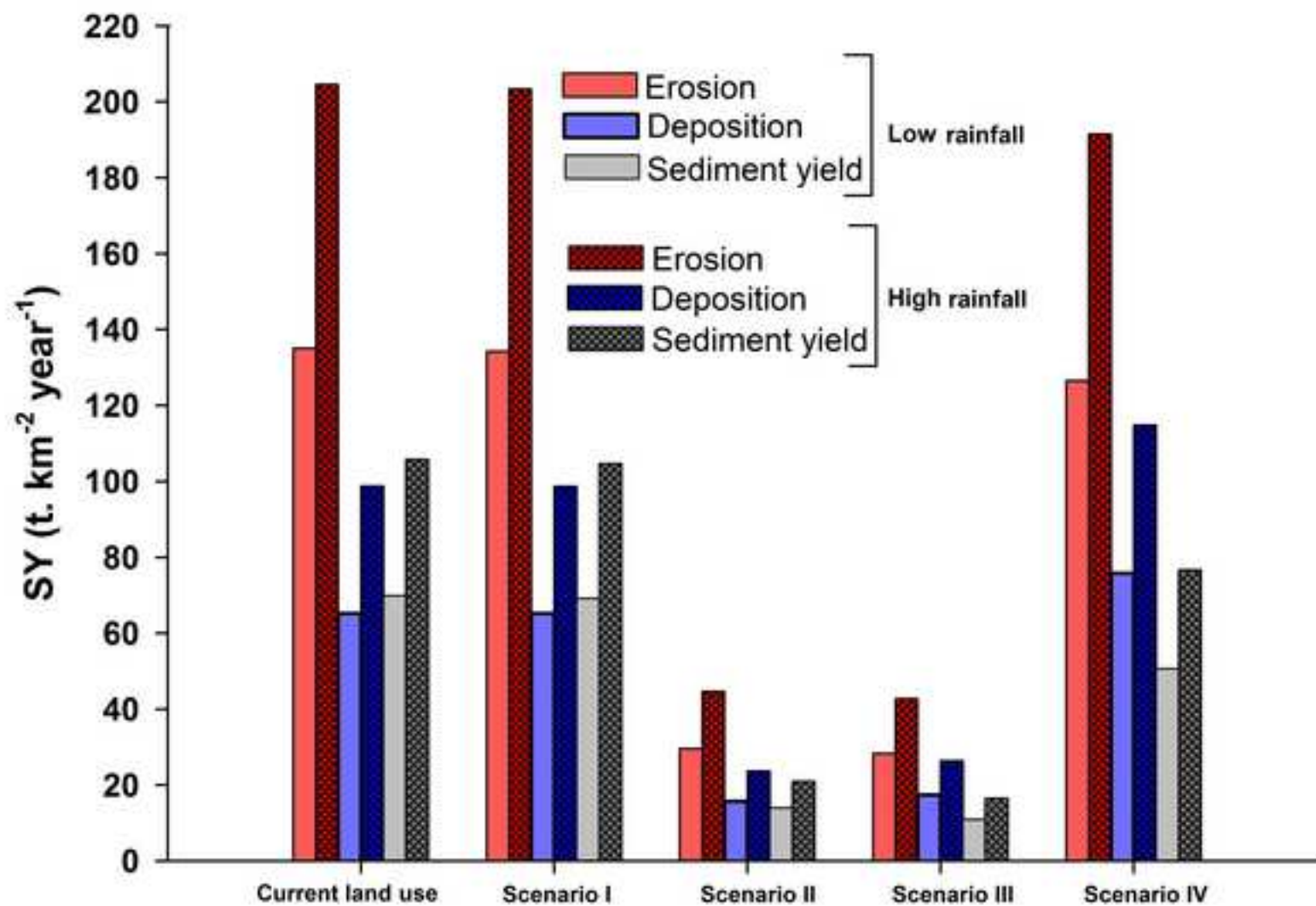


Figure 6
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