

Identification of soil factors that relate to plant parasitic nematode communities
on tomato and yam in the French West Indies.

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Abstract

A soil and nematode survey of tomato and yam crops was made in Martinique (French West Indies). Each sample was divided into two parts, one for the nematode study and one for the soil analysis. The coupling of the data was made using the coinertia analysis. For tomato plants, which were grown from seeds, the nematode-soil relationships were very strong. For the two varieties of yams, Dioscorea cayenensis-rotundata and D. alata, whose infested seedtubers carry nematodes into the field, the relationships were weaker and depended on the yam variety. For D. cayenensis-rotundata, which was attacked by the endemic parasite Pratylenchus coffeae, the relationship between nematode community and soil type was strong. For D. alata, this relationship was weaker because it is mainly parasitized by the exotic species, Scutellonema bradys, which is exclusively introduced into the field with the seedtuber, whatever the soil type. Soil texture was the most important factor to explain the presence of some species, however Meloidogyne spp. and the ectoparasitic species such as Xiphinema spp. were associated with light andosols; Aorolaimus luci needed, in addition, higher levels of organic matter. P. coffeae preferred any type of soil rich

in organic matter and its abundance seemed influenced by calcium and magnesium content or pH. In contrast, P. brachyurus did not appear to be sensitive to any of the measured physico-chemical soil characteristics.

Key-words : Plant parasitic nematodes, Nematode-soil relationships, Co-inertia analysis, Martinique, Dioscorea spp., Lycopersicon esculentum.

Introduction

Plant parasitic nematodes have biological characteristics that distinguish them from other organisms that affect the growth of plants, *viz*, they are relatively immobile and all spend at least part of their life cycle within the soil matrix (Wallace, 1963). There, in the soil, they are dependent upon all events that happen in and on the field in which they live. As such, they are comparable to an agronomic factor, such as organic matter and they can be managed in the same way, at the field scale (Greenland and Nye, 1959; Yeates, 1984). For example, fallowing can be used to increase the organic matter content of soil (Floret and Serpantié, 1993) and to reduce the number of nematodes (Ferris and Bernard, 1971; Nestcher, 1985; Aung and Prot, 1990). Nematode abundance is highly dependent on the presence of the host plants. However, they are also influenced to a greater or lesser extent by most of the biological, chemical and physical components of the soil environment (Upadhyay *et al.*, 1972; Jacq and Fortuner, 1979; Yeates, 1976 & 1981; Cuc and Prot, 1992). As a result, there are soils or regions within soils that are unsuitable for particular nematode species and which thus contain fewer individuals or different nematode communities than more favourable environments. In the sugarcane fields in Martinique, when the lower soil horizons are brought to the surface, the balance between species in the community changes (Cadet and Albrecht, 1992). Generally, where low nematode numbers result from a biological cause, the soils are referred to as suppressive (Alabouvette, 1993; Stirling, 1991). Where they result from abiotic factors, the soils can be referred to as "resistant" (Amir and Alabouvette, 1993). For example, it is well known that Meloidogyne species are usually not abundant in clay soil (Kincaid, 1946). The term resistant soils could also include those in which crop damage is less than would be expected from the size of the nematode populations. Thus, for sugarcane, damage is less important in heavier soils than in sandy soils (Spaull and Cadet, 1990). This is not a result of fewer nematodes but rather a consequence of a slower rate of invasion of the roots by the nematodes, which allows sufficient time for the plant to develop its root system and thus to overcome subsequent injuries (Cadet, Quénehervé and Merny, 1982).

It is well known that populations of plant parasitic nematodes can be controlled by growing resistant host plants. Nematode development can be prevented or limited by means of a

genetic modification of the host (Berthou et al., 1989; Luc and Reversat, 1985). In a similar way, it seems possible that nematode populations could be controlled by modifying the abiotic components of their environment to create a resistant soil. So we can define mesological control as the reduction in size of the nematode populations, the change of the species balance in the communities and/or a reduction in the amount of root damage following the change in the abiotic environment (Cadet, Thioulouse and Albrecht, 1994). For example, in South Africa and in West Africa, the same sugarcane varieties are cultivated on very similar sandy soils and they are parasitized by the same species. But the composition of the ectoparasitic communities is different (Cadet and Spaul, 1985). In South Africa, it is dominated by Xiphinema and trichodorids whereas in West Africa, it is dominated by Helicotylenchus. Despite the fact that the West African ectoparasite community is much larger than that of South Africa, the damage to ratoon crops occurs only in South Africa (Spaul and Cadet, 1990). If we could change the balance between species in the South African community, by increasing the proportion of Helicotylenchus, we would expect the damage to disappear in ratoon crops.

The influence of various types of soil on the distribution of nematodes has been reported by many authors (Castro et al,1990; Norton,1979 & 1989; Prot and Van Gundy, 1979). The aim of the present study is to identify the physico-chemical factors which, independently from the type of soil, are correlated to the nematode communities which parasite tomato and yam crops in Martinique.

Material and methods

The survey was made in Martinique in the French West Indies. Seventy three tomato fields (150 m² to 1,5 ha) were sampled between the fruit initiation stage and the first yield. Three to five subsamples were collected in each field, roughly along a transect. Each subsample comprised an entire tomato plant with its root system and soil from the rhizosphere. Roots were cut into about 1 mm lengths and the nematodes extracted from a 30 g subsample in a mistchamber (Seinhorst, 1950). Each soil subsample was divided in two parts. The nematodes were extracted from each subsample by elutriation (Seinhorst, 1962). The level of infestation in the field was assumed to be equal to the average of the results obtained. For economical reasons, only one physico-chemical

analysis was performed on a mixture of the subsamples to obtain the mean parameters of the field. The analyses performed on the soil samples were : carbon (C), nitrogen (N), organic matter (OM), pH (water : pH_O and KCl : pH_K), soil texture (clay : Cla; fine silt : FS_i; coarse silt : CS_i; fine sand : FS_a; coarse sand : CS_a), total phosphorus (P₂O), exchange capacity (CEC), calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), saturation coefficient (V%), wilting points (2.5 : WP₂; 3.0 : WP₃; 4.2 : WP₄).

For yam (Dioscorea cayenensis-rotundata (CR) and D. alata (AL), totaling 94 % of the yam fields), samples were taken after the emergence of the new tubers. As mixed plantations were very frequent, yams were sampled by variety, even if they were located on adjacent rows. Two varieties were selected. For each variety, three to five subsamples of soil from the rhizosphere, roots and new tuber skin (from the proximal area) were collected in the same bag. In the laboratory, nematodes were extracted separately from each of the root and tuber samples, but the soil samples coming from the same field were mixed before soil analysis.

Three nematode species were found in the roots and tubers of yam : Pratylenchus coffeae, Scutellonema bradys and, very infrequently, Meloidogyne sp. (Kermarrec *et al.*, 1987; Jatala and Bridge, 1990). These nematodes first multiply in the roots before invading the new tuber (Bridge, 1982; Cadet and Quénehervé, 1994). In other words, if a root system is infested, the new tuber will also become infested. For the data analysis, only the highest infestation density observed in the yam roots or in the new tuber of each plant has been used.

From these results, six data tables were built. Each row represented one tomato field or one yam field. Columns represented nematode species or soil parameters. Thus, the six tables are :

- nematological table for tomato fields : 73 rows and 17 columns,
- pedological table for tomato fields : 73 rows and 20 columns,
- nematological table for D. cayenensis-rotundata fields : 63 rows and 12 columns,
- pedological table for D. cayenensis-rotundata fields : 63 rows and 20 columns,
- nematological table for D. alata fields : 89 rows and 12 columns,
- pedological table for D. alata fields : 89 rows and 20 columns.

The abundance of nematode species or genera observed on these crops are listed in Table 1. The nematode numbers were transformed to log (x+1). These data sets were first studied separately with Principal Components Analysis (PCA) on correlation matrix. For pedological data,

PCA on correlation matrix is well adapted because variables are expressed in different units. To analyse the nematological data, we could have used Correspondence Analysis, but we have preferred to use a PCA after logarithm transformation because of the very high variability of the number of nematodes. This high variability causes stability problems in CA and PCA is therefore preferable. The fauna and the soil data were then coupled with coinertia analysis (Chessel and Mercier, 1993; Dolédec and Chessel, 1994). Computations and graphical displays were made with the ADE-4 software (Thioulouse *et al.*, 1995, Thioulouse *et al.*, 1997) and GraphMu (Thioulouse 1989). On the factor maps, fields are grouped according to their geographical locality on the island (Fig.1).

Interpreting the results of coinertia analysis rests on the following mathematical property : the covariance between the principal axes in the nematological and pedological spaces is maximum. Two important steps must be considered :

- the comparison between the PCA and coinertia analysis factor maps shows wich species and wich variables are of interest : the most interesting ones are the ones which positions are different in the PCA factor map and in the coinertia analysis factor map.

- The comparison between the nematological and the pedological coinertia analysis factor maps shows which species are correlated with which variables : the species with high factor scores are correlated with variables having a high factor score on the same axis and in the same direction.

Results

1. Nematological and soil characteristics of the tomato fields

1.1 Soil analysis

The results of the analysis of the 20 soil variables collected from each field were subjected to the PCA. On the correlation circle built with the first two factors (67 % of the variability), the soil variables were distributed in three groups (Fig. 2A). One corresponding to proportions of sand (FSa and Csa) and coarse silt (CSi), a second group with variables corresponding to the finer

particles, clay (Cla) and fine silt (FSi), as well as cations, exchange capacity (CEC) and WP. The third group was characterised by organic matter and the phosphorus content.

Points corresponding to the different fields were projected in the first factor map and named according to their position on the island (Fig. 2B). Fields located in the south of the island (S), whose vertisols have a high clay content are separated from those located in the north of the island (NC, NA, NN), whose andosols contained a high proportion of sand (pumice stones). In this cloud, two groups could be distinguished : one corresponding to fields situated on the Pelée Mountain sides (NN), and one corresponding to fields located on the atlantic (NA) or caribbean (NC) coasts. The soils of the Pelée Mountain sides are rich in carbon as a result of previous volcanic eruptions, whereas more distant soils have lower carbon content.

1.2 Nematological analysis

Tylenchorhynchus sp. which was only observed in one field was removed from the fauna data before PCA. In the correlation circle, the different species were spread out in many groups (Fig. 2C). Telotylenchus (Telo) and Pratylenchus (Prar) were opposed to Meloidogyne (Melr, Mels) and Rotylenchulus (Rotr, Rots), both groups separated from Helicotylenchus (Hels, Helr) and Aorolaimus (Aoro). In the center appeared Hemicriciconemoides (Hemi).

In the factor map (Fig. 2D), fields located in the south (S) of Martinique were infested by Pratylenchus and Telotylenchus, but not with Meloidogyne. Fields in the north of the island were generally infested by a more diverse community, including mainly Meloidogyne and Rotylenchulus. In this cloud, plots corresponding to fields located on the hillsides of the Pelée Mountain (NN) were grouped, because of large populations of Helicotylenchus and Aorolaimus. The fields located on the coast (NA and NC) contained Hoplolaimus and Xiphinema.

2. Soil and nematological characteristics according to the cultivated yam variety.

2.1 D. cayennensis rotundata

The simultaneous comparison of the correlation circle and factor map arising from the PCA of the soil data, showed that points corresponding to fields located in the center (C) and the south (S) of the island, where the soil is more clayey, were opposed to fields located in the north and Atlantic center (N and CA) because their soils are more sandy and rich in organic matter (Figs 3A & 3B). On the nematological side, the factor map underlined the opposition between Scutellonema and Pratylenchus (Figs 3C & 3D). A "size effect" appeared, because very few fields were infested by S. bradys. The points corresponding to fields infested with P. coffeae were grouped and a gradient of infestation in P. coffeae appeared from Atlantic center (CA), to the south (S) where it was more abundant.

2.2 D. alata

A particle size gradient is shown by the soil data analysis. Points corresponding to clay fields in the south of the island are opposed to those corresponding to the few sandy pumice stone fields of the north (Figs 3E & 3F), but the discrimination is not as sharp as for D. cayennensis rotundata. Some fields in the south disturbed this repartition, due to the pH. On the second factor, the separation of the fields depended on phosphorus, potassium content and on calcium content.

There was little obvious structure in the factor map resulting from the analysis of the nematological data (Figs 3G & 3H). Points corresponding to the location of the different fields were, for the most part, in the centre of the map. They did not show a strong relationship with their geographical position on the island (compared to D. cayennensis rotundata), but rather with the decreasing abundance of S. bradys, from the first to the third quadrant, and with the presence of Meloidogyne.

3. Nematode-soil relationships for tomato

The coinertia analysis did not induce major changes (Table 3) but it showed the strong relationships between nematode numbers and soil characteristics (Fig. 4). It confirmed the link between the pumice stones andosol of the north of the island and the presence of Meloidogyne, whereas Pratylenchus and, in particular, Telotylenchus were associated with the fields on the

slopes of the volcano, which were very rich in organic matter. Conversely, Helicotylenchus which occupied all types of soil was positioned in the centre of the factor map.

Co-inertia analysis produced an approximate mirror image of the factor map (Fig. 4A). It still showed the particle size gradient (clay-sand), and a gradient of decreasing amount of organic matter.

The factor map derived from the nematological data (Fig. 4C) rotated around the horizontal axis, to reinforce some relationships : between Meloidogyne and the pumice andosol, between Aorolaimus and soils rich in organic matter, between Telotylenchus and the clay soils. Pratylenchus (P. brachyurus) and Helicotylenchus, which were not affected by soil type, were located in the middle of the map. All other species were more abundant in light soil. In addition, for Hoplolaimus or Longidorus, their pH tended to be higher (and the organic matter content lower) than for Criconebella and Rotylenchulus.

Both factor maps established from fauna and soil data were similar to those of the PCA. The Monte-Carlo test was highly significant : the 10,000 row permutations provided no inertia value higher than that obtained with the original (non permuted) data (Fig. 6A).

4. Nematode-soil relationships for the yam varieties

4.1 D. cayennensis rotundata

The map rotated on the vertical axis. The coinertia analysis restored the particle size gradient (Fig. 5A) and the gradients for calcium, magnesium, phosphorus and pH. The importance of organic matter is underlined. The north (N) and Atlantic center (CA) samples contained a high proportion of organic matter and coarse particles, while the south (S) and center samples (C) had a high proportion of clay particles (Fig. 5B).

There were few changes in the factor map derived from the nematode data (Fig. 5C). Aorolaimus moved on the map according to its association with andosol rich in organic matter. For P. coffeae, its presence in the soil was linked to a relatively higher exchange capacity, high rate of magnesium and calcium (Table 2) and lower pH. The relative positions of geographical regions obtained in the pedological analysis is conserved in the nematological analysis (Fig. 5D).

The Monte-Carlo test was highly significant ($p < 10^{-5}$, Fig. 6B).

4.2 D. alata

The factor map obtained after coinertia analysis of the soil variables described the soil particle size gradient, but by taking the finer particles (clay and fine sand) into account (Fig. 5E). There was a notable change in the position of 2 groups of variables, *viz.*, the wilting point values, the importance of which decreased by slipping closer to the origin, and organic matter, which migrated to underline the relationship with Aorolaimus.

Almost all nematode species occupied different positions on the factor map were resulting from the coinertia analysis (Fig. 5G). S. bradys in roots was no longer a deciding factor and moved close to the center of the map, far from P. coffeae in the field soils with low pH, high sodium content and poor in calcium and magnesium (Table 2).

There did not appear to be any obvious structures on the factor maps derived from the coinertia analysis of the nematological data or the soil data, except the opposition between the heavy soil of the south of the island and the lighter pumice stone soil of the north (Figs 5F & 5H).

The Monte-Carlo test by row permutation showed a spread out histogram (Fig. 6C). Among 10,000 permutations, 29 (0.29%) gave a result identical or superior to that obtained with the original (non permuted) data set. This result, although still highly significant, is very different from the one obtained for D. cayennensis rotundata (Fig. 6B).

Discussion

In Martinique, tomato and yam were often cultivated in the same areas, but generally, tomato fields were more numerous in the north, whereas yam fields were more frequent in the south. Both crops were linked to the soil particle size gradient. This structure was maintained after coinertia analysis, but is less strong for D. alata. The study of the yam fields was characterized by an opposition between two nematode species : P. coffeae and S. bradys. This opposition derived from the different host-parasite relationships of the two most cultivated yam varieties : D.

cayenensis rotundata was attacked almost exclusively by P. coffeae and D. alata, was attacked in addition by S. bradys (Castagnone Sereno and Kermarrec, 1988).

These results add to those of others (Wallace, 1969; Cadet, & Albrecht, 1992; Prot and Van Gundy, 1981) that show soil texture plays an important role in explaining the relationships between soil and nematode species. In our study was with the parasitic nematode community of tomato that these relationships appeared the best, because the planting out of plants grown in a nursery avoided the introduction of nematodes with the planting material. The plants were attacked only by a nematode community already existing in the soil of the field. Obviously, if these nematodes were present in the soil, environmental conditions must have been favourable for their survival. For the tomato crop, most of the nematode species, such as Meloidogyne, preferred soils with coarse particles. But, whereas for endoparasitic rootknot nematodes, the relationship appeared strictly dependant on soil particle size, for ectoparasitic species, chemical factors (pH, phosphorus) and, for Aorolaimus, organic matter may have a secondary influence on their abundance. Pratylenchus brachyurus was present in all types of soil and thus did not appear to be influenced by the soil physico-chemical characteristics.

For yam, the nematode-soil relationships were the same as for the tomato and were issued mainly from the affinity of ectoparasitic species (or of Meloidogyne) for the light andosols, or from the affinity of Aorolaimus for the same soil but rich in organic matter. For D. cayenensis rotundata, the species P. coffeae did not seem strongly linked to a specific soil texture, but appeared to be influenced secondarily by some soil chemical characteristics, such as calcium and magnesium or pH. This result can be explained because this species, even though it was often brought to the field in the yam seed tuber, is found naturally in the field as an endemic species (Kermarrec et al., 1987). It can develop on other plants, such as, for example, banana, which is frequently grown in rotation with yam (Fargette and Quénehervé, 1988; Fournet, Kermarrec and Dos Santos, 1990; Quénehervé, Drob and Topart, 1995).

For D. alata, the nematode-soil relationship also exists because this variety is parasitized by the same nematode species as D. cayenensis rotundata. But the relationship is weaker (as shown by coinertia analysis permutation test, fig. 6C) because D. alata is also parasitized by S. bradys. As revealed by coinertia analysis, this species is not dependent from soil factors (shift toward the center of the factor map, fig 5G). This situation can be explained by the origin of the infestation by

S. bradys. This exotic species, which was introduced into Martinique in the 1970's, with the D. alata variety, was brought into the field within the seed tubers (Jatala and Bridge, 1990). It does not survive in the soil after the yam crop is harvested. In addition, S. bradys and P. coffeae rarely cohabit in the same tuber (Castagnone-Sereno and Kermarrec, 1988), with the result that the corresponding variable (P. coffeae in the roots) was thrown in the opposite position on the coinertia factor map. The P. coffeae-soil relationships were expressed from its abundance in soil (variable P. coffeae in the soil). We found, in particular, an influence of pH, and sodium, calcium and magnesium content. The results obtained are not inconsistent because as the two varieties were not cultivated in exactly the same area, the lowest content of one element for D. alata was higher to the highest content of the same element for D. cayenensis rotundata.

The behaviour of S. bradys explains why the nematode-soil relationships for D. alata, were weak, as shown by the row permutation test. For D. cayenensis rotundata, or for the tomato, the test was very highly significant. In these cases, nematode-soil relationships were very strong because all parasitizing nematodes carried out a part of their life in the soil. The validity of the results was reinforced by the fact that the same relationships were emphasized for the yam and the tomato surveys.

Twenty five years after S. bradys was introduced into Martinique, it is surprising that its cohabitation with P. coffeae in the tubers of D. alata was not more frequent, as P. coffeae occurs naturally in the soil. To explain this phenomenon, we hypothesize that the presence of P. coffeae in the soil before planting gives a deciding advantage to this species. From the soil, it has the opportunity to invade the yam roots before S. bradys, which was found only in the seed tuber where it had first to multiply before migrating to the roots. Therefore, the roots constituted an intermediate centre of multiplication, which allowed the nematodes to "wait" for the emergence of the new tuber (Bridge, 1982; Cadet and Quénéhervé, 1994). If these roots are already occupied by P. coffeae, it is possible that S. bradys is unable to compete and to multiply. Thus, the new tubers are usually only infested by P. coffeae. On this basis, S. bradys could eventually disappear from Martinique. In addition, the reverse situation does not exist, that is to say P. coffeae in yam plants was never in competition with S. bradys which was not found in the soil, except for the females that leave the infested tuber after planting. However, the economic problem would not be resolved

with the disappearance of S. bradys because P. coffeae causes equivalent damage (Acosta and Ayala, 1976).

The study revealed that the abundance of P. coffeae was linked to particular soil chemical characteristics such as pH, and sodium, calcium or magnesium content. The manipulation of these environmental abiotic factors is technically possible and could reduce the multiplication of P. coffeae during the period the yams are in the soil and thus reduce the damage caused after harvest during the storage period (Adesiyun, Odihirin and Adeniji 1975; Cadet and Daly, 1996). This method of control can however only be considered for nematode species which are susceptible to chemical factors.

When soil texture is involved, cultural control methods could be developed. For example, the addition of organic matter to light textured soils infested with Meloidogyne is known to considerably decrease the damage caused by these parasites (Akhtar and Alam, 1993; Goswami and Meshram, 1991). Several hypothesis could explain this phenomenon, such as organic acid toxicity, development of predatory fungi and bacteria, antagonistic organisms. However, from our results the modification of the soil texture by the organic matter could be the principal factor.

Conclusion

It is worth to notice that in this study, the coinertia analysis permutation tests reveal the peculiarity of nematode parasitism by showing a weaker relationship between an exotic nematode species and the soil variables. This method is a useful mathematical technique to identify relationships between the presence of some nematode species and physico-chemical characteristics of the soil. Manipulating certain chemical elements present in very low proportions in the soil, for example by the addition of chemical fertilizer, could influence nematode community by creating an unfavourable soil environment, without destroying the overall balance of the ecosystem.

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Table 1 : List of species and genera of plant parasitic nematodes found in yam and tomato crops in Martinique. (* not used in the calculations)

Species	code		Tomato		Yam	
	Soil	Root	Soil	Root	Soil	Root
<u>Scutellonema bradys</u>	Scus	Scur	-	-	+	+
<u>Pratylenchus brachyurus</u>	Pras	Prar	+	+	-	-
<u>Pratylenchus coffeae</u>	Pras	Prar	-	-	+	+
<u>Hoplolaimus seinhorsti</u>	Hops	Hopr	+	+	-	-
<u>Aorolaimus luci</u>	Aoro		+	-	+	-
<u>Hemicriconemoides cocophilus</u>	Hemi		+	-	+	-
<u>Meloidogyne incognita & arenaria</u>	Mels	Melr	+	+	+	+
<u>Criconemella ornata & onoensis</u>	Cric		+	-	+	-
<u>Helicotylenchus dihystra,</u> <u>erythrinae & retusus</u>	Hels	Helr	+	+	+	-
<u>Rotylenchulus reniformis</u>	Rots	Rotr	+	+	+	-
<u>Telotylenchus ventralis</u>	Telo		+	-	-	-
<u>Longidorus</u> sp.	Long		+	-	-	-
<u>Paratrichodorus</u> sp.	Para		+	-	-	-
<u>Xiphinema</u> spp.	Xiph		+	-	+	-
<u>Tylenchorhynchus</u> sp. *	-		+	-	-	-

Table 2 : Average exchangeable Calcium and Magnesium (meq%) in the sample with low (-) and high (+) population of P. coffeae, for D. alata and D. cayennensis-rotundata.

<u>P. coffeae</u>	<u>D. alata</u>		<u>D. cayennensis-rotundata</u>	
	-	+	+	-
Ca	7,5	5,6	4,9	4
Mg	3,6	2,7	2,3	1,8

Table 3 : Statistical characteristics of the coinertia analysis. First two columns : correlation between nematode (N) and soil (S) factors (F1 and F2) for PCA and coinertia analysis. Last two columns : percentages of the PCA inertia conserved by the coinertia analysis. Co-inertia analysis steadily improves the correlation between nematode (N) and soil (S) factors, while keeping most of the inertia taken into account by PCA.

		Correlation F1 (N) vs. F1 (S)	Correlation F2 (N) vs. F2 (S)	Conserved inertia (N)	Conserved inertia (S)
Tomato	PCA	- 0,71	- 0,47		
	Co-inertia	- 0,78	- 0,79	99 %	89 %
<u>D. cayenensis</u>	PCA	- 0,44	- 0,026		
	Co-inertia	- 0,78	- 0,52	97 %	82 %
<u>D. alata</u>	PCA	- 0,142	- 0,04		
	Co-inertia	- 0,61	- 0,54	57 %	70 %

Figure legends

Figure 1 : Geographical map of the Martinique showing tomato (above) and yam (below) crop zones defined on the island : N : North, NC = North Caribbean, NN = North (Pelée Mountain), NA = North Atlantic, S = South, CA = Center Atlantic, C = Center.

P. Cadet - Figure 1

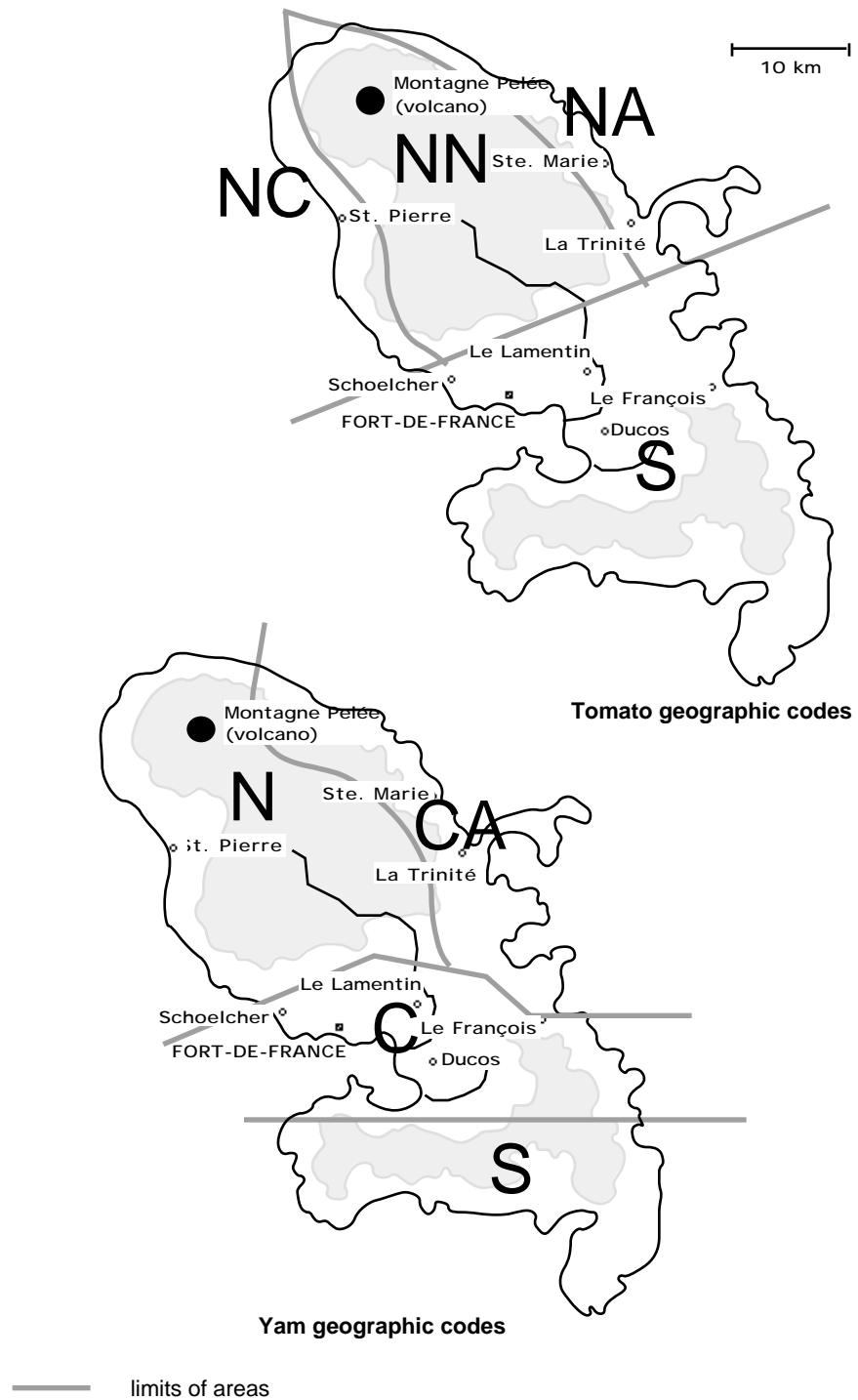


Figure 2 : Correlation circles and factor map (F1 x F2) of the PCA on pedological variables (A, B) and nematode species (C, D) for tomato fields. Nematode species codes are given in Table 1, and pedological variable codes are given in the text (material and methods). On the factor maps, the fields are grouped according to the region to which they belong on the island (see Fig. 1). Each field is linked to the gravity center of its region, and these gravity centers are labeled with region codes.

P. Cadet - Figure 2

TOMATO

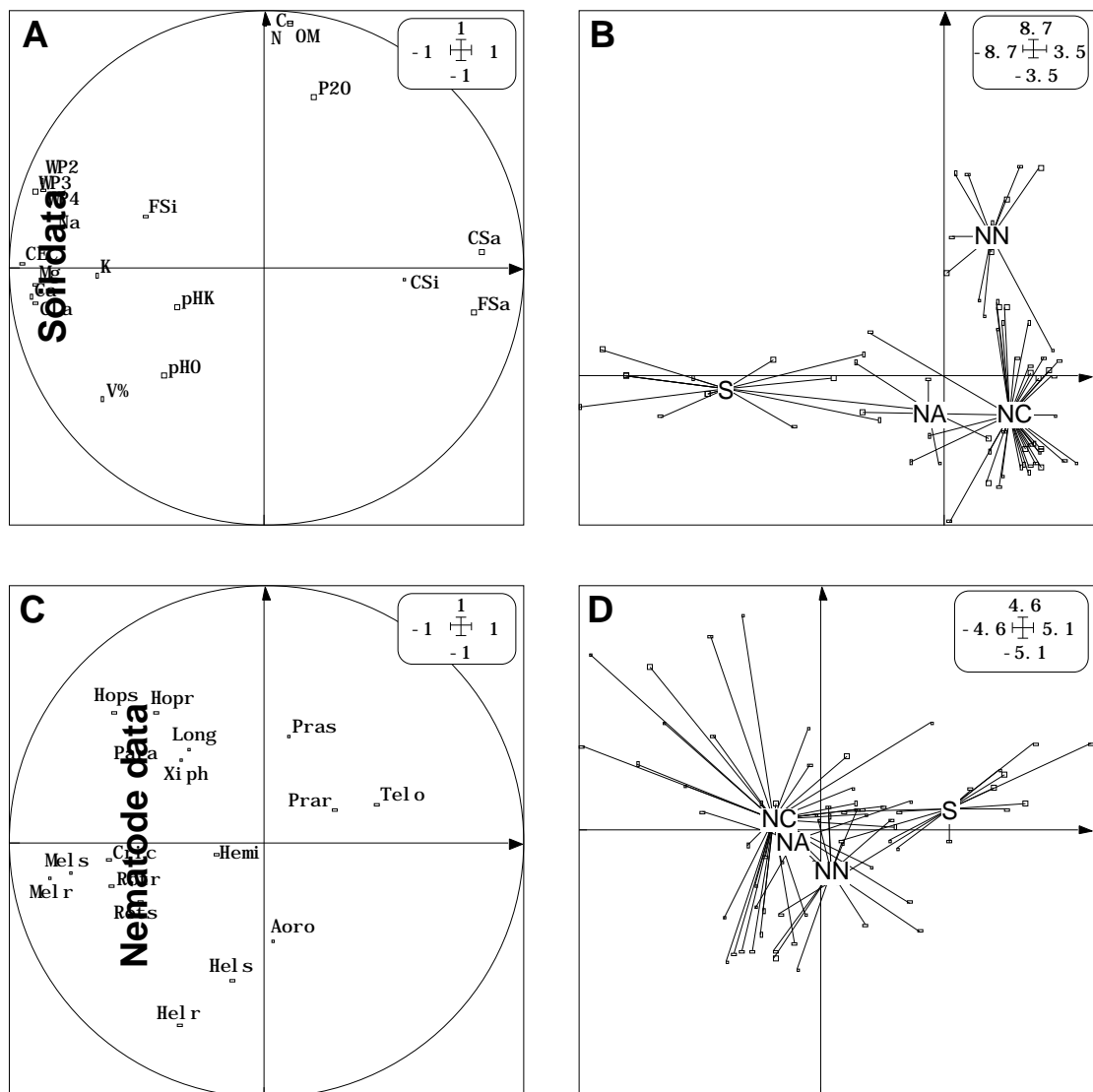


Figure 3 : Correlation circles and factor maps (F1 x F2) of the PCA on pedological variables (A, B, E, F) and nematode species (C, D, G, H) for the two varieties of yam : *D. cayenensis-rotundata* (A, B, C, D) and *D. alata* (E, F, G, H). Nematode species codes are given in Table 1, and pedological variable codes are given in the text (material and methods). On the factor maps, the fields are grouped according to the region to which they belong on the island (see legend to Fig. 2).

P. Cadet - Figure 3

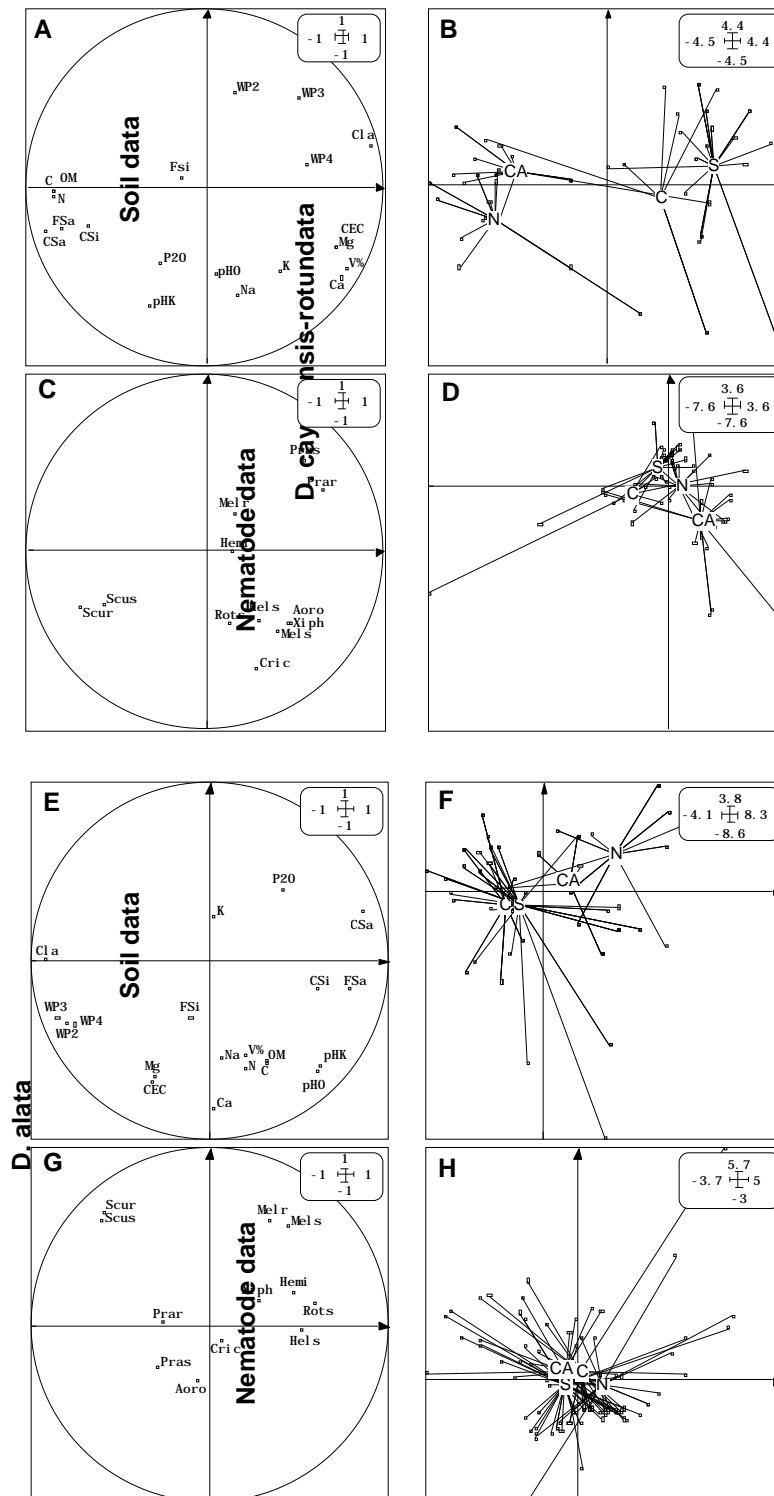


Figure 4 : Factor maps (F1 x F2) of the coinertia analysis on pedological variables (A, B) and nematode species (C, D) for tomato fields. Nematode species codes are given in Table 1, and pedological variable codes are given in the text (material and methods). On the factor maps, the fields are grouped according to the region to which they belong on the island (see legend to Fig. 2).

P. Cadet - Figure 4

TOMATO

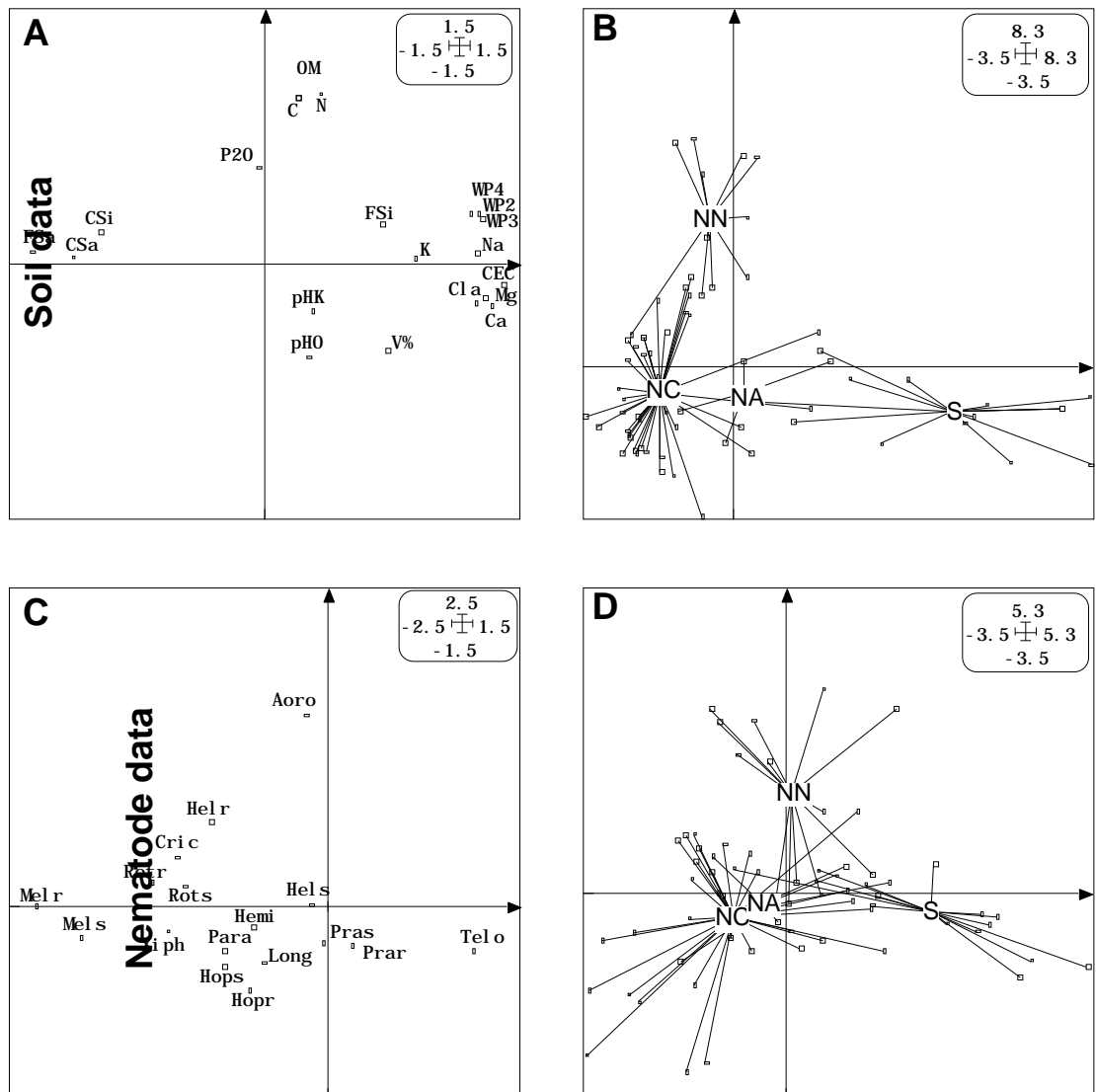


Figure 5 : Factor maps (F1 x F2) of the coinertia analysis on pedological variables (A, B, E, F) and nematode species (C, D, G, H) for the two varieties of yam : *D. cayenensis-rotundata* (A, B, C, D) and *D. alata* (E, F, G, H). Nematode species codes are given in Table 1, and pedological variable codes are given in the text (material and methods). On the factor maps, the fields are grouped according to the region to which they belong on the island (see legend to Fig. 2).

P. Cadet - Figure 5

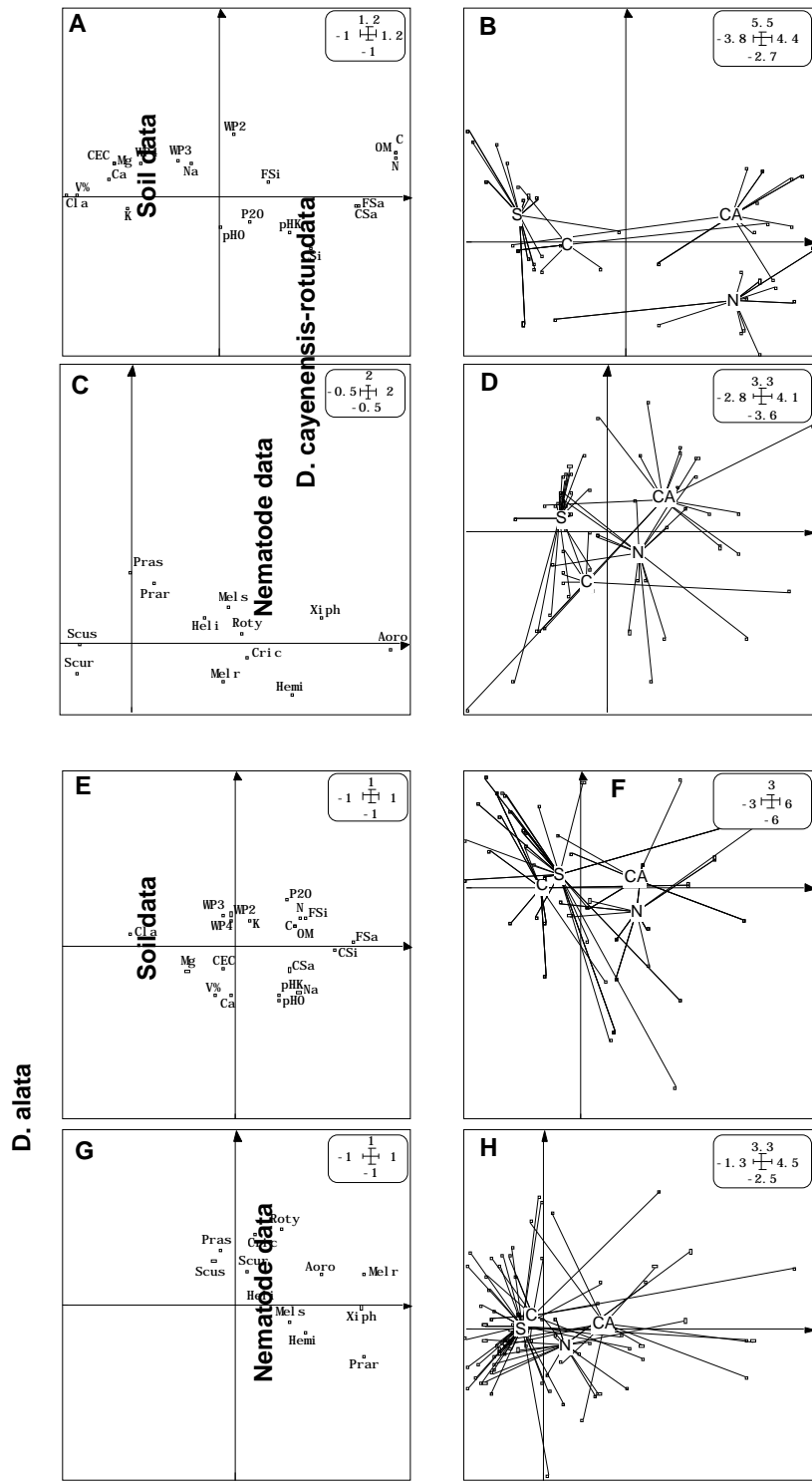


Figure 6 : Monte-Carlo tests of the coinertia analysis for the tomato data (A), and each yam variety (B: *D. cayenensis-rotundata*, and C: *D. alata*). The "Observed situation" point corresponds to the original coinertia analysis (with non permuted rows). The value of the inertia for this situation is given in the first row. The histograms show the distribution of the criterion (total inertia) for the 10,000 analyses with randomly permuted rows.

P. Cadet - Figure 6

