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1 **Management practices and incidence of pests in Plantain (*Musa paradisiaca***
2 **AAB) crops. Consequences on the sustainability of the cropping systems.**

3

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28 **ABSTRACT**

29 Plantain (*Musa paradisiaca* AAB) is one of the most important staple crops in the tropics,
30 particularly in the Caribbean. Pests are the main constraint to plantain production and yield
31 increases may be possible by improving pest management. However, there is a lack of data
32 on these cropping systems and a need to identify new elements of improved production
33 systems that can control pests in line with the principles of agroecological transition. In this
34 study, we test the hypothesis that crops grown in good quality soils are less susceptible to
35 pests. To this end, an agroecological diagnosis of the biological, physical, morphological and
36 chemical soil conditions and the occurrence of pests, in particular plant-parasitic nematodes,
37 was carried out on 21 plantain plots with contrasting management in Guadeloupe (French
38 West Indies). After classifying these plots according to their management practices, from
39 conventional to agroecological, we searched for relationships between cropping systems, soil
40 quality and pests using a series of synthetic quality indices. Four different cropping systems
41 were identified and compared: conventional intensive, intermediate, low-input and
42 agroecological, according to the type and amount of agrochemicals used. Our data showed
43 that the Chemical Index was significantly improved in the agroecological systems due to
44 increases in pH, CEC, base saturation and total C and N content. The Morphological Index
45 increased regularly from intensive to agroecological systems and was significantly higher in
46 agroecological systems with higher proportions of biogenic aggregates. Soil
47 macroinvertebrate communities were significantly influenced by production systems, with the
48 highest values of the Macrofauna Index in low input and agroecological production systems.
49 We also showed that plant parasitic nematodes were better regulated in agroecological
50 production systems. Furthermore, the agroecological system achieved similar levels of crop
51 production to conventional systems, without the use of pesticides. In addition, these
52 agroecological cropping systems extend the duration of plantain plots, which is an indicator
53 of the good health of these systems.

54

55 *Keywords:* Agroecological diagnosis; Pest control; Plant health; Soil biodiversity; Tropical
56 agroecosystems

57

58 **1. Introduction**

59 Plantain (*Musa paradisiaca*, AAB) is a major food resource in the tropics. This crop plays an
60 important socio-economic role for developing countries in tropical and subtropical zones.

61 Indeed, plantain provided food security and income for small growers who represent the
62 majority of producers in the tropics (Kahane et al., 2013). It generates an important source of
63 income for producing countries (Tchango Tchango et al., 1999) and constitutes the staple
64 diet of more than 400 million people living in many developing countries, particularly in Africa,
65 Latin America and the Caribbean (Lassoudière, 2011). In 2020, plantain was grown in 54
66 countries and more than 43 million tons were produced worldwide (FAOSTAT, 2021). Latin
67 America and the Caribbean produced 18% of the global production of plantain (FAOSTAT,
68 2021). Therefore, sustainable production of plantain in this region is crucial to provide food
69 security and income to millions of people (Picq et al., 1998). In spite of this, plantain is
70 confronted to numerous sanitary constraints, which affect its sustainability. Accordingly,
71 production and yield gains can be increased through pest control improving, indeed the
72 major constraint for plantain production (Godefroid et al., 2017).

73 Soil organisms provide essential ecological functions in agricultural and natural ecosystems.
74 These functions are the basis for the provision of ecosystem services (Bardgett and Van der
75 Putten, 2014; Adhikari and Hartemink, 2016; Brussaard, 2021). Agriculture is one of the
76 human activities that relies on the soil as a support, but also as a resource. However,
77 artificializing practices of conventional agriculture have often had negative impacts on the
78 environment, such as groundwater contamination, biodiversity loss and soil degradation
79 (Tamburini et al., 2020; Lavelle et al., 2022). These environmental disturbances result in the
80 degradation of some of the ecosystem services provided by soils (Millennium Ecosystem
81 Assessment, 2005).

82 The major underground pests in plantain cropping systems are nematodes (mainly
83 *Radopholus*, *Pratylenchus* and *Helicotylenchus*) and black weevils (Gold and Tinzaara,
84 2008; Quénéhervé, 2009). Plant parasitic nematodes attack roots, inducing plant toppling
85 and yield reduction. The banana black weevil, *Cosmopolites sordidus*, attacks the plant
86 underground corm, causing stem breakage. At the present time, these pests are mainly
87 controlled by synthetic pesticides which has generated major side effects on environment
88 (soil and water pollution, disappearance of domestic biodiversity and auxiliary fauna, ...) but
89 also on human health (Millennium Ecosystem Assessment, 2005). As an example, in
90 Guadeloupe, the use of chlordecone to control *C. sordidus* in dessert banana plantations has
91 resulted in a severe long-term pollution of soils and water and has reinforced the anxiety of
92 consumers about the quality and safety of food production (Cabidoche et al., 2009; Levillain
93 et al., 2012). There is a critical need for alternative plantain cropping systems that better
94 conserve environmental quality while sustaining crop yield and regulating pests (Loranger-
95 Merciris et al., 2022). Reduction of agrochemical inputs is the target proposed, especially in
96 Guadeloupe where ecosystems have attained high levels of contamination (Ozier-Lafontaine
97 and Lesueur-Jannoyer, 2014).

98 Soil organisms but also physical and chemical properties of soil affect plant vigour. Low soil
99 biodiversity is actually associated with greater vulnerability to pests, due to altered natural
100 regulation of these pests (Nielsen et al., 2015). Moreover, some studies showed an
101 unexpected positive relationship between the frequency of pesticide applications and the
102 occurrence of pests and diseases (Altieri and Nicholls, 2000). On the other hand, only few
103 studies have actually reported a positive relationship between soil quality, plant health and
104 pest regulation (e.g., D'Hose et al., 2014), and none to our knowledge, has been done in
105 plantain plantations.

106 This study aimed at identifying elements of cropping systems that would reduce the impact of
107 pests and diseases and, thus, decrease the need for pesticides. For this, we realized an
108 extensive comparative diagnosis of biological, morphological, physical and chemical soil
109 conditions and plant disease occurrence in 21 farms with contrasted management of plantain

110 in Guadeloupe (French West Indies). Plots were classified according to their management
111 practices. We then calculated synthetic indexes to summarize the information collected for
112 soil quality and plant health at each farm, and we linked these indexes to the types of
113 management practices. Throughout this study, we tested the hypothesis that plants grown in
114 good quality soils are less prone to pests.

115

116 **2. Material and Methods**

117 *2.1. Site information and study design*

118 The study was carried out in the western island (Basse-Terre) of the Guadeloupe
119 archipelago (15°59'-16°9' N, 61°34'-61°43' W) in the Caribbean, where most plantain
120 plantations are found. We selected a plot in twenty-one farms. Farms were selected on the
121 basis of a preliminary survey of 100 farms to have a representation of all production systems.
122 Plots were all located between 0 m and 150 m altitude, with annual rainfall ranging from 2 to
123 3 m and mean annual temperature around 23°C. Soils are Haplic Nitisols (FAO-UNESCO
124 classification, Driessen et al., 2001) developed on volcanic ashes. They are clayey and are
125 mainly composed of halloysite (Clermont-Dauphin et al., 2004). Nitisols are similar to
126 Ferralsols, but they are younger and therefore less evolved, less desaturated and generally
127 less acidic. The cation contents (Ca, Mg and K) are typically higher than in Ferralsols.
128 For each plot, cropping systems were described with seven variables: the origin of plants
129 (plants issued for tissue culture vs. suckers); the previous crop (fallow, plantain or
130 pineapple); the longevity of the plot (perennial vs. annual); the number of pesticide
131 applications (0, 1 or 2 applications of Nemathorin® per year); herbicide applications (0 to 2 or
132 3 to 5 applications of Basta® per year); fertilization (organic manure, low input chemical -2 to
133 3 applications of N20-P20-K20 fertilizer per year-, high input chemical -4 to 8 applications of
134 N20-P20-K20 fertilizer per year-); and soil tillage before plantain plantation (with or without).
135 All plots were planted with French cultivar.
136 In each plot, soil chemical, morphological and physical parameters, soil macroinvertebrate
137 and plant-root parasitic nematode communities were assessed next to the stem of five plants

138 selected at random at the flowering stage. Data collected within each plot were averaged to
139 provide mean values for each of the 21 selected plots. Thus, for each measured variable
140 within each plot values represent means of five replicates.

141

142 *2.2. Soil chemical characteristics*

143 Soil chemical properties were measured 30 cm apart from each selected plantain plant. For
144 each plant, a sample was taken from a soil block and analysed for total soil C and N using an
145 auto-analyser (NF ISO 13878, 1998). Available P was measured using the Olsen method
146 (Dabin, 1967). Soil mineral N (NO_3^- and NH_4^+) was measured by colorimetry after extraction
147 with a 0.5M KCl solution. Exchangeable Ca^{2+} , Mg^{2+} , K^+ and Na^+ were determined after
148 extraction with ammonium acetate (NF X 31108). Cation-exchange capacity (CEC) was
149 measured with IF07-10D (NFX 31-130) method and pH-H₂O and pH-KCl with NF ISO 1770,
150 3696 and 11464.

151

152 *2.3. Soil physical and morphological characteristics*

153 Soil physical properties were measured 50 cm apart from each selected plantain plant. Three
154 undisturbed 100 cm³ soil cores (50 mm in diameter × 50 mm in length) were collected in
155 order to measure bulk density, water content, useful water reserve and water retention at two
156 different potentials, pF 2 (-0.01 MPa) and pF 4.2 (-1.5 MPa).

157 A morphological assessment of soil macroaggregates and other elements (Velasquez et al.,
158 2007b) provided an integrative measure of accumulated soil biological activity (Lavelle et al.,
159 2014). An undisturbed soil sample taken with an 8 cm diameter × 8.5 cm height cylinder was
160 collected 50 cm apart from each selected plantain plant. In the laboratory, blocks were gently
161 separated and the samples were air-dried then sieved at 2 mm. The soil retained by the
162 sieve was placed on a filter paper and the various elements were separated according to
163 their origin and shape. The elements were sorted according to five categories: i) biogenic
164 aggregates of rounded forms, created by macroinvertebrates, ii) root aggregates, iii) physical
165 aggregates of angular forms, produced by the physical processes of the environment

166 (especially alternating dry and wet periods), iv) non-macro aggregated soil (soil passing
167 through the 2 mm sieve), and v) other components (roots, stones, litter, wood...). The
168 separated elements were put in an oven at 60 °C for 15 days and weighed (Velasquez et al.,
169 2007b).

170

171 *2.4. Macroinvertebrate communities*

172 Soil macro-invertebrates were hand sorted from soil monoliths taken 30 cm apart from the 5
173 selected plants of each plot, following the ISO 23611-S methodology (ISO, 2011). A central
174 monolith 25 cm × 25 cm × 20 cm was completed with two lateral 25 cm × 25 cm × 10 cm
175 blocks located 1 m N and S, respectively, apart from the central point. Macro-invertebrates
176 were classified into fifteen groups: Diplopoda, Ants, Termites, Earthworms, Coleoptera,
177 Chilopoda, Isopoda, Dermaptera, Blattodea, Araneidae, Heteroptera, Gasteropoda,
178 terrestrial Turbellaria, Homoptera and Orthoptera. Macroinvertebrate density at each point
179 was taken as the sum of the three monoliths. Individuals were also classified in three
180 functional groups: ecosystem engineers, litter transformers and predators (Turbé et al.,
181 2010).

182

183 *2.5. Pests and plant characteristics*

184 Primary roots were removed from a 25 cm × 25 cm × 30 cm soil block located 30 cm apart
185 from the 5 sampled plants. Plant-feeding nematodes were extracted from an aliquot of the
186 roots (100 g) using a centrifugal-flotation method (Coolen and d'Herde, 1972).
187 Populations were counted in aliquots and expressed as number of nematodes per 100 grams
188 of root fresh biomass. The main plant-parasitic species were identified and counted under a
189 light microscope.
190 To assess the severity of root damage, a 25 cm × 25 cm × 30 cm soil block located 30 cm
191 apart from the 5 sampled plants was removed. Roots were removed in the whole volume of
192 soil, carefully washed and cut longitudinally. Necrosis rates on the respective external and

193 internal surfaces of these roots were scanned independently using the WinRHIZO 2009a
194 Software (Regent Instruments Canada, Inc.). The colour of root necrosis due to soil-borne
195 pathogens varied from reddish to black while healthy roots were white. The necrosis index
196 was expressed as necrosed surface area over total root surface area.
197 Weevil *C. sordidus* populations were estimated using pheromone-baited pitfall traps (Reddy
198 et al., 2008). One trap was put in the middle of each plot and was collected after 30 days
199 (one sample by plot). Weevils were trapped in soapy water. Plant yield was estimated by
200 bunch weight for each selected plantain plant. The average harvest time is 12 months from
201 planting.

202

203 2.6. Data analyses

204 All the data sets used for statistical treatments are grouped in Supplementary Table S1. All
205 analyses were performed with the R software (R Core Team, 2013, R 3.1.2).

206 A multiple correspondence analysis (MCA) was run on the 7 variables describing the
207 cropping systems (function “*dudi.pca*”, package “*ade4*”, Chessel et al., 2004). A hierarchical
208 cluster analysis using the Ward linkage method (minimum variance criterion) and Euclidian
209 distances was run on MCA-axes 1 and 2 scores, to analyse distances between plots and
210 group plots according to their cropping systems. Differences in MCA-axes 1 and 2 scores
211 among groups were further tested by one-way ANOVAs (normality was assessed with
212 Shapiro-Wilk tests), followed by Tukey post hoc tests (function “*Tukey HSD*”, package
213 “*stats*”).

214 Principal Component Analysis (PCA) of each of the 5 sets of data (chemical soil properties,
215 physical soil properties, soil morphological characteristics, macroinvertebrate communities,
216 and pests) were performed. Monte Carlo tests on the coordinates of plots on the factorial
217 axes allowed identifying significant differences among cropping systems. These analyses
218 were done with the *ade4* library (Chessel et al., 2004).

219 We then calculated synthetic indexes, defined as a set of statistically selected soil attributes
220 that incorporate key functions, which for our study corresponded to: soil physical properties,

221 soil morphological characteristics, soil chemical properties, macroinvertebrate communities,
222 and plant pests. Synthetic indicators were designed and calculated for each point using a
223 methodology proposed by Velasquez et al. (2007a). Briefly, for each PCA, we selected, for
224 the two first axes, the variables with highest contributions (with a weight at least higher than
225 50% of the maximum contribution calculated for F1 and F2 of the PCA). Then, the values of
226 each variable set, adjusted to a range of 0.1 to 1.0 by a homothetic transformation, were
227 multiplied by their corresponding weight factors and summed, giving i) Physical Index, ii)
228 Morphological Index, iii) Chemical Index, iv) Macrofauna Index, and v) Pest Index (for the
229 calculation details, see Rodriguez et al., 2021).

230 In a last step, a PCA analysis of all plots characterized by the set of the 5 synthetic indexes
231 generated allowed to analyse co-variations among the indicators and localize each plot in the
232 factorial space thus defined. Finally, a Monte Carlo test on plot coordinates allowed to test
233 significant differences among cropping systems. These analyses were done with the ade4
234 library (Chessel et al., 2004).

235

236 **3. Results**

237 *3.1. Cropping systems*

238 The first two axes of the MCA run on the seven variables related to the cropping system
239 (Supplementary Table S1) explained 46.9% of the total variance of the observations (data
240 not shown). The first axis alone explained 33.6% of this variance and opposed sites with
241 highly intensive practices (tillage, 5 to 6 applications of chemical fertilizer, repeated pesticide
242 applications and annual cropping systems with local seeds), to sites with agroecological
243 practices (organic fertilization, zero application of chemical fertilizer, limited use of herbicides
244 and planting with vitroplant seeds in perennial crops), (Supplementary Fig. S1). Plots were
245 divided in 4 clearly separated groups (Fig. 1; Supplementary Fig. S2).

246 Groups 1, 2 and 3 are annual plots planted with suckers separated along axis 2 of the
247 analysis according to their relative degree of intensification that increases from 3 to 1 (Table
248 1). Group 1, called “intensive” cropping system, is characterized by high levels of pesticides

249 (2 applications during the crop cycle), herbicides (3 to 5 applications) and mineral fertilizers
250 use (4 to 8 applications). Group 2, called “intermediate” cropping system, is characterized by
251 an intensive use of herbicides (3 to 5 applications during the plantation cycle), moderate use
252 of pesticides (1 application at the plantation) and moderate use of mineral fertilizers (2 to 3
253 applications during the plantation cycle). Group 3, referred as “low input” cropping system, is
254 characterized by moderate levels of pesticides and mineral fertilizer applications
255 (respectively 1, and 2 to 3 applications during the plantation cycle) and no herbicides. Group
256 4 (called “agroecological” system) is separated from the other 3 along axis 1 of the MCA (Fig.
257 1). It is comprised of perennial plots, planted with seeds issued from tissue culture conducted
258 with organic fertilization (manure). Pesticides were not used and 0 to 2 applications of
259 herbicides had occurred in the last 12 months. In this group, unlike the others, there was no
260 tillage.

261

262 *3.2. Soil chemical characteristics*

263 PCA analysis performed on the matrix of chemical characteristics significantly separated the
264 four production systems ($p < 0.01$). Factor 1 (48.61% explained variance) separated the
265 agroecological system, with better chemical conditions (Fig. 2a, 2b). Analyses of variance
266 showed that soil pH-H₂O and pH-KCl were significantly higher in agroecological systems
267 compared to other systems. Soil N-NH₄, N-NO₃, total N, total C, CEC, K, Mg, P and Na
268 content did not significantly differ among the four cropping systems. Despite this, the highest
269 total C and N contents were observed in the agroecological system. Moreover, Ca content
270 was significantly higher in agroecological systems compared to intensive systems. Therefore,
271 the Chemical Index was significantly enhanced in agroecological systems compared to other
272 systems, due to high pH, CEC, base saturation and total C and N contents (Fig. 2c).

273

274 *3.3. Soil physical and morphological characteristics*

275 PCA analysis performed on the matrix of physical characteristics did not separate the four
276 production systems ($p > 0.01$). Soils generally had rather low bulk densities around 0.9,

277 especially in the conventional cropping systems (Supplementary Table S1). Soil in the
278 agroecological systems were comparatively more compact, although with bulk densities of
279 less than 1.2, and a remarkably low value of water retention at pF 4.2 which indicate of a
280 very low proportion of pores of $\leq 0.15 \mu\text{m}$. The Physical Index did not exhibit significant
281 differences among cropping systems.

282 PCA analysis performed on the matrix of morphological characteristics significantly
283 separated the agroecological system from the others ($p < 0.01$, Fig. 3a, 3b). On average, a
284 rather large proportion (49.4%) of the soil volume was macro-aggregated with large
285 variations from 14.1 to 81.3% depending on treatments and sites. Biogenic aggregates
286 comprised 31.4% of the total soil mass and physical aggregates 5.9%. There was a clear
287 trend for soils to have a larger proportion of biogenic aggregates along the sequence from
288 high inputs (23.8% of the total soil weight on average), to intermediate and low and
289 agroecological cropping systems (46.1% of the total soil weight). Agroecological systems had
290 significantly higher proportions of biogenic aggregates than the other three, and lower
291 proportions of physical aggregates and non-aggregated soils than intensive and low input
292 systems. Subsequently, the non-aggregated soil volume was higher in other systems
293 (54.8%) compared to agroecological systems (33.9%). The proportion of physical aggregates
294 was also higher in intensive systems (8.7%) as compared to low input systems (4.7%). The
295 Morphological Index regularly increased from intensive to agroecological systems; it was
296 significantly higher in agroecological than in conventional systems (Fig. 3c).

297

298 *3.4. Soil macroinvertebrate communities*

299 Soil macroinvertebrate communities varied among cropping systems, with respective
300 densities ranging from a minimum value of $357 \pm 48 \text{ ind.m}^{-2}$ to a maximum of 886 ± 112
301 ind.m^{-2} and an overall average of $618 \pm 135 \text{ ind.m}^{-2}$. Regardless the cropping system type,
302 ants were the most abundant group (26%) followed by earthworms (25%), diplopods (23%)
303 and termites (7%). Communities were significantly impacted by production systems (global
304 PCA randtest $p < 0.01$, Fig. 4a, 4b) with highest values of the Macrofauna Index in low input

305 (3) and agroecological (4) production systems (Fig. 4c). Taxonomic richness did not vary
306 significantly among cropping systems.

307

308 3.5. Pests and plant production

309 PCA analysis performed on the matrix of pests did not separate the four production systems
310 ($p>0.01$). However, plant parasitic nematode communities varied among cropping systems,
311 ranging from 60809 ± 39413 to 180166 ± 53667 ind.100 g roots⁻¹ Total population of plant
312 parasitic nematodes was not significantly different among cropping systems. Nevertheless,
313 *Radopholus similis* population was significantly reduced in agroecological and intensive
314 systems and was higher in intermediate and low input systems (Table 2). *Helicotylenchus*
315 *multicinctus* population, on the contrary, was significantly higher in agroecological cropping
316 systems (Table 2).

317 The severity of root damage induced by parasites also varied within cropping systems. The
318 root necrosis index was lower, although not significantly, in intensive and agroecological
319 systems (respectively, 37 ± 3 % and 36 ± 5 %) compared to intermediate and low input
320 systems (respectively, 54 ± 4 % and 43 ± 3 %).

321 Black weevil captures varied among cropping systems, ranging from 16 ± 2 ind.month⁻¹ to 64
322 ± 3 ind.month⁻¹. The abundance of black weevils was not significantly different among
323 cropping systems.

324 The Pest Index exhibited rather important variations among cropping systems, with highest
325 values in the intermediate system and lowest on average in the intensive system despite a
326 large variability.

327 Plant yield (expressed by bunch weight) averaged 15.6 ± 0.8 kg in low input systems, $16.6 \pm$
328 1.3 kg in intermediate systems, 17.2 ± 1.5 kg in agroecological systems and 19.7 ± 0.8 kg in
329 intensive systems. Differences, however, were not significant.

330

331 3.6. Covariations

332 PCA analysis performed on the matrix of farm general Chemical, Physical, Morphological,
333 Macrofauna and Pest indexes significantly separated the four production systems ($p < 0.01$).
334 Factor 1 (40% explained variance) separated the agroecological system, with better
335 morphological and chemical conditions from the other 3 ones that had higher values of the
336 physical indicator. Factor 2 showed a clear opposition between sites with high macrofaunal
337 index (mostly found in low input (3) and agroecological (4) systems) and sites of production
338 systems 1 and 2 with higher values of the Pest Index (Fig. 5a, 5b).

339

340 **4. Discussion**

341 *4.1. Cropping systems and soil health*

342 Around the world, plantain is mostly cultivated in traditional, extensive systems, and
343 consumed locally (Tchango Tchango et al., 1999). Plantain cropping systems in Guadeloupe
344 are comparatively more intensive with high inputs of mineral fertilizers, pesticides and
345 herbicides. Only 14% of the plots have been classified as agroecological and 28% as low
346 input, characterized by the predominant use of organic fertilizers, and low applications of
347 pesticides and herbicides. In Guadeloupe, plantain plantations are mainly found in the
348 banana crop region. They coexist with intensive banana dessert monocultures that use high
349 amounts of pesticide and mineral fertilizers (Sierra et al., 2015). Most plantain producers
350 indeed use similar farming practices as those used in banana dessert crops with 8-12
351 applications of chemical fertilizer during the growth season in monocultures (Sierra et al.,
352 2015).

353 Our study showed that soil morphological, macrofauna and chemical characteristics were
354 improved under agroecological plantain cropping systems. We observed in these systems a
355 significant accumulation of biogenic aggregates. The high concentration of biogenic
356 aggregates in agroecological plots can be partly explained by the reduction of tillage, which
357 results in improved stability of the soil structure within a few years (Haynes, 2000). This can
358 be reinforced by the maintenance of a permanent litter of plant residues on the soil surface.
359 A previous study carried out on Guadeloupean andosols showed that deep tillage caused a

360 decrease in soil organic matter content (Clermont-Dauphin et al., 2004). Indeed, our results
361 suggest that in agroecological systems, favourable soil structure could be maintained by
362 macrofaunal activity, as previously reported by Velasquez and Lavelle, 2019.
363 Macrofauna characteristics were also improved in low input and agroecological cropping
364 systems. In a recent study, Lavelle et al. (2022) showed that the worldwide abundance of soil
365 macroinvertebrate communities drastically decreases in conventional cropping systems. In
366 our study, the increase in macrofauna abundance within the ecological friendly cropping
367 systems may be due to moderate levels of pesticides, herbicides and mineral fertilizer
368 applications (Sánchez-Moreno et al., 2009; Niedobová et al. 2019; Loranger-Merciris et al.,
369 2022; Zulu et al. 2022).

370 In addition, our results showed that the Chemical Index was significantly enhanced in
371 agroecological systems compared to other systems, due to high pH, CEC, base saturation
372 and C and N contents. Sihi et al. (2017) found that long-term application of organic residues
373 in basmati rice crop improved physical, chemical, and biological indicators of soil health.
374 These authors observed that organic residues addition favoured biologically available
375 nutrients in organic systems, and stimulated soil microorganisms that produce enzymes
376 responsible for the conversion of unavailable nutrients to plant available forms. Thus, this
377 study indicates, as ours, that agroecological farming practices may promote biotic and abiotic
378 interactions in the soil which may support sustainable agriculture.

379

380 *4.2. Cropping systems, pests and plant health*

381 The plant-parasitic nematode communities sampled in our investigation (*H. multincinctus*,
382 *Hoplolaimus* sp, *Meloidogyne* sp, *Pratylenchus coffeae*, *R. similis*, *Rotylenchus reniformis*)
383 was similar to previous studies carried out on plantain cropping systems in Côte d'Ivoire
384 (Adiko and Badou N'Guessan, 1999), Rwanda (Sebasigari, 1990), and Cuba (Rodriguez and
385 Rodriguez, 1999). An interesting result of our study was that *R. similis*, the most destructive
386 species on *Musa* sp., was absent in the agroecological perennial cropping systems. This can
387 be explained by the fact that these plots were planted with vitroplants and thus were healthy

388 at the beginning. This result highlights that particular attention should be paid to the sanitary
389 state of the plant material used during plantain plantation for ensuring plantation durability. In
390 this sense, it has been already observed that the use of healthy plants, obtained through the
391 PIF technique (Lefranc et al., 2010; Sodom et al., 2010), significantly reduced pest
392 infestations at the beginning of the plantation (Loranger-Merciris et al., 2022). In contrast, the
393 higher density of *H. multincinctus* observed in agroecological perennial banana plantations
394 showed that these ectoparasite nematodes are more persistent in more organic cropping
395 systems. This same result was obtained by Pierrot et al. (2002) in plantain plantations in
396 Cameroon. An important fact is that *H. multincinctus* is not the most damaging on banana
397 (effect on bunch weight) as shown by Moens et al. (2006). The dynamics of plantain roots
398 can also alter the ratio of *H. multincinctus* to *R. similis* (Quénéhervé et al., 2011). Indeed, the
399 proportion of old roots (potential resource for *H. multincinctus*) increased in agroecological
400 perennial plantain plots compared to that of young roots (potential resource for *R. similis*),
401 (Tixier et al., 2008).

402 We also showed that pest occurrence, in particular plant-parasitic nematodes communities,
403 was minimal in agroecological cropping systems. Our study revealed that cropping systems
404 may impact populations of the plant parasitic nematode *R. similis* and subsequent effects on
405 plant health. In fact, *R. similis* population was significantly reduced in agroecological systems
406 characterized by a low use of agrochemicals, which indicates that organic amendments can
407 regulate plant parasitic nematode populations in plantain crops, as already observed for
408 banana (Pattison et al., 2006; Tabarant et al., 2011). These authors suggested that the
409 regulation of these plant parasitic nematodes was associated with an increase in the diversity
410 and functional composition of soil nematode communities. In particular, the supply of organic
411 matter boosted the populations of microbivorous nematodes, particularly bacterivores (Ferris
412 and Bongers, 2006) and of carnivorous nematode populations (Tabarant et al., 2011) and not
413 of plant parasitic nematodes. The equilibrium state of communities also limits pest
414 development (Altieri, 1999). As an example, in Senegal, millet is attacked by two main
415 nematode species, *Tylenchorhynchus gladiolatus* and *Scutellonema cavenessi*. These two

416 species represent more than 95% of the nematode community of these agroecosystems.
417 When millet fields were left fallow, the number of these two nematodes decreased, while
418 there was a marked increase in the numbers of other nematodes. Interestingly, the level of
419 damage caused by the two main pest nematode species was reduced when they were
420 associated with other plant-feeding nematodes such as one of those recovering during fallow
421 periods, *Helicotylenchus dihystera* (Cadet et al., 2002).
422 *R. similis* populations were also reduced in intensive cropping systems presumably as a
423 result of the application of chemical nematicides which protected plants, as least temporarily.
424 In fact, chemical nematicides only allow a partial and short-term control of nematodes
425 (Moens et al., 2004). This justifies, the local adoption of short-time duration of intensive
426 plantain plots; e.g., 1 cycle in 85% of the cases, and 2 or more cycles in 15%. Nevertheless,
427 these chemical nematicides can be damaging to human health and the environment
428 (Matthews, 2006). Overall, our study highlights the fact that the agroecological system has
429 the same performance in terms of pest control as the conventional system, but without the
430 application of pesticides.

431

432 **Conclusion**

433 Our study clearly showed that well managed agroecological systems can provide the same
434 level of production and plant protection than intensive conventional systems, while improving
435 soil quality and pest regulation. As a matter of fact, our data highlighted that there was a
436 significant improvement in Chemical, Morphological and Macrofauna indexes in
437 agroecological plantain cropping systems as well as a better regulation of plant parasitic
438 nematodes. Moreover, these agroecological cropping systems lengthen the duration of
439 plantain plots (in our study, agroecological systems are cultivated for the duration of 3 to 10
440 cycles). This longevity is an indicator of the good health of the agroecological cropping
441 systems. Furthermore, in these agroecological systems, production costs may be
442 significantly reduced by eliminating costly replanting and equally costly pesticide
443 applications, while maintaining yield levels that are at least equivalent to conventional

444 intensive cropping systems, characterized by a strong use of agrochemicals. However, the
445 problems faced by plantain production, particularly a high level of telluric parasitism, led the
446 majority of farmers to promote intensive cultural practices that aim at reducing pests without
447 restoring soil health and the sustainability of the cropping systems. Yearly plant renewal and
448 a massive use of agrochemicals in conventional systems enable to compensate for the lower
449 general quality of the soil. Fast transitions from conventional to agroecological systems are
450 possible. However, the main condition for rapid adoption of these eco-friendly cropping
451 systems is the implementation of appropriate public policies.

452

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460

461 **References**

- 462 Adhikari, K., Hartemink, A.E., 2016. Linking soils to ecosystem services. A global review.
463 *Geoderma* 262, 101-111. <https://doi.org/10.1016/j.geoderma.2015.08.009>
- 464 Adiko, A., Badou N'Guessan, A., 1999. Evolution de la nématofaune du bananier plantain
465 (*Musa* AAB) en Côte d'Ivoire, *InfoMusa* 10, 26-27.
- 466 Altieri, M.A., 1999. The ecological role of biodiversity in agroecosystems. *Agric. Ecosyst.*
467 *Environ.* 74, 19-31. [https://doi.org/10.1016/S0167-8809\(99\)00028-6](https://doi.org/10.1016/S0167-8809(99)00028-6)
- 468 Altieri, M.A., Nicholls, C.I., 2000. *Agroecología: teoría y práctica para una agricultura*
469 *sustentable*. First Ed. Programa de las Naciones Unidas para el Medio Ambiente, México.
- 470 Bardgett, R.D., van der Putten W.H., 2014. Belowground biodiversity and ecosystem
471 functioning. *Nature* 515, 505-511. <https://doi.org/10.1038/nature13855>

472 Brussaard, L., 2021. Biodiversity and ecosystem functioning in soil: The dark side of nature
473 and the bright side of life. *Ambio* 50, 1286-1288. [https://doi.org/10.1007/s1328002101507-](https://doi.org/10.1007/s1328002101507-z)
474 z

475 Cabidoche, Y.M., Achard R., Cattan P., Clermont-Dauphin C., Massat F., Sansoulet J., 2009.
476 Long term pollution by chlordecone of tropical volcanic soils in the French West Indies: A
477 simple leaching model accounts for current residues. *Environ. Pollut.* 157, 1697-1705.
478 <https://doi.org/10.1016/j.envpol.2008.12.015>

479 Cadet, P., Spaull, V.W., McArthur, D.G., 2002. Role of plant parasitic nematodes and abiotic
480 soil factors in growth heterogeneity of sugarcane on a sandy soil in South Africa. *Plant*
481 *Soil.* 246, 259-271. <https://doi.org/10.1023/A:1020624114434>

482 Chessel, D., Dufour, A.B., Thioulouse, J., 2004. The ade4 package -I- One-table methods. *R*
483 *News* 4:5-10.

484 Clermont-Dauphin, C., Cabidoche, Y.M., Meynard, J.M., 2004. Effects of intensive
485 monocropping of bananas on properties of volcanic soils in the uplands of the French
486 west indies. *Soil Use Manage.* 20, 105-113.
487 <https://doi.org/10.1111/j.14752743.2004.tb00345.x>

488 Coolen, W.A., D'herde, C. J., 1972. A method for the quantitative extraction of nematodes
489 from plant tissue. Ghent, State Nematology and Entomology Research Station, 77 p.

490 Dabin B., 1967. Sur une méthode d'analyse du phosphore dans les sols tropicaux. Colloque
491 sur la fertilité des sols tropicaux. Tananarive, 19-25 Nov., I, 99-115.

492 D'Hose, T., Cougnon, M., De Vliegheer, A., Vandecasteele, B., Viaene, N., Cornelis, W., Van
493 Bockstaele, E. and Reheul, D., 2014. The positive relationship between soil quality and
494 crop production: a case study on the effect of farm compost application. *Appl. Soil Ecol.*
495 75, 189-198. <https://doi.org/10.1016/j.apsoil.2013.11.013>

496 Driessen, P., Deckers, J., Spaargaren, O., Nachtergaele, F., 2001. Lecture notes on the major
497 soils of the world. FAO, Rome.

498 Ferris H., Bongers T., 2006. Nematode indicators of organic enrichment. *J. Nematol.* 38, 3-
499 12.

500 FAOSTAT, 2021. Food and Agriculture Organization of the United Nations. FAO Rome.

501 Godefroid, M., Tixier, P., Chabrier, C., Djigal, D., Quénéhervé, P., 2017. Associations of soil
502 type and previous crop with plant-feeding nematode communities in plantain agrosystems.
503 App. Soil Ecol. 113, 63-70. <https://doi.org/10.1016/j.apsoil.2017.01.012>

504 Gold, C.S., Tinzaara, W., 2008. Banana Weevil, *Cosmopolites sordidus* (Germar)
505 (Coleoptera: Curculionidae). In: Capinera, J.L. (Ed) Encyclopedia of Entomology.
506 Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-6359-6_224

507 Haynes, R.J., 2000. Labile organic matter as an indicator of organic matter quality in arable
508 and pastoral soils in New Zealand. Soil Biol. Biochem. 32, 211-219.
509 [https://doi.org/10.1016/S0038-0717\(99\)00148-0](https://doi.org/10.1016/S0038-0717(99)00148-0)

510 ISO, 2011. Qualité du sol - Prélèvement des invertébrés du sol - Partie 5: Prélèvement et
511 extraction des macro-invertébrés du sol. ISO 23611-5: 2011.

512 Kahane, R., Hodgkin, T., Jaenicke, H. Hoogendoorn, C., Hermann, M., Keatinge, D.J.D.H.,
513 D'arros, H.J., Padulosi, S., Looney, N.E., 2013. Agrobiodiversity for food security, health
514 and income. Agron. Sustain. Dev. 33, 671-693. [https://doi.org/10.1007/s13593-013-0147-](https://doi.org/10.1007/s13593-013-0147-8)
515 8

516 Lassoudière, A., 2011. Le bananier, un enjeu mondial. Pour la Science n° 400, février 2011.

517 Lavelle, P., Rodríguez, N., Arguello, O., Bernal, J., Botero, C., Chaparro, P., Gómez, Y.,
518 Gutiérrez, A., Hurtado, M., Loaiza, S., Xiomara Pullido, S., Rodríguez, E., Sanabria, C.,
519 Velásquez, E., Fonte, S.J., 2014. Soil ecosystem services and land use in the rapidly
520 changing Orinoco River Basin of Colombia. Agric. Ecosyst. Environ. 185, 106-117.
521 <https://doi.org/10.1016/j.agee.2013.12.020>

522 Lavelle, P., Mathieu, J., Spain, A., Brown, G., Fragoso, C., Lapied, E., De Aquino, A., Barois,
523 I., Barrios, E., Barros, M. E., Bedano, J. C, Blanchart, E., Caulfield, M., Chagueza, Y., Dai,
524 J., Decaens, T., Dominguez, A., Dominguez, Y., Feijoo, A., Folgarait, P., Fonte, S. J.,
525 Gorosito, N., Huerta, E., Jimenez, J. J., Kelly, C., Loranger, G., Marchao, R., Marichal, R.,
526 Praxedes, C., Rodriguez, L., Rousseau, G., Rousseau, L., Sanabria, C., Suarez, J. C.,
527 Tondoh, J. E., De Valenca, A., Vanek, S. J., Vasquez, J., Velasquez, E., Webster, E. and

528 Zhang, C. (2022). Soil macroinvertebrate communities: a worldwide assessment. Glob.
529 Ecol. Biogeogr. 31,1261-1276. <https://doi.org/10.1111/geb.13492>

530 Lefranc, L.M., Lescot, T., Staver, C., Nkapnang, I., Temple, L., 2010. Macropropagation as
531 an innovative technology: Lessons and observations from projects in Cameroon. Acta
532 Hortic. 879, 727-734. <https://doi.org/10.17660/ActaHortic.2010.879.78>

533 Levillain, J., Cattan, P., Colin, F., Voltz, M., Cabidoche, Y.M., 2012. Analysis of
534 environmental and farming factors of soil contamination by a persistent organic pollutant,
535 chlordecone, in a banana production area of French West Indies. Agric. Ecosyst. Environ.
536 159, 123-132. <https://doi.org/10.1016/j.agee.2012.07.005>

537 Loranger-Merciris, G., Ozier-Lafontaine, H., Diman, J.L., Sierra, J., Lavelle, P. (2022). Fast
538 improvement of macrofauna communities and soil quality in plantain crops converted to
539 agroecological practices. Pedobiologia 93-94, 150823,
540 <https://doi.org/10.1016/j.pedobi.2022.150823>.

541 Matthews, G.A., 2006. Pesticides: health, safety, and the environment. Blackwell, Oxford,
542 248 p.

543 Millennium Ecosystem Assessment, 2005. Ecosystem and Human Well-Being: Synthesis,
544 Island Press, 137 p.

545 Moens, T., Araya, M., Swennen, R., de Waele D., 2004. Enhanced biodegradation of
546 nematicides after repetitive applications and its effect on root and yield parameters in
547 commercial banana plantations. Biol. Fertil. Soil 39, 407-414.
548 <https://doi.org/10.1007/s00374-004-0726-6>

549 Moens, T., Araya, M., Swennen, R., Waele, D., 2006. Reproduction and pathogenicity of
550 *Helicotylenchus multicinctus*, *Meloidogyne incognita* and *Pratylenchus coffeae*, and their
551 interaction with *Radopholus similis* on *Musa*. Nematology 8, 45-58.
552 <https://doi.org/10.1163/156854106776179999>

553 Niedobová, J., Křištofová, L., Michalko, R., Hula, V., Kýnický, J., Brtnický, M., 2019. Effects of
554 glufosinate-ammonium herbicide and pod sealant on spider *Pardosa agrestis*. J. Appl.
555 Entomol. 143, 196-203. <https://doi.org/10.1111/jen.12574>

556 Nielsen, U.N., Wall, D.H. and Six J. (2015). Soil Biodiversity and the Environment. Annu Rev.
557 Environ. Resour. 40, 63-90. <https://doi.org/10.1146/annurev-environ-102014-021257>

558 Ozier-Lafontaine, H., Lesueur-Jannoyer, M., 2014 (Eds). Sustain. Agric. Rev. 14,
559 Agroecology and Global Change.

560 Pattison, T., Cobon, J., Sikora R., 2006. Soil quality improvement and nematode
561 management on banana farms in Australia. XVII Reunião Internacional ACORBAT, 15-20
562 october 2006, Vol. 1, Joinville, Santa Catarina, Brasil, pp. 268-283.

563 Picq, C. Fouré, E., Frison, E.A., 1998. Bananas and Food Security. Les productions
564 bananières : un enjeu économique majeur pour la sécurité alimentaire. International
565 symposium, Douala, Cameroon, 10-14 November 1998. INIBAP, Montpellier, 797 p.
566 <https://agritrop.cirad.fr/300693/1/ID300693.pdf>

567 Pierrot, J., Achard, R., Temple, L., Abadie, C., Fogain, R., 2002. Déterminants de la
568 production de plantain dans le sud-ouest du Cameroun : intérêt d'un observatoire. Fruits
569 57, 75-86.

570 Quénéhervé, P., 2009. Integrated management of banana nematodes. In: Ciancio, A.,
571 Mukerji, K. (eds) Integrated management of fruit crops nematodes. Integrated
572 management of plant pests and diseases, vol 4. Springer, Dordrecht.
573 https://doi.org/10.1007/978-1-4020-9858-1_1

574 Quénéhervé, P., Barrière, V., Salmon, F., Houdin, F., Achard, R., Gertrude, J-C., Marie-Luce,
575 S., Chabrier, C., Duyck, P.F., Tixier, P., 2011. Effect of banana crop mixtures on the plant-
576 feeding nematode community. Appl. Soil Ecol. 49,40-45.
577 <https://doi.org/10.1016/j.apsoil.2011.07.003>

578 R Core team, 2013. R: A language and environment for statistical computing. R Foundation
579 for Statistical Computing, Vienna, Austria. URL <http://www.R-project.org/>

580 Reddy, G.V.P., Cruz, Z.T., Naz, F. and Muniappan, R. (2008). A pheromone-based trapping
581 system for monitoring the population of *Cosmopolites sordidus* (germar) (Coleoptera:
582 Curculionidae). J. Plant Prot. Res. 48, 515-527. <https://doi.org/10.2478/v10045-009-0001->
583 1

584 Rodriguez, S.A, Rodriguez J.L., 1999. Aspectos socio económicos del cultivo del plátano en
585 Colombia. Oficina Regional de Planeación-Corpoica, Regional Nueve. Manizales, 6-9.

586 Rodriguez, L., Suárez, J.C., Pulleman, M., Guaca, L., Rico, A., Romero, M., Quintero, M.,
587 Lavelle, P., 2021. Agroforestry systems in the Colombian Amazon improve the provision
588 of soil ecosystem services, *Appl. Soil Ecol.* 164, 103933,
589 <https://doi.org/10.1016/j.apsoil.2021.103933>

590 Sadom, L., Tomekpé, K., Folliot, M., Côte, F.X., 2010. Comparaison de l'efficacité de deux
591 méthodes de multiplication rapide de plants de bananier à partir de l'étude des
592 caractéristiques agronomiques d'un hybride de bananier plantain (*Musa* spp.). *Fruits* 65,
593 3-9. <https://doi.org/10.1051/fruits/2009036>

594 Sánchez-Moreno, S., Alonso-Prados, E., Alonso-Prados, J.L., García-Baudín, J.M., 2009.
595 Multivariate analysis of toxicological and environmental properties of soil nematicides.
596 *Pest Manag. Sci.* 65, 82-92. <https://doi.org/10.1002/ps.1650>

597 Sebasigari, K., 1990, les charançons et les nématodes du bananier dans les pays C.E.P,
598 Burundi, Rwanda-Zaire, 80-81.

599 Sierra, J., Causeret, F., Diman, J.L., Publicol, M., Desfontaines, L., Cavalier, A., Chopin, P.,
600 2015. Observed and predicted changes in soil carbon stocks under export and diversified
601 agriculture in the Caribbean. The case study of Guadeloupe. *Agric. Ecosyst. Environ.* 213,
602 252-264. <https://doi.org/10.1016/j.agee.2015.08.015>

603 Sihi, D., Dari, B., Sharma, D.K., Pathak, H., Nain, L., Sharma, O.P., 2017. Evaluation of soil
604 health in organic vs. conventional farming of basmati rice in North India. *J. Plant Nutr. Soil*
605 *Sc.* 180, 389-406. <https://doi.org/10.1002/jpln.201700128>

606 Tabarant, P., Villenave, C., Risède J.M., Estrade, J.R., Thuriès, L., Dorel, M., 2011. Effects
607 of four organic amendments on banana parasitic nematodes and soil nematode
608 communities. *Appl. Soil Ecol.* 49, 59-67. <https://doi.org/10.1016/j.apsoil.2011.07.001>

609 Tamburini, G., Bommarco, R., Wanger, T.C., Kremen, C., van der Heijden, M.G.A., Liebman
610 M., Hallin, S., 2020. Agricultural diversification promotes multiple ecosystem services

611 without compromising yield, *Sci. Adv.* 6(45):eaba1715,
612 <https://doi.org/10.1126/sciadv.aba1715>

613 Tchango Tchango, J., Bikoï, A., Achard, R., Escalan, J.V., Ngalani, J.A., 1999. Plantain:
614 post-harvest operations. AGSI/FAO, 60 p.

615 Tixier, P., Salmon, F., Chabrier, C., Quénéhervé, P., 2008. Modelling pest dynamics of new
616 crop cultivars: the FB920 banana with the *Helicotylenchus multicinctus* - *Radopholus*
617 *similis* nematode complex in Martinique. *Crop Prot.* 27, 1427-1431.
618 <https://doi.org/10.1016/j.cropro.2008.06.004>

619 Turbé, A., Toni, A., Benito, P., Lavelle, P., Ruiz, N., Van der Putten, W.H., Labouze, E.,
620 Mudgal, S., 2010. Soil biodiversity: functions, threats and tools for policy makers. Bio
621 Intelligence Service, IRD, and NIOO, Report for European Commission (DG
622 Environment).

623 Velasquez E., Lavelle, P., Andrade, M., 2007a. GISQ, a multifunctional indicator of soil
624 quality. *Soil Biol. Biochem.* 39, 3066-3080. <https://doi.org/10.1016/j.soilbio.2007.06.013>

625 Velasquez, E., Pelosi, C., Brunet, D., Grimaldi, M., Martins, M., Rendeiro, A.C., Barrios, E.,
626 Lavelle, P., 2007b. This ped is my ped: Visual separation and near infrared spectra allow
627 determination of the origins of soil macroaggregates. *Pedobiologia* 51, 75-87.
628 <https://doi.org/10.1016/j.pedobi.2007.01.002>

629 Velasquez, E., Lavelle, P., 2019. Soil macrofauna as an indicator for evaluating soil based
630 ecosystem services in agricultural landscapes. *Acta Oecol.* 100, 103446.
631 <https://doi.org/10.1016/j.actao.2019.103446>

632 Zulu, S.G., Motsa, N.M., Sithole, N.J., Magwaza, L.S., Ncama, K., Soil macrofauna
633 abundance and taxonomic richness under long-term no-till conservation agriculture in a
634 semi-arid environment of South Africa. *Agronomy* 12, 722.
635 <https://doi.org/10.3390/agronomy12030722>

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639 **Table 1**

640 Description of the four groups of plantain plots identified in the hierarchical analysis and
 641 described as different cropping systems. Number into brackets following pesticide, herbicide
 642 and fertilizer levels are the mean number of applications during the plantation cycle observed
 643 in the plots of these groups.

	Group 1	Group 2	Group 3	Group 4
Cropping system name	Intensive	Intermediate	Low input	Integrated
Origin of plant material	Sucker	Sucker	Sucker	Tissue culture
Plot longevity	Annual	Annual	Annual	Perennial†
Pesticide application‡	High (2)	Moderate (1)	Moderate (1)	None (0)
Herbicide application§	High (3-5)	High (3-5)	None	Low (0-2)
Fertilization	Mineral# (4-8)	Mineral# (2-3)	Mineral# (2-3)	Organic
Tillage	Annual	Annual	Annual	None (0)

644 † 3 to 10 cycles

645 ‡ 1 application of Nemathorin® (active ingredient Fosthiazate) at the plantation or 2
 646 applications of Nemathorin® at the plantation and 6 months after the plantation.

647 § application of Basta ® (active ingredient Glufosinate)

648 # 1 application of Diammonium phosphate (DAP) at the plantation, then application of a
 649 complete N20-P20-K20 fertilizer

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659 **Table 2**

660 Plant parasitic nematode communities in 4 types of plantain cropping systems in
 661 Guadeloupe. Values are means of 5 samples (\pm SE). For each nematode species, means
 662 with different upper script letter are significantly different based on HSD test ($P \leq 0.05$).

	Intensive	Intermediate	Low Input	Agroecological	P
<i>R. similis</i>	2093 \pm 2017 ^a	18294 \pm 12630 ^{ab}	39758 \pm 16102 ^b	0 \pm 0 ^a	0.003
<i>P. coffeae</i>	116769 \pm 34910 ^a	137516 \pm 80124 ^a	85987 \pm 29217 ^a	37527 \pm 32568 ^a	0.621
<i>H. multicinctus</i>	320 \pm 255 ^{ab}	21690 \pm 21603 ^{ab}	19 \pm 19 ^a	20776 \pm 16780 ^b	0.031
<i>Meloidogyne</i> sp.	3171 \pm 1964 ^a	2666 \pm 1611 ^a	1378 \pm 1105 ^a	2471 \pm 1444 ^a	0.556
<i>R. reniformis</i>	80 \pm 46 ^a	0 \pm 0 ^a	135 \pm 85 ^a	18 \pm 10 ^a	0.271
<i>Hoplolaimus</i> sp.	70 \pm 53 ^a	0 \pm 0 ^a	0 \pm 0 ^a	17 \pm 12 ^a	0.120

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678 **Figure captions**

679

680 **Fig. 1.** Distribution of plots and groups in the F1F2 factorial plane of the MCA. G1:
681 “intensive”, G2: “intermediate”, G3: “low input” and G4: “agroecological” cropping system.

682

683 **Fig. 2.** Projection of (a) plots and groups and (b) variables in the factorial plane F1F2 of a
684 PCA analysis of a matrix of chemical characteristics in plantain cropping systems. c) Soil
685 Chemical Index in plantain cropping systems. 1: “intensive”, 2: “intermediate”, 3: “low input”
686 and 4: “agroecological” cropping systems. Means with different upper script letter are
687 significantly different based on HSD test.

688

689 **Fig. 3.** Projection of (a) plots and groups and (b) variables in the factorial plane F1F2 of a
690 PCA analysis of a matrix of morphological characteristics in plantain cropping systems. AB:
691 Biogenic aggregates, AR: Root aggregates, AP: Physical aggregates, NA: non
692 macroaggregated soil. c) Soil Morphological Index in plantain cropping systems. 1:
693 “intensive”, 2: “intermediate”, 3: “low input” and 4: “agroecological” cropping systems. Means
694 with different upper script letter are significantly different based on HSD test.

695

696 **Fig. 4.** Projection of (a) plots and groups and (b) variables in the factorial plane F1F2 of a
697 PCA analysis of a matrix of macroinvertebrates communities in plantain cropping systems.
698 OLI: Earthworms, ISO: Isopoda, DIPL: Diplopoda, CHI: Chilopoda, DER: Dermaptera, FOR:
699 Formicidae, TER: Termites, COL: Coleoptera, RTAX: Taxonomic richness. c) Soil
700 Macrofauna Index in plantain cropping systems. 1: “intensive”, 2: “intermediate”, 3: “low
701 input” and 4: “agroecological” cropping systems. Means with different upper script letter are
702 significantly different based on HSD test.

703

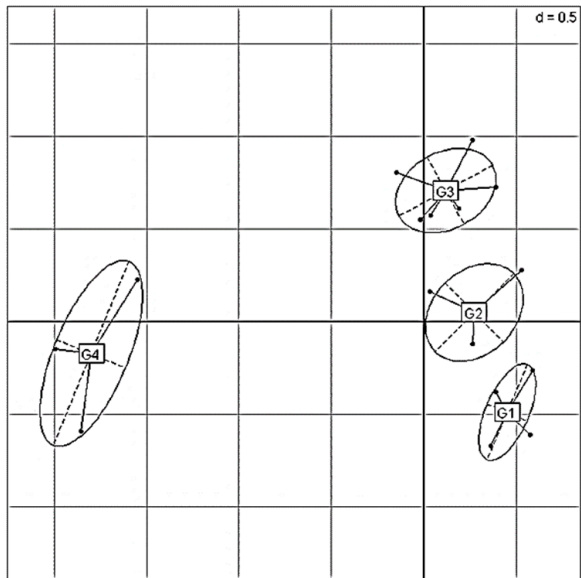
704

705 **Fig. 5.** Projection of (a) plots and (b) variables grouped into plantain cropping systems of
706 decreasing intensity from 1 (Intensive) to 4 (Agroecological) in the factorial plane F1F2 of a
707 PCA analysis of a matrix of soil indexes.

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709 **Fig. 1**

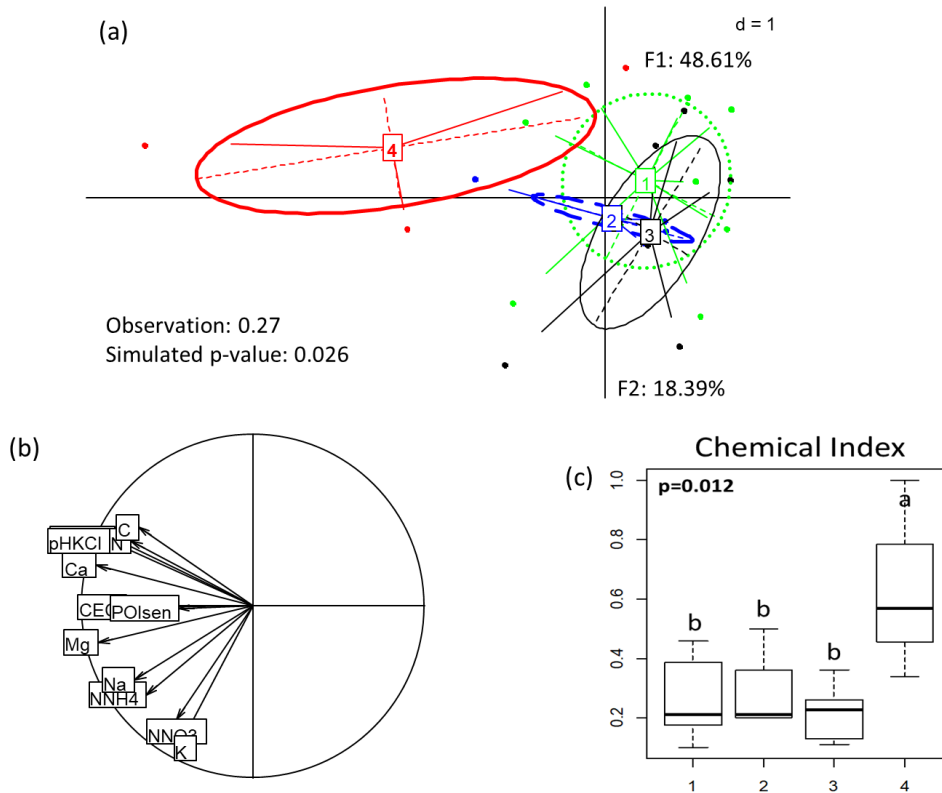
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712 **Fig. 2**

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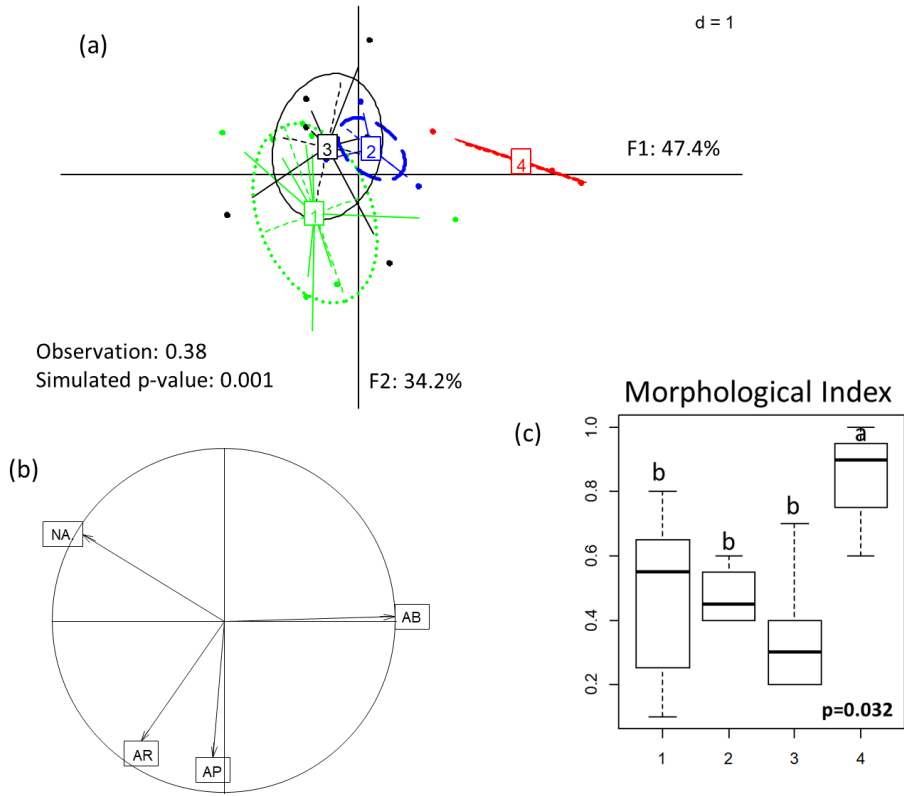
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728 **Fig. 3**

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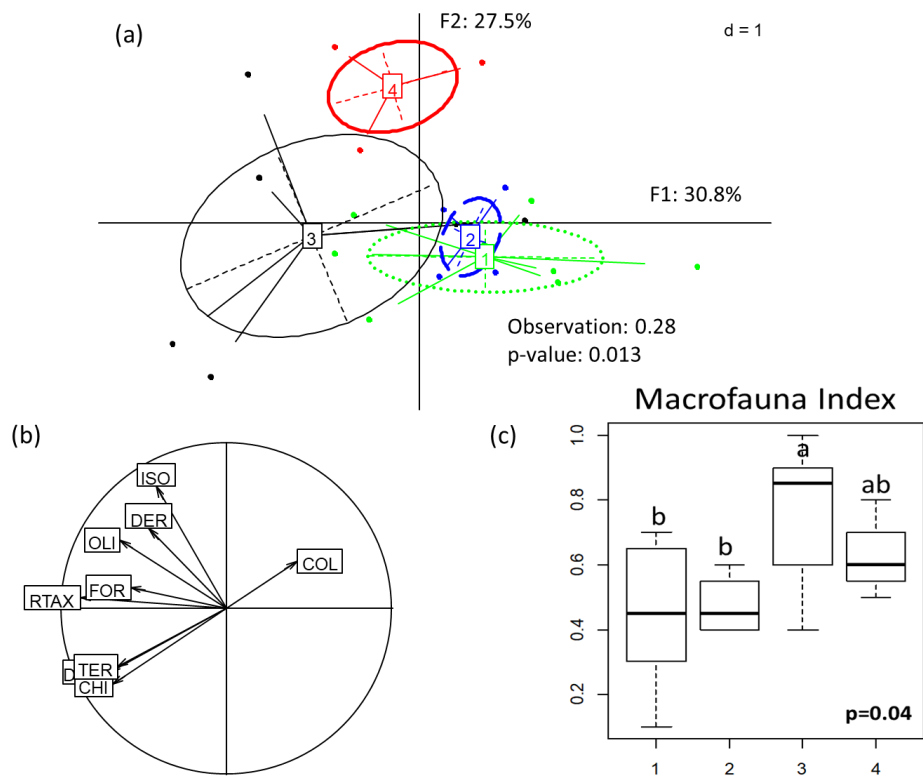
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733 **Fig. 4**

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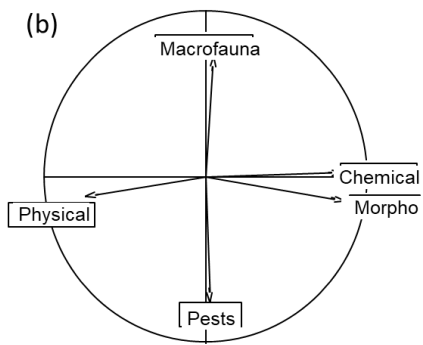
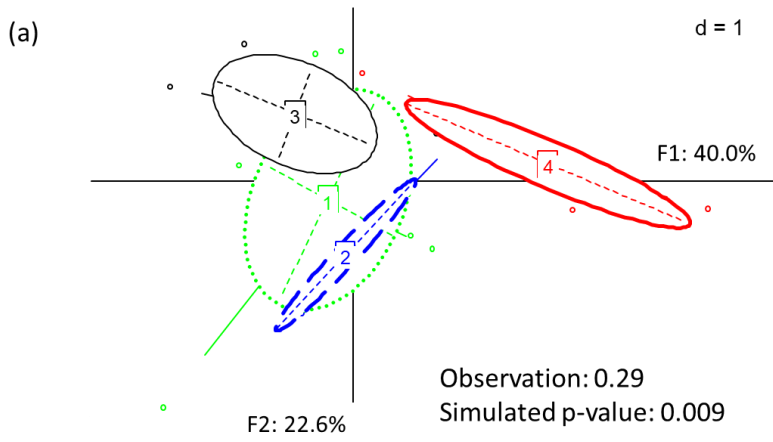
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739 **Fig. 5**

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