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1 **Short-term dynamics of soil aggregate stability in the field**

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8

9 **Abstract**

10 Aggregate stability is a key property affecting the movement and storage of water, seedling
11 emergence and soil sensitivity to erosion. Many studies have shown that aggregate stability
12 changes through time. Field monitoring studies performed with a relatively large (monthly)
13 time step showed seasonal trend of aggregate stability. But shorter time step monitoring are
14 required to explore dynamics of aggregate stability at short term. For now, biological
15 activity was recognized to be the main factor of aggregate stability dynamic. But previous
16 studies were currently based on the external stimulation of aggregate stability. The
17 objectives of the study were to assess variations in aggregate stability at short time steps in
18 the field and to identify the factors controlling these variations of stability. A six months
19 field monitoring was performed at short time step (two to five days) on a bare field on

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20 Luvisol without organic amendment. Aggregate stability was measured for both on surface
21 and subsurface materials by the ISO/DIS 10930 method. Rain amount and intensity, air
22 temperature and humidity, soil temperature, water content and hydric history, soil water
23 repellency were measured as explanatory factors. The results showed that aggregate
24 stability varied greatly (up to 40%) over a few days for both surface and subsurface. Short
25 term dynamics of aggregate stability were already shown by laboratory experiments, but
26 such dynamics was never observed in the field for a bare soil without external stimulation
27 of biological activity. For the surface, short time step variations of surface aggregate
28 stability were primarily controlled by soil water content (WC_0 and $WC_{1/2}$), hydric history
29 (ΔWC_4 and API) and rain intensity. While large changes in aggregate stability were found
30 for the subsurface, explanatory factors remain to be found.

31 **Introduction**

32 Aggregate stability corresponds to the capacity of a soil aggregate to keep its cohesion
33 and not to break up into smaller fragments when it is submitted to the effect of water. The
34 stability of soil aggregates is a key property since it affects the movement and storage of
35 water, soil aeration, biological activity, seedling emergence, and root penetration (Gallardo-
36 Carrera et al., 2007). It also affects soil sensitivity to erosion and crusting (Le Bissonnais,
37 1996; Bajracharya et al., 1998; Wang et al., 2013).

38 It is well-established that aggregate stability is a time dependent variable (e.g.
39 Bullock et al. 1988; Caron et al., 1992; Bajracharya et al., 1998; Denef et al., 2001). For
40 now, numerous field monitoring studies have identified a seasonal pattern, with the largest
41 aggregate stabilities recorded in summer and the lowest values in winter (Bullock et al.
42 1988; Blackman, 1992; Chan et al. 1994; Dimoyiannis, 2009). Such studies have shown
43 that the temporal variability of the aggregate stability, as measured at monthly time steps
44 over a year, varied between 20% and 30%, depending upon the study. If seasonal trends of

45 aggregate stability variation are well identified, there is a lack of knowledge concerning the
46 temporal dynamic of aggregate stability at shorter time step (few days).

47 Laboratory studies performed at short-term explored the mechanisms of aggregate
48 stability variation and the influence of various factors: the biological activity, the wetting
49 and drying cycles, the rain intensity and the freezing-thawing cycles. Such studies showed
50 that aggregate stability increased when the biological activity was stimulated by organic
51 amendment (e.g. Tisdall and Oades, 1982, Le Guillou et al., 2012), underlining that
52 microbial activity has a positive effect on aggregate stability (e.g., Tisdall and Oades,
53 1982; Chenu et al. 2000). Soil temperature affects aggregate stability directly through
54 freezing (Bullock et al. 1988) and indirectly through the stimulation of microbial activity.
55 Rain affects aggregate stability of the soil surface through several processes, including the
56 kinetic energy of raindrop impact and slaking (Shainberg et al., 2003). Soil water content at
57 the time of sampling was found negatively correlated with aggregate stability (Perfect et al.
58 1990; Caron et al., 1992). Soil hydric history affects aggregate stability through physico-
59 chemical processes (Utomo and Dexter, 1982; Kemper and Rosenau, 1984) and through its
60 influence on microbial activity (Denef et al., 2001). Water repellency was shown to affect
61 aggregate stability by decreasing the aggregates wetting rate, limiting the effect of slaking
62 and microcracks formation (Piccolo and Mbagwu, 1999; Cosentino et al. 2006). According
63 to this literature (e.g. Perfect et al. 1990; Blackman 1992; Suwardji and Eberbach, 1998;
64 Denef et al., 2001; Cosentino et al., 2006), temporal dynamics of aggregate stability should
65 be primarily controlled by biological activity. However, such studies have generally been
66 based on either the external stimulation of biological activity by organic amendments
67 (amended soils compared to non-amended soils) (e.g., Cosentino et al., 2006; Abiven et al.,
68 2007; Le Guillou et al., 2012) or the comparison of soils with highly contrasting organic
69 matter contents or management practices (e.g., Blackman 1992; Suwardji and Eberbach,

70 1998). Thus, there is a lack of information concerning the factors of aggregate stability
71 temporal variation without external stimulation of the biological activity.

72 In the present study, a field monitoring of aggregate stability variations over time steps of a
73 few days was conducted on a bare soil without stimulation of biological activity. The
74 objectives were: 1) to assess how much aggregate stability can vary in the field at short
75 time steps, and 2) to identify the factors controlling the variations of aggregate stability
76 without stimulation of biological activity.

77 **Material and method**

78 *Sampling sites*

79 Field monitoring was performed on a site located in the southern part of the Parisian
80 Basin (France), 15 kilometers southwest of the city of Chartres (48°21'5.12"N;
81 1°16'0.55"E). This site was located on a cultivated field on a typic Luvisol with a gentle
82 slope (7%) oriented to the north. The field was sown with wheat, and soil was drained by
83 subsurface pipes. The A horizons was a silt loam (Soil Survey Division Staff, 1993), with
84 16% clay and 2.2% organic matter. Other soil characteristics are shown in table 1.

85 *Monitoring and sampling setup*

86 A 50 m² rectangular plot (12 meter in length and 4 meter in width) was defined within
87 the crop field. The plot was kept bare with herbicide (Bayer jardin, versatile weedkiller, 7
88 g/l glyphosate) during the 6 months of monitoring to facilitate sampling and minimize the
89 effects of vegetation on aggregate stability. The effect of glyphosate on aggregate stability
90 has never been studied according to our knowledge. Monitoring was conducted during six
91 months in 2011. It started just after the seedbed preparation and sowing, on 9 March and it
92 ended on 18 August.

93 The plot was divided in one-meter-square subplots using plastic sticks. During the
94 monitoring, each subplot was sampled only once. Sampling was carried out at two time
95 scales: a regular monthly time step and at a shorter time step (two to five days) during the
96 two weeks after a significant rain event (Table 2). For each monthly sampling, three
97 distinct samples were collected on non-adjacent subplots from each 50 m² plot to assess the
98 spatial variability of the measured variables within a plot. During the monitoring, 6 rain
99 events were considered as significant based on their duration, rain amount and maximum
100 intensity. Sampling at shorter time step (2 to 5 days) was performed during the inter-rain
101 periods (Table 2).

102 From a subplot, paired samples of surface and subsurface materials were always
103 collected separately. For the surface samples, material was carefully collected from the top
104 5 mm using a small spatula. When the soil surface was crusted (Bresson and Boiffin,
105 1990), large pieces (2-to-20 cm²) of the crust material were collected using a sharp knife to
106 cut through the crust without affecting its structure. The subsurface material was defined as
107 the material between 1 cm and 5 cm below the soil surface. It was carefully collected using
108 a small spade. After May 5, the soil surfaces presented a structural crust, which developed
109 into a sedimentary crust after August 2.

110 For each material (surface and subsurface), samples were divided into 5 subsamples in
111 order to measure aggregate stability, water content at the sampling time, organic matter
112 content, microbial biomass and water repellency. For aggregate stability, samples were
113 dried at 40°C during 2 days and stored at 4°C before measurement. For organic matter
114 content and microbial biomass, fresh soil samples were sieved at 5 mm and stored at 4°C
115 before measurement. For water repellency, fresh samples were stored at 4°C.

116 *Measurements*

117 *Aggregate stability*

118 Aggregate stability was measured using a modified version of the ISO/DIS 10930
119 (2012) method which is based on Le Bissonnais (1996). Two tests were considered: fast
120 wetting (FW) and slow wetting (SW). 5 g sub-samples were dried at 40°C for 24 h prior to
121 each test, and each test was replicated three times. Following each stability test, the
122 resulting fragments were sieved in ethanol, and results are presented using the mean
123 weighted diameter of the fragments (MWD) (Le Bissonnais, 1996). The results of each test
124 (hereafter referred as MWD_{FW} and MWD_{SW}) were considered separately to analyze the
125 resistance of the material against specific processes (slaking for the fast wetting test and
126 differential clay swelling for the slow wetting test). Each MWD value corresponds to one
127 of five classes of stability: MWD above 2 mm corresponds to very stable material,
128 between 2 and 1.3 mm corresponds to stable material, between 1.3 and 0.8 mm
129 corresponds to median stability, between 0.8 and 0.4 mm corresponds to unstable material,
130 and lower than 0.4 mm corresponds to very low stability (Le Bissonnais, 1996).

131 *Organic matter content and microbial biomass*

132 As soil was kept bare and no organic amendment was incorporated, biological activity
133 was not expected to change much during the monitoring. Organic matter content and
134 microbial biomass were measured, as control measurements, to characterize the biological
135 activity. Organic matter content was measured using the sulfochromic oxidation method
136 (ISO 14235, 1998), microbial biomass using the fumigation method (ISO 14240-2, 1997).

137 *Potential explanatory variables*

138 Air relative humidity and temperature, rain amount and intensity, soil water content and
139 hydric history, and water repellency of the aggregates, were considered as potential
140 explanatory factors of aggregate stability variations.

141 The air relative humidity and temperature were recorded hourly (Vaisala, HMP45C) at
142 1.5 m above ground.

143 Rain amount was measured hourly using a rain gauge (Campbell Scientific, ARG 100).
144 Average rain intensity and maximum rain intensity was calculated for each rain event. To
145 characterize the amount of rainfall in the days preceding a sampling date, an antecedent
146 precipitation index (API) was calculated from the rainfall data using a 7-day duration as:

147 P_i

148 where i is the i^{th} day before sampling and P_i (in mm) is the total precipitation height on
149 the i^{th} day.

150 Soil water content was measured at each sampling time by the gravimetric method
151 carried out on the surface and subsurface samples. Volumetric soil water content and soil
152 temperature were measured hourly using TDR and thermistor probes (Decagon Devices,
153 soil moisture sensor 5TE) at two depths (1 cm and 5 cm) and at two different locations in
154 each plot (4 probes per plot) for the whole monitoring duration. According to their design
155 principle, TDR probes are known to show approximate data for very top soils. A
156 preliminary analysis was performed to compare gravimetric water content data and
157 volumetric water content data for the 19 sampling times. Results showed that these
158 measurements were significantly correlated and showed similar results ($r^2= 0.79$).

159 To characterize the hydric history of the soil, two indices were calculated from the
160 water content data: the mean of water content for a duration t (in days) prior sampling
161 (WC_t) and the difference in water content between the beginning and the end of that period

162 (ΔWC_t). A preliminary analysis based on a correlation analysis was performed to identify
163 the duration of both hydric history indices that was the most relevant to aggregate stability
164 changes. For both indices, durations ranging from 0.25 to 8 days were tested. Results
165 showed that the most-significant durations were half day for water content ($WC_{1/2}$) and 4
166 days for the difference in water content (ΔWC_4).

167 Subcritical water repellency was measured with the intrinsic sorptivity method
168 (Tillman et al., 1989). The experimental design described by Hallett and Young (1999) was
169 used. Measurements were performed on 1-cm-diameter aggregates, on surface samples
170 only. Samples were dried at 40°C during the 48 h prior to measurements. When the soil
171 surface was crusted, measurements were made on the top of 1 cm² crust fragments.
172 Subcritical water repellency was expressed as the water repellency index R defined by
173 Tillman et al. (1989). The given R value corresponds to the mean of 10 replicates. A higher
174 R value means a larger water repellency. An R index equal to 1.0 corresponds to a
175 completely non-repellent material, an R index between 1.0 and 1.95 corresponds to a non-
176 repellent material and an R index higher than 1.95 corresponds to a subcritical water
177 repellent material (Tillman et al., 1989).

178 **Statistical analysis**

179 Statistical analysis were completed using R software version 2.9.2 (R Development
180 Core Team, 2011). The short time step variability was considered as significant when its
181 coefficient of variation (CV) was significantly larger than the CV of the spatial variability
182 measured at the monthly time step. Throughout the whole study, a 5% significance level
183 was considered. Linear correlation analysis (Pearson's coefficient) were used to identify
184 relationships between the MWD and the other factors. This analysis was carried out for the
185 surface and subsurface datasets separately. In order to classify the identified factors, and to

186 measure their combined effect on aggregate stability (MWD), simple and multiple
187 regression analysis were carried out.

188 **Results**

189 **Temporal variation of aggregate stability**

190 MWD_{FW} and MWD_{SW} were significantly correlated ($r=0.82$, p -value <0.001). Because
191 the slow wetting test exhibited the largest temporal dynamics, only this test is detailed in
192 the present section (Figures 1 and 2).

193 Based on the monthly samples, the largest spatial variability of the MWD_{SW} at a given
194 time was 9% for the surface and 12% for the subsurface (Figure 1a). As it was explained
195 previously, variations above this threshold were considered as significant. During the
196 monitoring period, aggregate stability varied greatly for both the surface and the
197 subsurface. The surface MWD_{SW} ranged from 0.34 mm (very unstable) to 0.99 mm
198 (medium stability), with a mean of 0.68 mm, a variance of 0.04 mm² and a CV of 29%.
199 The subsurface MWD_{SW} ranged from 0.39 mm (very unstable) to 1.08 mm (medium
200 stability), with a mean of 0.60 mm, a variance of 0.04 mm² and a CV of 32%. Such
201 dynamics in time are considered significant because there are larger than the spatial
202 variability assessed at a given time by the monthly sampling (Figure 1a).

203 Considering the monthly time step only (Figure 1a), the CV of aggregate stability was
204 29% for the surface and 32% for the subsurface. Considering the short time step, aggregate
205 stability also varied greatly for both surface and subsurface: the same CV were found for
206 both surface and subsurface. Variance of the aggregate stability was similar between the
207 monthly time step and the short time step monitoring (p -value = 0.8 for both surface and
208 subsurface).

209 Short time step sampling periods showed various trends in aggregate stability (Figure
210 2). During the May short-time monitoring period (Figure 2a), the variance of surface

211 MWD_{SW} was 0.01 mm² for both surface (CV=9%) and subsurface (CV=17%). The surface
212 MWD_{SW} decreased significantly immediately after rain 1, but did not changed after R2.
213 Subsurface MWD_{SW} did not varied significantly after both rain events. During June short-
214 time monitoring period (Figure 2b), the surface MWD_{SW} showed a variance of 0.05 mm²
215 with a CV of 42%, while the subsurface MWD_{SW} was much more stable (variance = 0.01
216 mm² and CV=15%). The surface MWD_{SW} decreased significantly after R3 and R4,
217 showing its largest decrease after R4: from 0.78 mm (10 June, prior rainfall 4) to 0.38 mm
218 (14 June). Inter-rain periods 3 and 4 showed a significant increase of the MWD_{SW} , the
219 largest increase of the MWD_{SW} occurring during the inter-rain period 3: from 0.34 mm (8
220 June) to 0.78 mm (10 June). During August short-time step monitoring (Figure 2c), the
221 variance of MWD_{SW} was 0.02 mm² for the surface (CV=20%) and 0.05 mm² for the
222 subsurface (CV=30%). Both surface and subsurface MWD_{SW} kept stable after R5 but
223 decreased significantly after R6. Inter-rain periods 5 and 6 showed significant increase of
224 MWD_{SW} for both surface and subsurface.

225 **Explanatory variables**

226 Results of the temporal dynamics of the explanatory variables are presented in Tables
227 3 and 4 and in Figures 3 and 4. Organic matter content varied between 1.8% and 1.4% ,
228 with a variance of 0.01 %² and a CV of 6% for both surface and subsurface (Figure 3a).
229 Microbial biomass showed a larger variability: a variance of 1609 and a CV of 26% for the
230 surface and a variance of 2767 and a CV of 43% for the subsurface (Figure 3b).

231 The R index of the surface was often larger than 1.95, indicating that the samples
232 could present a subcritical hydrophobicity. Water repellency showed a large temporal
233 variability with a CV of 50% (Table 3, Figure 3c).

234 Air temperature varied between 1.6°C and 36.1°C. Air temperature was always
235 positive during the monitoring period, hence no freezing occurred. Soil surface
236 temperature varied between 4.8°C and 31.2°C with a CV of 32%, while subsurface
237 temperature varied between 9.7°C and 30.4°C with a CV of 19% (Figure 4a and 4b). The
238 studied site exhibited a cumulated rain of 219 mm. Among the 6 rain event considered, R3
239 (June 4) presented the highest rain amount (26.2 mm in 7 hours) and a maximum intensity
240 of 16.8 mm h⁻¹ (table 4b). The dynamic of the soil water content was very different between
241 the surface and the subsurface. Surface water content showed a variance of 10.3 %² and a
242 CV of 28% while subsurface water content remained very stable (variance = 0.06 %² and
243 CV=4%) (Table 3c; Figure 4c).

244 **Relationships between aggregate stability and explanatory variables**

245 Aggregate stability did not significantly correlated with microbial biomass, organic
246 matter and water repellency whatever the stability test (Table 5). The same results were
247 found between MWD and air temperature, soil temperature or air humidity (not shown).

248 A correlation analysis was performed to test the influence of the rain characteristic on
249 aggregate stability. For the 6 considered rain events, correlation coefficient were calculated
250 between rain amount, mean intensity and maximum intensity, and the MWD value
251 measured immediately after the rain event. The best correlation coefficient was found
252 between the maximum intensity of the rain event and the surface MWD measured
253 immediately after the rain event ($r = -0.77$ for MWD_{FW} and -0.83 for MWD_{SW}). Mean rain
254 intensity and total rain amount did not correlate significantly with aggregate stability.
255 Subsurface MWD did not correlate with rain event characteristics. The same analysis was
256 performed between rain characteristics and the difference between MWD before and after
257 the rain event. Here also, the best correlation coefficient was found between the maximum
258 intensity of the rain event and the difference between MWD before and after the rain event

259 ($r = 0.82$ for MWD_{FW} and 0.80 for MWD_{SW}). Considering the soil water content and hydric
260 history, for the surface, the MWD was significantly and negatively correlated with the
261 WC_0 , $WC_{1/2}$, ΔWC_4 and API for both stability tests (Table 6). For the subsurface, no
262 significant correlation were found between any of the MWD and the variables linked to
263 hydric history (API, WC_0 , $WC_{1/2}$ and ΔWC_4), except for the MWD_{SW} that significantly and
264 negatively correlated with WC_0 ($r = -0.57$) (table 6).

265 In order to classify the influence of each variable found to be significantly correlated
266 with aggregate stability, and to measure the combined effect of these variables, regression
267 analysis were done. The considered variables were: WC_0 , $WC_{1/2}$, API and ΔWC_4 for the
268 surface, and WC_0 for the subsurface. At first, simple regression analysis was conducted
269 (Table 7). For the subsurface, none of the simple regression models were significant,
270 regardless of the aggregate stability test. Considering the surface MWD_{FW} , the best simple
271 regression model was with $WC_{1/2}$ (54% of MWD_{FW} variation). Models with WC_0 or API
272 were also statistically significant ($r^2 = 51\%$ and 37% , respectively). For the slow wetting
273 test, all four models were significant, with r^2 between 39% and 50% (Table 7). The
274 variables found to be significant during this simple regression analysis were combined in
275 multiple regression models (except WC_0 , $WC_{1/2}$, and API, which were not independent).
276 Among all combinations, the only valid multiple regression models were found for the
277 surface. $WC_{1/2}$ and ΔWC_4 together accounted for 59% of the MWD_{SW} , and the combination
278 of WC_0 and ΔWC_4 accounted for 57% of the MWD_{SW} .

279 Discussion

280 Aggregate stability varied significantly at short time step

281 The results show that the aggregate stability in the field varied greatly at short time
282 steps (of a few days). Variations up to 32% were measured for both surface and subsurface
283 materials. Short term dynamics of aggregate stability was already observed during

284 laboratory experiments (e.g. Utomo and Dexter, 1982; Deneff et al., 2001; Cosentino et al.,
285 2006), but, according to our knowledge, only one study observed it in the field (Caron et
286 al., 1992). Moreover, the variability of aggregate stability was never observed by field
287 measurements for a bare soil without any external stimulation of biological activity.

288 Up to now, most field monitoring studies used monthly samplings to assess aggregate
289 stability dynamics (Blackman, 1992; Bajracharya et al., 1998; Suwardji and Eberbach,
290 1998; Dimoyiannis, 2009). Such studies showed that during the year, aggregate stability
291 could vary between 20% up to 30%. The present study showed that same variability of
292 aggregate stability was occurring at a much smaller time scale. Moreover, for specific
293 periods, aggregate stability can show a larger variability at short time step than at monthly
294 time step. It was the case for the June monitoring period when surface aggregate stability
295 varied up to 46% over a 7-day period, proving that large changes in aggregate stability are
296 occurring over a few days. In some cases, variations in aggregate stability at short time
297 steps induced changes of up to two stability classes. Such large changes would affect soil
298 properties, such as storage of water, root penetration (Gallardo-Carrera et al., 2007) or soil
299 sensitivity to erosion (Le Bissonnais, 1996; Bajracharya et al., 1998; Wang et al., 2013), and
300 thus, should not be ignored by future studies.

301 Considering this short term dynamics, it appears clearly that monthly measurements
302 are not enough to assess precisely the temporal dynamic of aggregate stability. Monthly
303 time step monitoring give information on the dynamics of aggregate stability at the
304 seasonal scale, but monthly estimation of aggregate stability cannot be used as actual
305 values of aggregate stability at a given time. Short time step measurements are required to
306 reach accurate assessments of aggregate stability.

307 **Aggregate stability variation was primarily controlled by the rain intensity, soil water**
308 **content and hydric history**

309 In the present study, soil was kept bare during all the monitoring, and no amendments
310 were incorporated. Aggregate stability did not significantly correlated with organic matter
311 content nor microbial biomass, for both surface and subsurface. This result leads us to
312 conclude that a stimulation of biologic activity (i.e. organic amendment) is required to
313 make it affect aggregate stability.

314 Water repellency of the surface aggregates varied independently from the aggregate
315 stability. Based on previous studies (Piccolo and Mbagwu, 1999; Cosentino et al., 2006;
316 Goebel et al., 2012) this variable was expected to influence aggregate stability. In our case,
317 the range of measured R index (between 1.9 and 7.0) did not correspond to very contrasted
318 water repellencies. It seems that more contrasted water repellencies are required to
319 influence aggregate stability.

320 The result of the present study underlined the significant influence of rain events on
321 surface aggregate stability dynamics. Aggregate stability decreased significantly after 4 of
322 the 6 rain events. The largest decrease was observed for the rain 4 which showed the
323 highest total rain amount and maximum rain intensity. According to the results of the
324 correlation analysis, the maximum rain intensity appeared to be the dominant factor of
325 aggregate stability decrease upon all the considered rain characteristics. The greater the
326 maximum rain intensity, the greater the aggregate stability decrease. Relationships between
327 rain amount and aggregate stability were observed in the field by monthly monitoring
328 studies (Blackman, 1992; Bajracharya et al., 1998; Suwardji and Eberbach, 1998;
329 Dimoyiannis, 2009). Usually, temporal patterns of precipitation are considered as an
330 important factor in aggregate stability decrease through raindrop impact, which affects the
331 structure of surface aggregates, and through the increase of soil water content (e.g.
332 Shainberg et al., 2003; Dimoyiannis, 2009). The present study underlines the importance of
333 rain intensity on the short time step aggregate stability decrease. More than the rain

334 amount, the maximum rain intensity seems to be a dominant indicator of surface aggregate
335 stability decrease. However, as only six rain events were considered, such result must be
336 taken carefully, and more detail studies should be conducted to confirm this observation.

337 Subsurface aggregate stability was not related to rainfall characteristics

338 The results also showed that the soil water content and its dynamics were dominant
339 factors of surface aggregate stability. Soil water content at the time of sampling (WC_0) and
340 few hours before sampling ($WC_{1/2}$) were significantly and negatively correlated with
341 aggregate stability. Simple regression models with WC_0 explained up to 51% of aggregate
342 stability variation (MWD_{FW}), while simple regression models that included $WC_{1/2}$
343 explained up to 54% of the aggregate stability variations (MWD_{FW}), making $WC_{1/2}$ the
344 dominant explanatory factor in aggregate stability variation at short time step.

345 Previous studies (e.g., Perfect et al., 1990; Blackman, 1992; Dymoyiannis, 2009) have
346 found negative correlations between water content and aggregate stability variation at the
347 monthly time step. The present study found similar relationships at a short time step (a few
348 days) but for surface aggregate stability only. In a field monitoring study performed at
349 short time step (2 days) on a bare soil, Caron et al. (1992) did not found significant
350 relationships between aggregate stability and WC_0 . In this previous study, samplings were
351 performed within the plowed layer (between -15 and -25 cm). Similarly, the present study
352 did not a relationship between aggregate stability and WC_0 for the plowed layer (-1 to -5
353 cm). Such a relationship was found only for the soil surface (0 to -0.5 cm).

354 The soil hydric history indices ΔWC_4 and API were found to be significant factors of
355 surface aggregate stability and were negatively correlated with aggregate stability for the
356 soil surface. The relationship between the water content history and aggregate stability give
357 two pieces of information. Firstly, aggregate stability decreases when the soil is getting
358 more humid: the greater the wetting, the larger the decrease of aggregate stability. This

359 result confirms the negative influence of rain amount and intensity on aggregate stability
360 that we previously observed. A high rain intensity provokes a rapid soil wetting with a
361 large wetting amplitude that decreases aggregate stability (e.g. R3), while a rain event with
362 a low rain intensity and thus a wetting with a small amplitude do not affect aggregate
363 stability (e.g. R5). Secondly, aggregate stability increases when the soil is drying, and the
364 more intense the drying, the larger the increase of aggregate stability: a large amplitude
365 drying caused an increase in aggregate stability as it was the case during IR 3 and 6, while
366 a small drying amplitude did not affect aggregate stability as for IR 1 and 2.

367 These results were previously observed by laboratory studies. They showed wetting
368 cause a decrease of aggregate stability through physico-chemical processes such as the loss
369 of inter-particle cohesion (Sheel et al., 2008), slaking (Zaher et al., 2005) and microcracking
370 (Le Bissonnais, 1996). They also showed that drying increases aggregate stability by the
371 formation of bonds between particles in relationship with clay flocculation and
372 precipitation of soluble components (Kemper and Rosenau, 1984; Kemper et al., 1987;
373 Dexter et al., 1988). While these relationships were only observed in laboratory
374 experiments, the present study clearly observed similar relationships for field conditions,
375 suggesting the same processes may be active.

376 **Conclusions**

377 Aggregate stability varied greatly over time steps of a few days for both surface and
378 subsurface. Short term dynamics of aggregate stability were already shown by laboratory
379 experiments, but such dynamics was never observed in the field for a bare soil without
380 external stimulation of biological activity (i.e. no organic amendment). MWD variations of
381 up to 42% were measured at short time step for specific periods proving that large changes
382 in aggregate stability are occurring even in a few days. Such large changes are likely to
383 affect soil properties such as storage of water and soil sensitivity to erosion, and thus,

384 should not be ignored. At the surface, short time step variations of aggregate stability were
385 primarily related with water: Rain maximum intensity, water content at or close to the time
386 of sampling (WC_0 and $WC_{1/2}$), and hydric history indices (ΔWC_4 and API) were the
387 dominant factors influencing surface aggregate stability. While large changes in aggregate
388 stability were found for the subsurface, explanatory factors remain to be found. These
389 results underline the dominant effect of abiotic factors such as water content dynamics on
390 aggregate stability variations at a short time step in the field in the absence of biological
391 activity stimulation. To improve the prediction of aggregate stability, further research
392 should analyze the interactions between abiotic and biotic factors at short time step in the
393 field.

394

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475 **Figure caption**

476 **Figure 1:** Temporal variation of aggregate stability for the slow wetting test of surface and
477 subsurface at monthly time step (a) and short time step (b).

478 MWD_{sw} monthly time step: each MWD_{sw} point corresponds on the mean of three samples
479 located on the same plot (spatial variability) and 3 replicates for each measurements ($n=9$).

480 Bars are standard errors.

481 MWD short time step: each MWD corresponds on the mean of three replicates ($n=3$). Bars
482 are standard error.s

483 Stable, Medium, Unstable, Very unstable, refers to the aggregate stability classes (Le
484 Bissonnais, 1996)

485 **Figure 2:** Temporal variation of aggregate stability for the slow wetting test at short time
486 step for (a) May , (b) June and (c) August.

487 MWD monthly time step: each MWD corresponds on the mean of three samples located on
488 the same plot (spatial variability) and 3 replicates for each measurements ($n=9$). Bars are
489 standard errors.

490 MWD short time step: each MWD corresponds on the mean of three replicates ($n=3$). Bars
491 are standard errors.

492 R1, R2, R3, R4, R5, and R6 refer to the number of the rain event.

493 **Figure 3:** Temporal variation in (a) organic matter content, (b) microbial biomass and (c)
494 water repellency.

495 a and b: each point is the mean of three replicates; bars are standard errors.

496 c: each point is the mean of 10 replicates; bars are standard errors.

497 **Figure 4:** Temporal dynamics of the soil variables; a) Surface soil temperature, b)
498 subsurface soil temperature, c) Volumic soil water content for surface and subsurface.

499 Curves are to the mean of two replicates

500

501

Table 1: Soil properties for the studied site

Culture (current/ antecedent)	Clay	Silt	Sand	Organic matter	CEC	pH	Ca	Mg	K	Na
	g kg ⁻¹		cmol kg ⁻¹			g kg ⁻¹				
Wheat/Maize	164	798	38	21.6	9.1	6.7	8.8	0.5	0.6	0.03

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Table 2: Sampling pattern and rain events during field monitoring

Date	Sampling		Rain event
	Monthly	Short term	
16/3	S0		
30/3	S1		
28/4	S2		
2/5			R1
3/5		S3	Inter-rain
5/5		S4	period 1
7/5			R2
9/5		S5	
11/5		S6	
13/5		S7	Inter-rain
16/5		S8	period 2
18/5		S9	
30/5	S10		
4/6			R3
7/6		S11	Inter-rain
8/6		S12	period 3
10/6		S13	
14/6		S14	R4
16/6		S15	Inter-rain
4/7	S16		period 4
2/8	S17		
4/8			R5
8/8		S18	Inter-rain
10/8		S19	period 5
12/8		S20	
14/8			R6
16/8		S21	Inter-rain
18/8		S22	period 6

504 S = sampling; R = rain event

505

506

507 Table 3: variability of the organic matter content, microbial biomass and water repellency

508 of aggregates

	Microbial biomass				Water repellency							
	Max	Min	Mean	CV	Max	Min	Mean	CV				
	mg kg⁻¹				%							
					R index							
					%							
Surface	1.8	1.4	1.7	6	234	72	147	26	7.4	1.2	3.3	50
Subsurface	1.8	1.5	1.7	7	256	37	117	46				

509

510

511 Table 4: variability of the a) atmospheric variables: air temperature (Air T), air humidity
 512 (Air H) and cumulated rain, b) rain event characteristics, and c) soil variables: soil
 513 temperature (Soil T) and soil water content (Soil WC) for the whole monitoring duration.

514 a)

Air T		Air H		Cumulated rain		mm
Max	Min	Mean	SD	Mean	SD	
°C		%				
36.1	1.6	16.1	5.3	76.8	20.5	219

515

516 b)

Rain event	Date	Duration	Rain amount	Maximum intensity
		h	mm	mm h ⁻¹
R1	2/5	5	4.0	2.0
R2	7/5	3	13.2	7.0
R3	4/6	7	26.2	16.8
R4	14/6	1	9.8	9.8
R5	4/8	8	13.5	4.0
R6	14/8	5	7.4	4.8

517

518 c)

	Soil T				Soil WC			
	Max	Min	Mean	CV	Max	Min	Mean	CV
	°C				%			
surface	31.2	4.8	19.1	32	22.5	6.1	11.7	28
subsurface	30.4	9.7	18.9	19	22.8	17.9	19.6	4

519

520 Table 5: correlations (Pearson's coefficient) between aggregate stability and organic matter

521 content, microbial biomass and water repellency.

	Surface		Subsurface		
	OM	BIOMI	WR	OM	BIOMI
MWD_{FW}	0.33 (ns)	0.25 (ns)	0.12 (ns)	0.34 (ns)	-0.07 (ns)
MWD_{sw}	0.14 (ns)	0.32 (ns)	0.24 (ns)	-0.29 (ns)	-0.06 (ns)

522 dataset: $n=19$; $df=17$; $\alpha=5\%$; $r=0.46$

523 ns=Not significant at the 5% level

524 OM = organic matter content

525 BIOMI = microbial biomass

526 WR=water repellency

527 Table 6: Correlations (Pearson's coefficient) between MWD and soil water indices

	Surface				Subsurface			
	WC_0	$WC_{1/2}$	ΔWC_4	API	WC_0	$WC_{1/2}$	ΔWC_4	API
MWD_{FW}	-0.73*	-0.76*	-0.54*	-0.63*	0.14(ns)	0.13(ns)	0.25(ns)	-0.18(ns)
MWD_{SW}	-0.69*	-0.72*	-0.70*	-0.65*	-0.57*	-0.37(ns)	-0.04(ns)	-0.25(ns)

528

529 dataset: $n=19$; $df=17$; $\alpha=5\%$; $r=0.46$

530 * significant at the 5% level

531 ns = not significant at the 5% level

532 WC_0 : soil water content at the time of sampling

533 $WC_{1/2}$: mean soil water content for half a day prior to sampling

534 ΔWC_4 : difference between water content at the time of sampling at water content 4 days

535 prior to sampling

536 API : antecedent precipitation index

537

538

Table 7: Simple regressions for MWD variations

Dataset	Df	WC ₀		WC _{1/2}		API		ΔWC ₄			
		R ²	level	R ²	level	R ²	level	R ²	level	R ²	level
Surface		FW	17	0.51	**	0.54	**	0.37	*	0.25	.
		SW	17	0.44	*	0.50	**	0.39	*	0.47	**
Subsurface		FW	17	0	ns	0	ns	0	ns	0.01	ns
		SW	17	0.23	.	0.29	.	0.07	ns	0	ns

539

540

Df= degrees of freedom; R²= adjusted coefficient of determination

541

FW: Fast wetting test. SW: Slow wetting test.

542

** Model significant at the 1 % level

543

* Model significant at the 5% level

544

. Model significant at the 10 % level

545

ns Model not significant at the 10 % level

546

WC₀: soil water content at the time of sampling

547

WC_{1/2}: average soil water content half a day prior to sampling

548

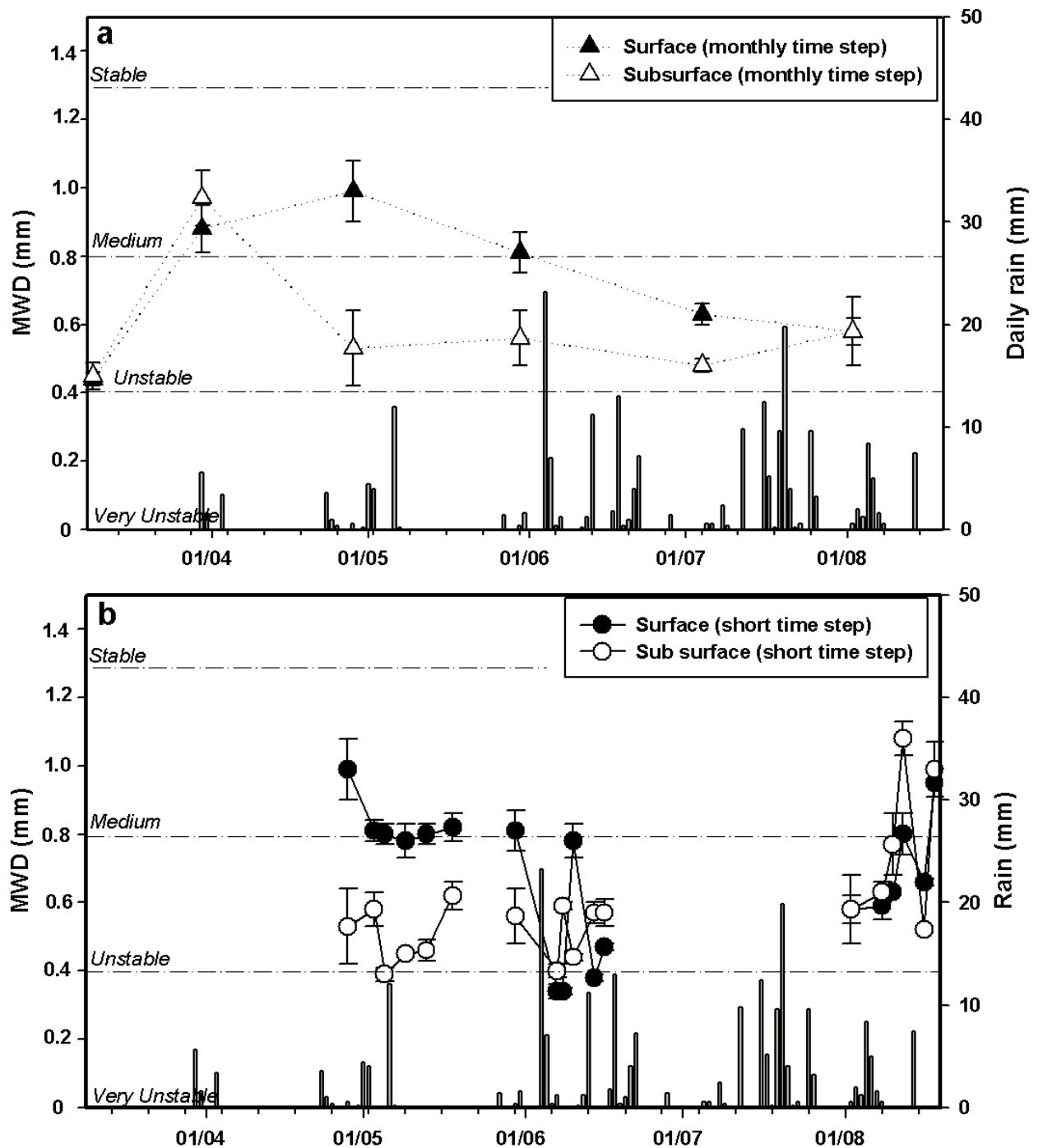
ΔWC₄ : difference between soil water content at the time of sampling and soil water

549

content four days before

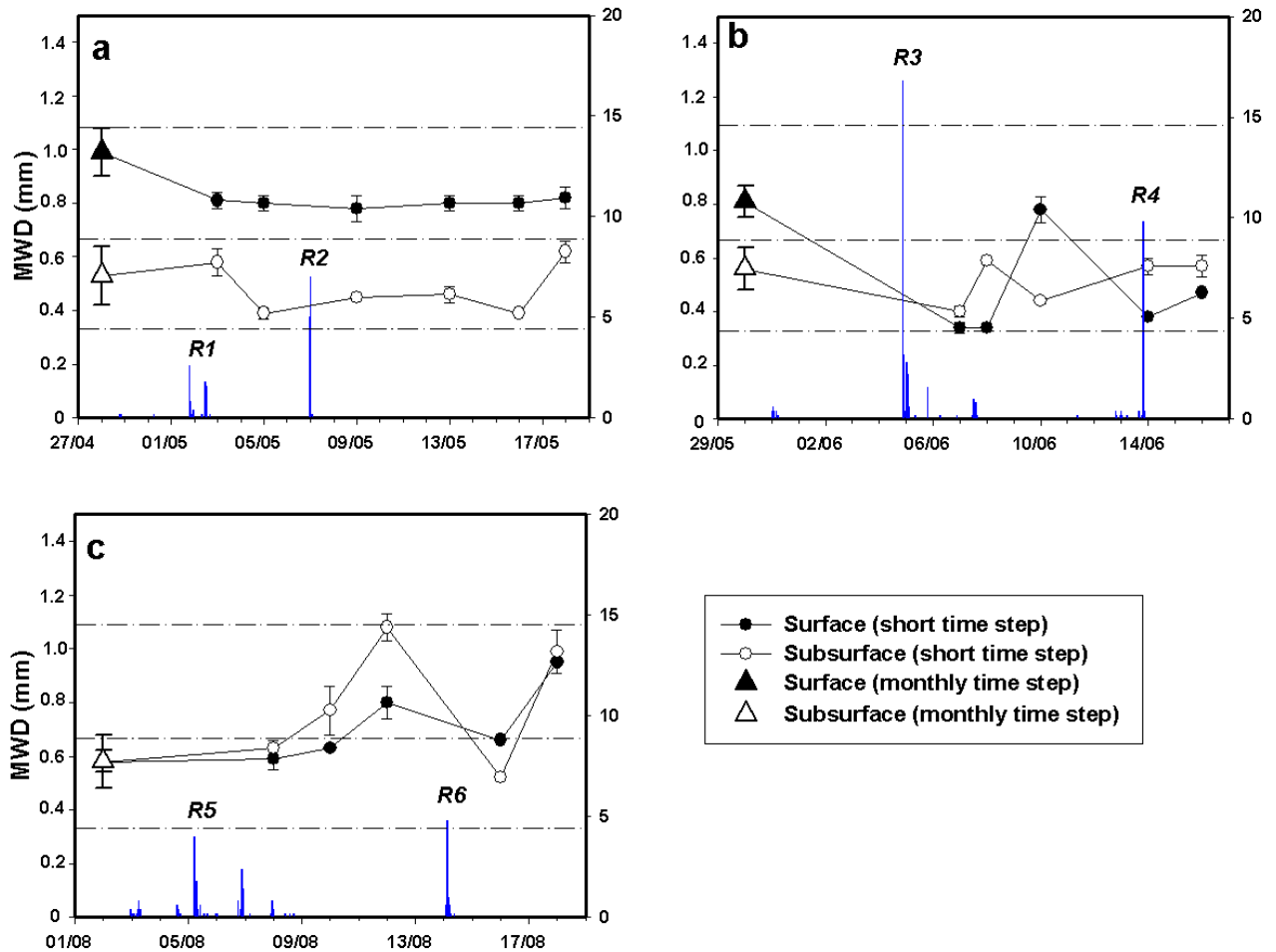
550

API: antecedent precipitation index



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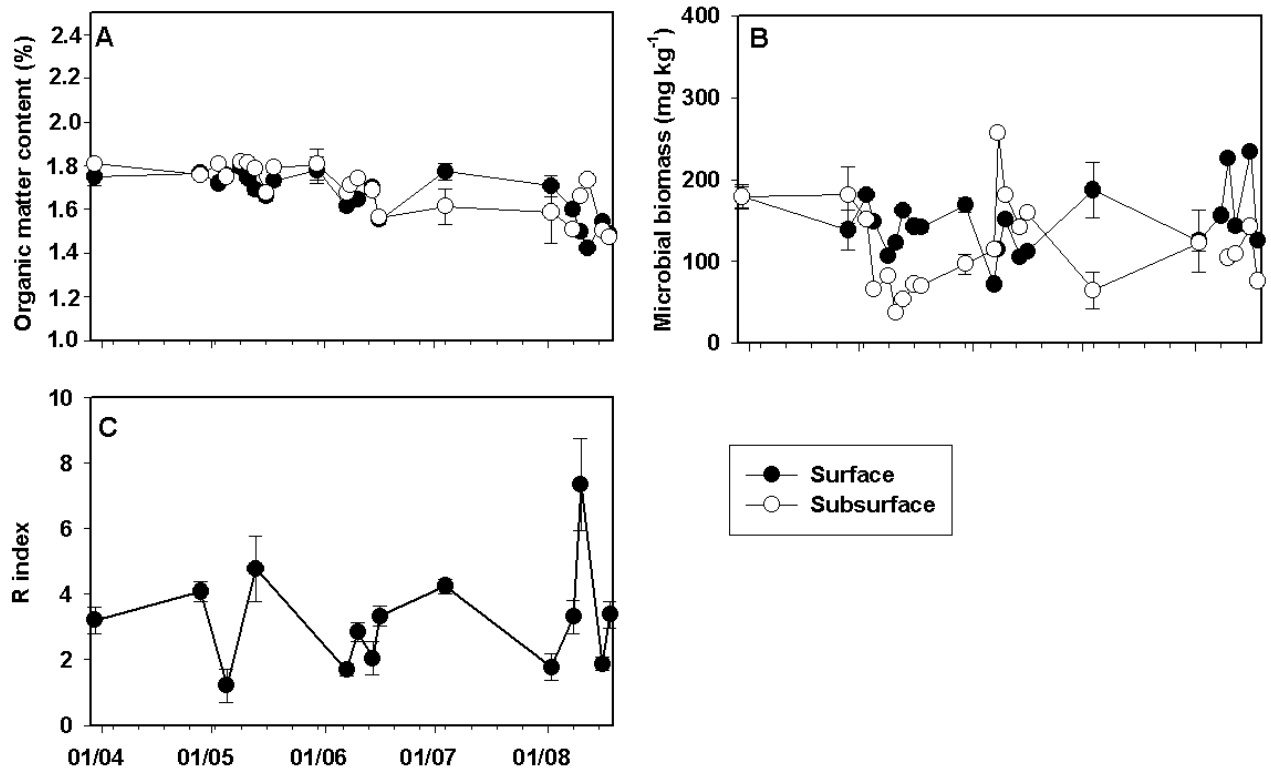
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 568 are standard errors.

569 R1, R2, R3, R4, R5, and R6 refer to the number of the rain event.

570



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576

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