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## The Rock-Eval® signature of soil organic carbon in arenosols of the Senegalese groundnut basin. How do agricultural practices matter?

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1 **Title:** The Rock-Eval signature of soil organic carbon in Arenosols of the  
2 Senegalese groundnut basin. How do agricultural practices matter?  
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18

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20 Africa

## 21 **Abstract**

22 Soil organic carbon (SOC) ensures soil quality and productivity of cultivated systems in  
23 the Sahelian region. This study uses Rock-Eval pyrolysis to examine how cultural  
24 practices impact the quantity of SOC and quality of SOM in cultivated sandy soils in the  
25 Senegal groundnut basin. This cost-effective method provides information on SOC  
26 thermal stability, which has been shown to be related qualitatively to biogeochemical  
27 stability of SOC. We sampled soils within two villages in agricultural plots representative  
28 of local agricultural systems, and in two local preserved areas (tree plantation and  
29 shrubby savanna). SOC concentrations ranged from 1.8 to 18.5 g.kg<sup>-1</sup> soil in the surface

30 layer (0-10 cm) and from 1.5 to 11.3 g.kg<sup>-1</sup> soil in the 10-30 cm layer. SOC contents of  
31 cultivated soils decreased significantly (p-value < 0.0001) according to field amendment,  
32 in the following order: addition of organic wastes > addition of manure > millet residues  
33 left after harvest > no organic input. We found that the quantity and the quality of SOC  
34 are linked, and that both depend on land-use and agricultural practices, especially upon  
35 the type of organic inputs. Quantity of SOC and quality of SOM are correlated strongly in  
36 the tree plantation ( $R^2 = 0.98$ ) and in the protected shrubby savanna ( $R^2 = 0.97$ ). They  
37 are also correlated significantly in cultivated soils receiving organic wastes ( $R^2 = 0.82$ ),  
38 manure ( $R^2$  from 0.74 and 0.91), or millet residues ( $R^2 = 0.91$ ) but not in soils that  
39 receive no organic inputs. Indexes based upon Rock-Eval pyrolysis were represented in  
40 an I/R diagram that illustrates the level of SOC stabilization. The indexes of the studied  
41 soils were plotted against comparable results from literature. Thermal signatures of the  
42 Senegalese Arenosols show an inversion of I and the R indexes compared to data from  
43 the literature. This result highlights SOC stabilization as a function of soil depth. Indeed,  
44 the refractory pool in the studied soils (where refractory pool ranged from 7.7 to 21.3 %  
45 in the 0-10 cm layer, and from 12.5 to 24.3 % in the 10-30 cm) was more abundant  
46 than in Ferralsols in natural conditions, where refractory pool ranged from 2 to 9%. The  
47 soil organic matter in these Arenosols while positively affected by organic inputs, is  
48 dominated by more or less labile forms that mineralize quickly: a quality that is excellent  
49 for productivity of these agrosystems, but not for mitigation of climate change in the long  
50 term.

51

## 52 **1. Introduction**

53 Carbon (C) is the key element for the overall flow of both matter and energy in terrestrial  
54 ecosystems. It is thus involved directly or indirectly in all ecological functions of soils. Soil  
55 organic matter (SOM) constitutes a C stock three times larger than that of the vegetation  
56 from which it comes (Schmidt et al., 2011; Scharlemann et al., 2014). This organic  
57 reservoir obviously plays an essential role in the proper functioning of ecosystems.  
58 Certain agricultural practices that improve soil organic carbon (SOC) contents could  
59 contribute to improving the quality of soils, and therefore to the sustainable productivity  
60 of agroecosystems (Lal, 2018, 2004), while reducing or even offsetting anthropogenic  
61 greenhouse gas emissions (Minasny et al., 2017; Soussana et al., 2017). Thus, although  
62 cropping practices are aimed primarily at improving the productivity of agrosystems, they  
63 increasingly occupy a place in national plans to combat climate change (Schlesinger and  
64 Amundson, 2018). In general, the linkage between agricultural productivity and carbon  
65 storage seems well established (Ogle et al., 2005; Howden et al., 2007; Wood et al.,  
66 2018; Oldfield et al., 2019). For example, Lal (2006) estimates that in the developing  
67 countries, an increase in the stock of SOC (by  $1 \text{ MgC}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$ ) may increase the yield of  
68 food crops by 24-39 million  $\text{Mg yr}^{-1}$  while offsetting fossil-fuel emissions by 0.5 Pg C per  
69 year. Theoretically, it therefore seems possible to couple food security (Chabbi et al.,  
70 2017; Nath et al., 2018) and mitigation of anthropogenic carbon fluxes (Paustian et al.,  
71 2016) by identifying and promoting agricultural practices that contribute to SOC storage.  
72 Several agriculture practices, especially those based upon the organic inputs (Eden et al.,  
73 2017; Maillard et Angers, 2014; Fujisaki et al., 2018a) have been shown to increase SOC  
74 (Powlson et al., 2016). In sub Saharan areas, agroforestry parks are also reported to  
75 increase SOC (Corbeels et al., 2018).

76

77 While the effects of agricultural practices on SOC stocks are quite well documented  
78 (Arrouays, 2008; Chenu et al., 2014; Paustian et al., 2016), the same is not true for the  
79 effects of those practices upon the forms in which SOC is stored (Fujisaki et al., 2018ab;

80 Singh et al., 2018). By analysing the distribution of C among the particle-size fractions of  
81 different soils, Fujisaki et al. (2018b) found that the SOC content in the coarse fraction  
82 ( $> 50 \mu\text{m}$ ) of sandy soils was higher than in other soil types (specifically, Cambisols,  
83 Acrisols, Luvisols, Lixisols, Ferralsols, Nitisols, and Andosols). This fraction, which  
84 includes particulate organic matter, contained on average  $41.3 \pm 15.4\%$  of SOC  
85 regardless of soil texture. Wood et al. (2016) showed that crop yields were positively  
86 related to fast-cycling, particulate organic matter but negatively linked to slower-cycling,  
87 mineral-associated organic matter, thus questioning the view that stabilization of organic  
88 matter improves food security. A key issue regarding the linkage between food security  
89 and carbon storage concerns the biogeochemical stability of SOM: C sequestration  
90 involves increasing the stocks of SOC preferentially in pools with slow turnover, while  
91 improvement of agricultural productivity requires that SOC be in quickly mineralizable  
92 organic forms that can release nutrients that are essential for plant growth (Janzen,  
93 2006). The labile forms are particularly important in sandy soils, which by nature have a  
94 limited capacity for SOC storage (Yost and Hartemink, 2019).

95 Meeting these two challenges (productivity and mitigation) simultaneously requires  
96 documentation of both the quantity and the quality of SOC so that the practices leading  
97 to the best possible trade-off may be identified. It is from this perspective that we focus  
98 on the agro-sylvo-pastoral systems of West Africa. In this region, the integration of  
99 agriculture and livestock plays an important role in agricultural productivity and soil  
100 fertility. Indeed, the sustainability of agriculture in this area is based upon a strong  
101 complementarity between agriculture and livestock—specifically millet and cattle  
102 (Lericollais, 1999). Livestock practices (overnight parking, cattle fattening, range  
103 pasturing, etc.) impact agricultural practices, particularly organic manuring, that are  
104 essential to supporting the fertility of these low-OM-content soils (Ganry and Badiane,  
105 1998; Guérin and Roose, 2017; Harris, 2002; Tschakert, 2004). Manlay et al. (2004)  
106 estimate that in these agro-sylvo pastoral systems, animal-husbandry practices  
107 contribute up to 80% of the carbon, nitrogen, and phosphorus inputs. Night parking of

108 ruminant livestock is one of the main sources of OM, in the form of animal faeces and  
109 urine (De Rouw, 1999; Grillot, 2018). Cattle fattening is another local practice that  
110 generates OM for improving soil fertility (Grillot, 2018). The OM from animal husbandry  
111 and other practices is not applied homogeneously in these agro-sylvo-pastoral systems;  
112 instead, the landscape is organized in halos around villages (Manlay et al., 2004;  
113 Ramisch, 2005). A compound ring of fields adjoining the houses receives regular inputs  
114 derived from organic resources (manure or household wastes), while a bush ring of  
115 distant fields generally receives smaller amounts of exogenous organic inputs. Usually,  
116 the only organic inputs to that ring are crop residues left on the soil surface.

117 The Rock-Eval pyrolysis, developed by IFPEN for petroleum industry (Espitalie et al.,  
118 1986; Lafargue et al., 1998), is a simple, fast, cost-effective method for obtaining  
119 information on the carbon content, composition, and thermal stability of OM. In the  
120 context of soil science, it is recommended for quantitative and qualitative  
121 characterization of SOM (Derenne and Quenea, 2015; Disnar et al., 2003; Feller et al.,  
122 2010). The literature has shown that the thermal status of SOM during Rock-Eval  
123 pyrolysis provides an overall approximation of its biogeochemical stability (Barré et al.,  
124 2016; Fernández et al., 2011; Gregorich et al., 2015; Plante et al., 2011).

125 This study aims at identifying how agricultural practices influence SOC quantitatively and  
126 qualitatively in Sahelian agroecosystems. Management practices that increase C inputs in  
127 soil may be relevant for meeting food security and climate change challenges. However,  
128 the balance for OM decomposition that would provide soil nutrients and OM stabilization  
129 that would increase long-term carbon storage depends on the stability of the carbon  
130 fraction where the C is stored. We anticipated that SOC would be increased after organic  
131 inputs on farmers' field. More interestingly, we also expected that organic inputs would  
132 be an important control on SOM thermal status in these systems. We hypothesized that  
133 SOC is dominated by thermally labile forms in link with the sandy nature of the soils.  
134 Then we expected that the carbon stored in the sandy soils of these agro-ecosystems  
135 responds more to productivity needs than to the challenge of climate-change mitigation.

## 136 **2. Material**

### 137 **2.1. Study area**

138 The study area is in the Senegal groundnut basin, which is the country's main growing  
139 region. In this agricultural landscape, woody vegetation is dominated by *Faidherbia*  
140 *albida* distributed in parkland. The geological substratum consists of tertiary sandstones.  
141 The soils that developed upon this substratum have incorporated materials from aeolian  
142 deposits. They are classified as Arenosols (IUSS Working Group WRB, 2015), and are  
143 mostly low in clay (less than 5%, mainly kaolinite). Fertility is low due to low buffering  
144 and ion-exchange capacity. The climate is Sudano-Sahelian (average annual  
145 temperature: 30 ° C; average annual rainfall: 530 mm), marked by a very strong  
146 seasonal contrast. The short rainy season (from July to October) is suitable for crops.  
147 Soils are not exploited during the long dry season.

148 As our study area, we selected two villages (Diohine Sassem: 14°29'51"N and  
149 16°30'36"W; Sob: 14°29'16"N and 16°26'3"W) in the Niakhar Population-Environment-  
150 Health Observatory. Lands around the villages are organized in halos. Plots in the house-  
151 fields (i.e., those closest to the concession) receive larger amounts of inputs than the  
152 distant plots, which are referred to as the out-fields (Ramisch, 2005). Specifically, house-  
153 fields in our study area received between 5 and 8 Mg ha<sup>-1</sup> yr<sup>-1</sup> (dry weight) of organic  
154 inputs, vs. ≤ 1 Mg ha<sup>-1</sup> yr<sup>-1</sup> for the out-fields (Toukara et al., 2020). However, the  
155 quantity and quality of organic inputs vary even among the plots within a given ring.

### 156 **2.2 Selection of the cultivated situations**

157 Agricultural plots were mapped in the area by previous research projects. Together, the  
158 sets of soil samples from each field constitute a pedological library of *ca.* 1800 fields,  
159 from which we selected those of interest according to several criteria (Table 1). The first  
160 criterion is the type of organic inputs received by the agricultural plots in the previous  
161 year: (1) millet residues left at soil surface after harvest (denoted "+Millet residues"; n =  
162 10 out-fields; Table 1), (2) manure, consisting of uneaten plant residues plus ruminant

163 faeces and urine (denoted "+Manure"; n = 20 house-fields + 20 out-fields; Table 1), and  
164 (3) organic residual products consisting of crop residues, organic wastes from the  
165 households, and ashes ("Organic wastes"; n = 10 house-fields). In this study, the term  
166 "exogenous inputs" refers to situations in which organic products were applied by  
167 farmers as manure or organic wastes. We also included "No-input" situations (n = 20  
168 house-fields + 40 out-fields), which were cultivated plots that received either no organic  
169 amendments during the previous year, or only the annual fallow. The latter case was  
170 included because farmers practice a biennial crop rotation—especially in the territory of  
171 Diohine Sassem.

172 The soil samples analysed in this study were collected during either the cropping cycle  
173 (corresponding to the rainy season) or the non-cropping period (dry season). Samples of  
174 topsoil were taken from a 1-m square at the centroid of each plot. Two layers were  
175 sampled: 0-10 cm and 10-30 cm. Both layers have, potentially, been impacted by  
176 agricultural activities (FAO, 2003). In addition, the 30-cm depth is the minimum  
177 recommended for studying carbon storage in soils (IPCC, 2006). For each layer in each  
178 plot, a composite sample was prepared by mixing five separate samples: one from the  
179 square's centre, plus one from each of the corners.

180

### 181 **2.3 Local unexploited situations**

182 As reference samples of local soils in the study area, we sampled unexploited soils from  
183 two "preserved" situations that had gone decades without anthropogenic impacts: (i) a  
184 savanna area protected against human activities and cattle for more than 30 years in  
185 Mbadane (the neighbouring village of Diohine Sassem, 14°29'23"N and 16°35'36"W),  
186 with the shrub *Guiera senegalensis* as the main species; and (ii) a tree plantation  
187 established in 1976, and not exploited since (Bandia, 14°34'19"N and 17°00'54"W).  
188 Because the profiles of the unexploited soils are a valuable local reference for  
189 characteristics of preserved soils, we sampled them at five depth intervals (0-10, 10-20,  
190 20-30, 30-40, and 40–50 cm) rather than (as in the case of cultivated soils) only two.



191 For each depth interval in each plot, we took samples from the corners and centre of a 1-  
192 m square at the plot's centroid, then blended them to make a composite sample.  
193 Therefore, the resulting dataset included a total of 10 composite samples.

### 194 **2.3. External reference dataset**

195 As a basis for comparing the studied Arenosols to other situations, we used data  
196 published by Sebag et al. (2016) on Ferralsols ( $\leq 0-15$  cm deep) from profiles of soils in  
197 Gabonese forests and savannahs that had not been disturbed by human activities. The  
198 Rock-Eval signatures of the selected 87 samples, corresponding to organic layers (OL,  
199 OF, OH and Op,  $n = 25$ ) and organo-mineral layers (A, Ah;  $n = 62$ ), are representative of  
200 the diverse undisturbed situations reported in Sebag et al.'s (2016) worldwide dataset.  
201 The signatures of these 87 samples were referred to as the "Humic trend" by Sebag et al.  
202 (2016), as described in more details in the following section.

## 203 **3. Methods**

### 204 **3.1. Rock-Eval pyrolysis**

205 Samples of soil ( $< 200 \mu\text{m}$ , mass = 55 to 73 mg) were analysed at the University of  
206 Lausanne using a Rock-Eval 6 pyrolyser manufactured by Vinci Technologies. The  
207 analytical protocol consisted of two phases: (i) pyrolysis by heating from  $200^\circ\text{C}$  to  $650^\circ\text{C}$   
208 at  $25^\circ\text{C}/\text{min}$  in an inert atmosphere ( $\text{N}_2$ ); and (ii) oxidation of residual carbon in an  
209 artificial atmosphere ( $\text{N}_2/\text{O}_2$ : 80/20, starting at  $400^\circ\text{C}$  and ending at  $850^\circ\text{C}$  with a  
210 heating rate at  $20^\circ\text{C}/\text{min}$  (Behar et al., 2001; Lafargue et al., 1998). Gases released  
211 were monitored by a flame ionisation detector (FID) for hydrocarbon compounds (HC),  
212 and by infrared detectors (IR) for CO and  $\text{CO}_2$ . Total Organic Carbon (TOC in wt%) and  
213 Mineral Carbon (MINC in wt%) were calculated by integrating the amounts of HC, CO,  
214 and  $\text{CO}_2$  produced during thermal cracking of OM between defined temperature limits  
215 (Behar et al., 2001; Lafargue et al., 1998). Because carbonates are not present in our  
216 Arenosols, the SOC values found via Rock-Eval measurements are equal to the sum TOC

217 + MINC. Those values were strongly and positively correlated ( $R^2 = 0.99$ ) to the TOC  
218 contents that were measured with a CHN analyser (Supplementary material S1).

219 In this study, thermal status of SOM was characterized by combining two indexes  
220 (denoted R and I) calculated from five subdivided areas of the S2 thermograms related  
221 to HC (Disnar et al., 2003; Sebag et al., 2006; 2016). Areas were calculated between the  
222 following bounds (or nodes): 200-340°C for A1, 340-400°C for A2, 400-460°C for A3,  
223 460-520°C for A4, and 520-650°C for A5. The forms of S2 thermograms depend upon  
224 the OM cracking temperature, as expressed through five pools corresponding to the  
225 sections of the thermograms: highly labile (A1), labile (A2), resistant (A3), refractory  
226 (A4) and highly refractory (A5) (Disnar et al., 2003; Sebag et al., 2016, 2006).

227 By construction, the R-index ( $R = [A3+A4+A5]/100$ ) relates to the most thermally  
228 resistant and refractory pools of organic matter, while the I-index ( $I = \log_{10}[(A1+A2)/A3]$ )  
229 is related to the most thermally labile pools (details in Sebag et al., 2016). As derived  
230 from a mathematical construct, these two indexes may be heavily inversely correlated to  
231 each other when OM stabilization results from progressive decomposition of organic  
232 components according to their biogeochemical stability (Lehmann and Kleber, 2015).  
233 Then, a decrease in labile (A1 and A2) pools result in a concomitant increase in more  
234 thermally stable pools (A3 to A5), as observed in compost samples by Albrecht et al.  
235 (2015). In other words, the stable pools increase at the expense of the labile pools  
236 during the decomposition of OM. Thus, SOM thermal stabilization can be followed on a I-  
237 index vs R-index diagram (called thereafter I/R diagram) along a strong linear  
238 relationship, described as "Humic trend" in Sebag et al. (2016), as a continuum of  
239 decomposing organic materials in soil profile from biological tissues to a mixture of  
240 organic constituents derived from SOM humification (Lehmann and Kleber, 2015).  
241 Therefore, the "Humic trend" reflects the linear relationship between decaying processes  
242 of labile organic pools and OM stabilization in undisturbed (non-agricultural or non-  
243 human impacted) soils. However, situations with OM mixture from different sources or  
244 where decomposition is so intense that it even affects the more thermally stable pools

245 (A3 to A5) may generate a distribution in the I/R diagram aside the "Humic trend", i.e. a  
246 poorly related I-R indexes. Such situations were observed for instance in Fluviosol  
247 (Sebag et al, 2016), in Arenosol (Romanens et al., 2019; Sebag et al., 2016), in the B  
248 horizons of alpine soils derived from calcareous lithologies containing inherited (or  
249 « petrogenic ») OM (Matteodo et al., 2018), and in artificial substrates mixing minerals  
250 and fresh plant tissues (Schomburg et al., 2019, 2018). In this work, we use the "Humic  
251 trend" as a reference model and we focused on Delta-R ( $\Delta R$ ) calculated as the distance  
252 (or residual) from the "Humic trend" line ( $\Delta R = R_{\text{measured}} - R_{\text{model}}$ ).

253 The synthesis conducted by Sebag et al. (2016) on a worldwide panel of soils  
254 representative of contrasting situations shows a continuous evolution of these thermal  
255 parameters in the main horizons of soil: decrease of labile pools (A1 and A2) and I-index,  
256 and increase of stable pools (A3, A4 and A5) and R-index. Nevertheless, as pointed out  
257 by Sebag et al. (2016), *"in order to avoid any misinterpretation, it is necessary to*  
258 *emphasize that [...] this approach based on the new Rock-Eval I- and R-indices does*  
259 *neither identify nor quantify the elementary chemical compounds because four basic*  
260 *components (A1 to A4) cannot accurately describe the diversity of biological compounds*  
261 *and their soil derivatives".* However, a few studies make it possible to relate the thermal  
262 status to the chemical composition (Barré et al., 2016; Carrie et al., 2012;  
263 Soucémarianadin et al., 2018). Albrecht et al. (2015) show, for example, that Alkyl C is  
264 significantly and positively correlated with the most labile pool (A1), O-alkyl C and alkyl C  
265 are together significantly and positively correlated with labile pools (A1 and A2), phenolic  
266 C is significantly and positively correlated with thermally stable pools (A3, A4 and A5),  
267 and aromatic C significantly and positively correlates with the most refractory pools (A4  
268 and A5). Similar results are also obtained using the same methodology ( $^{13}\text{C}$  MNR  
269 spectroscopy) in a new recent publication (Le Mer et al., 2020). With another approach,  
270 Sanderman and Grandy (2020) recently indicated that the thermal fractions are, except  
271 for the most stable fraction, heterogeneous mixtures of fast- and slow- cycling SOM.  
272 Moreover detailed composition of different thermal fractions analyzed using stepped

273 pyrolysis–gas chromatography–mass spectrometry (Py-GC/MS) show a reproducible shift  
274 in the chemistry of pyrolysis products across the temperature gradient (between 330 to  
275 735°C) trending from mainly polysaccharides and lipids at low temperature to lignin- and  
276 biological-derived compounds at middle temperatures and dominant phenol, aromatic  
277 and unknown compounds at the highest temperatures (Sanderman and Grandy, 2020).

278

### 279 **3.2. Statistical analyses**

280 We used R software (R Development Core Team, 2013) for all statistical analyses.  
281 Analyses of variance (ANOVA) employed the Tukey test (HSD) at probability level  $p =$   
282 0.05. Linear, logarithmic, and power-law regressions used the ggplot2 package's *lm*  
283 function. Student's t-tests were carried out to determine the significance of the  
284 regressions. To display the distributions of data, we constructed box plots that show the  
285 minimums, the first quartiles, the median values, the third quartiles, and the maximum  
286 values, as well as the outliers when appropriate.

## 287 **4. Results**

### 288 **4.1. Soil organic carbon content**

289 SOC contents of Arenosols in preserved situations decreased gradually with depth (Figure  
290 1a). The average SOC in those soils was 4.5 g.kg<sup>-1</sup> soil in the 0-10 cm layer, versus 2.1  
291 g.kg<sup>-1</sup> in the 40-50 cm layer.

292 SOC contents in cultivated plots differed significantly, at both sampled depths, from  
293 those in "preserved" soils ( $p$ -value < 0.0001 for the 0-10 cm depth;  $p$ -value = 0.03 for  
294 the 10-30 cm depth). The magnitude of the difference depended upon the soil  
295 amendments. SOC contents were highest in situations where organic wastes were  
296 applied (Figure 1b). SOC contents in situations without exogenous organic inputs (No  
297 input;  $n = 60$ ; Figure 1b) were significantly higher at the surface than at depth ( $p =$   
298 0.01). In situations with millet residues left on field (+Millet residues;  $n = 10$ ; Figure 1b),

299 the SOC content measured at the surface was not significantly different ( $p = 0.05$ ) from  
300 the content at depth. In cultivated situations with manure inputs (+Manure;  $n = 40$ ;  
301 Figure 1b), SOC was significantly higher in the upper soil layer than below ( $p = 0.002$ ).  
302 In cultivated situations with organic-waste inputs (+Organic wastes;  $n = 10$ ; Figure 1b),  
303 SOC was also significantly higher at the surface than at depth ( $p$ -value = 0.01).

304 The location of the fields also seemed to impact SOC contents. House-fields had  
305 significantly higher SOC contents than out-fields ( $p$ -value < 0.0001). The SOC in fields  
306 that received manure was significantly higher in house-fields than in out-fields ( $p$ -value =  
307 0.02; Supplementary material 2a). In the plots that did not receive exogenous organic  
308 inputs, SOC was significantly higher in house-fields than in out-fields ( $p$ -value < 0.03;  
309 Supplementary material 2b). In contrast, the season (i.e. rainy or dry) does not seem to  
310 affect SOC contents significantly at any depth ( $p$ -value = 0.64; Supplementary material  
311 2c).

## 312 **4.2. Measurement of thermal stability by the Rock-Eval pyrolysis method**

### 313 **4.2.1. R-index**

314 For the studied Senegalese Arenosols, average R-index values were between 0.4 and 0.6  
315 at all depths and in all situations. The average R value was  $0.5 \pm 0.003$  (Figure 2). In  
316 Arenosols of preserved situations, the R-index decreased with depth (Figure 2a). In 0-10  
317 cm layer, the average R-index was 0.54, versus 0.5 in the 40-50 cm layer. In the surface  
318 layers (0-10 cm) of cultivated situations, the R-index did not differ significantly upon the  
319 soil amendments ( $p$ -value = 0.09). However, the R-index differed significantly according  
320 to soil amendments in the 10-30 cm layer ( $p$ -value < 0.01).

321 In situations without any exogenous organic input, the R-index was significantly higher at  
322 the surface than at depth ( $p$ -value < 0.02). This trend (surface R-index > R-index at  
323 depth) was also observed in situations with millet residue left in the field ( $p$ -value <  
324 0.03) and in situations where organic wastes were applied ( $p$ -value < 0.002). In  
325 contrast, in situations with manure the R-index was not significantly different in the 0-10

326 cm layer than in the 10-30 cm layer (p-value < 0.09). It should also be noted that in the  
327 0-10 cm depth, the R-index in preserved situations was not significantly different from  
328 that in the cultivated situations (p-value = 0.6).

#### 329 **4.2.2. I-index**

330 For the studied Senegalese Arenosols, average values of the I-index varied between 0.14  
331 and 0.6 in all depths, with an average value of  $0.34 \pm 0.01$  (Figure 3). In preserved  
332 situations, the I-index increased with depth (Figure 3a). The average I-index was 0.3 in  
333 the 0-10 cm layer and 0.5 in the 10-30 cm layer.

334 In cultivated situations, the I-index did not differ significantly upon the soil amendments  
335 at any depth (p-value > 0.4). In situations with no exogenous organic inputs, the I-index  
336 was significantly lower in the surface layer than in the 10-30 cm layer (p-value <  
337 0.0001). This trend (I-index in surface layer < I-index at depth) was also observed in  
338 situations with millet residue left in the field (p-value < 0.01) and in situations with  
339 manure (p-value < 0.004). On the other hand, in situations with organic wastes the I-  
340 index did not vary significantly with depth (p-value = 0.1). Moreover, the measured I-  
341 index in the 0-10 cm depth was not significantly different in preserved situations than in  
342 cultivated situations (p-value = 0.9).

#### 343 **4.2.3. R versus I**

344 For all situations, the correlation between R and I indexes of the studied Senegalese  
345 Arenosols is strong and linear (Figure 4). However, the slope of the regression line  
346 derived from the Senegalese Arenosols was larger (more negative) than that of the  
347 "Humic trend" derived from the Ferralsols studied by Sebag et al. (2016). This "Humic  
348 trend" is a satisfactory external reference set for our samples because according to the  
349 literature, organic compounds (such as composts) and the main soil classes studied thus  
350 far by the Rock-Eval pyrolysis fall along or close to the "Humic trend" line (Albrecht et  
351 al., 2015; Sebag et al., 2016; Matteodo et al., 2018; Schomburg et al., 2018, 2019).

352 Signatures of soils from preserved situations and plots that received the "+Millet  
353 residues" situation are fairly similar (Figure 4). R-index values for those soils are lower  
354 than for other cultivated soils, and their regression-line slopes are larger. Signatures are  
355 fairly comparable for cultivated soils amended with manure or with no exogenous organic  
356 inputs, although some samples of soil amended with manure fall along the "Humic  
357 trend". Signatures of soils that received organic wastes vary with depth: data points for  
358 the 0-10 cm layer fall along the "Humic trend", while signatures for samples from the 10-  
359 30 cm layer are comparable to those of the surface horizon of Senegalese Arenosols that  
360 either received no inputs, or were amended with manure.

#### 361 **4.2.4. S2 thermograms**

362 The average S2 thermograms and associated standard deviations in cultivated situations  
363 are shown in Figures 5a (for the 0–10 cm layer) and 5b (for the 10–30 cm layer). The  
364 area below each curve corresponds to the total HC amount (with respect to an equivalent  
365 sample weight) released during the pyrolysis phase. Those amounts are directly  
366 correlated to the amounts of organic carbon ( $R^2 = 0.81$ ; p-value <0.0001).

367 For each situation, HC contents were significantly larger in surface samples than in  
368 deeper layers, in agreement with results obtained for SOC contents (Figure 1). Moreover,  
369 S2 thermograms of surface-layer soils are qualitatively different from those from deeper  
370 layers (Figure 5ab): S2 thermograms of surface soils tend to be bimodal, but S2  
371 thermograms for deeper soils tend to be unimodal.

372 S2 thermograms for the 0-10 cm layer of preserved soils (savanna and tree plantation)  
373 are fairly comparable to those of cultivated soils that received either millet residues or no  
374 exogenous organic inputs. These S2 thermograms are different from those obtained for  
375 cultivated situations that received manure or organic-waste amendments. Indeed, the S2  
376 thermograms for situations with exogenous organic inputs (+Manure and +Organic  
377 wastes) have a bimodal distribution. The first mode corresponds to a relative enrichment  
378 of labile pools, mainly A2. The second mode corresponds mainly to an enrichment of  
379 more resistant or refractory pools, primarily A3 and A4.

380 Shapes of S2 thermograms for soils at lower depths in preserved situations are quite  
381 similar to those of cultivated soils that received either no exogenous organic inputs, or  
382 only the millet residues left on the field after harvest. The S2 thermograms for these  
383 situations are dominated significantly by A2, A3, and A4. In addition, their pool sizes  
384 show very little variance. The S2 thermograms obtained from soils at depth in situations  
385 with no inputs are unimodal. The peak corresponds to a relative enrichment of the  
386 resistant or refractory pools, mainly A3 and A4. In addition, the variability of pool sizes  
387 was quite large in S2 thermograms of soils collected at depth in the preserved situations,  
388 and in cultivated soils without any exogenous organic inputs. Specifically, the pools for  
389 no-input fields were distinct from those where millet residues were left on the soil surface  
390 after harvesting the crop.

## 391 **5. Discussion**

### 392 **5.1. SOC contents**

393 The SOC contents measured in preserved unexploited situations, in situations without  
394 any exogenous organic inputs, and in situations with millet residues left on field after  
395 harvest are comparable to those reported in the literature for sandy soils. Indeed, the  
396 meta-analysis by Yost and Hartemink (2019) has shown that in sandy soils in arid zones,  
397 the average levels of SOC are less than 5 g.kg<sup>-1</sup> soil. Feller (1979) reported SOC values  
398 ranging between 3 and 5 g.kg<sup>-1</sup> soil for sandy soils in Senegal. Bationo and Buerkert  
399 (2001) have reported SOC contents ranging between 1 and 8 g.kg<sup>-1</sup> soil in the Sudano-  
400 Sahelian zone of West Africa. Those results confirms that sandy soils are naturally poor in  
401 OM (Osman, 2018; McClintock and Diop, 2005). The SOC contents in our situations with  
402 millet residues left on fields are comparable to values found in Niger by Bationo and  
403 Buerkert (2001) during a long-term experiment (between 1984 and 1996) that applied 4  
404 T of crop residue ha<sup>-1</sup> along with mineral fertilisers (SOC between 1.7 and 3.3 g.kg<sup>-1</sup>  
405 soil). However, Yost and Hartemink (2019) and Bationo and Buerkert (2001) have both  
406 shown that organic inputs increase SOC in sandy soils. The SOC contents in our



407 situations with exogenous organic inputs (+Manure or +Organic wastes) were higher  
408 than those measured in other situations; i.e. in preserved sites, or in agricultural systems  
409 with either no inputs, or the "+Millet residues" application. These SOC contents were of  
410 the same order of magnitude as those measured by Šimanský et al. (2019) during 25  
411 years of experiments on sandy soils with inputs of manure (6.07 g.kg<sup>-1</sup> soil), or of  
412 manure + NPK (8.38 g.kg<sup>-1</sup> soil).

413 In preserved soils, the SOC was low despite regular additions of OM through litterfall  
414 from trees or shrubs. Arenosols are poor in SOC due to a fairly low primary production  
415 (Bationo et al., 2007; Blanchart et al., 2007), and to the sandy texture, which favours  
416 decomposition of OM and mineralization of SOC (Feller et al., 1991; Don et al., 2009).

417 In cultivated soils that received no exogenous organic inputs, or only the millet residues  
418 left in the field, SOC contents were fairly comparable on the whole to those for preserved  
419 soils. This result corroborates findings of Blanchart et al. (2007). Those authors have  
420 shown that in sandy soils, the content of SOC under perennial vegetation is comparable  
421 to that of soils in annual cultivation because sandy soils have a very low potential for  
422 carbon storage, given the quick decay of plant debris and soil OM. On the other hand,  
423 SOC content is significantly higher in situations with manure or organic wastes. This  
424 relative enrichment is particularly marked in samples taken from the 0–10 cm layer,  
425 because OM inputs constitute the most important lever for increasing SOC levels in  
426 tropical soils (Blanchart et al., 2007; Fujisaki et al., 2018a) as well as in temperate soils  
427 (Chenu et al., 2014). Numerous studies have shown that manure additions increase the  
428 organic carbon content of the soil (Haynes and Naidu, 1998; Li et al., 2018; Liu et al.,  
429 2013). Long-term treatment of soils with organic inputs can increase organic carbon  
430 contents in the topsoil by +24 to +92% depending on the type of organic amendment  
431 (Diacono and Montemurro, 2010). Daouk et al., (2015) showed that organic amendments  
432 contribute to increasing SOC significantly in sandy soils north-west of Dakar, particularly  
433 in the 0-10 cm layer. Liu et al. (2013) have also shown that improving soils with manure  
434 has positive effects on SOC stocks. Li et al. (2018) estimate that the composition of

435 manures rich in recalcitrant organic compounds contributes to high levels of organic  
436 carbon in soils treated with manure.

437 It also appears that SOC contents are affected by differences in management practices  
438 and inputs, which are in turn related to the "halo" arrangement of the village landscape:  
439 SOC contents are generally higher in house-fields than in out-fields. Because plot  
440 productivity relies upon the organic inputs, farmers concentrate organic amendments  
441 upon the house-fields in order to maximize agricultural yields near the compounds. This  
442 result agrees with findings obtained by Manlay et al. (2004) in Southern Senegal; by  
443 Corbeels et al. (2018) in East Africa; by Tiftonell et al. (2013) in Kenya and Uganda; and  
444 by Zingore et al. (2011) in Zimbabwe. All of these authors reported finding organic-  
445 carbon gradients in connection with an unequal allocation of organic resources between  
446 the fields closest to the compounds (house-fields) and the most distant (out-fields).

447

## 448 **5.2. Thermal stability as an indicator of SOC quality**

449  
450 Calculated R-index values of the Senegalese Arenosol topsoils were significantly lower (p-  
451 value < 0.0001) than those of the Gabonese Ferralsols (Sebag et al., 2016) that we used  
452 as a reference for general undisturbed situations (Figure 6a). However, Figure 6a shows  
453 that the R-index values for Arenosol topsoils with SOC < 5 g.kg<sup>-1</sup> soil are comparable to  
454 those of the Ah horizons of soils in the reference set (with SOC between 15.5 and 57.2  
455 g.kg<sup>-1</sup> soil). Those values for the two soils are comparable even though the R-index  
456 values of the Arenosol topsoils were lower than those of the A horizons in the reference  
457 set that had SOC contents between 3 and 73.2 g.kg<sup>-1</sup> soil.

458 Similarly, the I-indexes derived from Senegalese Arenosols were similar to those of the  
459 reference set's Ah horizons, and significantly higher than those of that set's A horizons  
460 (Figure 6b).

461 In summary, I/R signatures of the Arenosols' surface layers are close to the "Humic  
462 trend" (Figure 4) defined by Sebag et al. (2016), but the signatures of the 10-30 cm  
463 layer in the Arenosols deviate from this model.

### 464 **5.3. OM quality as a function of depth**

465 The surface layers of Senegalese Arenosols have higher R-index values and lower I-index  
466 values than the deeper layers. These signatures are contrary to those documented in  
467 other situations by Sebag et al. (2016) and Matteodo et al. (2018), who found that I-  
468 indexes decrease with depth, and that R-indexes increase. This inversion can be  
469 understood by examining the S2 thermograms from which we extracted the data (i.e.,  
470 the contributions of A1 to A5) used to calculate the two indexes.

471 The bimodal pattern of topsoil S2 thermograms reflects a relative enrichment of the labile  
472 (A2) and refractory (A4) C pools, and a corresponding impoverishment of the resistant C  
473 pool (A3). S2 thermograms of deeper soils have a unimodal pattern in which the  
474 resistant C pool (A3) predominates.

475 These characteristics provide an explanation for the differences between I/R signatures  
476 of the Senegalese Arenosols and those of the A horizons of the reference Gabonese  
477 Ferralsols, which are from natural situations but have similar contents of SOC. The A1  
478 contributions are slightly larger in the Arenosols (Supplementary material S3), than in  
479 the Ferralsols, but the A3 contributions are significantly smaller (Supplementary material  
480 S5). In both soils, the A2 contributions are broadly comparable (Supplementary material  
481 S4). Therefore, the I-index ( $I = \log_{10}[(A1+A2)/A3]$ ) in Arenosols is lower at the surface  
482 and higher at depth than in the Gabonese Ferralsols.

483 The inversion of the R-index trend may be explained by differences between the A3, A4,  
484 and A5 contributions. The A3 and A4 contributions are slightly smaller in the Arenosols  
485 (Supplementary materials S5 and S6), but the A5 contributions is two to three times  
486 larger (Figure 7). Therefore, the R-index ( $R = [A3+A4+A5]/100$ ), in the Senegalese  
487 Arenosols is higher at the surface than at depth, while the reverse is true in the

488 Gabonese Ferralsols that were used as references for plotting the I/R diagram (Figure 4).  
489 The higher values of A5 in our study, compared to those reported by Sebag et al.,  
490 (2016), reveal an extreme decomposition of OM in the sandy Arenosols: residual carbon  
491 generated by mineralization of C in pools A1 to A4 accumulates in the most-refractory  
492 pool (A5).

#### 493 **5.4. Quality of the OM according to the situations**

494 Analyses of the S2 thermograms highlight how the different situations affect the quality  
495 of OM.

496 The forms of the S2 thermograms of soils from preserved situations indicate small labile  
497 C pools, but larger pools of resistant and refractory C. The small size of labile C pools can  
498 be explained by high decomposition of OM in sandy soils (Feller et al., 1991). In the  
499 studied region, the combination of a long dry season and year-long high temperatures  
500 favours mineralization of labile C pools that are not physically protected (Badiane et al.,  
501 2000; Bationo et al., 2007). Therefore, both the resistant pool (A3) and the refractory  
502 (A4) pools increase, and become dominant over the more labile A1 and A2 pools.  
503 Albrecht et al. (2015), who considered composts an excellent material for studying the  
504 evolution of organic products, observed that Rock-Eval signatures change during the  
505 composting process: the A1 labile pool decreased from 32 to 23% between the 4<sup>th</sup> day  
506 and the 128<sup>th</sup> day of composting, while the A2 labile pool decreased from 33 to 26%  
507 during the same period. The more stable pool (A3 + A4 + A5) increased correspondingly.  
508 Our results are comparable: the resistant pool (A3) and the refractory pool (A4)  
509 decreased, leading to a relative increase in the most-refractory pool (A5).

510 S2 thermograms of soils in cultivated situations that received no exogenous organic  
511 inputs are similar to those that received only some millet residues: the labile pools in  
512 both are larger than those of soils in preserved situations. This labile C pool favours the  
513 growth of crops that produce more biomass (fine roots and future litter) capable of  
514 enriching soils with fast-cycling carbon (Balesdent et al., 2013). In contrast, vegetation

515 in soils of preserved areas consists of woody species with larger roots. Balesdent et al.  
516 (2013) have shown, for example, that the carbon transferred by roots of wheat plants  
517 consists largely of sugars which decay very quickly, thereby contributing to increasing  
518 the labile C pools. The increase of that pool is also favoured by tillage and coarse soils,  
519 both of which increase soil aeration, and thereby provide aerobic conditions that speed  
520 the decay of organic compounds.

521 Compared to other cultivated situations, those that received organic wastes or manure  
522 had larger labile, resistant, and refractory pools. The literature reports that manure  
523 applications increase slow-cycling C pools while contributing, as well, to growth of labile  
524 C pools (Majumder et al., 2008; Liu et al, 2018; Liang et al., 2012). Indeed, the bimodal  
525 shape of the S2 thermograms for situations that received organic wastes or manure  
526 shows that the thermal C pools were not increased equally. Organic inputs increased the  
527 size of the most labile C pools (A1 and A2, grouped in the first peak of the  
528 thermograms), which mineralize very quickly because they are more sensitive to land  
529 management (Bongiorno et al., 2019; Awale et al., 2017) and to activity of soil  
530 microorganisms (Pansu, 1991; von Lützwow et al., 2007). The greater variability of the  
531 labile pool size in soils receiving manure or organic wastes could be explained by  
532 differences in the quantity and the frequencies of inputs, the methods of application and  
533 the quality of the amendments (Bhogal et al., 2018), which all differ among households.  
534 In contrast, the size of more refractory C pool can be explained by Dragon and Icard  
535 (2010)'s finding that OM which has not decomposed became more complex and  
536 stabilized. The burning of some components collected from households generates ashes,  
537 the presence of which in household wastes (which are applied mainly to house-fields)  
538 could explain the size of the refractory C pool. Lutfalla et al. (2017) reported that  
539 combustion of organic products has such an effect on refractory-C pools in temperate  
540 soils. Sandermann and Grandy (2019) also reported that stable aromatics and phenols  
541 that may compose the most thermal refractory pool can be attributed to the fire events.

542 In summary, results from the Rock-Eval pyrolysis highlighted the presence of (i) a  
543 significant refractory C pool that is quite comparable in size for all situations in the  
544 studied agrosystem, and (ii) the dominance of a thermally labile C pool that does vary  
545 among situations. Specifically, the size of that pool increases as follows: preserved < No-  
546 input < +Millet residues < +Manure < +Organic wastes. Le Mer et al. (2020) recently  
547 showed that OM stabilization through the formation of aggregates and/or organo-mineral  
548 associations resulted in an increase of the most stable pools. However, as the Arenosols  
549 are poor in clay, it can be assumed that beside A1 and A2 pools the A3 and even A4  
550 pools could also be mineralized because they were not protected from degradation by  
551 organo-mineral complexation, or by formation of aggregates (as a consequence of  
552 dominance of quartz particles in sandy soils; Lehmann and Kleber, 2015; Osman, 2018).  
553 The lack of OM protection, associated with a low SOC content, suggest an easy access to,  
554 and a rapid turnover of SOC in Arenosols. This extreme mineralization impedes renewal  
555 of the A3 and A4 pools, thereby leading to a relative accumulation of organic C in the  
556 most-refractory pool (A5), but this slow-cycling C pool is also limited in size by the sandy  
557 nature of soils nonetheless (Yost and Hartemink, 2019). This mineralization of relatively  
558 stable C pool (i.e. A3 and A4) would also explain the particular signature of the studied  
559 soils in the I/R diagram (i.e. above the "Humic trend"): the decrease in the relative  
560 contributions of A3 and A4 is counterbalanced by the corresponding increase of A5 in the  
561 calculation of the R-index ( $R = [A3+A4+A5]/100$ ), but the decrease in A3 results in a  
562 relative increase in the I-index ( $I = \log_{10}[(A1+A2)/A3]$ ) compared to soils with an  
563 equivalent R-index. This hypothesis appears to be consistent with the results recently  
564 published by Sanderman & Grandy (2020) which confirm that the most abundant  
565 compounds at middle pyrolysis temperatures (between 400 and 500°C) are still  
566 mineralizable, especially those corresponding to A3 which are still rich in polysaccharides.  
567 It would then be logical to generalize this hypothesis to all sandy soils, which is  
568 consistent with previous results showing that other Arenosols (in Niger, North Cameroon  
569 and Bolivia; in Fig. 3D from Sebag et al., 2016) or sandy soils (Botswana, in fig. 4 from  
570 Romanens et al, 2019) have a specific signature above the "Humic trend".

571 Some researchers have argued strongly that the long-term build-up of SOM will have co-  
572 benefits for both food security and climate change mitigation (Lal, 2004). Arenosols have  
573 low SOC that mainly relied on the thermal labile C pools which are affected by short-term  
574 organic inputs, confirming reports from literature on low biogeochemical stability of SOM  
575 in sandy soils (e.g., Fujisaki et al, 2018; Yost and Hartmink, 2019). Previous studies  
576 reported the relationship between the thermally labile SOC pool obtained from Rock-Eval  
577 pyrolysis and C derived from a SOM fractionation scheme isolating particulate organic  
578 matter (POM; Saenger et al., 2015; Soucémarianadin et al., 2018). POM represents a  
579 fast-cycling SOC pool with a residence time of ca. a couple decades that is meaningful  
580 regarding SOC stock changes. However, fast SOM decomposition in the studied Arenosols  
581 seems to also affect SOC pools that would be considered as more thermally stable in  
582 other environments. Then, organic annual inputs would therefore be necessary to keep  
583 SOM at an adequate level for soil fertility, to ensure stability of yields and contribute to  
584 food security. But, especially within the context of high competition for organic resources  
585 in sub-Saharan Africa, these organic inputs could be insufficient to replenish mineralized  
586 labile C at a level that would allow on the long term accumulation of SOC in soils serving  
587 SOC sequestration and climate change mitigation purpose.

## 588 **5.5. SOC quantity versus SOM quality depending upon the situations**

589 As described in Section 3.1, the value of Delta-R ( $\Delta R$ ) for each soil sample was calculated  
590 as the deviation of that sample's R-index from the reference model obtained for  
591 Gabonese Ferralsols, which we considered representative of general undisturbed  
592 situations (Sebag et al., 2016). By construction, positive Delta-R values reflect an excess  
593 of more thermally stable C pools (A3+A4+A5) compared to soils in the reference set.  
594 Interpretation of the  $\Delta R$  values is aided by a study of the relative sizes of the resistant,  
595 refractory, and highly refractory pools (A3, A4, and A5 respectively) involved in the  
596 calculation of the R-index. Linear regressions between  $\Delta R$  and each of these pools (Table  
597 2) reveal that the A5 pool is strongly and positively correlated to  $\Delta R$  ( $R^2 = 0.92$ ; p-value

598 < 0.0001). On the other hand,  $\Delta R$  is strongly and negatively correlated with A3 ( $R^2 =$   
599 0.88; p-value < 0.0001) and more weakly with A4 ( $R^2 = 0.46$ ; p-value < 0.0001).

600 Moreover,  $\Delta R$  is linearly and strongly correlated with SOC content in the two preserved  
601 situations ( $R^2 = 0.96$  in both the tree plantation and the protected savanna area; Figure  
602 8a). At these two sites, the  $\Delta R$  value is low at the surface and higher at depth (Figure  
603 8a). The surface layers in these unexploited soils are enriched in carbon by biological  
604 contributions from woody vegetation. The strong linear correlation between SOC and  $\Delta R$ ,  
605 together with an increase in the refractory C pool and the gradual decrease in SOC,  
606 suggest that the labile biological contribution in these soils is being diluted by stabilized  
607 refractory SOC from surface to depth.

608 In the No-input situations, the correlations between SOC and  $\Delta R$  are generally weak with  
609 coefficients of determination ranging from 0.15 to 0.54 and not significant (Figure 8bcd).  
610 The absence of relationship between the two terms means that in the absence of  
611 significant biological contributions, SOC levels are generally low, and the processes of OM  
612 decomposition and SOC mineralization that can be variable in time and space lead to the  
613 quality of OM being independent of the quantity of SOC.

614 In situations with organic inputs (+Millet residues, +Manure and +Organic wastes) the  
615 deterministic (logarithmic-type) and significant relationships between SOC content and  
616  $\Delta R$  ( $R^2$  ranging from 0.74 to 0.91;  $p < 0.001$ ) would suggest that organic inputs and  
617 their stability constitute in cultivated Arenosols a key factor, linking quality of SOM and  
618 quantity of SOC (Figure 8efg). Indeed, as previously discussed the thermal A3 pool in  
619 these soils may be subjected to relatively fast decomposing processes so that a decrease  
620 in its relative contribution benefits to the A5 pool into the calculation of the R-index ( $R =$   
621  $[A3+A4+A5]/100$ ), affecting in turn the deviation of that R-index from the "Humic  
622 trend". In the reference model obtained from Ferralsols, the A3 pool is considered as a  
623 thermally resistant C pool being relatively protected from degradation by association with  
624 minerals (Sebag et al., 2016). In addition, the logarithmic type of the relationship  
625 between SOC content and  $\Delta R$  in cultivated situations compared to the linear one in



626 preserved situations suggests that these anthropogenic inputs are more efficient in terms  
627 of C storage in soils than natural inputs since, for equivalent quality, the lower  $\Delta R$ , the  
628 higher SOC contents. This result is in agreement with studies which have shown that in  
629 tropical sandy soils, the organic inputs, especially those exogenous, are essential for  
630 their fertility and influences the forms of SOC, especially the fast-cycling ones (Feller and  
631 Beare, 1997; Fujisaki et al., 2018a).

## 632 **5.6. Limitations of the study**

633 SOC contents are known to be affected by soil management, and may change quickly due to high  
634 decomposition of SOM and mineralization of SOC. The sample set used in the study was derived from  
635 an existing soil collection that didn't allow us to investigate the possibility that decomposition and  
636 mineralization processes vary seasonally. Although most of the management practices employed in  
637 the region's cultivated systems are consistent over the years, only the management used on each  
638 plot during the previous year was used as a criterion for sorting soil samples into categories.  
639 Moreover, amounts of organic inputs applied on soil were not recorded. Additionally, the dominance  
640 of the labile C pools in surface layers of cultivated soils that received manure or organic wastes may  
641 reflect a phenomenon known as 'priming', in which these inputs cause changes to the dynamics of  
642 SOC. Either a more-oriented sampling or an experiment design with controlled applications of  
643 organic products would address current limitations, and improve the understanding of the link  
644 between SOC quantity and SOM quality in these Arenosols.

645

## 646 **6. Conclusion**

647 Rock-Eval signatures of these sandy soils reveal an inversion of I and R indexes  
648 compared to those reported in the literature for other classes of soils and then a specific  
649 I/R signature for Arenosols. In cultivated soils of the Senegal groundnut basin, SOC  
650 storage is highly dependent upon the type of farming practices. Cultivation practices

651 based upon the organic amendments like manure or organic wastes influence the  
652 quantity of SOC and quality of SOM, which are closely linked. Indeed, this study made it  
653 possible to show that the nature of organic inputs, which affects the forms in which SOC  
654 will be stored, is an important driver in conditioning SOM thermal stability. In these  
655 Arenosols of Sahelian agrosystems, the thermally highly-refractory pool that is probably  
656 generated by high SOM decomposition and SOC mineralization is relatively more  
657 important in these soils than in Ferralsols but not affected by agricultural practices. Thus  
658 SOC variations in Arenosols are governed by organic inputs that generates thermally  
659 labile OM forms which would decompose quickly, supplying nutrients to the crops. In  
660 other words, the SOM in these agrosystems contributes to soil fertility, and thus  
661 responds more to the needs of agricultural production than to climate change mitigation,  
662 which requires long-term C storage. Even if Arenosols cannot store large amounts of C  
663 and thus cannot contribute significantly to climate change mitigation, regular applications  
664 of exogenous organic matter in these cultivated systems is essential for improving  
665 productivity and for adaptation to climate change. Enhancing food production is still the  
666 major goal in many tropical countries, especially in sub-arid Western Africa but  
667 competition for organic resources is high in local agro-pastoral systems and organic  
668 inputs may not be available enough to farm smallholders.

669 The findings from this study add to the growing body of literature using Rock-Eval  
670 pyrolysis as a tool to understand the thermal status of SOM when managing agricultural  
671 systems but still need clarification on the mechanisms behind and real impact on crop  
672 yields. Future work should rely on *in-situ* experimental design testing amounts and type  
673 of organic inputs in cropping systems and push forward with studies connecting thermal  
674 approach to SOM cycling concept to avoid misinterpretations on the biogeochemical  
675 stability, especially in the particulate context of Arenosols.

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989 **Tables**

990 Table 1. Selection criteria for the 120 plots chosen among the *ca* 1,800 cultivated  
 991 situations composing the agricultural mapping of the area.

Selected situations	N	Place of collection		Land-use		Time of collection	
		House- fields (n)	Out- fields (n)	Annual Fallow	Under cultivation	Cropping season	Off-crop cycle
No input	60	+ (20)	+ (40)	+	+	+	+
+Millet residues	10	-	+ (10)	n.a.	+	+	-
+Manure	40	+ (20)	+ (20)	n.a.	+	+	+
+Organic wastes	10	+ (10)	n.a.	n.a.	+	-	+

*The plus (+) sign means that the situation was collected in the existing sample set and selected in the studied set as representative of the agriculture systems; The minus (-) sign means that the situation was considered uncommon, and wasn't collected in the existing sample set; n.a., non-applicable, refers to situations that do not exist in the agricultural systems of the studied area.*

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1003 Table 2. Correlation matrix between Delta-R and the resistant pool (A3%), the refractory  
 1004 pool (A4%), and the highly refractory pool (A5%) in all situations studied.

<b>Delta-R vs.</b>			
	Resistant pool (A3 %)	Refractory pool (A4 %)	Refractory pool (A5%)
Equation	$y = - 0.009 * x + 0.28$	$y = - 0.012 * x + 0.26$	$y = 0.0093 * x + 0.08$
R <sup>2</sup> value	0.88	0.49	0.92
p-value <sup>a</sup>	***	***	***

<sup>a</sup> \*\*\* indicates that the difference was significant at  $p < 0.001$

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1007 **Figure captions**

1008 Figure 1. Soil organic carbon (SOC) contents (a) along the soil profile in the unexploited  
1009 situations (tree plantation and preserved shrubby savanna), (b) at 0-10 and 10-30 cm  
1010 depths in the different agricultural situations. Lines corresponded to average values, by  
1011 depth, of all situations being considered.

1012 Figure 2. R-index in (a) preserved situations according to soil depth, and (b) agricultural  
1013 systems according to amendment application and soil depth.

1014 Figure 3. I-indexes in (a) preserved situations according to soil depth, and (b)  
1015 agricultural systems according to amendment application and soil depth.

1016 Figure 4. R vs I indexes derived from the Rock-Eval pyrolysis performed on the  
1017 Senegalese Arenosols (the present study), and compared to the model derived from  
1018 Gabonese Ferralsols used as an external reference (Sebag et al., 2016).

1019 Figure 5. S2 thermograms obtained by [Rock-Eval](#) pyrolysis of (a) the surface layer, and  
1020 (b) the deep layer for the different situations: preserved (grey), no input (black),  
1021 +millet residues (brown), +manure (deep pink), and +organic wastes (dark green).  
1022 Note that the vertical-axis scales are not the same for (a) and (b).

1023 Figure 6. R-indexes (a) and I-indexes (b) in the surface layers (0-10 cm) of Senegalese  
1024 Arenosols (this study) compared to the same indexes in the A or Ah horizons (depth  $\leq$   
1025 15 cm) of Gabonese Ferralsols used as the external reference set (Sebag et al., 2016).

1026 Figure 7. A5 contribution (%) in the surface layers (0-10 cm) of Senegalese Arenosols  
1027 (this study) compared to the contributions of A5 in the A or Ah horizons (depth  $\leq$  15  
1028 cm) of Gabonese Ferralsols (serving as the external reference set; Sebag et al., 2016).

1029 Figure 8. Correlations between SOC ( $\text{g.kg}^{-1}$  soil) and Delta-R: (a) for all analysed soil  
1030 depths in the two preserved situations; (b) for cultivated situations (collected during or  
1031 outside of the crop cycle ) in house-fields that received no organic inputs, at soil depths

1032 0-10 and 10-30 cm; (c) same as (b), but in out-fields; (d) in annual fallows; (e), with  
1033 manure application in house-fields; (f) with manure application in out-fields; and (g), in  
1034 out-fields with millet residues or house-fields receiving organic wastes.

### 1035 **Supplementary materials - Figure captions**

1036 Supplementary Material S1. Correlation between SOC contents ( $\text{g.kg}^{-1}$  soil) measured by  
1037 Rock-Eval pyrolysis and by dry combustion with a CHN analyser.

1038 Supplementary material S2. SOC ( $\text{g.kg}^{-1}$  soil) in the different situations, according to (a)  
1039 the field location, (b) the use of the plot, and (c) the season.

1040 Supplementary Material S3. A1 contributions (%) in the S2 thermograms obtained by  
1041 Rock-Eval pyrolysis of the surface layers (0-10 cm) of Senegalese Arenosols (this  
1042 study) compared to values in the A or Ah horizons (depth  $\leq$  15 cm) of Gabonese  
1043 Ferralsols (serving as the external reference set; Sebag et al., 2016).

1044 Supplementary Material S4. A2 contributions (%) in the S2 thermograms obtained by  
1045 Rock-Eval pyrolysis of the surface layers (0-10 cm) of Senegalese Arenosols (this  
1046 study) compared to values in the A or Ah horizons (depth  $\leq$  15 cm) of Gabonese  
1047 Ferralsols (serving as the external reference set; Sebag et al., 2016).

1048 Supplementary Material S5. A3 contributions (%) in the S2 thermograms obtained by  
1049 Rock-Eval pyrolysis of the surface layers (0-10 cm) of Senegalese Arenosols (this  
1050 study) compared to values in the A or Ah horizons (depth  $\leq$  15 cm) of Gabonese  
1051 Ferralsols (serving as the external reference set; Sebag et al., 2016).

1052 Supplementary Material S6. A4 contributions (%) in the S2 thermograms obtained by  
1053 Rock-Eval pyrolysis of the surface layers (0-10 cm) of Senegalese Arenosols (this  
1054 study) compared to values in the A or Ah horizons (depth  $\leq$  15 cm) of Gabonese  
1055 Ferralsols (serving as the external reference set; Sebag et al., 2016).