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1 Cover crops reduce drainage but not always soil water content due to 2 interactions between rainfall distribution and management

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7 1. Introduction

8 Intensive agriculture has reached a critical point, particularly in Europe and temperate climate zones.
9 Conventional agriculture is increasingly shown to be responsible for multiple problems, such as
10 stagnating yields, a decrease in soil fertility, pollution of groundwater and rivers, and soil erosion.
11 Agriculture must adapt in response to climate change, which is causing more droughts, less water
12 availability, and more extreme climatic events (IPCC, 2013). Therefore, scientists, farmers and policy
13 makers urgently need to find more sustainable and resilient cropping and farming systems. The use of
14 cover crops could help cropping systems become more agroecological and diversified. Cover crops are
15 sown after one cash crop is harvested and terminated before the next one is sown. Their residues are
16 retained as a mulch or incorporated into the soil by plowing or shallow tillage, such as disking. Cover
17 crops provide a wide range of ecosystem services, including reducing nitrate leaching (Tonitto et al.,
18 2006); providing a “green manure” effect (Tosti et al., 2014; Tribouillois et al., 2015); improving
19 physical properties of soil that reduce erosion or compaction (Chen and Weil, 2010; Ryder and Fares,
20 2008); decreasing greenhouse gas emissions; increasing carbon (C) storage in the soil (Poeplau and
21 Don, 2015; Tribouillois et al., 2018a); and controlling pests, diseases, and weeds (Couëdel et al.,
22 2018a; Haramoto and Gallandt, 2005; Schipanski et al., 2014). Using cover crops could also help
23 mitigate and adapt to climate change (Kaye and Quemada, 2017). Tribouillois et al. (2018b)
24 demonstrated the effective mitigating influence of cover crops and highlighted the challenge of finding
25 a good compromise between certain ecosystem services they provide and the decrease in groundwater
26 recharge they cause by increasing evapotranspiration of cropping systems.

27 Cover crops influence the soil water balance and water fluxes. They reduce water drainage in
28 temperate climates (Meyer et al., 2019) and increase transpiration by increasing leaf cover
29 transpiration and decreasing soil evaporation (Nielsen et al., 2015b; Qi et al., 2011). When well
30 established, they can also increase water infiltration and reduce runoff (Eshel et al., 2015; Yu et al.,
31 2016). However, the importance of these processes depends on cover crop management, climate, and
32 soil type. No consensus exists about the impact of cover crops on soil water availability for the next
33 cash crop. Corak et al. (1991) and Restovich et al. (2012) reported less water available with cover
34 crops compared to that with bare soil, while Chen et al. (2014) and Daigh et al. (2014) found no

35 significant differences between these two treatments at sowing of the next crop. Several studies
36 reported more water in the topsoil (0-20 cm depth) (Blanco-Canqui et al., 2011; Wells et al., 2014).
37 Likewise, no consensus exists about the impact of management of cover crop residues after cover
38 crops are terminated. Several studies reported an increase in soil water content (SWC) up to 20 cm
39 deep (Alliaume et al., 2014; Moschler et al., 1967; Stipešević and Kladičko, 2005). Williams and Weil
40 (2004) observed no differences in soil moisture 20-50 cm deep between cover crop mulch and bare
41 soil. Pedrosa De Azevedo et al. (1999) observed no significant difference in soil moisture between
42 keeping cover crops alive during the fallow period and crushing them and leaving their residues as
43 mulch. Kornecki et al. (2013) observed a small difference between these two treatments, with more
44 soil moisture under the mulched cover crop.

45 It is also difficult to generalize the impact of cover crops on water balance because studies are
46 performed in different contexts of fallow periods (e.g. August-November vs. October-April), climate
47 conditions, and cover crop management. In some studies, cover crops are terminated in late winter or
48 early spring, while in others they are terminated the day before sowing the next cash crop, especially
49 when herbicide termination is used. These differences are crucial to understanding cover crop impacts,
50 since multiple processes, of variable intensity, interact in these dynamics. Thus, spring rainfall can
51 recharge the soil and mask differences in SWC and in the topsoil (seedbed of the next cash crop), even
52 though water fluxes (e.g. drainage, evapotranspiration) flow simultaneously. Dynamic soil-crop
53 models can be useful tools to estimate water fluxes that are difficult to measure in field experiments,
54 such as drainage, evaporation, and transpiration, and can do so accurately over long periods. These
55 models also can simulate a wide range of cover crop management practices under several soil and
56 climate conditions and extrapolate results of field experiments that are expensive, time consuming,
57 and rare (Bergez et al., 2010).

58 The goal of our study was to understand and quantify impacts of cover crops and their management on
59 water flux dynamics (e.g. soil evaporation, plant transpiration, drainage) and balance at the crop
60 rotation scale. Two components of the water balance were a particular focus of analysis: (1) drainage,
61 which governs groundwater recharge, and (2) water availability for the next cash crop, which
62 determines the risk of water deficit for crop emergence and early growth. We combined a two-year
63 field experiment with simulation modeling to address this issue. The field experiment was performed
64 to analyze impacts of cover crop management on dynamics of SWC and cover crop biomass. This
65 field experiment was supplemented with a modeling approach using the STICS soil-crop model to
66 understand and quantify the water flux dynamics (drainage, evaporation, and transpiration) not
67 measured during the experiment.

68 2. Materials and methods

69 2.1 Methodological approach

70 To determine the impact of various cover crop management practices on soil water balance during the
71 fallow period and soil water availability for the next spring/summer cash crop, the following
72 methodological approach was used:

- 73 1. A two-year field experiment was performed to quantify the impact of three cover crop
74 management practices on SWC in multiple soil layers during the fallow period compared to
75 the SWC under bare soil, used as a control.
- 76 2. The dynamics of SWC and cover crop biomass measured in the experiment were used to
77 calibrate the STICS soil-crop model for the mixed cover crop sown in the experiment and
78 evaluate the model's ability to predict the experiment. The objective was to simulate soil and
79 plant dynamics sufficiently well to obtain accurate simulations of water fluxes.
- 80 3. We assumed that if dynamics of SWC and crop biomass were simulated accurately, then those
81 of water fluxes would also be simulated accurately. After verifying satisfactory agreement
82 between model predictions and experimental observations, STICS was used to predict
83 dynamics of soil evaporation, plant transpiration, and water drainage (processes not measured
84 in the field) and the complete water balance for the two experimental years.
- 85 4. To place the weather during the two experimental years in the study site's interannual
86 variability in climate, we used the calibrated STICS to simulate a 20-year climate series to
87 better understand and generalize the impact of cover crop management on water fluxes and the
88 complete water balance.

89

90 2.2 Case study site

91 2.2.1 Climate characteristics

92 A two-year experiment was performed from 2017-2018 and 2018-2019 (hereafter, "2017" and "2018",
93 respectively) in southwestern France near Toulouse (43°31' N, 1°30' E). The site has a temperate
94 climate corresponding to Cfb in the Köppen climate classification. Over the past two decades (1998-
95 2018), the site's mean (± 1 standard deviation (SD)) annual temperature was $13.8 \pm 0.5^\circ\text{C}$, annual
96 potential evapotranspiration (PET) (Penman equation) was 962 ± 51 mm, and annual rainfall was 655
97 ± 105 mm. The weather conditions from cover crop sowing in July-August to termination in March-
98 April differed during the two years of the experiment (Fig. 1). For 2017 and 2018, cumulative rainfall
99 was 504 mm and 343 mm, and cumulative PET was 437 mm and 334 mm, respectively. In 2017,
100 autumn was dry and winter and spring were rainy, with a high PET in the three months following the

101 sowing of cover crops. Conversely, in 2018, autumn and early winter were rainy, with a low PET, and
102 late winter and spring were dry. Cumulative temperature (calculated with base 0) from the day of
103 cover crop sowing (31 July in 2017 and 28 August in 2018) until 9 April was 2920°C in 2017 and
104 2490°C in 2018.

105 (Figure 1)

106 2.2.2 Soil characteristics

107 The two-year experiment was performed at an Institut National de la Recherche Agronomique (INRA)
108 experimental station on two field plots with similar soil characteristics: clay loam in 2017 and loam in
109 2018 (Table 1). Soil moisture at field capacity (FC) corresponded to the maximum observed during
110 the experiment. Soil moisture at wilting point (WP) and bulk density (BD) were estimated based on
111 soil texture classification and measurements at the experimental station (Jamagne et al. 1977;
112 Tribouillois et al., 2016). Total available water capacity for plants (TAWC, SWC between FC and
113 WP) was calculated down to 120 cm deep (the maximum root depth observed at this site; Tribouillois
114 et al. (2016)). TAWC was nearly the same for the two plots: 152 and 164 mm in 2017 and 2018,
115 respectively. The SWC at FC was 347 and 328 mm in 2017 and 2018, respectively.

116 (Table 1)

117 2.3 Field experiment

118 2.3.1 Experimental design

119 The experimental design was the same for both years: four treatments and four replicates per
120 treatment. The treatments were (1) bare soil (BS) as a control without plant transpiration; (2) cover
121 crops mechanically terminated by crushing in autumn and left as mulch on the soil surface (CC_M) until
122 spring; (3) cover crops mechanically terminated by crushing in autumn and buried by plowing (CC_P)
123 during winter when soil conditions were suitable (to avoid compaction); and (4) cover crops
124 mechanically terminated by crushing in April (CC_L) immediately before sowing the next
125 spring/summer cash crop. The surface area of an elementary plot was 44 and 70 m² in 2017 and 2018,
126 respectively. The preceding cash crop for both years was durum wheat harvested in late June/early
127 July.

128 Cover crop species were selected for their ability to grow rapidly during the summer and their
129 tolerance to freezing temperatures. They were also selected to favor complementary abiotic resource
130 acquisition, based on previous studies performed under the same climatic conditions (Couédel et al.,
131 2018b; Tribouillois et al., 2016) and to cover the soil during the entire fallow period due to
132 complementary development. A bispecific mixture was chosen: one crucifer, Ethiopian mustard
133 (*Brassica carinata*), and one legume, crimson clover (*Trifolium incarnatum*). The crucifer grew

134 rapidly after sowing and during autumn. The legume was able to grow during winter under the
135 mustard and could grow more rapidly in early spring, maintaining soil cover and plant transpiration
136 until April.

137 Seeds were sown respectively at 3 kg.ha⁻¹ and 7.5 kg.ha⁻¹ of seeds. Shallow tillage was performed in
138 both years before sowing. In both years, 70 mm of irrigation was applied twice after sowing to ensure
139 homogenous emergence and establishment of cover crops to guarantee spatial homogeneity of the soil-
140 crop system. Weeds were controlled on BS using a herbicidal spray in October of both years.

141 2.3.2 Cover crop biomass and soil water content measurements

142 Aerial biomass (Mg.ha⁻¹) was sampled from a 0.5 m² area in each replicate plot of the cover crop
143 treatments on each termination date (autumn and spring). Mustard and clover biomass was separated
144 and measured. When present, weed biomass was also measured in the cover crop treatments, but it
145 was always low. Dry matter was weighed after 48 h in an 80°C oven.

146 SWC (mm) was measured once per month for 8-9 months from cover crop sowing to the following
147 April. The soil profile was sampled from 0-120 cm deep in layers 20 cm thick. Five samples were
148 collected per replicate plot and then pooled by layer for each plot. Measurements in each of the four
149 replicates were taken independently. Soil samples were weighed before and after 48 h in a 105°C oven
150 to measure gravimetric soil moisture (cg water g⁻¹ soil).

151

152 2.4 Simulation approach

153 2.4.1 Model overview

154 We used the soil-crop model STICS (Brisson et al., 2003), which simulates daily crop growth, light,
155 water, C and nitrogen (N) balances based on soil, climate, crop species, and agricultural management.
156 A tipping-bucket approach is used to model the soil, which is divided into five layers with specific
157 characteristics, such as BD, as well as SWC at FC and WP. The water balance was simulated daily by
158 adding soil water supply and subtracting plant transpiration and soil evaporation (Brisson et al., 2009).
159 STICS was evaluated as accurate for a wide range of agro-environmental contexts in France for plant,
160 water, and N outputs for bare soil and many types of cash crops (Brisson et al., 2003; 2009). STICS
161 was also used to simulate cover crops and analyze water, C and N balances and the associated
162 ecosystem services (Tribouillois et al., 2018a). STICS was also successfully evaluated for water
163 drainage (Beaudoin et al., 2008; Constantin et al., 2012).

164 2.4.2 Model initialization and calibration on-site

165 2.4.2.1 Soil parameterization and initialization

166 There was no calibration done on bare soil. Two soils were parameterized separately to simulate each
167 year of the field experiment. For model evaluation, the SWC measured at the beginning of the
168 experiment for each treatment was used, and the soil moisture at FC of each layer was adjusted for
169 each treatment to correspond as closely as possible to field observations. To initialize each soil layer in
170 the model for simulations, the mean SWC and soil mineral N measured in the four treatments at the
171 beginning of the experiment was used for each treatment (Table 1).

172 (Table 2)

173 2.4.2.2 Crop calibration

174 STICS has been calibrated for a wide range of species used as cover crops, such as mustard, rapeseed,
175 radish, ryegrass, oat, pea, vetch, and clover (Constantin et al., 2012; Tribouillois et al., 2018b);
176 however, no parameterization for a mixture of species was available. To simulate the field experiment
177 accurately, we parameterized STICS for the mustard-clover cover crop mixture. The objective was to
178 simulate, as accurately as possible, the main processes governing water balance dynamics, such as
179 cover crop development, biomass growth, changes in soil moisture over time in each soil layer, and
180 total SWC. Starting with parameters already calibrated for rapeseed (the crop most similar to
181 Ethiopian mustard) and crimson clover, we optimized three parameters for cover crop development,
182 N₂ fixation (for clover), and cover crop water requirements to generate the most accurate joint
183 predictions of the dynamics of biomass and SWC in each layer and in total for both experimental
184 years. Mathematical optimization was based on the method developed by Wallach et al. (2011) using
185 the Simplex algorithm, which is available with the STICS model software (Java interface;
186 https://www6.paca.inra.fr/stics_eng).

187 2.4.3 Water flux simulations of the field experiment

188 After calibration, model predictions of water drainage, soil evaporation, and plant transpiration were
189 available for each of the four treatments for each year of the field experiment (Table 2); they were
190 used to calculate total water balance and quantify the fluxes. For the 2017 experimental year,
191 simulations began 28 July and ended 28 March. For the 2018 experimental year, simulations began on
192 1 August and ended on 5 April. Since crimson clover was observed to regrow in both years after being
193 crushed in the CC_M treatment, the model was calibrated to simulate this regrowth as well, using only
194 crimson clover parameters as the crop in a second simulation step.

195 2.4.4 Simulation of water fluxes over 20 years

196 To evaluate the impact of cover crops on soil water variables over a long time series, a 20-year
197 simulation was performed using a climate series from 1999-2018, from an INRA weather station
198 installed at the study site. The soil was parameterized and initialized with the field data measured in
199 2017. Then we run simulations twice, once with dates of technical operations of 2017-crop

200 management for all 20 years and once with dates of the technical operations of 2018-crop management
201 for all 20 years, since each year had different field-operation dates (Table 2). The simulations started
202 on 1 August and finished on 1 April for each year of the 20-year simulation. Predicted SWC and
203 cumulative water drainage on 1 April were also recorded. As in the two-year experiment, potential
204 regrowth of crimson clover after being crushed in the CC_M treatment was simulated.

205

206 2.5 Statistical analysis

207 All statistical analyses were performed using R software (R Core Team, 2018).

208 2.5.1 STICS evaluation and prediction

209 2.5.1.1 Model evaluation criteria

210 Simulations were performed using the model calibrated for the six cover crop treatments (3 treatments
211 × 2 experimental years). Three statistical criteria were used to evaluate the quality of agreement
212 between observed and simulated variables after calibrating STICS for the cover crop mixture – mean
213 deviation (MD), relative root mean square error (rRMSE), model efficiency (EF) – calculated as
214 follows:

$$MD = \frac{1}{n} \sum_{i=1}^n (S_i - O_i)$$

215 $rRMSE = 100 \frac{RMSE}{\bar{O}}$ with $RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (S_i - O_i)^2}$

$$EF = \frac{\sum_{i=1}^n (O_i - \bar{O})^2 - \sum_{i=1}^n (S_i - O_i)^2}{\sum_{i=1}^n (O_i - \bar{O})^2}$$

216 where n is the number of observations; S_i and O_i are the simulated and observed values, respectively,
217 and \bar{O} is the mean value of the observed data.

218 The three criteria provide a good overview of model performance. MD and rRMSE indicate
219 systematic bias and the dispersal of model simulations compared to observations, respectively. The
220 lower their value, the better is the model prediction. EF, which measures agreement between
221 simulations and observations, varies from 1 (perfect prediction) to $-\infty$. A negative value indicates that
222 the mean of observations is a better predictor than the model.

223 2.5.1.2 STICS prediction quality

224 To assess the ability of STICS to simulate biomass, each soil layer's moisture, and total SWC, the
225 relative root mean square error of prediction (rRMSEP) was calculated using cross-validation and a

226 leave-one-out method (Wallach, 2014). The six cover crop treatments were separated into two
227 subsamples: one containing five treatments, to estimate crop parameters, and the other containing the
228 sixth treatment to evaluate the prediction quality of STICS compared to observed data. This procedure
229 was applied six times to assess the prediction quality of STICS for the six treatments by calculating
230 individual RMSE_p for each treatment.

$$RMSEp = \sqrt{\frac{1}{n} \sum_{i=1}^n (P_i - O_i)^2}$$

231 $rRMSEp = 100 \frac{RMSEP}{\bar{o}}$

$$RMSEP = \overline{RMSEp}$$

232 where P_i are the predicted values.

233 2.5.2 Field experiment and 20-year simulations

234 2.5.2.1 Field experiment

235 Statistical analyses of SWC and soil moisture for each layer in the experiment were performed. Based
236 on the dataset, and after testing the homogeneity of the variables, a non-parametric Kruskal-Wallis
237 test was used to test the impact of the cover crop management practices on the experimental data. A
238 non-parametric Wilcoxon test was used to compare each pair of cover crop treatments. For all
239 analyses, differences among treatments were considered significant at $P < 0.05$.

240 2.5.2.2 Twenty-year simulations

241 Statistical analyses of SWC (total and in the 0-10 cm layer) and the difference in drainage predicted in
242 the 20-year simulations were performed. A non-parametric Kruskal-Wallis test was used to test the
243 impact of the cover crop management practices on the simulated data. A non-parametric Wilcoxon test
244 was used to compare each pair of cover crop treatments. For all analyses, differences among
245 treatments were considered significant at $P < 0.05$.

246 3. Results

247 3.1 Field experiment

248 3.1.1 Aerial biomass of cover crop mixtures

249 On the date of autumn termination for CC_M and CC_P, cover crops reached a mean aerial biomass of 4.2
250 Mg.ha⁻¹ (76% mustard, 24% clover) in 2017 and 3.5 Mg.ha⁻¹ (83% mustard, 17% clover) in 2018 (Fig.
251 2). Afterwards, the clover regrew in CC_M, reaching a biomass of 3.6 and 3.1 Mg.ha⁻¹ at the end of the

252 2017 and 2018 experimental years (early spring), respectively. In contrast, for CC_L at the end of the
253 experimental years, aerial biomass was 7.5 Mg.ha⁻¹ (35% mustard, 65% clover) in 2017 and 8.9
254 Mg.ha⁻¹ (88% mustard, 12% clover) in 2018. These results illustrate the temporal complementarity of
255 the two species' growth, which covered the soil throughout the fallow period. Ethiopian mustard
256 develops very quickly in late summer and autumn, while clover growth is particularly important in
257 winter and spring.

258 (Figure 2)

259 3.1.2 Soil water measurements during the fallow period

260 Soil water profiles during the fallow period varied by treatment in both years of the experiment,
261 showing no similar trends or final results (Figs. 3a & b). From July-August to November-December,
262 cover crops had significantly less water under them in the soil profile in 2017 than BS did, but they
263 showed no difference compared to BS in 2018. For both years of the experiment, cover crops and BS
264 showed no difference in SWC during winter. From February to March-April, SWC differed
265 significantly between CC_L or CC_M and BS or CC_P in the layers 20-60 cm deep in 2017 and 2018 (Figs.
266 3a & b).

267 (Figure 3a&b)

268 The change in SWC depended on the yearly rainfall distribution (Fig. 4). In 2017, October and
269 November were dry, each receiving less than 50 mm of rainfall. During these months, measured SWC
270 differed significantly between BS and the cover crop treatments. In December, the difference was ca.
271 50 mm, due to cover crops having higher actual evapotranspiration (AET) than BS. December and
272 January each received ca. 200 mm of rainfall, which caused soils of all treatments to reach FC. With
273 lower rainfall in March, a significant difference in SWC was observed between BS and CC_P, which
274 had no vegetation, and CC_L and CC_M, which did (Fig. 4a). In 2018, rainfall distribution was more
275 regular than that in 2017. From August-February, 50-100 mm of rain fell each month, which explains
276 the lack of a significant difference among the four treatments during this period. February and March
277 were dry, but resulted in non-significant differences in SWC in the upper layers among the four
278 treatments (Fig. 4b).

279 (Figure 4a&b)

280 3.2 STICS calibration and evaluation

281 3.2.1 Calibration of the cover crop mixture and quality of calibration of STICS for the two
282 years of the experiment

283 STICS simulated aerial cover crop biomass well: EF was high (0.82) with a non-significant low MD
284 of 0.2 Mg.ha⁻¹ of biomass, and rRMSE was only 18.2%. STICS also predicted SWC well, with a high
285 EF (0.87), no significant MD (1 mm of water), and a low rRMSE (4.7%) (Table 3 & Fig. 5)
286 (Supplementary Materials, Figs. S1-S8). STICS predicted water distribution in the soil well, with MD
287 less than 1 cg.g⁻¹ and EF always greater than 0.4 for the five soil layers. Dynamics of the upper layers
288 subject to soil evaporation and root uptake of water were simulated accurately, as indicated by an
289 rRMSE of 13.8% and 9.1% for the 0-20 and 20-40 cm layers, respectively. The rRMSE for the three
290 deepest layers was low (< 9%). The dynamics of SWC and the soil water profile were satisfactory
291 (Supplementary Materials, Figs. S1-S8). SWC differed between BS and cover crops somewhat more
292 in the simulations than in the experiment. However, simulation results lay within 1 SD of the
293 observations, indicating that model error was in the same range as the variability in the field
294 measurements.

295 (Figure 5)

296 3.2.2 Evaluation of the predictive quality

297 Using cross-validation to assess the predictive quality of STICS for simulating biomass, soil moisture
298 in each layer, and SWC provided satisfactory results, indicating an acceptable accuracy of the
299 simulations. The rRMSEP of soil moisture were ca. 15% for soil layers 0-40 cm deep and less than
300 10% for the deeper layers. The rRMSEP of cover crop biomass were less than 10%, and those of SWC
301 were ca. 5% (Table 3).

302 (Table 3)

303 3.3 Simulated water fluxes

304 Like the measurements, predicted SWC was lower for the three cover crop treatments than for BS
305 from late August until the date when FC was reached after winter rainfall (Fig. 6). In 2018, the SWC
306 of cover crops treatments was no more than 15 mm less than that of BS. SWC was 60 mm lower from
307 50 days after sowing (DAS) to 150 DAS in 2017, while it was 10 mm lower from 20-50 DAS in 2018.

308 Differences in SWC among the three cover crop treatments depended on the field experiment. No
309 difference in SWC was observed between the three cover crop treatments in 2017, while several
310 differences were measured and simulated in 2018 from 150 DAS. Difference in SWC between CC_M
311 and CC_L first appeared at 150 DAS, resulting in SWC 18 mm higher for CC_M than CC_L in late March.
312 At the same time in March, the SWC for CC_P was the same as that for BS and 70 mm higher than that
313 for CC_M (Table 3). From 170 DAS to the end of the experiment, the difference in simulated SWC
314 increased between BS and CC_P and between CC_L and CC_M, which was similar to the measurements.
315 Simulated SWC decreased more for CC_L and CC_M than for BS and CC_P. The maximum difference in

316 simulated SWC at the end of experiment was 89 mm, which was similar to the difference measured
317 between CC_L and BS (Fig. 6). Simulated cumulative water fluxes for the entire experiment are
318 summarized in Table 4.

319 For both years of the experiment, higher AET was simulated for all cover crop treatments than for BS,
320 due to an increase in leaf transpiration and a concomitant decrease in soil evaporation due to plant
321 cover. In 2017, the three cover crop treatments had similar simulated evapotranspiration, which was
322 70 mm higher than BS evaporation. The relative amounts of soil evaporation and plant transpiration
323 differed among the cover crop treatments. CC_P had 77 mm less simulated transpiration than CC_M and
324 87 mm less than CC_L, which followed the trends for dynamics and amount of aerial biomass. The
325 difference in soil evaporation was inversely proportional to transpiration. In 2018, BS had simulated
326 evapotranspiration 36, 93 and 111 mm lower than those for CC_P, CC_M and CC_L, respectively. The
327 relative amounts of simulated evaporation and transpiration were similar in both years of the
328 experiment for a given treatment (Table 3).

329 Consequently, cover crops reduced predicted water drainage by the same degree, regardless of their
330 management in a given year. Compared to BS, reductions of ca. 60 and 15 mm were predicted in 2017
331 and 2018, respectively. Water drained 14 and 10 days later under cover crop treatments than under BS
332 in 2017 and 2018, respectively, indicating a delay in filling in the soil water reserve due to higher
333 AET.

334 (Figure 6)

335 3.4 Water balance in the 20-year simulations

336 For the two 20-year simulations, cover crop biomass simulated for CC_L ranged from 1.9-8.0 ha⁻¹
337 (mean = 5.0 Mg.ha⁻¹), indicating that the biomass measured during the experiment corresponded to the
338 largest range of biomass that could be expected at this site. Simulated cover crop biomass for CC_M and
339 CC_P at autumn termination ranged from 2.2-6.6 Mg.ha⁻¹ (mean = 4.1 Mg.ha⁻¹), indicating that the
340 biomass measured during the experiment lay around the mean biomass that could be expected at this
341 site. The clover regrowth simulated for CC_M ranged from 1.0-3.5 Mg.ha⁻¹ (mean = 2.0 Mg.ha⁻¹),
342 indicating that its regrowth measured during the experiment corresponded to the largest range of
343 regrowth that could be expected at this site.

344 Over 20 years, the SWC simulated on 1 April for CC_L and CC_M differed significantly from that for BS
345 (Fig. 7), confirming the potential impact of cover crops on the water supply of the next cash crop in
346 certain years. Simulated mean SWC was 50 mm between CC_L and BS (significantly different) and 60
347 mm between CC_M and BS, corresponding to the range simulated for the experiment. Simulated mean
348 SWC of CC_P did not differ significantly from that of BS over the 20 years, regardless the management
349 year used (2017 or 2018), and was often near FC. For the 2017 management, mean SWC of CC_L
350 differed significantly from those of CC_P and BS. The impact of CC_M depended greatly on the climate

351 year, with high variability and a mean reduction compared to BS of ca. 60 mm. For the 2018
352 management, the difference in SWC between BS and CC_M was ca. 20 mm. Differences in simulated
353 SWC were compared for 1 April. BS and CC_P reached FC (or nearly so), with little variability among
354 climate years. Simulated SWC varied greatly for CC_L and CC_M: for 25% of climate years, it was less
355 than 55% of TAWC. Only three of the 20 simulated years showed no difference in SWC between
356 treatments. These years were particularly rainy in winter and spring, which frequently increased SWC
357 to FC. The influence of sowing and termination dates was large, with the difference between SWC for
358 CC_L and CC_M inverted depending on the year of cover crop management simulated: median SWC
359 for CC_M was ca. 25 mm higher and ca. 15 mm lower than that for CC_L for 2017 and 2018
360 management, respectively. However, these differences were not statistically significant over the 20
361 simulated years. Differences in simulated SWC were not due to differences in soil moisture of the 0-
362 20 cm layer, which did not differ significantly on 1 April among the BS, CC_P, CC_M, and CC_L
363 treatments (14.8, 14.8, 15.4, and 15.0 cg.g⁻¹, respectively). SWC simulated over the 20 years differed
364 from that measured in 2017, during which all treatments reached FC, and in 2018, during which cover
365 crops reduced SWC in spring to a degree found at the higher end of the range simulated over the 20
366 years.

367 Water drainage for BS ranged from 0-235 mm for the 20 simulated years. Three years had no drainage
368 for both the 2017 and 2018 management years. Mean and median simulated drainage was 67 mm and
369 48 mm, respectively, which correspond to low drainage at that site. This indicates that the drainage
370 observed during the experiment was among the highest 25% in 20 years, due to the high winter
371 rainfall. The mean difference in drainage of the cover crop treatments compared to BS was 45 mm and
372 20 mm for the 2017 and 2018 management years, respectively (Fig. 7). These differences represented
373 a reduction in total drainage of ca. 50% and 25% for 2017 and 2018, respectively. For 25% of the 20
374 years, no drainage was simulated for the three cover crop treatments, unlike under BS, regardless of
375 the management year used. Over 20 years with the 2018 management, CC_M had three years with the
376 same or slightly higher drainage than BS (mean difference = +4 mm). Drainage under cover crops
377 treatments had greater variability than that under BS: in some years, simulated drainage started on the
378 same date under the cover crops and BS, due to a rainy autumn, while in others, drainage started up to
379 3 months later under cover crops than under BS, especially after a dry autumn. However, the median
380 difference for the beginning of drainage between BS and the cover crop treatments was 14 days, which
381 corresponds roughly to that observed in the experiment.

382 Like in the experiment, BS had significantly lower simulated AET over the 20 years than the cover
383 crop treatments due to the lack of transpiration. The difference in AET between the three cover crop
384 treatments was small but significant for 2017 management, but not significant for 2018 management.
385 Compared to the other fluxes, AET varied the least over the 20 years.

386 (Figure 7)

387 4. Discussion

388 4.1 Influence of cover crops on soil water content for the next cash crop depends 389 on their termination date

390 Although the two years of the field experiment had similar cover crop biomass, impact of biomass on
391 the soil water profile differed over time. From sowing to autumn termination in 2017, water depletion
392 was observed along the profile, while in 2018, no difference in the water profile was observed among
393 the treatments. Differences in rainfall dynamics explain why the four treatments showed no
394 differences in the water profile in 2017's spring, while in 2018, there was less water in the soil layers
395 20-60 cm deep under CC_L and CC_M .

396 Some studies indicated that cover crops did not influence SWC in spring, as in 2017 in our field
397 experiment (Daigh et al., 2014), while others reported a decrease in SWC due to low rainfall in spring,
398 as in 2018 in our field experiment (Corak et al., 1991; Restovich et al., 2012). Blanco-Canqui et al.
399 (2011) suggested that soil moisture increases from 0-20 cm deep, but we found no difference among
400 the treatments over the experiments or the 20-year simulations. Little rainfall before the last sampling
401 date could have removed differences in soil moisture from 0-20 cm, which could explain why a
402 difference was observed only from 20-60 cm.

403 The impact of cover crops on the yield of the following cash crop differs in the literature: some studies
404 reported a decrease in yield (Nielsen et al., 2015b), while others reported no negative impacts (Eshel et
405 al., 2015). In some cases, yield can increase after a cover crop, especially when legumes are used
406 (Tonitto et al., 2006). However, these studies did not always identify why yield differed. Yield may
407 decrease due to water stress at the beginning of the cash crop, but it can also be caused by allelopathic
408 effects (Kessavalou and Walters, 1997) or a decrease in soil N content compared to that of bare soil
409 (Tonitto et al., 2006). In both years of the experiment, CC_L and CC_M had lower SWC in soil layers 20-
410 60 cm deep than BS and CC_P at the end of the experiment, which suggests that late termination of a
411 cover crop decreases SWC due to spring transpiration. If spring rainfall is too low to make up for this
412 difference, growth of the next cash crop could decrease. Krueger et al. (2011) highlighted the
413 importance of the termination date on reducing the negative impact of cover crops on yields.

414 The 20-year simulations showed that cover crops reduced both mean and median SWC simulated on 1
415 April and that spring rainfall was not sufficient to make up for the cover crops' lower SWC compared
416 to that of BS. Indeed, the effective rainfall: which can indicate refilling of soil water, was positive for
417 only five of the 20 years, and of these five, the soil was refilled up to FC in only two of them. SWC of
418 CC_P did not differ significantly from that of BS, which indicates that sufficient rain fell from
419 termination to early spring to compensate for cover crop transpiration. This indicates that early cover
420 crop termination avoids large differences in SWC in spring between cover crops and bare soil in
421 temperate and Mediterranean climates, as suggested by Alonso-Ayuso et al. (2014). Early termination

422 could be a good way to avoid negative impact, such as pre-emptive competition for water, on the next
423 crop. Termination dates between November and April could be a good compromise to avoid a
424 negative impact on SWC and also could reduce nitrate leaching and soil erosion better and maximize
425 soil C storage. Terminating cover crops before winter could be the best solution in dry regions where
426 water is scarce. Since we tested only two termination dates per year, however, we could not determine
427 an optimal termination date. This should be investigated in the future, such as in a site-specific
428 simulation study.

429 4.2 Sowing date of cover crops is key to minimizing reduction in drainage

430 In a recent meta-analysis, Meyer et al. (2019) reported that cover crops reduce water drainage by a
431 mean of 27 mm compared to that under bare soil, but the reduction varies widely among studies.
432 Depending on the year and regardless of the cover crop management, our field experiment indicated
433 that cover crops reduce drainage by 20-60 mm, which lies in the range found in the meta-analysis.
434 Early cover crop termination in autumn or early winter did not influence the reduction greatly, since
435 the same drainage reduction was observed regardless of the termination date or residue management in
436 the two years of the experiment. The 20-year simulations confirmed results of the experiment,
437 showing no difference in drainage reduction among the cover crop treatments for a given sowing date
438 and year. The range of annual reduction in predicted drainage over the 20 years (0-80 mm) was
439 consistent with the variability in results reported in the literature and can explain this variability, since
440 the impact on drainage depends on the interaction between weather conditions and cover crop
441 management. These differences can represent a reduction of nearly 50% in years with high drainage
442 and a complete lack of drainage in drier years. In our experiment, the decrease in drainage due to
443 cover crops was one-third the amount with later sowing (late August) than early sowing (late July).
444 This indicates that sowing date could be a key point to consider when analyzing the impact of cover
445 crops on drainage, as demonstrated by Justes et al. (2017).

446

447 4.3 No direct relationship observed between cover crop biomass and impact on 448 water fluxes above a certain level

449 Compared to bare soil, cover crops increase evapotranspiration by increasing transpiration even
450 though their cover decreases soil evaporation. In the experiment, cover crops increased
451 evapotranspiration by a mean of 30%. This result agrees with the literature (Nielsen et al., 2015a; Qi
452 and Helmers, 2010), in which several studies mention the relationship between biomass and
453 transpiration (Suyker and Verma, 2009; Tolk and Howell, 2009). However, no significant relationship
454 was observed between cover crop biomass and evapotranspiration or drainage in either year of the
455 experiment. Tribouillois et al. (2018) reported a correlation between cover crop biomass and an
456 evapotranspiration. They assessed cover crops with lower biomass ($0.5-2.5 \text{ Mg}\cdot\text{ha}^{-1} \text{ yr}^{-1}$) than we did

457 (> 8 Mg.ha⁻¹). Crops transpiration is linked with the biomass through the leaf area index (LAI) and it is
458 assumed that above a certain level of LAI, transpiration does not increase in proportion, and remains
459 constant from a certain level (Kang et al., 2003; Kristensen, 1974). This could explain why we did
460 observed no correlation between cover crop biomass and evapotranspiration or drainage. Tribouillois
461 et al. (2018b) also reported a strong negative correlation between the mean decrease in annual
462 drainage and the mean increase in annual evapotranspiration due to cover crops. This latter result was
463 found in the 2017 experimental year. However, in 2018, no significant correlation was observed
464 between the difference in drainage and evapotranspiration. The increase in evapotranspiration
465 influenced not only drainage, which decreased only slightly, but also the soil water content in spring,
466 which was much lower for CC_L and CC_M than for BS. This could have been due to differences in
467 rainfall distribution during the fallow period.

468

469 4.4 Study boundaries

470 4.4.1 Field experiment and simulations

471 Irrigation was applied after sowing the cover crop to ensure homogenous emergence and
472 establishment. Irrigation in summer, which is a dry period in southwestern France, could explain the
473 large amount of biomass observed, since strong growth of juvenile stages favored crop establishment.
474 Since we included irrigation in the 20-year simulations, STICS also predicted large amounts of
475 biomass. However, farmers in the region currently do not irrigate cover crops. Consequently, water
476 stress could occur with an early sowing date, such as July or early August in our conditions, which
477 could result in lower biomass. The impact of cover crops on the water balance could change, since the
478 climate in southwestern France is dry in summer, and August rain is not always sufficient to ensure
479 adequate emergence and development of cover crops to produce a sufficient amount of biomass. To
480 evaluate the impact of irrigation, we also performed the 20-year simulations without irrigation. The
481 results (not shown) indicated that drainage was slightly lower, but not significantly so. Predictions for
482 the impact on SWC and the difference in drainage compared to BS were similar with or without
483 irrigation. Without irrigation, the cover crop did not develop in some dry summers, or developed later.
484 In such cases, cover crops would not influence water fluxes.

485 The field experiment was performed on two similar soils at the same INRA experimental station. The
486 soils had high SWC due to their great depth. More investigation is required to determine the
487 importance of cover crops on shallow soils. On shallow soils, cover crops could have less impact on
488 drainage due to less water lost via transpiration because their roots would not extend as deep.

489 In 2018, soil texture in the deeper layers of the field plot varied greatly, even over short distances,
490 which could have masked significant differences in SWC due to cover crop treatments, as predicted in
491 the 20-year simulation. This highlights the ability of the strong complementarity between field

492 experiments and modeling to help understand and quantify dynamic interactions between treatments
493 and weather conditions.

494

495 4.4.2 STICS parameterization and initialization

496 An initial step in our study was to evaluate the ability of STICS to predict aerial biomass of cover
497 crops and SWC over time for the entire fallow period to obtain satisfactory water flux simulations.
498 Biomass and SWC were simulated sufficiently well for both years and were similar to or even an
499 improvement on results of previous studies (Brisson et al. 2002; Coucheney et al. 2015). STICS,
500 already used successfully to simulate drainage under cover crops (Constantin et al., 2012; Tribouillois
501 et al., 2016), remained accurate in our study. We can therefore assume that STICS simulated the fluxes
502 under different management practices sufficiently well. Nonetheless, we could have improved
503 calibration of the cover crop mixture had we measured dynamics of the leaf area index, since leaf area
504 governs transpiration.

505 SWC predictions would have been more accurate if soil water content had been initialized for each
506 treatment based on measurements. However, we initialized the soil with the mean SWC measured in
507 the four treatments to ensure that differences in simulated water fluxes would be due only to the
508 management practices, not to different initial states caused by natural field variability. Consequently,
509 STICS slightly overestimated the difference in SWC between CC_L and BS in 2018 and thus could have
510 slightly overestimated the difference in drainage and evapotranspiration between cover crops and BS.
511 Nevertheless, the simulated SWC always lay within 1 SD of observed values, which indicates that
512 overestimates were consistent with experimental results and that predicted differences in water balance
513 among treatments were acceptable.

514

515 4.5 Cover crop residues left as mulch can reduce soil evaporation and thus actual 516 evapotranspiration

517 One objective of our study was to analyze the impact of cover crop residues left as mulch via
518 mechanical crushing after the first autumn termination (CC_M) on the water balance, since no reference
519 was available in the literature, despite this practice's great benefit for farmers. Although not planned,
520 the crimson clover regrew after crushing and produced a large amount of biomass. Consequently, CC_M
521 caused changes in the water balance similar to those of CC_L. Cover crop mulch can increase SWC in
522 the surface layer by reducing evaporation (Alliaume et al., 2014; Moschler et al., 1967; Stipešević and
523 Kladienko, 2005), but we did not observe this effect for clover regrowth in the field experiment. It is
524 well known that residue mulch decreases evaporation. Evapotranspiration under a cover crop
525 terminated early and left as mulch could result in the same cumulative AET as that under bare soil,
526 since compared a bare soil, AET would be higher during cover crop growth, and soil evaporation

527 would be lower after cover crop termination. Thus, a cover crop terminated early and left as mulch
528 could reduce drainage less than a cover crop terminated late. It could also increase soil moisture on the
529 surface (i.e. 0-10 cm) and avoid an overly dry seedbed when the next cash crop is sown. However, it
530 could also make the soil too wet for sowing and cause bearing-capacity problems. This demonstrates
531 that cover crop management, especially the termination date, is important for cover crops to provide a
532 sufficient level of services, such as capturing nitrate or improving soil physical properties (Alonso-
533 Ayuso et al., 2018). In dry areas where water is scarce, cover crops can reduce drainage and shallow
534 groundwater recharge, and we hypothesis that mulching could be a good practice to maintain the
535 services expected from cover crops, resulting in a good comprise between services and disservices.
536 Thus, this practice could encourage green manure or catch crop services and avoid disservices by
537 minimizing negative impacts on water-balance fluxes due to pre-emptive competition for water, which
538 reduces drainage and water availability for the next cash crop.

539

540 Conclusion

541 The choice of cover crop termination date and management of cover crop residues could be a way to
542 benefit from all the services they provide, such as the green manure effect or increasing soil physical
543 properties in agroecological systems, while reducing their potential negative effects on the water
544 balance. Our study highlighted the impact of different cover crop management practices and the
545 variability of their water balance compared to that of bare soil. Cover crops clearly increase AET and
546 reduce drainage, but do not always reduce SWC at sowing of the next cash crop, which depends
547 greatly on the rainfall after cover crop termination. A decrease in groundwater recharge must be
548 considered when generalizing cover crops at the regional scale, especially that of shallow
549 groundwater, which is determined by drainage from agricultural soils. We demonstrated that later
550 termination of cover crops could have a negative impact on the next cash crop, even when depending
551 on spring rainfall. However, an optimal solution for cover crop management could include
552 mechanically crushing the cover crop in autumn and leaving the residues as mulch but new
553 experiments must be carried out to verify this hypothesis. Studies that combine field experiments and
554 simulation modeling are required to assess this management practice for other soil and climate
555 conditions, since the issue is also site-specific due to interactions between soil type and depth, and the
556 amount and distribution of rainfall. The potential of cover crop mulch to reduce soil evaporation
557 before sowing the next cash crop could be a good compromise between improving cover crop services
558 and decreasing negative impact on the water balance and its resulting consequences.

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566

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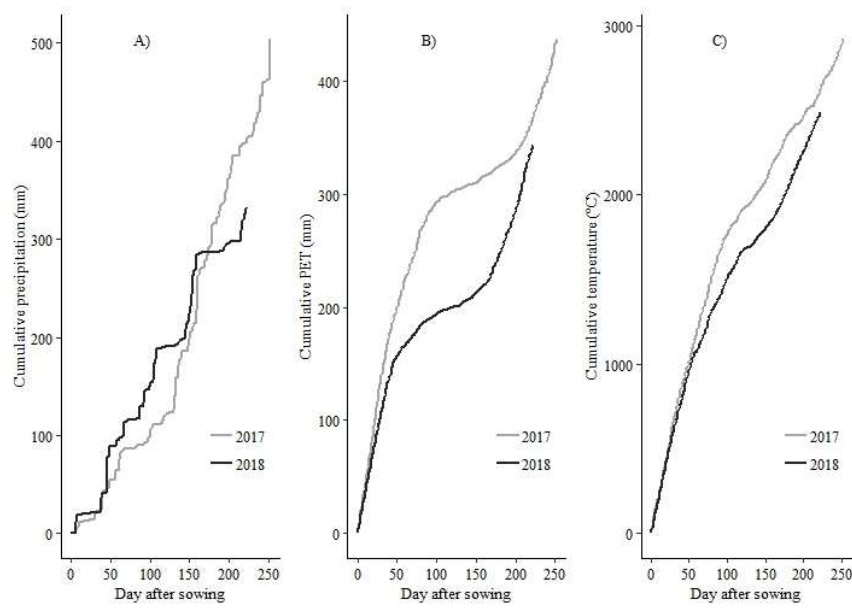


Figure 1. Cumulative (A) rainfall, (B) potential evapotranspiration (PET), and (C) temperature of the study site after sowing cover crops during the 2017 and 2018 experimental years.

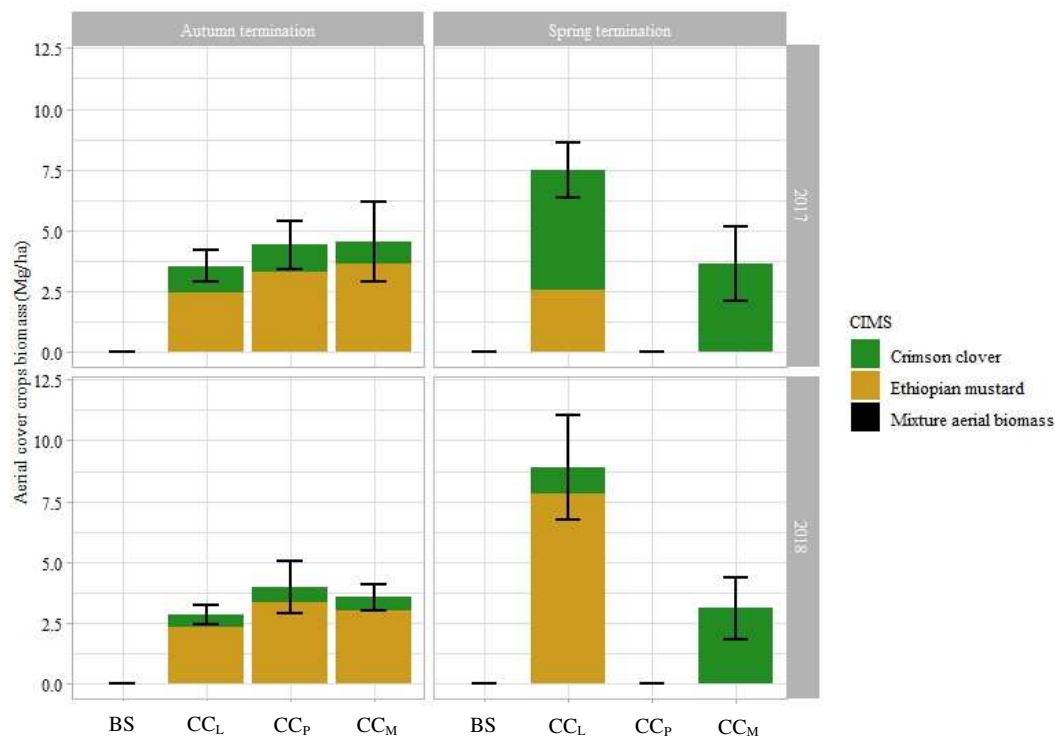


Figure 2. Cover crop biomass at (left) autumn or (right) spring destruction in the (top) 2017 and (bottom) 2018 experimental years for the four treatments: bare soil (BS), cover crop crushed in autumn and left as mulch on the soil surface (CC_M), cover crop crushed in autumn and buried by plowing (CC_P), and cover crop destroyed in April (CC_L). Error bars represent ± 1 standard deviation.

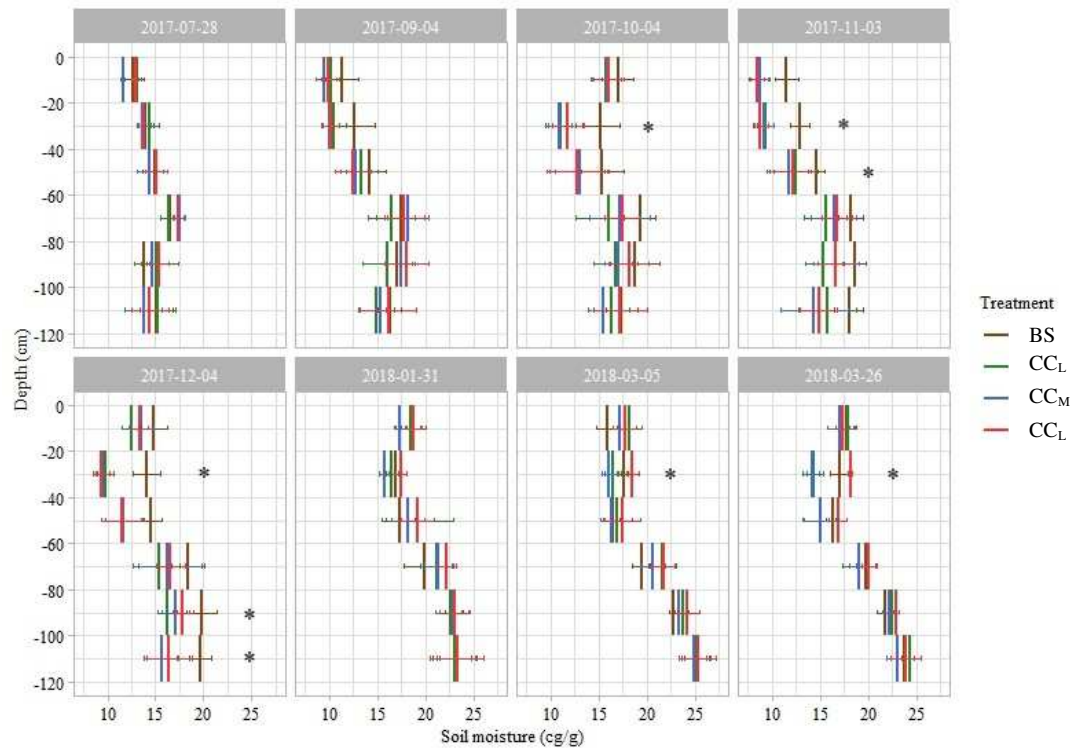


Figure 3a. Mean soil moisture (cg g^{-1} soil) in each 20 cm layer in the 2017 experiment for the four treatments: bare soil (BS), cover crop crushed in autumn and left as mulch on the soil surface (CC_M), cover crop crushed in autumn and buried by plowing (CC_P), and cover crop destroyed in April (CC_L). Horizontal error bars represent ± 1 standard deviation. Asterisks indicate a significant ($P < 0.05$) difference according to the Kruskal-Wallis test.

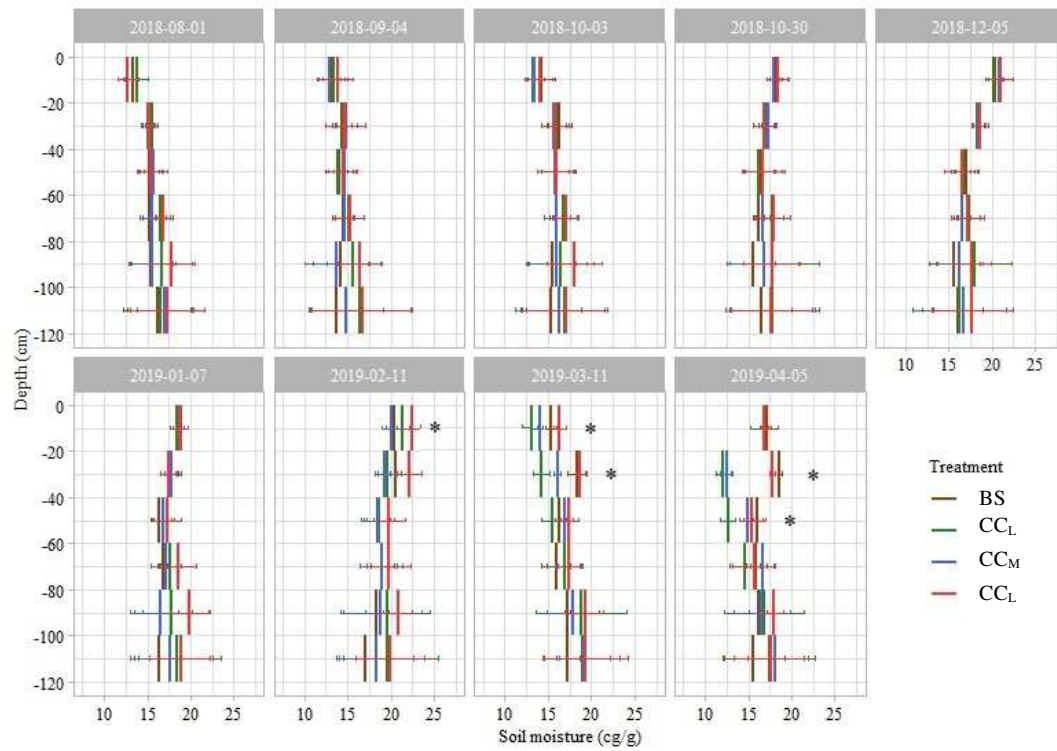


Figure 3b. Mean soil moisture (cg g^{-1} soil) in each 20 cm layer in the 2018 experiment for the four treatments: bare soil (BS), cover crop crushed in autumn and left as mulch on the soil surface (CC_M), cover crop crushed in autumn and buried by plowing (CC_P), and cover crop destroyed in April (CC_L). Horizontal segments represent ± 1 standard deviation. Asterisks indicate a significant ($P < 0.05$) difference according to the Kruskal-Wallis test.

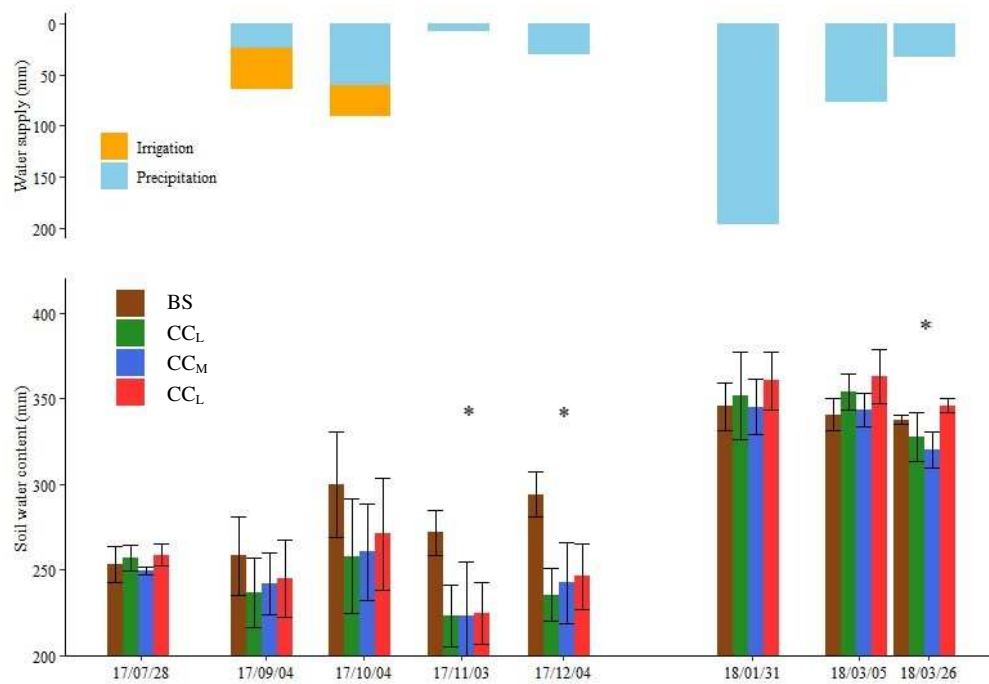


Figure 4a. (top) Water supply (irrigation + rainfall) and (bottom) soil water content (0-120 cm deep) between each gravimetric measurement in the 2017 experiment for the four treatments: bare soil (BS), cover crop crushed in autumn and left as mulch on the soil surface (CC_M), cover crop crushed in autumn and buried by plowing (CC_P), and cover crop destroyed in April (CC_L). Error bars represent ± 1 standard deviation. Asterisks indicate a significant ($P < 0.05$) difference according to the Kruskal-Wallis test.

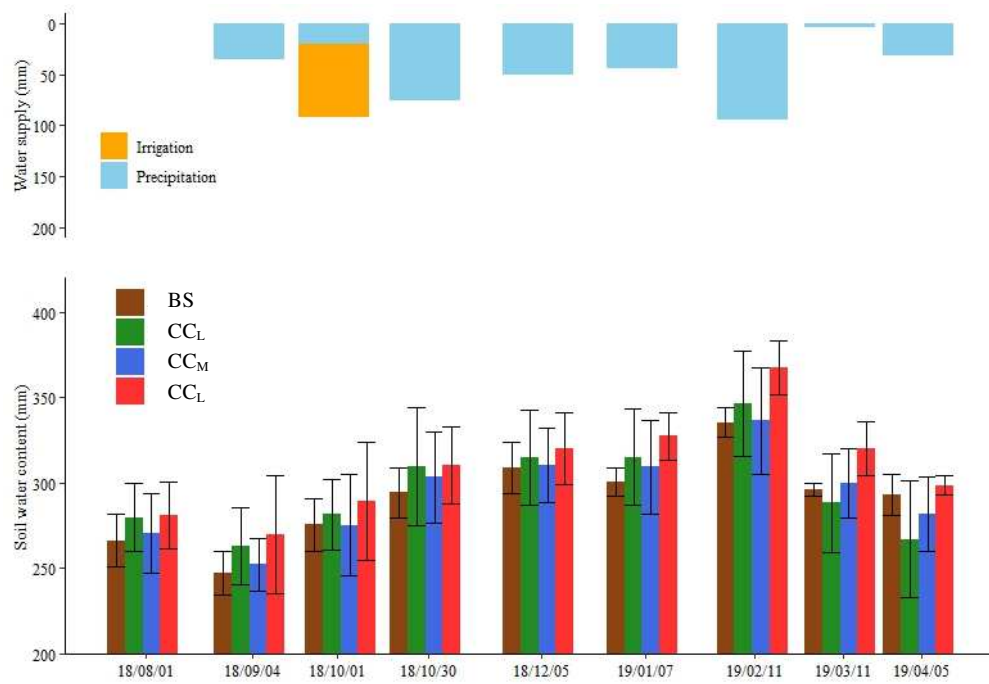


Figure 4b. (top) Water supply (irrigation + rainfall) and (bottom) soil water content (0-120 cm deep) between each gravimetric measurement in the 2018 experiment for the four treatments: bare soil (BS), cover crop crushed in autumn and left as mulch on the soil surface (CC_M), cover crop crushed in autumn and buried by plowing (CC_P), and cover crop destroyed in April (CC_L). Error bars represent ± 1 standard deviation.

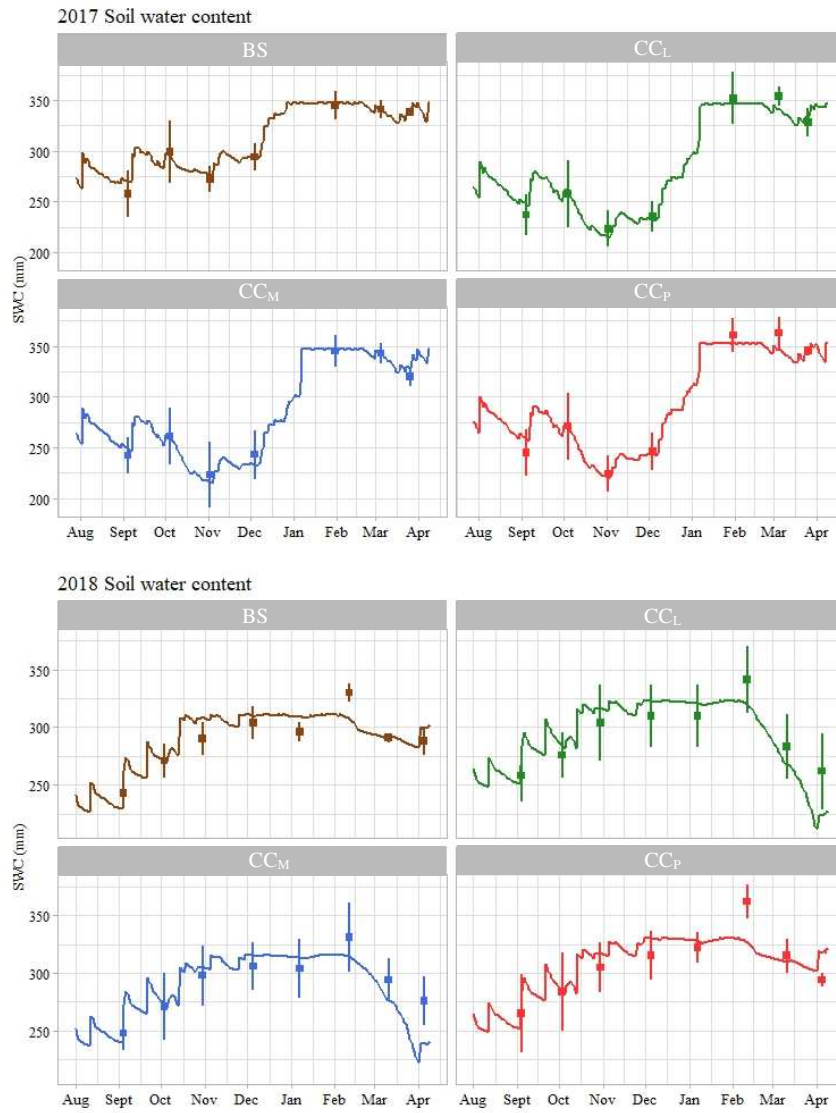


Figure 5. Predicted dynamics of soil water content (0-120 cm deep) during the (top) 2017 and (bottom) 2018 experimental years for the four treatments: bare soil (BS), cover crop crushed in autumn and left as mulch on the soil surface (CC_M), cover crop crushed in autumn and buried by plowing (CC_P), and cover crop destroyed in April (CC_L). Squares represent observed mean soil water contents, and error bars represent ± 1 SD.

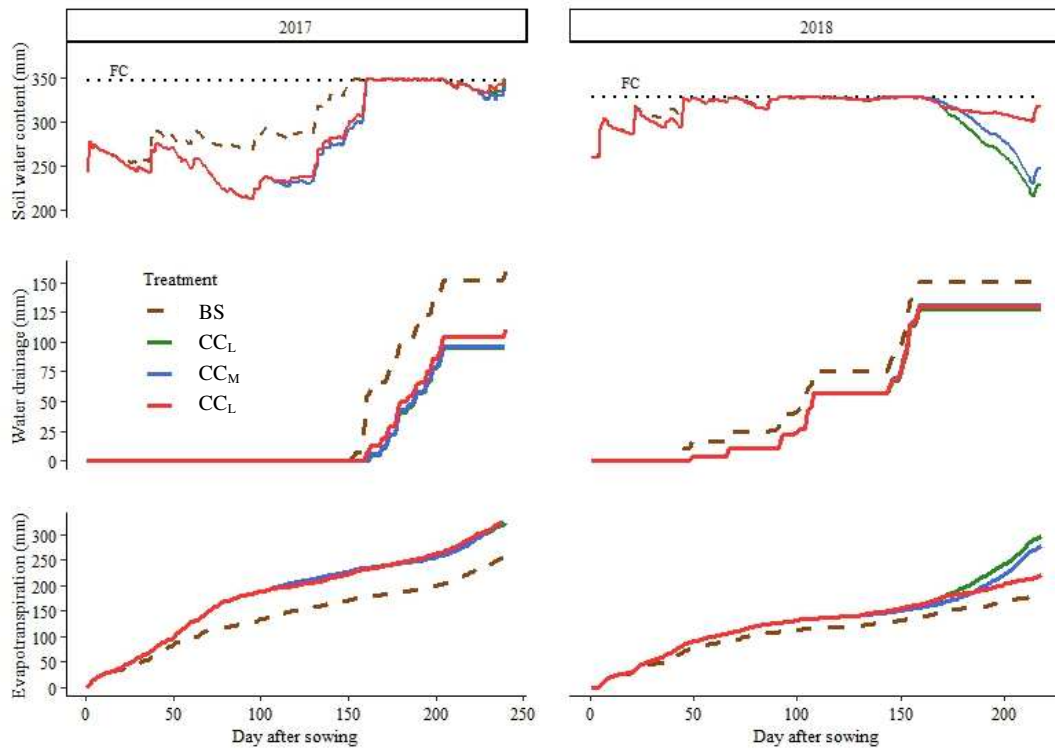


Figure 6. (top) Soil water content (0-120 cm deep), (middle) water drainage, and (bottom) evapotranspiration after sowing cover crops during the (left) 2017 and (right) 2018 experimental years for (dashed lines) bare soil (BS) and (solid lines) the three cover crop treatments: cover crop crushed in autumn and left as mulch on the soil surface (CC_M), cover crop crushed in autumn and buried by plowing (CC_P), and cover crop destroyed in April (CC_L). Dotted lines represent field capacity (FC).

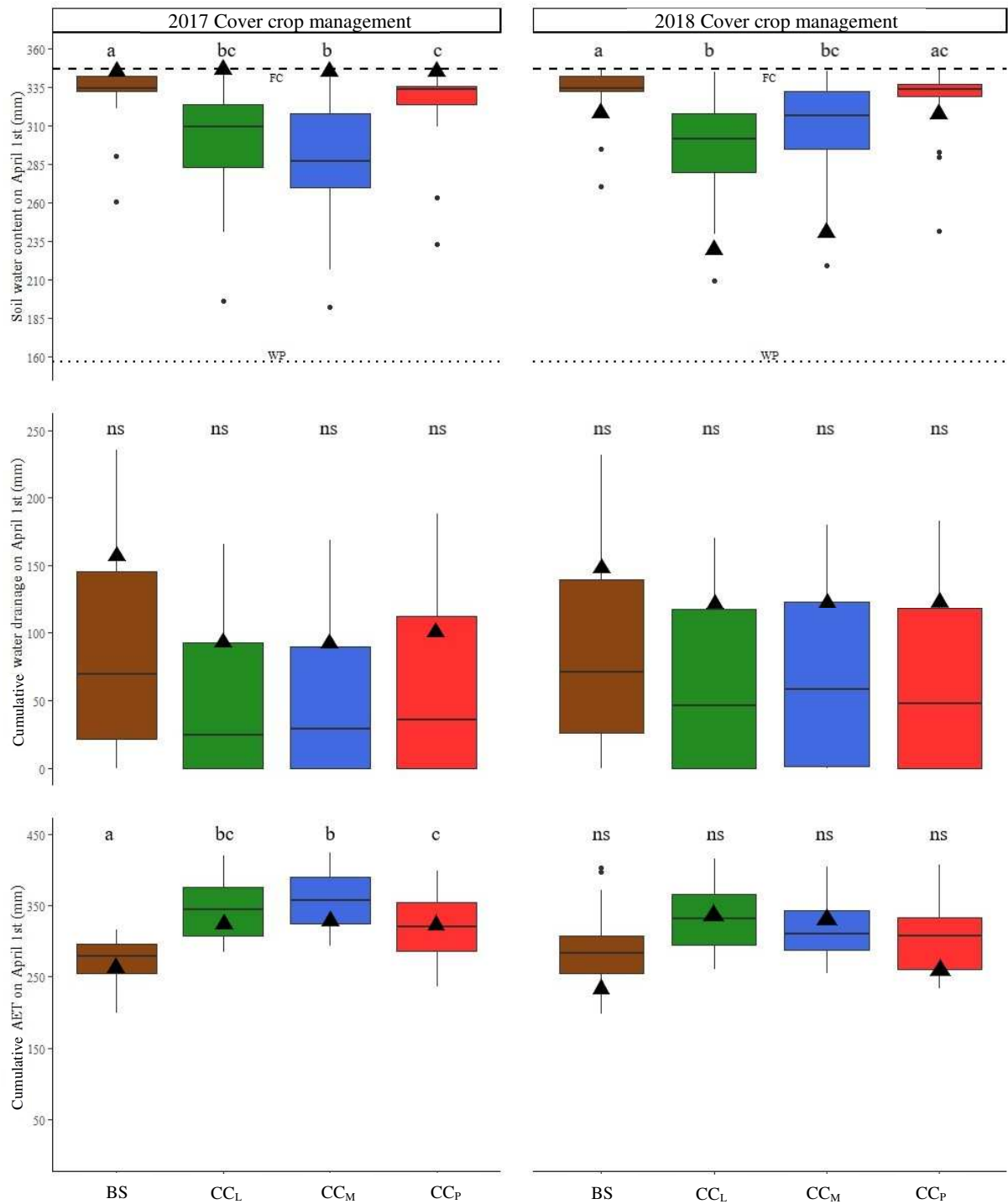


Figure 7. Boxplots of (top) soil water content (0-120 cm deep), (middle) cumulative drainage, and (bottom) cumulative AET on 1 April in the (left) 2017 and (right) 2018 experimental years according to the four treatments: bare soil (BS), cover crop crushed in autumn and left as mulch on the soil surface (CC_M), cover crop crushed in autumn and buried by plowing (CC_P), and cover crop destroyed in April (CC_L). Dashed lines represent field capacity, while dotted lines represent wilting point. triangles represent the fluxes simulated for the 2017 and 2018 experimental years. Different letters indicate a significant difference ($P < 0.05$) between treatments. ns: no significant difference. Each experimental year was analyzed separately.

Table 1. Mean soil texture and physical properties by soil layer at the study site in 2017 and 2018

Experiment	Depth (cm)	Clay (%)	Loam (%)	Sand (%)	Bulk density (g cm ⁻³)	Field capacity (cg g ⁻¹)	Wilting point (cg g ⁻¹)
2017	0 – 20	25.8	30.7	43.5	1.50	17.8	8.9
	20 – 40	24.8	30.0	45.2	1.50	17.5	8.8
	40 – 60	28.2	30.1	41.7	1.50	17.1	8.5
	60 – 80	38.9	33.5	27.6	1.45	20.0	13.5
	80 – 100	38.6	40.0	21.4	1.40	23.6	13.9
	100 – 120	31.3	47.4	21.3	1.40	23.6	11.8
2018	0 – 20	24.7	31.4	43.8	1.45	20.0	10.0
	20 – 40	23.3	31.0	45.7	1.45	20.0	10.0
	40 – 60	22.1	32.0	45.9	1.45	17.5	8.7
	60 – 80	21.2	29.7	49.1	1.50	18.0	9.0
	80 – 100	20.3	26.6	53.1	1.50	17.8	8.9
	100 – 120	20.8	28.5	50.7	1.5	17.8	8.9

Table 2. Cover crop management at the study site in 2017 and 2018 for the four treatments: bare soil (BS), cover crop crushed in autumn and left as mulch on the soil surface (CC_M), cover crop crushed in autumn and buried by plowing (CC_P), and cover crop destroyed in April (CC_L).

Characteristic	2017				2018			
Previous crop	Durum wheat				Durum wheat			
Treatment*	BS	CC _M	CC _P	CC _L	BS	CC _M	CC _P	CC _L
Sowing date	-	31 July			-	28 Aug		
Destruction date	-	15 Nov	15 Nov	11 Apr	-	07 Jan	07 Jan	09 Apr
Plowing date	13 Dec	-	13 Dec	-	08 Jan	-	08 Jan	-

Table 3. Relative root mean square error of predictions (rRMSEP) of interest of the STICS model

	Soil moisture (cg g ⁻¹)						Cover crop biomass (Mg.ha ⁻¹)
	0-20 cm	20-40 cm	40-60 cm	60-80 cm	80-120 cm	0-120 cm	
rRMSEP (%)	15.2	13.0	8.1	5.9	8.5	5.6	9.2

Table 4. Simulated soil water cycle variables for 2017 and 2018 (all in mm) in the four treatments: bare soil (BS), cover crop crushed in autumn and left as mulch on the soil surface (CC_M), cover crop crushed in autumn and buried by plowing (CC_P), and cover crop destroyed in April (CC_L). SWC = soil water content.

Experiment	Treatment	Initial SWC	Evaporation	Transpiration	AET	Drainage	Final SWC
2017	BS	254	269	0	269	158	347
	CC _P	254	229	111	341	110	347
	CC _M	254	151	188	340	97	343
	CC _L	254	136	198	335	95	347
2018	BS	275	236	0	236	150	317
	CC _P	275	201	71	272	130	316
	CC _M	275	149	180	329	131	246
	CC _L	275	134	213	347	127	228