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## Humus components and biogenic structures under tropical slash-and-burn agriculture

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1 **Humus components and biogenic structures under tropical slash-and-**  
2 **burn agriculture**

3

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9

10 *Short running title: Humus under slash-and-burn cultivation*

11

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15

16 **Summary**

17

18 Slash-and-burn cultivation in the humid tropics can cause changes in the  
19 composition of topsoil, depending on the duration of the fallow. We studied  
20 differences between practices, using the small-volume micromorphological  
21 method, to quantify the distribution of solid components in the topsoil,  
22 concentrating on plant organs and biogenic structures created by soil animals.  
23 We compared samples of topsoil from five plots, two at Maripasoula, an Aluku  
24 village along the river Maroni (French Guiana), with short fallow ( $\leq 8$  years), and  
25 the other three at Elahe, a Wayana village along the same river, with long fallow

26 ( $\geq 25$  years). At both sites structures created by arthropods other than ants  
27 gave way to ones formed by ants and annelids under the influence of fire and  
28 cultivation. This change was more abrupt under long fallow, because of the time  
29 needed to restore the arthropod community. Charcoal and charred plant  
30 material were incorporated by earthworms into the mineral soil, forming dark  
31 grey to black aggregates. Charcoal became mixed with the mineral soil faster at  
32 Elahe than at Maripasoula, where it accumulated in the topsoil. The reason  
33 seems to be an imbalance between charcoal inputs (from repeated fires) and  
34 the capacity of burrowing animals (earthworms, ants) to mix it with the mineral  
35 soil.

36

## 37 **Introduction**

38

39 Traditional shifting agriculture in the tropics balanced food production and  
40 nature conservation. In French Guiana, this long-lasting equilibrium is  
41 threatened by increasing demographic pressure and settling of cultivators for  
42 social welfare, schools, medical care and administration. In Maripasoula  
43 (population 1200), a settlement along the Maroni river (bordering French  
44 Guiana and Suriname) of mostly Aluku people (of African lineage), the duration  
45 of fallow in the slash-and-burn system has decreased from 15 to 7-8 years in  
46 the last thirty years. It is much shorter than the 15 to more than 100 years in the  
47 traditional shifting cultivation still practised by Wayana Amerindians as in the  
48 village of Elahe (Fleury, 1998).

49

50 Under traditional shifting cultivation (alternating short periods of cropping  
51 with long fallows), burning of woody vegetation before cultivation fertilizes the  
52 soil with ashes. During the fallow, the nutrient status of the soil, impoverished by  
53 crops, regenerates after several years from the organic matter added by the  
54 regrowth of vegetation, and we know from many accounts how important soil  
55 organic matter is for the maintenance of soil fertility in the tropics. The  
56 stabilization of soil organic matter within biogenic structures such as earthworm  
57 faeces help to preserve a reservoir of water, nutrients and space in which plant  
58 roots, animals and microbes can grow. Among other approaches, the fate of  
59 charcoal, from incomplete combustion of wood, has been considered of  
60 potential use for alternative systems of tropical agriculture (Glaser *et al.*, 2002;  
61 Lehmann *et al.*, 2003; Glaser & Woods, 2004). Glaser *et al.* (2001) found that  
62 charcoal is a source of stable and fertile humus in Amazonian Terra Preta. Our  
63 own experiments showed that the combined use of charcoal and manioc peel  
64 could sustain legume production on rather infertile tropical soils (Topoliantz *et*  
65 *al.*, 2005).

66

67 The present study was done in southern French Guiana. Its aim was to  
68 compare the impact of slash-and-burn cultivation on humus components and  
69 biogenic structures in the soil of two agricultural systems, differing in the  
70 duration of the fallow (8 years in Maripasoula and >100 years in Elahe) and that  
71 of continuous cultivation (1 year in Maripasoula, 3 years in Elahe). Manioc  
72 (*Manihot esculenta* Cranz) was the major crop in both villages. These sites  
73 were chosen as typical examples of (i) traditional shifting agriculture, and (ii)  
74 change to permanent agriculture, on the basis of preliminary investigations on

75 the impact of agricultural practices on soil fertility along the Maroni river  
76 (Grandisson, 1997). The crop (manioc) was the same and the soils (Oxisols)  
77 are similar. The two sites differ only in the way they are managed.

78

## 79 **Materials and methods**

80

### 81 *Study sites*

82

83 The first site, typical of traditional slash-and-burn shifting agriculture, is  
84 upstream of the Amerindian Wayana village of Elahe, on the Tampock river, a  
85 subsidiary of Maroni (N 3°26'; W 53°59'). Three years ago a family had cut and  
86 burned contiguous fields (abattis) within a secondary forest. This forest seemed,  
87 from a census of woody species typical of mature forests such as *Astrocaryum*  
88 *sciophilum* (Miquel) Pulle and *Dicorynia guianensis* Amsh. (Poncy *et al.*, 2001),  
89 to have been let untouched for at least 100 years. We sampled an abattis which  
90 had been under cultivation for 3 years (EA), and the nearby untouched old  
91 secondary forest (EF) in July 1999, approximately 100 m from EA. The plot in  
92 the secondary forest was resampled in May 2000 after it was burnt in December  
93 1999 for cultivation (EFB).

94

95 The second site is by the Maroni river (N 3°39'; W 54°2') near  
96 Maripasoula, 25 km downstream of the first site. It is in a large village inhabited  
97 mostly by Aluku people (black people of African lineage, descended from slaves  
98 who escaped at the end of the 18th century). During the last thirty years the  
99 increase of the population decreased the surface of cultivable land per family

100 and the duration of the fallow (Fleury, 1998). We sampled a one-year-old abattis  
101 at the end of the crop period, opened by an Aluku family by burning an 8-year-  
102 old woody fallow (MA), and the nearby unburnt fallow (MF), approximately 100  
103 m from MA. The latter plot was characterized by typical pioneer woody species  
104 such as *Cecropia latiloba* Miq. and *Inga capitata* Desv. Unlike the inhabitants of  
105 Elahe village, who can exploit the same abattis for two or three years because  
106 cultivation occurs after long fallow, cultivators living in Maripasoula do not crop  
107 the same field for more than one season, due to a rapid decrease of yield and  
108 the invasion of their fields by weeds and crop parasites (Fleury, 1998). As  
109 above we sampled both plots in July 1999. We intended to resample in 2000  
110 the woody fallow plot (MF), which should have been burnt in December 1999 by  
111 the Aluku family, but as it was not burnt and so we could not resample it as for  
112 EFB.

113

114         The mean size of abattis is 2 ha at Maripasoula and 1 ha at Elahe. At  
115 both sites, manioc is the basic food crop, and is supplemented by fishing and  
116 hunting. Abattis are roughly circular, originating from cutting and burning the  
117 forest in places accessible by foot or by canoe. The people of both communities  
118 prefer soils that are sandy. The Wayanas also prefer dark soils. Both people  
119 avoid valleys. In each abattis all tree trunks and saplings are cut, except those  
120 kept as holy trees. The felled trees are allowed to dry. Some wood is taken for  
121 timber and cooking, and the rest is burned and its residues left on the field.  
122 Manioc cuttings, from previous crop, are planted after resprouting. The soil is  
123 not cultivated, but excavated locally to plant the cuttings and then refilled with a  
124 hoe. The aspect of the site is used to select places proper for burying manioc

125 cuttings. Hollows in the undulating terrain are often used for bananas or rice.  
126 The main differences between Aluku and Wayana practices lie in the duration of  
127 the crop. Each year Alukus cut and burn new abattis around the village,  
128 whereas the Wayanas use the same abattis for two or three years, the precise  
129 duration depending on the soil's fertility and the spontaneous establishment and  
130 resprouting of vegetation, then shift to another place. They weed only by hand  
131 during the first four months following manioc planting, and they do not use  
132 herbicides, pesticides or fertilizers.

133

134 The climate is warm (mean annual temperature 26°C) and rainy (2000  
135 mm per year), with a main dry season from September to December and a  
136 shorter one from March to April. Table 1 lists the main physico-chemical  
137 properties of the topsoil (Oxisol) which was sampled in the study plots. At both  
138 sites the soil was sandy and acidic, although slightly less acidic in Maripasoula  
139 (pH~5.0) than at Elahe (pH~4.7). The soil was air-dried before transport to the  
140 laboratory for chemical analyses. Soil pH was measured electrometrically on a  
141 1:2.5 soil:water mixture. Total C and N were measured by the dry combustion  
142 method after hydrochloric dissolution of carbonates according to ISO 10694 and  
143 ISO 13878, respectively (Anonymous, 1999).

144

145 *Soil micromorphology: the small-volume method*

146

147 We studied the distribution of humus components and biogenic structures in  
148 topsoil by small-volume micromorphology *sensu* Bernier & Ponge (1994),  
149 further refined for biogenic structures by Peltier *et al.* (2001) and adapted by us

150 to agricultural soils (Topoliantz *et al.*, 2000). This optical method allows one to  
151 identify and estimate the proportion of solid components in successive layers of  
152 a given soil profile. Combined with multivariate methods, it can be used to  
153 compare soil profiles along gradients (Peltier *et al.*, 2001; Frak & Ponge, 2002;  
154 Sadaka & Ponge, 2003) and in vegetation patchworks (Patzel & Ponge, 2001).

155

156 Five samples for micromorphological analyses and five samples for  
157 physico-chemical analyses were taken in each of the five study plots. They  
158 were regularly spaced along a 30-m transect crossing the centre of each plot.  
159 This allowed us to embrace within-plot variation while avoiding edge effects.

160

161 For micromorphological investigations we took soil blocks 7 cm x 7 cm x  
162 6 cm (length x width x height) which we shaped with a sharp knife without  
163 disturbing litter nor soil structure. Then we separated the top 5 cm by hand in  
164 successive layers 0.5 to 3 cm thick according to their appearance, which we  
165 considered homogeneous. Each layer was immediately fixed in 95% ethyl  
166 alcohol then transported to the laboratory for further analysis. In the immediate  
167 vicinity of each sampling plot another sample (10 cm deep) was taken, air-dried  
168 as soon as possible before transport to the laboratory for physico-chemical  
169 analyses. A total of 251 layers (for micromorphological analyses) and 25 topsoil  
170 profiles (for physico-chemical analyses) were sampled.

171

172 The material from each layer was gently spread in a Petri dish (150 mm  
173 diameter), with as little disturbance of the aggregates as possible, and then  
174 covered with alcohol. Ethyl alcohol precipitates colloids, thereby helping to



175 preserve aggregates, provided they are not crushed by forcing them with an  
176 instrument. We observed each layer under a dissecting microscope after  
177 covering the layer of solid matter with a transparent 600-pt grid, which we had  
178 previously prepared by piercing a transparency film at nodes of a 5-mm grid.  
179 Following dot lines under the dissecting microscope and changing the focusing  
180 plane every time a dot was encountered, each element which was located just  
181 below a node of the grid was identified then counted. This method allowed us to  
182 estimate the relative volume of components of the soil matrix, including plant  
183 organs at varying stages of development (for subterranean organs) or  
184 decomposition, mineral particles of varying size and nature, aggregates of  
185 varying colour, size and shape. The Munsell® code for soil colours was used to  
186 classify colours of aggregates into five broad classes (light, light brown, brown,  
187 light grey, grey, black).

188

#### 189 *Data analysis*

190

191 Micromorphological data were analysed by correspondence analysis, CA  
192 (Greenacre, 1984). The matrix analysed crossed 81 layers (as columns) and 82  
193 classes (as rows). Additional (passive) variables were added as rows, in order  
194 (i) to facilitate the interpretation of the factor axes, and (ii) to discern mean  
195 trends in the vertical distribution of humus components in the five plots studied.  
196 They comprised the five plots (MA, MF, EA, EF, EFB) and, for each plot, five  
197 depth levels (0-1 cm, 1-2 cm, 2-3 cm, 3-4 cm, 4-5 cm).

198

199 **Results**

200

201 Table 2 lists the 82 classes that were identified under the dissecting  
202 microscope. The projection of classes (topsoil components) in the plane of the  
203 first two factor axes of the CA (11% and 8% of total variance, respectively)  
204 displayed three branches (Figure 1). The percentages of variance extracted by  
205 axes 1 and 2 (19%) far exceeded the confidence interval given by random  
206 permutation of rows and columns (Lebart *et al.*, 1979), thus giving us  
207 confidence in the significance of these two axes. Axis 1 separated classes  
208 typical of woody sites (EF and MF, with positive values) from those typical of  
209 clearings (EA, EFB and MA, with negative values). Axis 2 separated EA (with  
210 positive values) from MA (with negative values), EFB being intermediate. The  
211 woody sites (EF and MF) were characterized by moss, leaf and wood litter at  
212 varying stages of decomposition, as well as a variety of holorganic (purely  
213 organic) faeces of arthropod origin (caterpillars, millipedes, springtails, mites,  
214 miscellaneous). Abattis (EA, EFB, MA) were characterized by annelid  
215 (earthworm, enchytraeid) faeces and ant pellets with varying carbon contents,  
216 charcoal (free or incorporated to faeces), roots and mineral particles. Within this  
217 group, the Elahe abattis (EA) was distinguished by the part played by dark  
218 (black, dark brown, dark grey) hemorganic material, and charred roots.

219

220 Changes in the vertical distribution of topsoil components were shown by  
221 the projection of depth indicators in the plane of Axes 1 and 2 of CA (Figure 2).  
222 At some depth (varying from 2 cm in MA to 3 or 4 cm in other plots) all sampled  
223 layers exhibited similar features, factor coordinates being negative both for axes

224 1 and 2. Prominent differences between plots were exhibited mostly in the top 1  
225 cm of the soil. The composition of the top centimetre in MA did not differ to a  
226 great extent from that of forest soils (MF and EF), both showing positive values  
227 along axis 1, although differences between surface and deeper soil were much  
228 less pronounced in MA, because there was less litter (Figure 2). In contrast, at  
229 Elahe the top 2 cm of the soil was strongly affected by the shift to agriculture  
230 (EA, EFB to a lesser extent), exhibiting positive and slightly negative values  
231 along axis 2, respectively.

232

233 Mean values for the top 5 cm of the soil can be calculated for each class  
234 and each profile and averaged over the five profiles taken at each plot, giving  
235 mean values for the five plots (Table 2). The correspondence analysis displayed  
236 some trends common to gross classes (leaf material, charred material,  
237 charcoal, black and dark humus). These were compared between the five plots  
238 (Table 3). It appears that leaf material was at least 4 times more abundant in  
239 woody sites (MF and EF) than in abattis (MA, EA, EFB), each of these groups  
240 being fairly homogeneous. In particular, the topsoil of older abattis (EA, MA)  
241 had the same leaf litter content than the recently burnt forest (EFB).

242

243 Slash-and-burn agriculture increased the content of the topsoil in black  
244 and dark hemorganic humus by a factor of 8 at Maripasoula. This class was 11  
245 times more abundant at Elahe (EF) than at Maripasoula (MF) woody sites and  
246 remained 6 times more abundant at Elahe (EA) than in the abattis at  
247 Maripasoula (MA). Differences in the charcoal content of the topsoil were not so  
248 pronounced. Charcoal was less abundant in EF than in all other plots, the

249 highest value being observed in MA (almost 2 times the value observed in EA).  
250 Charred material was most abundant in the recently burnt forest (EFB), where it  
251 was 2.6 times more abundant than in the nearby untouched forest (EF). The  
252 least amount of charred material was in the Maripasoula woody fallow (MF).

253

254         The mean vertical distribution of these bulk classes is apparent in Figure  
255 3. The leaf material, which was more abundant in woody sites (EF and MF) than  
256 in abattis, disappeared rapidly in the top 2 cm of the soil in all plots. The charred  
257 material, which was abundant at the soil surface in the two abattis at Elahe (EA,  
258 EFB), decreased with depth in these two plots. However, it disappeared much  
259 less rapidly than did the leaf material. In the other three plots, it increased  
260 progressively down to 1.5 to 2 cm, then decreased progressively. The vertical  
261 distribution of charcoal was similar to that of charred material in the recently  
262 burnt forest and in the cultivated abattis at Elahe, decreasing abruptly from 1.5  
263 to 2.5 cm, then more progressively below this depth. In the Elahe forest (EF),  
264 there was a progressive increase in charcoal content from the surface to 2-3  
265 cm, but the content remained very small. At Maripasoula (MA and MF), more  
266 charcoal had accumulated below 2.5 cm. In the abattis (MA), it reached on  
267 average 10% of the total solid matter at 2.5 cm, then decreased progressively.  
268 In the Maripasoula forest (MF) the charcoal content increased progressively,  
269 from 0 at the surface to a maximum of 6% from 3 to 5 cm. Over this depth  
270 range, there was no difference in charcoal content between the 8-year-old  
271 woody fallow and the abattis. Black and dark humus was much more abundant  
272 in Elahe abattis (EA, EFB) than in all other plots. It was already present as a  
273 large proportion of total soil volume near the soil surface, reaching 9% and 6%

274 of the total solid matter in EA and EFB, respectively. The proportion remained  
275 constant to 2 cm, then decreased progressively with increasing depth.

276

## 277 **Discussion**

278

279 Pronounced differences according to agricultural use of the rain forest were  
280 revealed by the biological material (leaf litter, charcoal and charred material,  
281 dark humus) which had accumulated in the topsoil. Biological activity in the soil  
282 was strongly affected by clearing of the forest. We registered a change from the  
283 activity of arthropods other than ants, as exemplified by the content in the  
284 topsoil of the faeces of caterpillars, millipedes, springtails and mites, to a  
285 community dominated by annelids and ants. The latter is characterized by (i)  
286 the incorporation of organic matter to mineral matter within earthworm and  
287 enchytraeid faeces and ant pellets, (ii) the building of an hemorganic humus  
288 profile (Figure 1). This pattern accords with the more even distribution of carbon  
289 in the topsoil after deforestation and cultivation observed in Amazonian soils by  
290 Nascimento *et al.* (1993). Our results point on the role of burrowing animals,  
291 namely earthworms, enchytraeids and ants, in this process. We did not record  
292 any faecal deposition by termites, although many termites are present in the  
293 soil. The incorporation of organic matter in mineral matter by tropical  
294 earthworms helps to stabilize organic matter, and associated water and  
295 nutrients (Lavelle *et al.*, 1998). Mutualistic interactions between earthworms and  
296 soil microbes (in particular the priming effect by intestinal mucus) were reasons  
297 to classify these animals as ecosystem engineers (Lavelle *et al.*, 1997).  
298 Earthworms, in association with additions of organic matter, have been used for

299 the bioremediation of tropical agricultural soils, increasing plant productivity and  
300 creating a stable soil structure (Pashanasi *et al.*, 1996; Brown *et al.*, 1999;  
301 Hallaire *et al.*, 2000). Ants, and moreover enchytraeids, are not widely  
302 recognized as promoting greater soil aggregation and stability, at least in the  
303 tropical world (Delabie & Fowler, 1995; Römbke & Meller, 1999). However, we  
304 found that earthworm faeces tunnelled by enchytraeids contributed noticeably to  
305 the total solid matter in the first 5 cm of the topsoil (Table 2).

306

307         Charcoal and charred material contributed substantially to the soil (Figure  
308 3). This material accumulates in the topsoil, unlike leaf material (Figure 3). It is  
309 also incorporated into a variety of black and dark humorganic faeces of  
310 earthworms, and into ant pellets (Table 2). In a previous paper (Topoliantz &  
311 Ponge, 2003), we showed experimentally that the peregrine earthworm  
312 *Pontoscolex corethrurus* could ingest small particles of charcoal and mix them  
313 with the mineral soil, then deposit dark excrement at varying depths. This  
314 activity is at the origin of a variety of dark colours of soil aggregates, which  
315 contain charcoal powdered by the earthworm gizzard then mixed in a liquid  
316 manner in the intestine (Barois *et al.*, 1993). We also observed that ants  
317 produced dark, even black, material (Table 2), but this material could come from  
318 ingested earthworm faeces of the same colour.

319

320         There was more black and dark humus and charred material and less  
321 charcoal in the 3-year-old abattis at Elahe than in the 1-year-old abattis at  
322 Maripasoula. These differences can be due (i) to a larger production of charcoal  
323 at Maripasoula where repeated burning (short fallow) leads to an accumulation

324 of charcoal in the course of the time (Van der Wal, 1999), and (ii) to a better  
325 incorporation of charcoal and charred material in the mineral soil at Elahe, as  
326 shown by our micromorphological data. Indeed, charred material and charcoal  
327 decreased from EFB (fire 6 months before) to EA (fire 3 years before) while  
328 black and dark humus increased during the same period. This suggests that  
329 both charcoal and charred material are sources of black and dark humus  
330 (Figure 3). At Maripasoula, the content of the black and dark humus in the  
331 topsoil was always small and charcoal accumulated, revealing the slow turnover  
332 of this type of carbon.

333

334         The origin of the fertile Terra Preta, or Amazonian Dark Earths, has been  
335 attributed to the incorporation of charcoal to the mineral soil, as a source of  
336 stable humus, once charcoal carbon becomes oxidized and chemically  
337 reorganized (Glaser *et al.*, 1998). Past bioturbation, in vanished civilizations of  
338 the Amazon Basin, has been postulated to explain the present-day enrichment  
339 of the soil in black carbon of charcoal origin at 30-40 cm depth (Glaser *et al.*,  
340 2000; Glaser & Woods, 2004). We can now explain this phenomenon by the  
341 charcoal-feeding activity of earthworms such as *P. corethrurus*, which are  
342 abundant in Amazonian pastures and forest clearings (Römbke & Verhaag,  
343 1992). The fact that black and dark hemorganic material was almost absent  
344 from the soil in the old forest, then increased in the recently burnt forest, then  
345 still further increased after 3 years of cultivation at Elahe (Figure 3), probably  
346 indicates that the process of incorporation is rapid, provided earthworms are  
347 sufficiently active, as observed in Elahe. In previous experiments we also  
348 showed that dark hemorganic humus (artificially made by mixing charcoal with

349 the mineral soil) was even ingested to a greater extent than pure charcoal,  
350 pointing on a positive feed-back (self-reinforcing) effect (Topoliantz & Ponge,  
351 2005).

352

353 Our study shows that traditional shifting cultivation, as currently practised  
354 by Wayana Amerindians, causes charcoal and charred material to become well  
355 incorporated into the soil and to change gradually into stable humus. This  
356 probably occurred in the past to a much larger extent in the Amazonian basin  
357 (Glaser & Woods, 2004). Prior to burning the forest, Wayana cultivators select  
358 darker soils (personal communication with local agriculturists). The dark colour  
359 of the topsoil is probably caused by past fires that enriched the soil with stable  
360 carbon, through earthworm activity. This preference for soils containing  
361 incorporated charcoal reinforces the positive feed-back loop already mentioned.  
362 At Maripasoula, the accumulation of charcoal in depth and the quasi absence of  
363 black and dark humus in the 8-years-old forest (MF) suggest that more than 8  
364 years are probably needed for complete incorporation of charcoal in dark  
365 humus. Frequent fires and short cultivation periods must not allow for a  
366 complete incorporation of charcoal by soil fauna, limiting to the short-term the  
367 fertilizing effect of burning the forest.

368

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370

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377

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512 **Figure headings**

513

514 **Figure 1.** Correspondence analysis (CA). Projection of active variables (humus  
515 classes, see Table 2) and passive variables (plot indicators) in the plane  
516 of the first two factorial axes. MA = Maripasoula Abattis, MF =  
517 Maripasoula Fallow, EA = Elahe Abattis, EF = Elahe Forest, EFB = Elahe  
518 Forest Burnt

519

520 **Figure 2.** Correspondence analysis (CA). Projection of depth indicators (for  
521 each plot and each depth) in the plane of the first two factorial axes.  
522 Successive sampling depths are shown at cm intervals. The top cm has  
523 been labelled, the lower samples follow the lines. Abbreviations as for  
524 Figure 1

525

526 **Figure 3.** Mean vertical distribution of gross categories of humus components in  
527 the five studied plots. Each point is the mean of five values from five  
528 topsoil profiles. Abbreviations as for Figure 1

529

**Table 1.** Main physico-chemical features of the five study sites. Data are means of five topsoils followed by minimum and maximum values. Charcoal carbon was included in total C

	Maripasoula Abattis	Maripasoula Fallow	Elahe Abattis	Elahe Forest	Elahe Forest Burnt
	MA	MF	EA	EF	EFB
Clay/%	22.4 (20.4-25.3)	16.9 (13.7-20)	20 (6.6-31.3)	17.5 (15.5-19.1)	16.8 (14.9-18.3)
Silt/%	12.4 (9.5-17.4)	7.9 (7-9.2)	20.9 (13.2-32.8)	8.7 (7.1-9.6)	9.2 (7.6-10.3)
Sand/%	65.1 (58.8-69.7)	75.2 (72.3-78.7)	59.1 (35.9-80.2)	73.8 (71.4-76.7)	74 (72.1-76.4)
pH	5.13 (5.02-5.37)	5.01 (4.6-5.66)	4.74 (4.37-4.91)	4.83 (4.58-5)	4.30 (3.79-5.59)
Total C/g.kg <sup>-1</sup>	24.6 (16.9-39.8)	22.5 (18.6-28.4)	25.8 (16.3-36.3)	19.1 (14.7-25.3)	18.6 (17.9-19.7)
Total N/g.kg <sup>-1</sup>	1.65 (1.21-2.49)	1.48 (1.28-1.88)	1.78 (1.29-2.4)	1.39 (1.12-1.7)	1.35 (1.33-1.38)
C/N	14.7 (13.2-16)	15.2 (14.5-15.7)	14.6 (12.6-16.1)	13.7 (12.8-14.9)	13.7 (13.3-14.3)

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531



**Table 2.** List of classes identified under the dissecting microscope with code number and mean percent volume of the topsoil (0-5 cm) matrix in the five studied sites (5 profiles each). MA = Maripasoula Abattis, MF = Maripasoula Fallow, EA = Elahe Abattis, EF = Elahe Forest, EFB = Elahe Forest Burnt

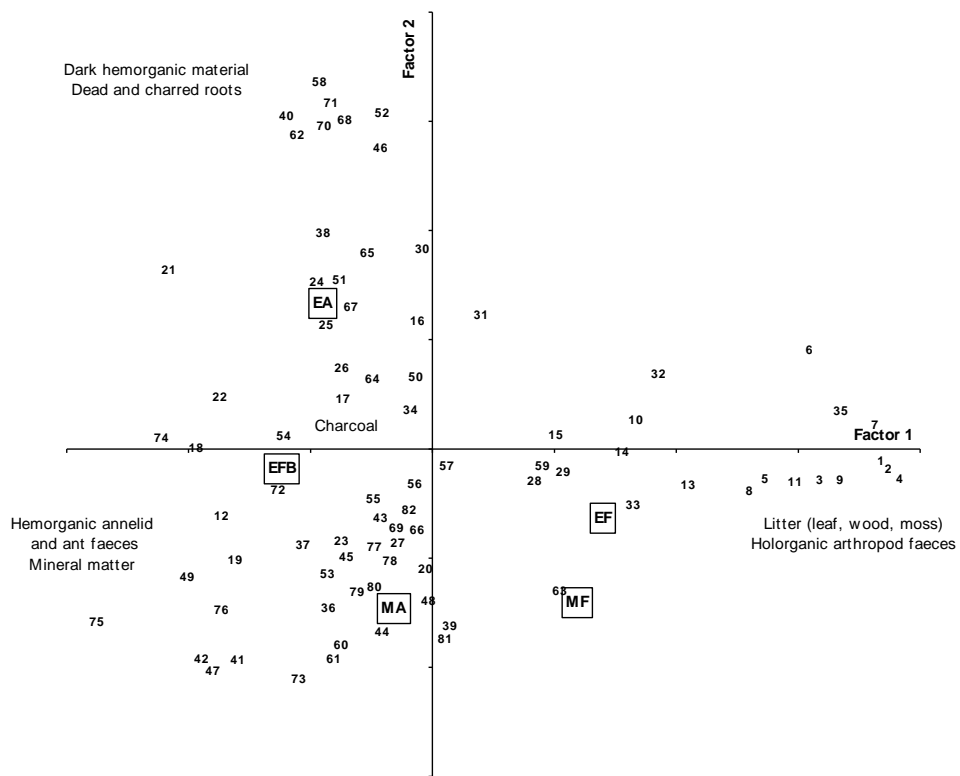
Code	Short description	MA	MF	EA	EF	EFB	Axis 1 of CA	Axis 2 of CA
1	Entire brown leaves	0.79	1.06	0.17	1.19	0.21	0.037	-0.002
2	Entire brown-orange leaves	0.59	5.03	0.05	3.58	0.18	0.037	-0.002
3	Entire red leaves	0.18	0.07	0.39	1.50	0.04	0.032	-0.003
4	Entire bleached leaves	0.12	3.77	0.24	2.70	0.12	0.038	-0.002
5	Entire blackened leaves	0.29	2.09	0.10	0.34	0.09	0.027	-0.003
6	Brown leaves nibbled by macrofauna	0.93	1.27	1.00	1.86	0.81	0.031	0.009
7	Brown-orange leaves nibbled by macrofauna	0.63	3.37	1.25	3.24	0.25	0.036	0.002
8	Red leaves nibbled by macrofauna	0.66	0.55	0.91	0.69	0.21	0.026	-0.004
9	Bleached leaves nibbled by macrofauna	0.11	1.62	0.08	1.36	0.37	0.033	-0.003
10	Blackened leaves nibbled by macrofauna	0.36	0.20	0.43	1.06	0.28	0.017	0.003
11	Skeletonized leaves	0.01	0.27	0.02	2.00	0.03	0.030	-0.003
12	Fungi	2.20	2.08	2.29	1.52	2.12	-0.017	-0.006
13	Moss	0.17	0.00	0.00	0.09	0.02	0.021	-0.003
14	Decaying stem/bark	2.53	1.71	1.10	1.85	2.16	0.016	0.000
15	Miscellaneous plant material	1.31	0.94	1.81	1.95	0.90	0.010	0.001
16	Miscellaneous charred material	1.46	0.51	1.73	2.54	6.14	-0.001	0.012
17	Free charcoal	4.94	2.35	1.88	1.05	3.90	-0.007	0.005
18	Living fine roots (< 2 mm)	10.06	17.84	13.15	13.14	13.62	-0.019	0.000
19	Living medium roots (2-4 mm)	1.44	2.36	1.01	2.69	2.06	-0.016	-0.010
20	Living large roots (> 4 mm)	1.74	1.70	0.63	1.92	1.36	-0.001	-0.011
21	Dead fine roots (< 2 mm)	2.05	0.81	2.93	2.46	2.54	-0.022	0.016
22	Dead medium roots (2-4 mm)	0.62	0.08	0.66	0.48	0.80	-0.017	0.005
23	Dead large roots (> 4 mm)	0.14	0.04	0.40	0.28	0.44	-0.007	-0.009
24	Charred fine roots (< 2 mm)	0.44	0.04	2.52	0.72	2.18	-0.009	0.015
25	Charred medium roots (2-4 mm)	0.06	0.00	1.85	0.29	0.80	-0.008	0.011
26	Charred large roots (> 4 mm)	0.00	0.00	1.28	0.05	0.27	-0.007	0.007
27	Type I holorganic macrofauna faeces	0.00	0.05	0.00	0.00	0.00	-0.003	-0.009
28	Holorganic caterpillar faeces	0.00	0.00	0.01	0.00	0.00	0.009	-0.002
29	Holorganic millipede faeces	0.02	0.01	0.00	0.04	0.06	0.010	-0.001
30	Holorganic earthworm faeces	0.13	0.00	1.04	0.24	0.52	-0.001	0.018
31	Holorganic enchytraeid faeces	0.05	0.06	2.48	0.47	0.08	0.004	0.012
32	Holorganic springtail faeces	0.01	0.00	0.05	0.04	0.02	0.019	0.007
33	Holorganic mite faeces	0.00	0.00	0.00	0.14	0.01	0.016	-0.005
34	Enchytraeid-crumbled holorganic earthworm faeces	0.00	0.00	1.39	0.00	0.00	-0.002	0.003
35	Miscellaneous holorganic faecal material	0.20	0.24	0.46	0.89	0.36	0.034	0.003
36	Light recent hemorganic earthworm faeces	7.89	2.52	7.86	0.22	1.35	-0.009	-0.015
37	Brown recent hemorganic earthworm faeces	6.71	7.77	10.19	0.75	2.51	-0.011	-0.009
38	Dark-brown recent hemorganic earthworm faeces	0.05	0.00	0.73	0.06	0.42	-0.009	0.020
39	Light-gray recent hemorganic earthworm faeces	1.46	6.98	0.65	0.04	0.11	0.001	-0.016
40	Dark-gray recent hemorganic earthworm faeces	0.08	0.03	0.65	0.14	0.15	-0.012	0.030
41	Light old hemorganic earthworm faeces	5.93	1.34	4.29	5.03	6.02	-0.016	-0.019
42	Brown old hemorganic earthworm faeces	7.65	4.69	4.00	6.84	9.26	-0.019	-0.019
43	Dark-brown old hemorganic earthworm faeces	0.21	0.00	0.18	0.34	0.32	-0.004	-0.007
44	Light-gray old hemorganic earthworm faeces	1.73	3.33	0.31	0.30	0.32	-0.004	-0.015
45	Dark-gray old hemorganic earthworm faeces	0.25	0.06	0.03	0.22	0.56	-0.007	-0.010
46	Black hemorganic earthworm faeces	0.22	0.01	1.47	0.19	1.58	-0.004	0.028
47	Light enchytraeid-crumbled hemorganic earthworm faeces	2.88	0.52	2.58	5.09	2.77	-0.018	-0.020
48	Light-gray enchytraeid-crumbled hemorganic earthworm faeces	0.12	0.91	0.04	0.14	0.03	0.000	-0.014
49	Brown enchytraeid-crumbled hemorganic earthworm faeces	2.60	3.07	4.59	3.96	4.05	-0.020	-0.012
50	Dark-brown enchytraeid-crumbled hemorganic earthworm faeces	0.01	0.00	1.20	0.08	0.03	-0.001	0.007
51	Dark-gray enchytraeid-crumbled hemorganic earthworm faeces	0.00	0.00	0.02	0.02	0.04	-0.008	0.015
52	Black enchytraeid-crumbled hemorganic earthworm faeces	0.00	0.00	0.64	0.05	0.10	-0.004	0.031
53	Light hemorganic ant pellets	0.14	0.00	0.04	0.06	0.09	-0.009	-0.012
54	Brown hemorganic ant pellets	0.08	0.00	0.18	0.23	0.19	-0.012	0.001
55	Dark-brown hemorganic ant pellets	0.00	0.00	0.02	0.00	0.00	-0.005	-0.005
56	Light-gray hemorganic ant pellets	0.00	0.00	0.00	0.00	0.01	-0.001	-0.003
57	Dark-gray hemorganic ant pellets	0.00	0.00	0.00	0.02	0.00	0.001	-0.002
58	Black hemorganic ant pellets	0.00	0.00	0.17	0.02	0.02	-0.008	0.032
59	Hemorganic springtail faeces	0.00	0.00	0.00	0.06	0.01	0.009	-0.002
60	Light friable hemorganic material	1.13	0.56	2.16	2.46	1.04	-0.008	-0.019
61	Brown friable hemorganic material	0.87	1.98	2.53	0.87	0.89	-0.008	-0.019
62	Dark-brown friable hemorganic material	0.00	0.00	0.08	0.00	0.02	-0.011	0.029
63	Light-gray friable hemorganic material	0.05	0.72	0.08	0.04	0.05	0.010	-0.013
64	Dark-grey friable hemorganic material	0.03	0.00	0.17	0.03	0.00	-0.005	0.006
65	Black friable hemorganic material	0.00	0.00	0.15	0.01	0.40	-0.005	0.018
66	Light compacted hemorganic material	3.00	0.00	0.00	0.00	0.00	-0.003	-0.007
67	Brown compacted hemorganic material	0.92	0.00	0.51	0.00	0.00	-0.007	0.011
68	Dark-brown compacted hemorganic material	0.00	0.00	0.02	0.00	0.00	-0.008	0.032
69	Light-gray compacted hemorganic material	0.18	0.00	0.00	0.00	0.00	-0.003	-0.007
70	Dark-gray compacted hemorganic material	0.03	0.00	0.11	0.00	0.00	-0.009	0.029
71	Black compacted hemorganic material	0.00	0.00	0.06	0.00	0.00	-0.008	0.032
72	Charcoal embedded in faeces	2.46	1.28	1.20	0.38	0.93	-0.013	-0.002
73	Humified plant material embedded in faeces	0.52	0.47	0.70	0.38	0.35	-0.011	-0.021
74	Fine sand (0.02-0.2 mm)	3.60	3.45	3.83	4.64	5.59	-0.022	0.001
75	Coarse sand ((0.2-2 mm)	11.03	8.37	4.63	14.29	16.60	-0.028	-0.016
76	Gravel (2-20 mm)	1.08	1.29	0.41	0.50	1.15	-0.017	-0.015
77	Boulder (> 20 mm)	0.41	0.42	0.00	0.00	0.00	-0.004	-0.010
78	Iron nodules	1.71	0.01	0.00	0.00	0.00	-0.004	-0.010
79	Manganese nodules	0.20	0.00	0.03	0.00	0.03	-0.006	-0.013
80	Miscellaneous minerals	0.28	0.01	0.03	0.00	0.03	-0.005	-0.013
81	Living and dead fauna	0.24	0.08	0.14	0.17	0.01	0.001	-0.018
82	Unidentified	0.01	0.00	0.00	0.00	0.00	-0.002	-0.007

**Table 3.** Mean percent by volume of some main components of the topsoil (0-5 cm) matrix. Data are means of five profiles followed by minimum and maximum values. MA = Maripasoula Abattis, MF = Maripasoula Fallow, EA = Elahe Abattis, EF = Elahe Forest, EFB = Elahe Forest Burnt

	MA	MF	EA	EF	EFB
Leaf material	4.66 (1.48-9.94)	19.30 (10.7-27)	4.63 (0.8-11)	19.50 (16.3-22.8)	2.59 (0.17-6.58)
Charred material	1.96 (0.27-3.78)	0.55 (0.14-1.24)	7.39 (2.33-19.41)	3.60 (1.75-6.12)	9.39 (6.17-14.84)
Charcoal	7.40 (2.73-14.52)	3.63 (1.38-5.5)	3.08 (1.56-4.45)	1.43 (0.47-2.58)	4.83 (1.71-9.43)
Black and dark humus	0.89 (0.39-1.82)	0.11 (0-0.27)	5.71 (1.11-10.76)	1.19 (0.12-2.2)	3.65 (1.09-8.43)

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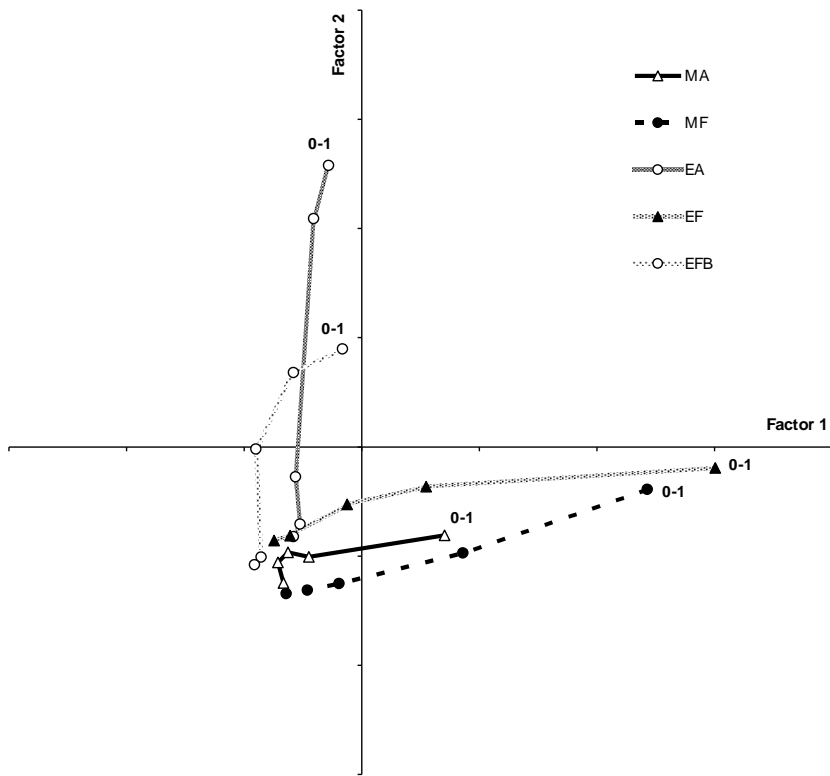
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536 **Figure 1**

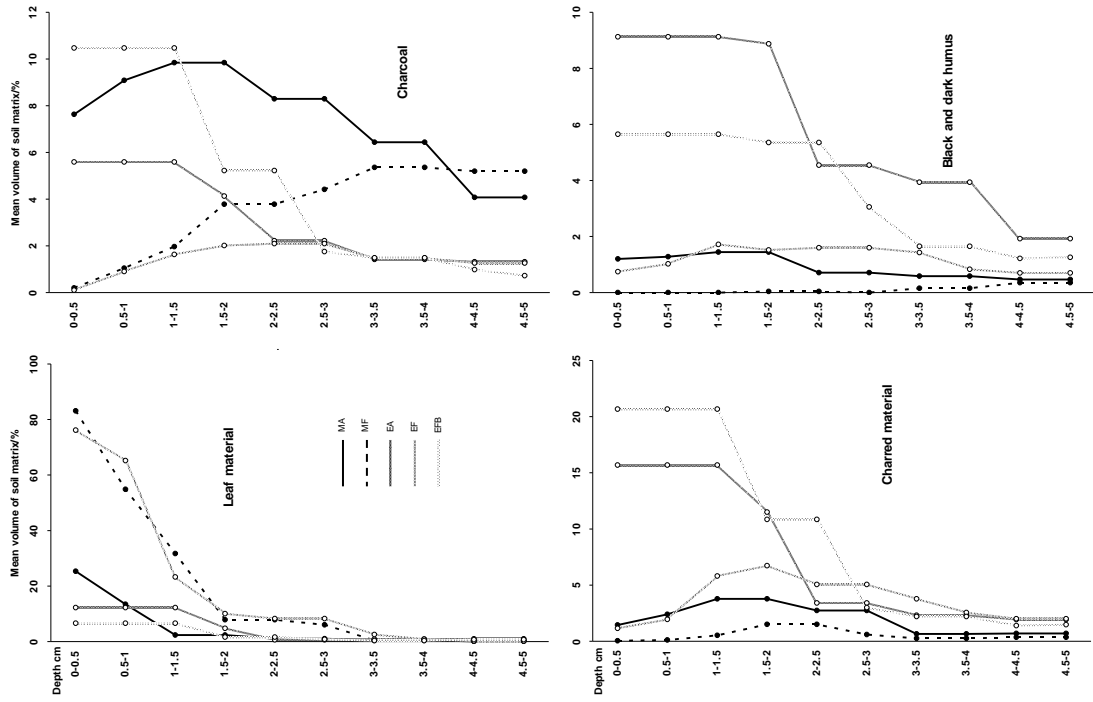
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539 **Figure 2**

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Figure 3