

Are carbon-storing soils more sensitive to climate change? A laboratory evaluation for agricultural temperate soils

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21	
22	Highlights
23 24	• Soil moisture regime and temperature significantly affect the carbon mineralization
2 7 25	 Dry wet cycles did not stimulate the carbon mineralization relative to wet controls
26	• Specific carbon mineralization did not differ among the three cropping systems at La Cage
27	• Lower specific carbon mineralization in soils receiving organic waste products at QualiAgro
28	• Carbon-storing soils have a similar sensitivity to climate events as baseline soils

- 29
- 30
- 31 Abstract
- 32

33 A range of agroecological practices allow to increase soil organic carbon (SOC) stocks, which 34 makes a positive impact on climate change mitigation and soil health, but the permanence of this 35 additional SOC storage can be questioned, in particular in a climate change context. Increased 36 temperatures, accentuated evaporation of terrestrial water and increased atmosphere moisture content 37 are anticipated, resulting in more frequent droughts and heavy precipitation events. Understanding the 38 SOC dynamics and assessing the sensitivity of carbon mineralization to these climatic events is 39 necessary to anticipate future carbon losses in terrestrial ecosystems. To this respect, it seems relevant 40 to investigate carbon-storing soils as increased carbon mineralization induced by climate change may 41 limit the carbon storing potential in agricultural soils. Thus, we evaluated the sensitivity of SOC 42 mineralization to increased temperature, decreased soil moisture and drying-rewetting cycles using soils 43 from long-term field experiments. We performed an incubation experiment on topsoil (0-30cm) samples 44 from temperate luvisols that had been under 20 years under conservation agriculture (CA), organic 45 agriculture (ORG) and conventional agriculture (CON-LC) at the La Cage experiment, and under 46 organic waste products (OWPs) applications in QualiAgro experiment, including biowaste composts 47 (BIOW), residual municipal solid waste composts (MSW), farmyard manure (FYM) and conventional 48 agriculture without organic inputs (CON-QA). Soil samples were incubated in the lab for 3 months 49 under different temperature conditions (20, 28 and 35°C) or under different moisture conditions (matric 50 potential: pF1.5; pF 2.5 and pF 4.2) or under several dry (pF 4.2)-wet (pF 1.5) cycles (DWC). The results 51 shown that, whatever the agricultural practices, soil moisture regime and temperature significantly affect 52 the SOC mineralization. Overall, the DWC did not stimulate soil carbon mineralization relative to wet 53 controls (pF1.5 and pF2.5). Whatever the soil moisture regime and temperature, specific carbon 54 mineralization was similar between agricultural practices at La Cage, while at QualiAgro, specific 55 carbon mineralization was lower in soils receiving organic waste products (OWPs) compared to the 56 baseline soil. These results suggest a strong carbon stabilization by OWPs in soils as assessed by 57 laboratory incubation experiments. Within each long-term experiment, we observed no significant 58 difference between the carbon-storing soils (CA, ORG, MSW, FYM and BIOW) and their respective 59 baseline soils (CON-LC and CON-QA) in the delta SOC mineralized whatever the soil moisture regime. 60 The Q_{10} also indicated no significant difference between carbon-storing soils and their respective 61 baseline soils. These results indicate that the SOC mineralization in carbon-storing soils had a similar 62 sensitivity to the soil moisture regime and temperature as the baseline ones. Hence, the implementation 63 of these agroecological practices appears beneficial for climate change mitigation, even in the context 64 of extreme climatic events.

<u>Keywords</u>: Carbon mineralization; agroecological practices; organic waste products; climate change;
 sensitivity

67 **1. Introduction**

68 The 4p1000 initiative encourages the establishment of agricultural practices that increase and/or 69 preserve soil carbon stocks (www.4p1000.org). At the field scale, changes in soil organic carbon (SOC) 70 stocks result from an imbalance between carbon inputs (crop residues, litterfall, root exudates, 71 exogeneous organic matter application, etc.) and carbon outputs due to SOC mineralization, leaching or 72 erosion (Lal, 2018). It is generally agreed that the most efficient way to increase SOC stocks is to 73 increase carbon inputs (e.g., Virto et al., 2012, Autret et al., 2016, Fujisaki et al., 2018). This can be 74 achieved by increasing field biomass production and residue return (e.g., cover crops, Poeplau & Don, 75 2015; Autret et al., 2016), or by mobilizing and spreading external carbon resources such as organic 76 waste products (OWPs) (Peltre et al., 2012, Paetsch et al., 2016). The implementation of agroecological 77 practices that increase carbon inputs and/or reduce carbon outputs (e.g., conservation agriculture, 78 organic agriculture, OWPs application) generally result to additional carbon storage (Peltre et al., 2012, 79 Autret et al., 2016, Paetsch et al., 2016, Pellerin et al., 2019); such soils are referred to "carbon storing 80 soils" in this study. However, the question is whether the adoption of these agroecological practices 81 would still be beneficial for carbon sequestration in a warmer, drier, wetter climate or with intense dry-82 wet cycles?

83

84 It is widely recognized that climate change affects carbon mineralization in soils (Joly et al., 85 2023). Climate change is leading to an overall temperature increase, as well as increases in the frequency 86 and intensity of extreme climatic events such as droughts, heavy precipitation, fires, or freeze-thaw 87 cycles (Shukla et al., 2019). There is also an increase in the evaporation of terrestrial water and an 88 increase in the moisture level in the atmosphere, leading to frequent cycles of drought and heavy rainfall 89 events (Dai, 2013, Donat et al., 2016). Overall, these climatic events could have positive or negative 90 impacts on CO₂ emissions into the atmosphere by affecting ecological processes which control the 91 dynamics of organic carbon in agricultural soils. The existence of this important feedback effect has 92 prompted several studies of how climate change affects the kinetics of SOC mineralization and the 93 emission of CO₂ from soils (Kirschbaum, 2000, Smith et al., 2008). For example, increased soil 94 temperature is known to accelerate SOC decomposition because temperature-dependent reactions 95 performed by microorganisms (Davidson and Janssens, 2006) result in more rapid CO₂ emissions from 96 soil to the atmosphere (Trumbore and Czimczik, 2008, Karhu et al., 2014). Soil moisture can have a 97 great impact on SOC decomposition by affecting the oxygen diffusion into the soil and the substrate 98 availability for soil microorganisms (Linn and Doran, 1984; Suseela et al., 2012, Moyano et al., 2013, 99 Wang et al., 2014, Zhou et al., 2014, Sierra et al., 2015). With climate change, it is expected that dry-100 wet cycles will increasingly occur across the globe. Droughts would tend to decrease biological activity, 101 but the subsequent precipitation would lead to "pulses" of CO₂ emissions to the atmosphere (Birch, 102 1958). Understanding the effects of temperature and soil moisture regime on SOC dynamics, especially 103 in carbon-storing soils, and assessing the sensitivity of carbon mineralization to these climatic events is 104 necessary to anticipate future carbon losses in terrestrial ecosystems under climate change. Climate 105 change will obviously also play on C inputs to soil which will influence SOC stock evolution, but this 106 is outside the scope of our present study.

107

108 Conant et al. (2011) define temperature sensitivity as the rate of a process (decomposition, 109 desorption) at a given temperature compared to a control temperature. Temperature sensitivity, 110 determined by Q₁₀, represents a proportional increase (or decrease) in SOC mineralization for a

111 temperature increase of a 10 °C (Kirschbaum, 1995). The Q₁₀ is an important parameter for predicting 112 the fates of SOC under warmer climate (Kan et al., 2020). Findings of other studies showed that Q₁₀ 113 values varied largely across the range of temperatures (Ghosh et al., 2016, 2018). Contrary to 114 temperature, there is no standardized parameter to assess the sensitivity of carbon mineralization to soil 115 moisture regime. In this study, we defined moisture sensitivity as the proportional response of soil 116 microbial respiration (SOC mineralization) of soils exposed to different moisture levels relative to a 117 control moisture. In addition to climatic factors, the quality of soil organic matter should also affect the 118 rate of decomposition (Guntiñas et al., 2013). In soils formed under similar climates and from similar 119 parent material, the quality of the organic matter depends on the vegetation cover, the quality of external 120 organic input and the type of use and management to which the soil is subjected. So, the implementation 121 of agroecological practices including conservation agriculture, organic agriculture and organic waste 122 products application (composts, manure) affects the quantity and quality of organic matter in soils 123 which, in turn, can play on the sensitivity of SOC mineralization to climate change.

124

125 No-tillage and crop rotation types under conservation agriculture affect the distribution of 126 carbon in soil fractions (Zhang et al., 2020b). Some research suggests that additional C from increased 127 residue inputs accumulates mostly in particulate organic matter (POM) fractions that are on average 128 easily mineralized and only small gains occur in the resistant C pool (Bhattacharyya et al., 2011, 129 Mitchell et al., 2018). Long-term organic waste supply significantly increased the POM fractions (Peltre 130 et al., 2012, Paetsch et al., 2016). These results show that the implementation of agroecological practices 131 increasing C inputs may affect SOC temporal stability. However, there is a lack of consensus in the 132 literature on how SOC accumulated under alternative practices respond to seasonal climate variability 133 and projected climate change (Davidson and Janssens, 2006, Carey et al., 2016). The carbon loss through 134 heterotrophic respiration is intrinsically related to the availability and quality of this organic carbon 135 (Lindén et al., 2014, Hopkins et al., 2014). The POM fraction is believed to be a quite labile carbon pool 136 in soils, with a mean residence time up to 20 years (Balesdent et al., 1998). Therefore, if additional SOC 137 carbon mainly comprises POM, as suggested in the literature, then the sensitivity of SOC mineralization 138 to temperature and moisture regime under agroecological practices (carbon-storing soils) could differ

139 from that of soils where agroecological practices have not been implemented (baseline soils). Indeed, 140 previous studies have shown that labile carbon is less sensitive to temperature than stable carbon (Liski 141 et al., 1999, Conen et al., 2008, Lefèvre et al., 2014, Xu et al., 2014). Based on these findings, we 142 hypothesized that SOC mineralization in carbon-storing soils would be relatively less sensitive to 143 temperature. Conversely, soil moisture affects the oxygenation of these POMs and their accessibility to 144 decomposers by increasing the probability of contact between organic substrates and microorganisms 145 (Monard et al., 2012). Thus, the sensitivity of SOC mineralization to soil moisture regime is expected 146 to be relatively higher in carbon-storing soils than in their baseline soils. Testing these hypotheses is 147 crucial to provide knowledge that will allow to identify the best management practices that reduce CO₂ 148 emissions and enhance the soil carbon sink effect, even under climate change.

149

150 We aimed to investigate in this study two related research questions. The first objective was to 151 assess the sensitivity of SOC mineralization to the soil moisture regime in carbon-storing soils compared 152 to baseline soils. To achieve this objective, we incubated in the laboratory soils collected from long-153 term field experiments at different matric potentials (pF 1.5; pF 2.5 and pF 4.2) and subsequent dry (pF 154 4.2)-wet (pF 1.5) cycles at 20°C and monitored continuously SOC mineralization in the incubation 155 flasks. We calculated the delta SOC mineralized due to the change in soil moisture to assess the 156 sensitivity of SOC mineralization to soil moisture regime. The second objective was to assess the 157 sensitivity of SOC mineralization to temperature increase in carbon-storing soils. To do this, we also 158 incubated replicates of the same soils in the laboratory at three temperatures (20, 28 and 35°C) in optimal 159 moisture (pF 2.5). We calculated Q_{10} using the equal carbon respired method (Conant et al., 2008) to 160 assess the sensitivity of SOC mineralization to temperature in carbon-storing soils and baseline soils.

161

2. Materials and methods

162

2.1. Field site and soil sampling

163 This study focuses on two French long-term experiments (LTEs) where agroecological practices
 164 including conservation agriculture, organic agriculture and the application of organic waste products

with contrasting biochemical quality have resulted in increased soil organic carbon contents and stocks relative to the baseline practices, i.e., conventional agriculture (Table. 1). This increase was named "additional soil organic carbon" (e.g., Bamière et al., 2022), and we used the term "carbon-storing soils" to refer to these soils that had stored additional carbon under agroecological practices.

169 La Cage LTE is conducted in Versailles (48°48'N,2°08'E). During the studied period (1998-170 2020), the mean annual temperature and precipitation were 11.6 °C and 633 mm respectively (Fig. 1). 171 The soil is a well-drained deep Luvisol (WRB, 2015). The experimental field is arranged in a 172 randomized complete block design, divided into two blocks, themselves divided into four plots for each 173 cropping system, and then into two subplots of 0.56 ha, so that wheat is present every year in one of the 174 subplots (Autret et al., 2020). A detailed presentation of crop rotations, soil management and fertilization 175 were given by Autret et al. (2016). The 4 year's crop rotation mainly consisted of rapeseed (Brassica 176 napus L.), winter wheat (Triticum aestivum L.), spring pea (Pisum sativum L.) and winter wheat. It 177 differed in conservation agriculture (CA) and organic agriculture (ORG) for some years, with the 178 replacement of rapeseed by maize (Zea mays L.) in CA or the introduction of alfalfa (Medicago sativa) 179 in CA and ORG.

- CON-LC is characterized by a soil and crop management representative of the Paris Basin cereal
 production, with annual soil ploughing, the absence of organic amendment, a mineral N
 fertilization (average rate = 143 kg N ha⁻¹ yr⁻¹) and a systematic use of pesticides.
- CA includes a permanent soil cover, initially fescue (*Festuca rubra*) and since 2008 alfalfa,
 grown under the main crops, except pea. The soil is not tilled.
- ORG is characterized by an alfalfa-alfalfa-wheat-wheat rotation. No pesticides nor mineral
 fertilizers are used.

The QualiAgro LTE is located at Feucherolles, 20 km west of Versailles (48°52′N, 1°57′E) (Fig.
1). The soil is a Luvisol (WRB, 2015), cultivated for 21 years with a conventional wheat-maize rotation
(Peltre et al., 2012). The mean annual temperature and precipitation for the last 20 years are 11 °C and
614 mm respectively. It is an LTE conducted in collaboration with INRAE and Veolia Environment

191	Research and Innovation since 1998, on which composts of organic waste products (OWPs) are applied
192	every 2 years before tillage, at a dose equivalent to ~4 t C. ha ⁻¹ from 1998 to 2013 and ~2 t C. ha ⁻¹ from
193	2015 to 2020. The completely randomized block comprised an area of 6 ha with 40 plots of 450 m^2 each
194	and 4 replicates per treatment. Since 2015, wheat and maize residues are buried in the soil. Three organic
195	amendments are considered in this study and compared to a conventional agriculture treatment without
196	organic inputs (CON-QA):

- 197 Biowaste compost (BIOW): composting of the fermentable fraction of selectively collected
 198 household waste, mixed with green waste;
- 199 Municipal solid waste compost (MSW): composting of the residual fraction of household waste
 200 after selective collection of packaging;
- 201 Farmyard manure (FYM) which represents the reference amendment in the region.

Soils from both LTEs were sampled at 30 ± 1 cm depth and stored in a chamber at 4°C after sieving to <203 <4 mm a composite sample per plot.

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2.2. Laboratory incubations

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Surface soils (0-30cm) sieved to <4 mm was used for a microcosms incubation experiment to determine the effects of temperature (T°C), soil moisture (pF), and dry-wet-cycles (DWC) on SOC mineralization. Before incubating the soil samples, a water content and matric potential response curve was established using Richard's presses. The water contents at saturation and corresponding to pF 1.5, pF 2.5 and pF 4.2 were determined for soils under each agricultural practice considered in this study (results presented in Table S1).

212

2.2.1. Soil cylinder construction and pre-incubation

Polyvinyl chloride (PVC) cylinders 5.7 cm in diameter and 4 cm in height with 2 mm perforations were used. A 50 µm mesh cloth at the bottom of the cylinder provided support for the soil while promoting gas exchange. Each cylinder was weighed empty and then with fresh soil equivalent to 100g dry soil. Samples were then brought to a bulk density of 1.3 g.cm⁻³ with a hand press and mold. Knowing the 217 initial water content, the samples were gradually brought to pF 2.5 adding water with a pasteur pipette. 218 Then the microcosms were mounted in 1L jars. The soil cylinders were placed on PVC supports and 15 219 mL of water was added to the bottom of the jars to stabilize the moisture. The jars were closed and the 220 whole set was put in the incubator at 20°C for a one-week pre-incubation. Four replicates per agricultural 221 practice and per moisture regime or temperature were prepared.

222

2.2.2. Experiment with soil moisture regime

223 To evaluate the effect of soil moisture regime on SOC mineralization, 4 soil moisture scenarios were 224 performed and applied at 20°C: a continuously wet scenario at pF 1.5 (WET); a continuously moderated 225 wet scenario at pF 2.5 (MWET); a continuously dry scenario at pF 4.2 (DRY) and a five subsequent 226 dry-wet cycles scenario (DWC). To obtain the continuously moisture scenario after pre-incubation at 227 pF 2.5, we added deionized water using a pasteur pipette to bring the replicates dedicated for WET 228 scenario to pF 1.5. For replicates dedicated to MWET scenario (pF 2.5), we checked if the soil moisture 229 corresponded to pF2.5. For the replicates dedicated to the DRY scenario, we introduced 50 g of silica-230 gel during the pre-incubation phase to dry the soil. As soon as the moisture level corresponding to pF4.2 231 was reached, we removed the silica-gel from the jars. For DWC scenario, five dry-wet cycles were 232 implemented during the experimental period (97 d). Each cycle contained two phases, 10 days of drying 233 phase, followed by 7 days of moist phase after rewetting. The drying phase consisted of adding silica 234 gel to the incubation jars to absorb the soil water and allow for a gradual soil drying. For this, perforated 235 PVC cylinders containing 50 g of silica gel were added to each jar and changed after 6 days when the 236 jars were vented after measuring the CO₂ concentration in the headspace by micro-chromatography. A 237 preliminary experiment had allowed to establish the amount of silica gel needed to dry the soil samples 238 to pF 4.2 in 10 days. At the end of the drying period, rapid rewetting was performed by adding deionized 239 water (the amount of water needed to reach pF 1.5) with a pasteur pipette. The same procedure was 240 repeated for 5 times to simulate the dry-wet cycles in the soils. The four scenarios are schematized in 241 Fig. 2.

242

2.2.3. Experiment with increased temperatures

243 To evaluate the effect of temperature on carbon mineralization, 3 temperature scenarios were compared: 244 20°C; 28°C and 35°C, using four replicates per scenario. The soil cylinders were kept at constant moisture (pF2.5). After the one-week pre-incubation the jars were placed either in an incubator set at 246 20°C, or in a thermostat chamber at 28°C and at 35°C and incubated for 92 days. We maintained constant 247 soil moisture by weighing each sample after each CO_2 measurement and adjusting the moisture content 248 to the target mass.

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2.2.4. Mineralization monitoring

Soil organic carbon (SOC) mineralization was monitored regularly for 97 days, with measurements on days 1, 3, 7, 13, 17, 24, 28, 34, 41, 45, 51, 59, 63, 69, 76, 80, 86 and 97 for each soil moisture scenario, and on days 1, 3, 7, 15, 22, 30, 37, 52, 65, 79 and 92 for each temperature scenario. SOC mineralization was measured non-destructively using a gas micro-chromatograph (μ GC 490; Agilent Technologie; USA). The absolute amount of CO₂ emitted is measured in parts per million (ppm). It is then converted to μ g C-CO₂ g⁻¹ dry soil with the following formula:

$$\mu g C-CO_2.g^{-1} dry soil = \frac{CO_2 (ppm) * M_c * V_b}{V_M * M_{soil}}$$
(1), (Védère et al., 2020), with CO₂ (ppm):

amount of CO_2 emitted measured by gas micro-chromatograph; Mc: molar mass of carbon in g.mol⁻¹; V_b: volume of the jar in L; V_M: molar volume of gas in L.mol⁻¹ and M_{soil}: mass of incubated soil in g. Then the absolute amount of carbon mineralized was expressed per unit of SOC to obtain the specific SOC mineralization in μ g C-CO₂/100 μ g SOC, i.e., % SOC mineralized.

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263 2.2.5. Soil moisture effect and sensitivity of SOC mineralization

The soil moisture effect on SOC mineralization was determined by calculating the delta SOC mineralized i.e., the difference in specific SOC mineralized between the high moisture (WET), lowmoisture (DRY) and dry-wet-cycle (DWC) with specific SOC mineralized under optimal moisture (MWET). A negative value indicates an inhibition of SOC mineralization, while a positive value indicates a stimulation of SOC mineralization. Furthermore, to assess the sensitivity of carbon-storing soils to the soil moisture regime, we compared the delta SOC mineralized under WET, DRY, and DWC

- 270 between baseline soils (CON-LC and CON-QA for La Cage and QualiAgro LTEs, respectively) and 271 soils under agroecological practices, i.e., CA, ORG, MSW, FYM and BIOW.
- 272

2.2.6. Temperature sensitivity of SOC mineralization

273 The Q_{10} was used in this study to estimate the sensitivity of organic carbon mineralization under different 274 agricultural practices to temperature increase. The method for calculating Q_{10} at equal carbon 275 mineralized $(Q_{10}-q)$ described by Conant et al. (2008) was carried out in this study. This method 276 involves determining the amount of time needed for a given amount of SOC to be respired at a given 277 temperature. The time required to respire a given amount of SOC at two temperatures is then used to 278 calculate a Q10 value. This method of analysis eliminates the problem of fixed incubation duration 279 leading to comparison of different SOC pools, which confounds characterization of temperature 280 sensitivity (Reichstein et al., 2000, 2005, Leifeld & Fuhrer, 2005). Therefore, the Q₁₀ was calculated for 281 1% and 3% of respired SOC. The Q₁₀ is calculated for 2 temperature ranges (20-28°C and 28-35°C) 282 with the following formula:

283
$$Q_{10}-q = \left(\frac{t_1}{t_2}\right) e\left(\frac{10}{(T^2-T_1)}\right)$$
(2) (Conant et al., 2008), with t_1 and t_2 the time required to

284 respired the same amount of carbon at low temperature (T_1) and high temperature (T_2) .

285

2.3. Statistical analysis

286 All data were tested for normality and homogeneity of variance. Log-transformation was applied, if the 287 transformation improved the normality and variance substantially. A one-way ANOVA with Tukey's 288 test was used to detect the differences in Q₁₀, the delta SOC mineralized and the amount of SOC 289 mineralized among soil moisture and temperature scenarios within each field site, then across all 290 scenarios in both sites. When the normality or homogeneity of the data was not confirmed, we applied 291 the non-parametric Kruskal-Wallis test. All statistical analyses were completed in R (version 4.0.2).

3. Results

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3.1. Soil carbon mineralization under diverse moisture regimes, temperatures and agricultural practices

295 Increasing soil moisture significantly affected SOC mineralization in the La Cage and 296 QualiAgro LTEs (Table. 2; p<0.05). Also, SOC mineralization followed a polynomial function with the 297 soil matric potential (Fig. 3). Carbon mineralization under soil moisture regime was in this order: 298 WET=MWET>DWC>DRY. To better observe the effect of soil moisture regime on carbon 299 mineralization, we considered the MWET as the moisture control in order to calculate the delta SOC 300 mineralization induced by the change in soil moisture. The delta SOC mineralized in the WET scenario 301 compared to MWET was on average +0.07 to +1.10 % of SOC (Fig. 6), showing a lack of or a weak 302 stimulation of SOC mineralization with increasing soil moisture above pF 2.5 (Fig. 6). The delta SOC 303 mineralized was significantly larger at La Cage (CON-LC: 1.10 ± 0.45 ; ORG: 0.89 ± 0.76 and CA: 0.69304 \pm 0.52% of SOC) than at QualiAgro (CON-QA: 0.12 \pm 0.43; MSW: 0.24 \pm 0.24; FYM: 0.07 \pm 0.12 and 305 BIOW: $0.30 \pm 0.10\%$ of SOC) (p<0.05; Fig. 6). Increasing the soil moisture from pF2.5 to pF1.5 did not 306 significantly increase carbon mineralization at QualiAgro. In contrast, the DWC and DRY scenarios 307 inhibited carbon mineralization relative to MWET scenario (Fig. 6). SOC mineralization in DWC 308 decreased on average between 1.15 to 2.16 % of SOC and in DRY scenario on average between 2.35 to 309 2.97 % SOC (Fig. 6). This result suggests that multiple dry-wet cycles (DWC) did not stimulate carbon 310 mineralization relative to the optimum soil moisture (MWET), whereas multiple DWC stimulated 311 carbon mineralization relative to the low moisture scenario (DRY).

312

313 Increasing temperature also significantly affected cumulative SOC mineralization in both LTEs 314 (Table 3; p<0.05). Except the CON-LC where no significant difference was found between 315 mineralization at 20 and 28°C, the soils under other agricultural practices showed significant differences 316 between 20, 28 and 35°C (Table. 3; p<0.05).

317

318 At QualiAgro, we observed a significantly larger specific SOC mineralization in the reference 319 plots (CON-QA) compared to the plots that received organic waste products (CON-QA>BIOW=FYM =MSW), whatever the soil moisture regime and temperature (Fig. 5, Fig. 7c, Fig. 7d), indicating less
stabilization of SOC in CON-QA. However, at La Cage, regardless of soil moisture regime and
temperature (Fig. 4, Fig. 7a, Fig. 7b), there was no difference in specific mineralization rates between
the treatments (ORG, CA) relative to the conventional agriculture (CON-LC).

324

325 In addition, the effect of agricultural practices in both LTEs reported in Table 2, indicates that 326 CON-LC baseline practice at La Cage and the CON-QA baseline practice at QualiAgro, not only had similar SOC contents (9.82 ± 0.48 g C.kg⁻¹ and 10.11 ± 1.12 g C.kg⁻¹ respectively) but also had the same 327 328 percentage of mineralized SOC whatever the soil moisture regime. Moreover, the percentage of SOC 329 mineralized under agroecological practices at La Cage (CA: 2.24 to 5.61 % SOC and ORG: 2.56 to 330 6.38 % SOC) was significantly larger than under organic waste products application (MSW: 1.46 to 331 4.09 % SOC; FYM: 1.48 to 4.06 % SOC and BIOW: 1.23 to 3.89 % SOC) (Table. 2). Also, when 332 comparing the agroecological practices in both LTEs, we found that the agroecological practices at La 333 Cage (ORG and CA) generated more SOC loss than agroecological practices at QualiAgro (BIOW, 334 MSW, and FYM) after 3 months of incubation at diverse temperatures (Table. 3).

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3.2. Sensitivity of SOC mineralization to soil moisture regime

The analysis of variance (ANOVA) revealed that within each LTE, we observed no significant difference between the carbon-storing soils (CA, ORG, MSW, FYM and BIOW) and their respective baseline soils (CON-LC and CON-QA) in the delta SOC mineralized whatever the soil moisture regime (Fig. 6). These results indicate that the carbon-storing soils had a similar sensitivity to the soil moisture regime as the baseline ones.

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343

3.3. Sensitivity of SOC mineralization to temperature increase

The mean Q_{10} corresponding to equal 1% mineralized SOC at QualiAgro ranged between 1.90 to 2.53 for the 20-28°C temperature range, compared to 1.38 to 1.55 at La Cage (Fig. 8). These Q_{10} did not change significantly from 1% to 3% mineralized SOC (Table S2). Furthermore, the Q_{10} for the temperature range 20-28°C was larger for the BIOW plot than for the CON-LC plot (Fig. 8; p<0.05), but no significant difference was found between agroecological practices (CA, ORG, MSW, FYM and FYM). For the temperature range 28-35°C we did not observe any significant difference between agricultural practices (Fig. 8, p>0.05). The SOC under OWPs practices (BIOW, FYM and MSW) had the same sensitivity of SOC mineralization to temperature as their baseline practice (CON-QA), as did the CA and ORG with their baseline practice (CON-LC). These results indicate that carbon-storing soils had a similar sensitivity of SOC mineralization to temperature increase as the baseline soils.

- **4. Discussion**
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4.1. Soil carbon mineralization under soil moisture regime and temperature

356 The interaction of soil microbes with their physical environment affects their ability to 357 mineralize SOC into CO₂. One of these environmental factors is soil moisture (Cook & Orchard, 2008). 358 The results of the present study indicated that SOC mineralization followed a polynomial function with 359 soil matric potential (Fig. 3). Manzoni et al. (2012) and Moyano et al. (2012) in their meta-analyses 360 found for their dataset that the soil heterotrophic respiration (mineralization) decreased steadily when 361 the matric potential became more negative, i.e., for high pF values. This result agrees with ours, where 362 SOC mineralization decreased as we reach higher pFs (pF1.5 \ge pF2.5>pF4.2), i.e., lower matric 363 potentials (-0.015 MPa \geq -0.033 MPa > -1.6 MPa). Such a decrease in respiration is associated with a 364 reduction in solute diffusivity in mineral soils at low soil moisture (pF4.2), because water-filled 365 capillaries become disconnected as the soil becomes drier (Moldrup et al., 2001). Therefore, solute 366 diffusivity (and thus substrate and nutrient bioavailability) may be the most limiting factor under dry 367 conditions (Skopp et al., 1990, Schjønning et al., 2003, Or et al., 2007, Moyano et al., 2013). Conversely, 368 increasing soil moisture increases solute diffusion rates in soils, enhancing the accessibility of substrates 369 by soil microorganisms (Monard et al., 2012, Moyano et al., 2013, Manzoni and Katul, 2014). Our 370 results are consistent with the hypothesis that higher soil moisture increase the accessibility of SOC to 371 decomposers and thus lead to more SOC mineralization than low moisture contents, provided the soil 372 moisture remains well below saturation, where oxygen diffusion rates becomes a limiting factor for 373 heterotrophic respiration (Cook and Orchard, 2008, Moyano et al., 2013).

375 In addition, the percentage of SOC mineralized at pF1.5 (WET) after 97 days are statistically 376 identical to the percentage at pF2.5 (MWET) (Table. 2), implying that the increase in soil moisture 377 beyond pF2.5 did not result in significant further CO₂ emission to the atmosphere. This result suggests 378 that at pF2.5, the mineralization optimum was reached, and increasing soil moisture to pF1.5 does not 379 yet alter SOC mineralization due to slight anoxia. Because the diffusion rate of oxygen through water is 380 much lower than through air (Cook and Knight, 2003), the metabolic activity of aerobic organisms also 381 decreases as soil pore space fills with water and approaches saturation levels (Franzluebbers, 1999). 382 Curtin et al. (2012) showed that the optimum matric potential for mineralization can be as high as -0.005 383 MPa; while the meta-analysis by Moyano et al. (2012) found an optimum matric potential for 384 mineralization of -0.001 MPa corresponding to pF 1. In our case, we observed no decrease in SOC 385 mineralization in the wettest state, i.e., -0.015 MPa (pF1.5). One possible explanation is that the soil was 386 sieved and repacked and the cores had a high inter-aggregate macroporosity favorable to air circulation, 387 preventing anoxia, or that at pF1.5 a slight anoxia at compensated for a better substrate diffusion 388 compared to pF2.5 resulting in similar SOC mineralization rates at pF1.5 and 2.5.

389

390 The dry-wet cycles scenario tested in this study did not induce substantial delta SOC 391 mineralization when compared to optimum moisture (MWET), but did if compared to low moisture 392 (DRY) scenario (Table. 2). The drying phase induced low carbon mineralization rates as a result of 393 reduced microbial activity (Franzluebbers et al., 1994, Pulleman and Tietema, 1999) and decreased 394 accessibility of the organic substrate to decomposers (Manzoni et al., 2012). This low mineralization 395 was not compensated by the flush observed after rewetting (Mikha et al., 2005, Yemadje et al., 2017). 396 Zhang et al. (2020) in their meta-analysis showed that, on average, dry-wet-cycles stimulated soil carbon 397 mineralization by 72% relative to mineralization at low-moisture and inhibited carbon mineralization 398 by 25% relative to incubation at high-moisture which is consistent with our results. Relevant controls 399 are indeed needed when evaluating the importance of the Birch effect (Kpemoua et al., 2023).

400

401 Temperature generally had a positive effect on cumulative SOC mineralization, which was 402 manifested by larger CO₂ emissions at higher temperatures (Table. 3). Similar increases in SOC

403	mineralization with increasing temperature have previously been observed in many other studies (e.g.,
404	Conant et al., 2008, Ghosh et al., 2016, Ghimire et al., 2019, Fu et al., 2020). Temperature rise affects
405	most of the physiological activity of microbial cell and accelerates residue decomposition (Reichstein
406	et al., 2000, Yun et al., 2019).

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4.2. Soil carbon mineralization under agricultural practices

409

410 We observed no significant difference in specific SOC mineralization rate between conventional 411 agriculture (CON-LC) and agroecological practices (ORG and CA) at La Cage, whatever soil moisture 412 regime and whatever the temperature. This result supports previous results obtained by Autret et al. 413 (2020) on the same LTE, where soil incubation at pF 3 reported similar specific carbon mineralization 414 between alternative practices (conservation, organic and low input agriculture) and conventional 415 agriculture. Some studies (Dendooven et al., 2012, Ussiri and Lal, 2009) did measure lower SOC 416 mineralization rates under no tillage, ascribed to less favorable local climatic conditions and better 417 physical protection of organic matter in the soil structure (Balesdent et al., 2000). Similarly to our 418 results, Zhang et al. (2020b), showed that tillage had no influence on specific C mineralization, while 419 the interaction of tillage and depth had a significant effect. In the present study, we incubated samples 420 from the surface to a depth equivalent to the soil mass of 4300 kg. ha⁻¹ (corresponding to 30 ± 1 cm), 421 regardless of agricultural practice. No-tillage typically results in carbon stratification in the soil (e.g., 422 Zhao et al., 2015). We hypothesize that the physical protection of carbon is increased in the first 10 cm 423 under no-tillage, but that considering a 0-30 cm soil layer cancels out this effect. Another hypothesis is 424 that sieving the soils to <4 mm before incubation would have removed the physical protection occurring 425 in macroaggregates in the CA soils.

426

427 At the QualiAgro LTE, the application of organic waste products (MSW, FYM and BIOW) 428 reduced significantly SOC mineralization, compared to conventional agriculture without organic inputs 429 (CON-QA) whatever soil moisture regime and whatever the temperature. These results can be explained 430 by the fact that composts and farmyard manure have previously undergone a period of decomposition 431 and therefore mineralize less rapidly than crop residues that contain higher proportions of easily 432 mineralizable organic carbon (Chodak et al., 2001, Leifeld et al., 2002). The physico-chemical 433 composition of the organic waste products (OWPs) has been analyzed by Peltre et al. (2012) at the 434 QualiAgro LTE. They show that residual municipal solid waste compost (MSW) is the OWP with the 435 least lignin, and biowaste compost (BIOW) the one with the most. Lignin is known to be a compound 436 resistant to microbial degradation at a year to decadal timescale, which would explain why BIOW tends 437 to mineralize less SOC than MSW and FYM (Table. 2). In the same way, an incubation study of 438 substrates of different quality showed that manure is less biodegradable than crop residues such as straw 439 and suggests that this is due to a more stable chemical quality, as manure is already biodegraded during 440 animal digestion and storage (Benbi and Khosa, 2014). Fortuna et al. (2003) found that easily 441 mineralizable C constituted less of the SOC in soils fertilized with compost as compared with soils that 442 were fertilized with mineral N. Other studies have also shown that the application of organic 443 amendments that include composts and manure have the potential to reduce CO₂ emission per unit of 444 SOC since these best management practices contribute to carbon stabilization (Dou et al., 2008, 445 Bhowmik et al., 2017).

446

447 Overall, the cumulative specific SOC mineralization in our incubations was much less for soils 448 that received organic waste products plus crop residues (MSW, FYM, BIOW) than for soils receiving 449 only crop residues (CON-QA, CON, ORG, CA) (Table. 2 and Table. 3). This result thus confirms that 450 soils that received organic waste were depleted in labile SOC compared to soils that received only crop 451 residues. In contrast to our results, Obriot (2016) had observed similar proportions of soil organic carbon 452 mineralization between the conventional system without organic inputs and plots that had received 7 453 successive applications of organic waste products. We assume that the long-term application (11 454 successive applications in our study) of organic waste products led to a greater stabilization of carbon 455 in the soil, which makes it less biodegraded by microorganisms.

456

457 458

4.3. Sensitivity of SOC mineralization to soil moisture regime

459 The results of the delta SOC mineralized due to soil moisture regime change indicated no 460 significant difference between carbon-storing soils (CA and ORG) and the baseline soil (CON-LC) at 461 La Cage (Fig. 6). These results suggest that the decomposability of organic carbon is similar under the 462 contrasted agricultural practices whatever the soil moisture regime, or the environmental conditions for 463 decomposers are the same (Autret et al., 2020). Regarding the decomposability of the organic carbon, it 464 is likely that the nature of organic inputs to soil is rather similar as soil organic matter exhibits similar 465 C/N ratio (Table. 1) and wheat is cropped one year out of two in all plots (Autret et al., 2016). The 466 sensitivity of SOC mineralization to soil moisture regime is not affected by the cropping system nor 467 tillage practice in this LTE.

468

469 At the QualiAgro LTE, the delta SOC mineralized due to changes in soil moisture regime also 470 showed no significant difference between the baseline soil (CON-QA) and carbon-storing soils (MSW, 471 BIOW and FYM). This result indicates that although the SOC in the baseline soil is more biodegradable 472 on average, it has similar sensitivity of carbon mineralization to soil moisture regime than the SOC of 473 carbon storing soils. The results in both experiments are contrary to our initial hypothesis concerning 474 the higher sensitivity of carbon mineralization to soil moisture regime in carbon-storing soils relative to 475 their baseline. Therefore, in a drier, wetter, or dry-wet conditions, the agroecological practices 476 implemented in both LTEs are still beneficial for climate change mitigation.

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- 478

4.4. Sensitivity of SOC mineralization to temperature increase

479

We found that the Q_{10} values (20-28°C: 1.38, 1.52 and 1.55 respectively for CON-LC, CA and ORG) were not significantly different under the contrasted agricultural practices at La Cage (Fig. 8). These results are contrary to those reported by Parihar et al. (2019), who found the extent of increase in mineralization with temperature elevation to be higher under conventional agriculture (high Q_{10}) than under conservation agriculture (low Q_{10}) whatever the soil depth. They justified their results by the high physical protection of the SOC under conservation agriculture limiting its accessibility to soil microbial degradation (Six et al., 2002). However, Autret et al (2016, 2020) had found in the La Cage LTE that 487 the increase in carbon stocks in conservation agriculture was mainly due to the carbon input rather than 488 to the expected physical protection. This result confirms ours, leading us to assume that neither tillage 489 practice nor cropping systems affected the sensitivity of SOC mineralization to temperature increase. 490 So, the carbon-storing soils (CA, ORG) at La Cage had a similar sensitivity of SOC mineralization to 491 temperature increases as the baseline soil (CON-LC).

492

493 At QualiAgro, the Q₁₀ value (Fig. 8) also did not reveal any significant difference between the 494 agricultural practices (20-28°C: 1.90; 2.44; 2.37 and 2.52 for CON-QA, MSW, FYM and BIOW 495 respectively). These results suggest that the carbon-storing soils (MSW, FYM, BIOW) at QualiAgro 496 and the baseline soil (CON-QA) had the same sensitivity of SOC mineralization to temperature increase. 497 This result contrasts with Benbi and Khosa (2014) who showed that temperature sensitivity depends on 498 the quality of the substrate, and that manure is more sensitive $(Q_{10} = 3)$ than green waste which is easily 499 decomposable ($Q_{10} = 2.5$). However, they measured the mineralization of manure and green waste 500 directly and not the soils that were amended with manure or green waste as we did.

501

502 In summary, the Q₁₀ values obtained in the present study were generally close to the values 503 reported in the meta-analysis by Hamdi et al. (2013) for agricultural soils. No differences were observed 504 between the agricultural practice in both LTEs on their temperature sensitivity, although slightly higher 505 Q₁₀ values were observed at QualiAgro, especially in OWPs practices than in conservation and organic 506 agriculture. To test the robustness of this result, we also calculated the Q₁₀ calculated for 3% of SOC 507 being mineralized in the incubations. We found it was not significantly different, neither across 508 agricultural practices nor from the Q10 calculated for 1% SOC mineralized (Table S2). This result 509 suggests that the carbon pool mineralized during 3 months incubation had similar quality and sensitivity 510 whatever the agricultural practice.

511

512 **5.** Conclusion

While a diversity of agroecological management options allow to store additional organic carbon in soil, a remaining question concerns the permanence and vulnerability of this stored carbon. This study examined the response of soil organic carbon stored by agroecological practices to climate change. We found that the heterotrophic respiration of "carbon-storing soils" had similar sensitivities compared to their baseline counterparts, regarding soil moisture regime changes and temperature increases. Hence, the implementation of these agroecological practices appears beneficial for climate change mitigation, even in the context of extreme climatic events.

521 Here were assessed the sensitivity of soils managed under different agricultural practices to climate 522 change, i.e., according to IPCC (2001) the degree to which a system or species is affected, either 523 adversely or beneficially, by climate variability or change. IPCC considers that the vulnerability to 524 climate change is wider, as it encompasses also the capacity to adapt to climate change. In further 525 studies, other aspects could be accounted for, such as the soils capacity to retain water, which our results 526 suggest to be increased in the carbon-storing soils, the changes moisture and temperature regime 527 consequent to the presence of a mulch, such as in conservation agriculture, or to changes in albedo, 528 consequent to OWPs applications.

529

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Table 1 Physical and chemical properties of the soil at "La Cage" (layer 0-25 cm) and "QualiAgro (layer
0-29 cm)" measured at the start of experiment in 1998 (Peltre et al., 2012; Autret et al., 2016) to 2020
at QualiAgro and La Cage (layer 0-30 cm). CON-LC (conventional agriculture); ORG (organic
agriculture); CA (conservation agriculture); CON-QA (conventional agriculture without organic inputs);
MSW (residual municipal solid waste compost); FYM (farmyard manure) and BIOW (biowaste
compost).

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854 **Table 2** Soil organic carbon content according to agricultural practices, percentage of SOC mineralized 855 according to soil moisture scenario: continuously wet scenario at pF1.5 (WET); continuously moderated 856 wet scenario at pF2.5 (MWET); continuously dry scenario at pF4.2 (DRY) and Dry-wet cycles scenario 857 (DWC). SOC: soil organic carbon; CON-LC: conventional agriculture; ORG: organic agriculture; CA: 858 conservation agriculture; CON-QA: conventional agriculture without organic waste products; MSW: 859 residual municipal solid waste compost; FYM: farmyard manure; BIOW: biowaste compost. NS: non-860 significant; ANOVA: analysis of the variance. (Y): p-value of soil moisture regime effect on SOC 861 mineralization and (\perp) : p-value of agricultural practices effect. Uppercase letters represent differences 862 between soil moisture scenarios and lowercase letters represent differences between agricultural 863 practices. A significant difference is obtained for p<0.05.

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865 **Table 3** Percentage of SOC mineralized according to temperature increasing. (Υ): p-value of incubation 866 temperature effect on SOC mineralization and (\bot): p-value of agricultural practices effect. Uppercase

867	letters represent differences between temperature scenarios and lowercase letters represent differences
868	between agricultural practices. A significant difference is obtained for p<0.05.
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871	List of figures
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873	Fig. 1: Map of the Yvelines department (France) showing the location of the two field sites.
874	
875	Fig. 2. A schematic diagram of the experimental design showing constant moisture scenarios (WET,
876	MWET, DRY) and dry-wet cycles scenario (DWC). WET represents a continuously wet scenario at pF
877	1.5; MWET a continuously moderated wet scenario at pF 2.5 and DRY a continuously dry scenario at
878	pF 4.2.
879	
880	Fig. 3. Relationship between cumulative carbon mineralization at the end of incubation (97 days) and
881	matric potential under (a) La Cage experiment and (b) QualiAgro Experiment.
882	
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884	cumulative carbon mineralization under conservation agriculture (CA), organic agriculture (ORG) and
885	conventional agriculture (CON-LC) at La Cage experiment. Error bars indicate standard deviation of 4
886	replicates per scenario. A significant difference between agricultural practices is obtained for p<0.05.
887	Letters represent differences between agricultural practices.
888	
889	Fig. 5. Continuously soil moisture (WET, DRY, MWET) and dry-wet-cycles (DWC) effect on specific
890	cumulative carbon mineralization under biowaste compost (BIOW), residual municipal solid waste
891	compost (MSW), farmyard manure (FYM) and control treatment (CON-QA) conventional agriculture
892	without organic inputs at QualiAgro experiment. Error bars indicate standard deviation of 4 replicates
893	per scenario. A significant difference between agricultural practices is obtained for p<0.05. Letters

894 represent differences between agricultural practices.

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Fig. 6. Delta SOC mineralized under WET, DWC and DRY scenarios relative to MWET scenario. Error bars indicate standard deviation of 4 replicates per scenario. Values above zero indicate that the scenario stimulates carbon mineralization relative to MWET scenario, and values below zero indicate that the scenario inhibits carbon mineralization relative to MWET scenario. A significant difference between carbon-storing soils and baseline soils is obtained for p<0.05. Letters represent differences between agricultural practices.

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Fig. 7. Temperature effect on specific cumulative soil organic carbon (SOC) mineralization under 28°C
[(a) and (c)] and 35°C [(b) and (d)] at QualiAgro and La Cage experiments. Error bars indicate standard
deviation of 4 replicates per scenario. A significant difference between agricultural practices is obtained
for p<0.05. Letters represent differences between agricultural practices.

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908Fig. 8. Q_{10} values distribution according to agricultural practices. On the left the Q_{10} for the temperature909range 20-28°C and on the right the Q_{10} for the range 28-35°C. The red dots inside the boxplot represent910the mean value whose numerical value is indicated above. A significant difference between agricultural911practices is obtained for p<0.05.</td>

Table. 1 Physical and chemical properties of the soil at "La Cage" (layer 0-25 cm) and "QualiAgro
(layer 0-29 cm)" measured at the start of experiment in 1998 (Peltre et al., 2012; Autret et al., 2016) to
2020 at QualiAgro and La Cage (layer 0-30 cm). CON-LC (conventional agriculture); ORG (organic
agriculture); CA (conservation agriculture); CON-QA (conventional agriculture without organic inputs);
MSW (residual municipal solid waste compost); FYM (farmyard manure) and BIOW (biowaste
compost).

LTEs	Agricultural	Tillage	Block	Clay	Silt	Sand	С	Ν	C/N	рН н20	Exchangeable cations (Cmol ⁺ .kg ⁻¹)			CEC	
	practices	modality				g.kg ⁻¹					K^+	Na ⁺	Ca ²⁺	Mg^{2+}	Cmol ⁺ . kg ⁻¹
La Ca	ge 1998		-				9.85	0.99	9.95	7.37	-	-	-	-	11.52
La Cage	CON-LC		1				10.05	0.88	11.55	7.20	0.546	0.039	13.80	1.78	11.10
2020		Tillage	2	170	560	270	9.25	0.91	10.15	7.15	0.584	0.039	13.30	1.75	9.85
	ORG		1				10.60	0.99	10.65	6.90	0.395	0.039	13.40	1.97	10.10
			2				10.05	0.95	10.60	7.20	0.474	0.039	13.00	2.01	9.80
	CA	No	1				13.55	1.32	10.25	7.15	0.707	0.039	13.95	2.28	10.95
		Tillage	2				12.05	1.06	11.50	7.15	0.679	0.039	13.70	2.33	10.75
QualiA	gro 1998		-				10.39	1.12	9.25	6.80	0.442	0.021	8.298	0.494	9.71
QualiAgro	CON-QA		-	156	778	65	10.11	1.04	9.65	6.74	0.270	0.032	7.67	0.455	8.25
2020	MSW	Tillage	-	150	//0	05	13.38	1.31	10.25	7.77	0.375	0.053	10.19	0.533	10.75
	FYM	-	-				14.30	1.41	10.16	7.31	0.922	0.039	8.65	0.950	10.27
	BIOW	-	-				16.62	1.66	9.12	7.71	0.610	0.04	10.86	0.650	11.77

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922 Table. 2 Soil organic carbon content according to agricultural practices, percentage of SOC mineralized 923 according to soil moisture scenario: continuously wet scenario at pF1.5 (WET); continuously moderated 924 wet scenario at pF2.5 (MWET); continuously dry scenario at pF4.2 (DRY) and Dry-wet cycles scenario 925 (DWC). SOC: soil organic carbon; CON-LC: conventional agriculture; ORG: organic agriculture; CA: conservation agriculture; CON-QA: conventional agriculture without organic waste products; MSW: 926 927 residual municipal solid waste compost; FYM: farmyard manure; BIOW: biowaste compost. NS: non-928 significant; ANOVA: analysis of the variance. (Υ): p-value of soil moisture regime effect on SOC 929 mineralization and (\perp) : p-value of agricultural practices effect. Uppercase letters represent differences 930 between soil moisture scenarios and lowercase letters represent differences between agricultural 931 practices. A significant difference is obtained for p<0.05.

		SOC		%	SOC mineralized	l	
LTE	Agricultural practices	g.kg ⁻¹	WET	MWET	DWC	DRY	p-value ^(Y) ANOVA
	CON-LC	$9.82\pm0.48^{\rm d}$	5.53 ± 0.44^{abA}	4.43 ± 0.74^{aA}	$3.27{\pm}~0.47^{abC}$	1.93 ± 0.26^{abD}	
La Cage	ORG CA	$\begin{array}{c} 10.39 \pm 0.42^{d} \\ 13.30 \pm 1.05^{b} \end{array}$	$\begin{array}{l} 6.38 \pm 0.52^{aA} \\ 5.61 \pm 0.88^{abA} \end{array}$	$\begin{array}{l} 5.57 \pm 0.31^{aA} \\ 4.67 \pm 0.26^{aA} \end{array}$	$\begin{array}{c} 3.33 \pm 0.43^{aC} \\ 3.28 \pm 0.67^{abB} \end{array}$	$\begin{array}{c} 2.56 \pm 0.33^{aD} \\ 2.24 \pm 0.26 \ ^{aC} \end{array}$	<i>p</i> <0.05
	CON-QA	$10.11\pm1.12^{\rm d}$	4.79 ± 0.26^{bcA}	4.92 ± 0.22^{abA}	3.22 ± 0.26^{abB}	1.95 ± 0.49^{bcC}	
QualiAgro	MSW	13.38 ± 0.45^{b}	4.09 ± 0.48^{cA}	3.86 ± 0.33^{bA}	2.55 ± 0.08^{bB}	$1.46\pm0.19^{\mathrm{cC}}$	
	FYM	14.31 ± 0.63^{ab}	$4.06\pm0.24^{\text{cA}}$	$3.99\pm0.24^{b\rm A}$	2.65 ± 0.11^{bB}	$1.48\pm0.17^{\rm cC}$	<i>p</i> <0.05
	BIOW	$15.81\pm1.23^{\rm a}$	$3.89\pm0.25^{\rm cA}$	$3.58\pm0.18^{b\rm A}$	2.43 ± 0.19^{bB}	$1.23\pm0.08^{\rm cC}$	
p-value ^(⊥) ANOVA		<i>p</i> <0.05	<i>p</i> <0.05	<i>p</i> <0.05	<i>p</i> <0.05	<i>p</i> <0.05	

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Table. 3 Percentage of SOC mineralized according to temperature increasing. (Y): p-value of incubation temperature effect on SOC mineralization and (\perp) : p-value of agricultural practices effect. Uppercase letters represent differences between temperature scenarios and lowercase letters represent differences between agricultural practices. A significant difference is obtained for p<0.05.

			% SOC mineralized		
LTEs	Agricultural practices	20°C	28°C	35°C	p-value ^(Y) ANOVA
	CON-LC	$4.28\pm0.72^{\mathrm{aA}}$	5.90 ± 1.07^{bA}	7.96 ± 0.79^{bB}	
I C	ORG	5.37 ± 0.31^{aA}	7.37 ± 0.52^{abB}	8.35 ± 0.36^{bC}	p < 0.05
La Cage	CA	$5.01\pm0.24^{\mathrm{aA}}$	7.26 ± 0.33^{abB}	8.55 ± 0.52^{bC}	
	CON-QA	$4.77\pm0.48^{\mathrm{aA}}$	7.89 ± 0.91^{aB}	9.54 ± 0.46^{aC}	
QualiAgro	MSW	3.74 ± 0.33^{bA}	6.01 ± 0.67^{bB}	7.91 ± 0.29^{bC}	
	FYM	3.87 ± 0.23^{bA}	6.13 ± 0.42^{bB}	8.40 ± 0.44^{bC}	p < 0.05
	BIOW	3.47 ± 0.18^{bA}	5.87 ± 0.51^{bB}	7.52 ± 0.41^{bC}	
p-value ⁽¹⁾ ANO	DVA/Kruskal test	<i>p</i> =0.02	p<0.05	<i>p</i> <0.05	

942 Fig. 1: Map of the Yvelines department (France) showing the location of the two field sites.



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Fig. 2. A schematic diagram of the experimental design showing constant moisture scenarios (WET,
MWET, DRY) and dry-wet cycles scenario (DWC). WET represents a continuously wet scenario at pF
1.5; MWET a continuously moderated wet scenario at pF 2.5 and DRY a continuously dry scenario at
pF 4.2.



Fig. 3. Relationship between cumulative carbon mineralization at the end of incubation (97 days) and
matric potential under (a) La Cage experiment and (b) QualiAgro Experiment.





957 Fig. 4. Continuously soil moisture (WET, DRY, MWET) and dry-wet-cycles (DWC) effect on specific 958 cumulative carbon mineralization under conservation agriculture (CA), organic agriculture (ORG) and 959 conventional agriculture (CON-LC) at La Cage experiment. Error bars indicate standard deviation of 4 960 replicates per scenario. A significant difference between agricultural practices is obtained for p<0.05. 961 Letters represent differences between agricultural practices.



963 Fig. 5. Continuously soil moisture (WET, DRY, MWET) and dry-wet-cycles (DWC) effect on specific 964 cumulative carbon mineralization under biowaste compost (BIOW), residual municipal solid waste 965 compost (MSW), farmyard manure (FYM) and control treatment (CON-QA) conventional agriculture 966 without organic inputs at QualiAgro experiment. Error bars indicate standard deviation of 4 replicates 967 per scenario. A significant difference between agricultural practices is obtained for p<0.05. Letters 968 represent differences between agricultural practices.



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977 Fig. 6. Delta SOC mineralized under WET, DWC and DRY scenarios relative to MWET scenario. Error 978 bars indicate standard deviation of 4 replicates per scenario. Values above zero indicate that the scenario 979 stimulates carbon mineralization relative to MWET scenario, and values below zero indicate that the 980 scenario inhibits carbon mineralization relative to MWET scenario. A significant difference between 981 carbon-storing soils and baseline soils is obtained for p<0.05. Letters represent differences between 982 agricultural practices.



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Fig. 7. Temperature effect on specific cumulative soil organic carbon (SOC) mineralization under 28°C
[(a) and (c)] and 35°C [(b) and (d)] at QualiAgro and La Cage experiments. Error bars indicate standard
deviation of 4 replicates per scenario. A significant difference between agricultural practices is obtained
for p<0.05. Letters represent differences between agricultural practices.



1008Fig. 8. Q_{10} values distribution according to agricultural practices. On the left the Q_{10} for the temperature1009range 20-28°C and on the right the Q_{10} for the range 28-35°C. The red dots inside the boxplot represent1010the mean value whose numerical value is indicated above. A significant difference between agricultural

1011 practices is obtained for p < 0.05.



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1015	Supplementary materials for:
1016 1017 1018	Are carbon-storing soils more sensitive to climate change? A laboratory evaluation for agricultural temperate soils
1019 1020 1021 1022	Tchodjowiè P. I. Kpemoua ^{1,3} , Sarah Leclerc ¹ , Pierre Barré ² , Sabine Houot ¹ , Valérie Pouteau ¹ , Cédric Plessis ¹ , Claire Chenu ¹
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1029	
1030	Table S1: Measured mass water contents for matric potentials pF 1.5; pF 2.5 and pF 4.2

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LTEs	Agricultural	pF1.5	pF2.5	pF4.2
	practices	-0.015 MPa	-0.033 MPa	-1.6 MPa
			W $(gH_20.g^{-1} soil)$)
	CON-LC	0.29 ± 0.01	0.26 ± 0.00	0.09 ± 0.02
La Cage	ORG	0.30 ± 0.01	0.27 ± 0.03	0.13 ± 0.02
	CA	0.30 ± 0.01	0.27 ± 0.02	0.12 ± 0.02
	CON-QA	0.25 ± 0.02	0.22 ± 0.01	0.09 ± 0.01
QualiAgro	MSW	0.26 ± 0.01	0.22 ± 0.00	0.10 ± 0.01
	FYM	0.26 ± 0.01	0.23 ± 0.01	0.10 ± 0.01
	BIOW	0.26 ± 0.03	0.23 ± 0.00	0.10 ± 0.01

¹⁰³³ for the temperature range between 20-28°C and 28-35°C.

LTEs	Agricultural practices	Q10 equal to 1% of SOC mineralized		Q10 equal to miner	3% of SOC alized	
		20 - 28°C	28-35°C	20 - 28°C	28-35°C	
	CON-LC	1.38 ± 0.18	2.12 ± 0.40	1.66 ± 0.19	2.08 ± 0.75	
	ORG	1.55 ± 0.19	1.88 ± 0.16	1.57 ± 0.17	1.49 ± 0.20	
La Cage	CA	1.52 ± 0.29	1.97 ± 0.38	1.62 ± 0.28	1.42 ± 0.28	
	CON-QA	1.90 ± 0.63	2.39 ± 0.93	1.80 ± 0.46	2.32 ± 0.68	
	MSW	2.44 ± 0.51	1.84 ± 0.47	2.57 ± 0.86	2.02 ± 0.66	
	FYM	2.37 ± 0.42	1.68 ± 0.37	2.36 ± 0.39	1.83 ± 0.58	
QualiAgro	BIOW	2.53 ± 0.84	1.91 ± 0.51	2.45 ± 0.37	1.90 ± 0.39	

Table S2: Q₁₀ values equal to 1% and 3% SOC mineralized according to cropping systems