

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

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1	Management practices and incidence of pests in Plantain (Musa paradisiaca					
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28 ABSTRACT

29 Plantain (*Musa paradisiaca* AAB) is one of the most important staple crops in the tropics, particularly in the Caribbean. Pests are the main constraint to plantain production and yield 30 31 increases may be possible by improving pest management. However, there is a lack of data on these cropping systems and a need to identify new elements of improved production 32 systems that can control pests in line with the principles of agroecological transition. In this 33 study, we test the hypothesis that crops grown in good quality soils are less susceptible to 34 35 pests. To this end, an agroecological diagnosis of the biological, physical, morphological and chemical soil conditions and the occurrence of pests, in particular plant-parasitic nematodes, 36 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 were identified and compared: conventional intensive, intermediate, low-input and 41 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 increases in pH, CEC, base saturation and total C and N content. The Morphological Index 44 increased regularly from intensive to agroecological systems and was significantly higher in 45 agroecological systems with higher proportions of biogenic aggregates. Soil 46 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. We also showed that plant parasitic nematodes were better regulated in agroecological 49 production systems. Furthermore, the agroecological system achieved similar levels of crop 50 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.

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

57

58 **1. Introduction**

Plantain (Musa paradisiaca, AAB) is a major food resource in the tropics. This crop plays an 59 important socio-economic role for developing countries in tropical and subtropical zones. 60 Indeed, plantain provided food security and income for small growers who represent the 61 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 diet of more than 400 million people living in many developing countries, particularly in Africa, 64 Latin America and the Caribbean (Lassoudière, 2011). In 2020, plantain was grown in 54 65 66 countries and more than 43 million tons were produced worldwide (FAOSTAT, 2021). Latin America and the Caribbean produced 18% of the global production of plantain (FAOSTAT, 67 2021). Therefore, sustainable production of plantain in this region is crucial to provide food 68 security and income to millions of people (Picq et al., 1998). In spite of this, plantain is 69 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). Soil organisms provide essential ecological functions in agricultural and natural ecosystems. 73 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, 2008; Quénéhervé, 2009). Plant parasitic nematodes attack roots, inducing plant toppling 84 85 and yield reduction. The banana black weevil, Cosmopolites sordidus, attacks the plant underground corm, causing stem breakage. At the present time, these pests are mainly 86 controlled by synthetic pesticides which has generated major side effects on environment 87 (soil and water pollution, disappearance of domestic biodiversity and auxiliary fauna, ...) but 88 89 also on human health (Millennium Ecosystem Assessment, 2005). As an example, in Guadeloupe, the use of chlordecone to control C. sordidus in dessert banana plantations has 90 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 conserve environmental quality while sustaining crop yield and regulating pests (Loranger-94 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-Jannover, 2014).

Soil organisms but also physical and chemical properties of soil affect plant vigour. Low soil 98 biodiversity is actually associated with greater vulnerability to pests, due to altered natural 99 regulation of these pests (Nielsen et al., 2015). Moreover, some studies showed an 100 101 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 pest regulation (e.g., D'Hose et al., 2014), and none to our knowledge, has been done in 104 105 plantain plantations.

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

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

115

116 2. Material and Methods

117 2.1. Site information and study design

The study was carried out in the western island (Basse-Terre) of the Guadeloupe 118 archipelago (15°59'-16°9' N, 61°34'-61°43' W) in the Caribbean, where most plantain 119 120 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 3 m and mean annual temperature around 23°C. Soils are Haplic Nitisols (FAO-UNESCO 123 classification, Driessen et al., 2001) developed on volcanic ashes. They are clayey and are 124 125 mainly composed of halloysite (Clermont-Dauphin et al., 2004). Nitisols are similar to Ferralsols, but they are younger and therefore less evolved, less desaturated and generally 126 less acidic. The cation contents (Ca, Mg and K) are typically higher than in Ferralsols. 127 128 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

and plant-root parasitic nematode communities were assessed next to the stem of five plants

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

141

142 2.2. Soil chemical characteristics

Soil chemical properties were measured 30 cm apart from each selected plantain plant. For 143 each plant, a sample was taken from a soil block and analysed for total soil C and N using an 144 145 auto-analyser (NF ISO 13878, 1998). Available P was measured using the Olsen method (Dabin, 1967). Soil mineral N (N03⁻ and NH4⁺) was measured by colorimetry after extraction 146 with a 0.5M KCl solution. Exchangeable Ca²⁺, Mg²⁺, K⁺ and Na⁺ were determined after 147 extraction with ammonium acetate (NF X 31108). Cation-exchange capacity (CEC) was 148 149 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

Soil physical properties were measured 50 cm apart from each selected plantain plant. Three undisturbed 100 cm³ soil cores (50 mm in diameter \times 50 mm in length) were collected in order to measure bulk density, water content, useful water reserve and water retention at two 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., 2014). An undisturbed soil sample taken with an 8 cm diameter \times 8.5 cm height cylinder was 159 collected 50 cm apart from each selected plantain plant. In the laboratory, blocks were gently 160 separated and the samples were air-dried then sieved at 2 mm. The soil retained by the 161 sieve was placed on a filter paper and the various elements were separated according to 162 163 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 aggregates of angular forms, produced by the physical processes of the environment 165

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

170

171 2.4. Macroinvertebrate communities

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

181 2010).

182

183 2.5. Pests and plant characteristics

Primary roots were removed from a 25 cm \times 25 cm \times 30 cm soil block located 30 cm apart from the 5 sampled plants. Plant-feeding nematodes were extracted from an aliquot of the

roots (100 g) using a centrifugal-flotation method (Coolen and d'Herde, 1972).

Populations were counted in aliquots and expressed as number of nematodes per 100 grams
of root fresh biomass. The main plant-parasitic species were identified and counted under a
light microscope.

To assess the severity of root damage, a $25 \text{ cm} \times 25 \text{ cm} \times 30 \text{ cm}$ soil block located 30 cm apart from the 5 sampled plants was removed. Roots were removed in the whole volume of soil, carefully washed and cut longitudinally. Necrosis rates on the respective external and

internal surfaces of these roots were scanned independently using the WinRHIZO 2009a
Software (Regent Instruments Canada, Inc.). The colour of root necrosis due to soil-borne
pathogens varied from reddish to black while healthy roots were white. The necrosis index
was expressed as necrosed surface area over total root surface area.

Weevil *C. sordidus* populations were estimated using pheromone-baited pitfall traps (Reddy
et al., 2008). One trap was put in the middle of each plot and was collected after 30 days
(one sample by plot). Weevils were trapped in soapy water. Plant yield was estimated by
bunch weight for each selected plantain plant. The average harvest time is 12 months from
planting.

202

203 2.6. Data analyses

All the data sets used for statistical treatments are grouped in Supplementary Table S1. All 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 group plots according to their cropping systems. Differences in MCA-axes 1 and 2 scores 210 among groups were further tested by one-way ANOVAs (normality was assessed with 211 212 Shapiro-Wilk tests), followed by Tukey post hoc tests (function "Tukey HSD", package 213 "stats").

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

We then calculated synthetic indexes, defined as a set of statistically selected soil attributesthat 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 50% of the maximum contribution calculated for F1 and F2 of the PCA). Then, the values of 225 each variable set, adjusted to a range of 0.1 to 1.0 by a homothetic transformation, were 226 227 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). In a last step, a PCA analysis of all plots characterized by the set of the 5 synthetic indexes 230 231 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

significant differences among cropping systems. These analyses were done with the ade4
library (Chessel et al., 2004).

235

236 3. Results

237 3.1. Cropping systems

The first two axes of the MCA run on the seven variables related to the cropping system 238 (Supplementary Table S1) explained 46.9% of the total variance of the observations (data 239 240 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 use (4 to 8 applications). Group 2, called "intermediate" cropping system, is characterized by 250 an intensive use of herbicides (3 to 5 applications during the plantation cycle), moderate use 251 252 of pesticides (1 application at the plantation) and moderate use of mineral fertilizers (2 to 3 applications during the plantation cycle). Group 3, referred as "low input" cropping system, is 253 characterized by moderate levels of pesticides and mineral fertilizer applications 254 (respectively 1, and 2 to 3 applications during the plantation cycle) and no herbicides. Group 255 256 4 (called "agroecological" system) is separated from the other 3 along axis 1 of the MCA (Fig. 1). It is comprised of perennial plots, planted with seeds issued from tissue culture conducted 257 with organic fertilization (manure). Pesticides were not used and 0 to 2 applications of 258 259 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

PCA analysis performed on the matrix of chemical characteristics significantly separated the 263 264 four production systems (p<0.01). Factor 1 (48.61% explained variance) separated the agroecological system, with better chemical conditions (Fig. 2a, 2b). Analyses of variance 265 showed that soil pH-H₂O and pH-KCI were significantly higher in agroecological systems 266 compared to other systems. Soil N-NH₄, N-NO₃, total N, total C, CEC, K, Mg, P and Na 267 268 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

3.3. Soil physical and morphological characteristics

275 PCA analysis performed on the matrix of physical characteristics did not separate the four

production systems (p>0.01). Soils generally had rather low bulk densities around 0.9,

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

282 PCA analysis performed on the matrix of morphological characteristics significantly separated the agroecological system from the others (p<0.01, Fig. 3a, 3b). On average, a 283 284 rather large proportion (49.4%) of the soil volume was macro-aggregated with large variations from 14.1 to 81.3% depending on treatments and sites. Biogenic aggregates 285 comprised 31.4% of the total soil mass and physical aggregates 5.9%. There was a clear 286 287 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

Soil macroinvertebrate communities varied among cropping systems, with respective densities ranging from a minimum value of 357 ± 48 ind.m⁻² to a maximum of 886 ± 112 ind.m⁻² and an overall average of 618 ± 135 ind.m⁻². Regardless the cropping system type, ants were the most abundant group (26%) followed by earthworms (25%), diplopods (23%) and termites (7%). Communities were significantly impacted by production systems (global 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, ranging from 60809 \pm 39413 to 180166 \pm 53667 ind.100 g roots⁻¹ Total population of plant 311 parasitic nematodes was not significantly different among cropping systems. Nevertheless, 312 Radopholus similis population was significantly reduced in agroecological and intensive 313 systems and was higher in intermediate and low input systems (Table 2). Helicotylenchus 314 315 multicinctus population, on the contrary, was significantly higher in agroecological cropping 316 systems (Table 2).

The severity of root damage induced by parasites also varied within cropping systems. The

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 %).

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

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

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

330

331 3.6. Covariations

PCA analysis performed on the matrix of farm general Chemical, Physical, Morphological,
Macrofauna and Pest indexes significantly separated the four production systems (p<0.01).
Factor 1 (40% explained variance) separated the agroecological system, with better
morphological and chemical conditions from the other 3 ones that had higher values of the
physical indicator. Factor 2 showed a clear opposition between sites with high macrofaunal
index (mostly found in low input (3) and agroecological (4) systems) and sites of production
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 are comparatively more intensive with high inputs of mineral fertilizers, pesticides and 344 herbicides. Only 14% of the plots have been classified as agroecological and 28% as low 345 input, characterized by the predominant use of organic fertilizers, and low applications of 346 347 pesticides and herbicides. In Guadeloupe, plantain plantations are mainly found in the banana crop region. They coexist with intensive banana dessert monocultures that use high 348 amounts of pesticide and mineral fertilizers (Sierra et al., 2015). Most plantain producers 349 indeed use similar farming practices as those used in banana dessert crops with 8-12 350 351 applications of chemical fertilizer during the growth season in monocultures (Sierra et al., 352 2015).

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

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

In addition, our results showed that the Chemical Index was significantly enhanced in 370 371 agroecological systems compared to other systems, due to high pH, CEC, base saturation and C and N contents. Sihi et al. (2017) found that long-term application of organic residues 372 373 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

The plant-parasitic nematode communities sampled in our investigation (*H. multicinctus*, *Hoplolaimus* sp, *Meloidogyne* sp, *Pratylenchus coffea*e, *R. similis*, *Rotylenchus reniformis*) was similar to previous studies carried out on plantain cropping systems in Côte d'Ivoire (Adiko and Badou N'Guessan, 1999), Rwanda (Sebasigari, 1990), and Cuba (Rodriguez and Rodriguez, 1999). An interesting result of our study was that *R. similis*, the most destructive species on *Musa* sp., was absent in the agroecological perennial cropping systems. This can 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; Sadom et al., 2010), significantly reduced pest infestations at the beginning of the plantation (Loranger-Merciris et al., 2022). In contrast, the 392 393 higher density of *H. multicinctus* 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. multicinctus* 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. multicinctus to R. similis (Quénéhervé et al., 2011). Indeed, the 399 proportion of old roots (potential resource for *H. multicinctus*) 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 may impact populations of the plant parasitic nematode R. similis and subsequent effects on 404 plant health. In fact, R. similis population was significantly reduced in agroecological systems 405 406 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

species represent more than 95% of the nematode community of these agroecosystems.
When millet fields were left fallow, the number of these two nematodes decreased, while
there was a marked increase in the numbers of other nematodes. Interestingly, the level of
damage caused by the two main pest nematode species was reduced when they were
associated with other plant-feeding nematodes such as one of those recovering during fallow
periods, *Helicotylenchus dihystera* (Cadet et al., 2002).

R. similis populations were also reduced in intensive cropping systems presumably as a 422 423 result of the application of chemical nematicides which protected plants, as least temporarily. In fact, chemical nematicides only allow a partial and short-term control of nematodes 424 425 (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 (Matthews, 2006). Overall, our study highlights the fact that the agroecological system has 428 429 the same performance in terms of pest control as the conventional system, but without the application of pesticides. 430

431

432 Conclusion

Our study clearly showed that well managed agroecological systems can provide the same 433 level of production and plant protection than intensive conventional systems, while improving 434 435 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

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

452

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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

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

45 ‡ 1 application of Nemathorin® (active ingredient <u>Fosthiazate</u>) at the plantation or 2

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
- 650
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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 (± SE). For each nematode species, means
- with different upper script letter are significantly different based on HSD test ($P \le 0.05$).

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

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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

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

688

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:

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

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

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704

- **Fig. 5.** Projection of (a) plots and (b) variables grouped into plantain cropping systems of
- 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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