Original Research Article

Fluctuation in Yam Nematodes Depending on the Phenological Stages of the Main Yam Species (*Dioscorea alata* L.) Cultivated in Côte d'Ivoire

ABSTRACT

The telluric factors favorable to nematode pathogenic diversity make yam nematode control ineffective. This work aims at studying the fluctuation in yam nematodes depending on yam phenological stages. Trials were implemented in four yam production areas in Côte d'Ivoire. After inventory of symptoms on yam tubers, the nematodes associated with the symptoms were extracted and identified. The correlation coefficients between the severity of symptoms on tubers and the size of the associated nematode populations were determined. The size of nematode populations associated with the symptoms were determined in 100 ml of soil and 100 g of yam peel were determined depending on the phenological stages of yam plants. Galls, cracks, dry and wet rot were observed on harvested yam tubers. *Globodera, Meloidogyne, Pratylenchus* and *Xiphinema* were the nematodes associated with the symptoms. *Pratylenchus* was strongly involved in the development of cracks (r = 0.75) and dry rot (r = 0.86) then *Meloidogyne* in that of galls (r = 0.78). *Pratylenchus* and *Meloidogyne* fluctuation in cultivation soils and yam tubers is influenced by yam phenological stages. Their numbers increase in soils and tubers before tuberization initiation. Producers could draw on the results of this study to establish a schedule of nematicide treatments that could start as soon as yam seeds are planted.

Keywords: Crop cycle, Dynamics, Yam, Nematodes, Phenological stages

1. INTRODUCTION

Yam (*Dioscorea* spp.) is the second root and tuber crop in the world after cassava [1]. It plays a very important role in food security. The consumption of yam tubers covers the needs for energy, proteins, mineral salts and vitamins better than other root and tuber crops [2]. Yam is important in West African trade, since its production represents 32% of peasants' income [3]. About 95% of world yam production is attributed to sub-Saharan Africa [4].

In Côte d'Ivoire, yam is the first food crop in terms of production [5, 6]. With 7.15 million tons of yam produced in 2018, Côte d'Ivoire is the world's third largest producer after Nigeria and Ghana [6]. Most of the Ivorian production is located in the Central and Northern part above the 8th parallel of north latitude [7]. However, yam production in forest areas is far from negligible [8]. Water yam (*Dioscorea alata* L.) represents 55 to 60% of the yam produced in Côte d'Ivoire [8].

Despite its importance, yam cultivation is subject to attacks by phytopathogenic nematodes [9]. Economic losses due to phytopathogenic nematodes on yam are estimated at 17.7% worldwide [10]. The main pathogenic nematodes of yam in West Africa are *Scutellonema bradys* and *Pratylenchus coffeae* responsible for dry rot and cracks and then *Meloidogyne* spp. causing yam galls [9]. In Côte d'Ivoire, dry rot, cracks and galls are also observed on freshly harvested tubers of water yam with infestation rates ranging from 9.17 to 21.5% in the main production areas [11]. Four genera of nematodes, *Globodera*, *Meloidogyne*, *Pratylenchus* and *Xiphinema* were found related to these symptoms with 3 to 153 individuals in 5g of yam peels [11]. These symptoms reduce the commercial value and the edible portion of yam tubers [12]. Yam producers, apart from the use of resistant or tolerant varieties, plant material free from nematodes and hydrothermal treatment, often resort to synthetic nematicides such as aldicarb, oxamyl, carbofuran, cadusafos and ethoprophos [9].

In contrast, yam, in Côte d'Ivoire, is an agricultural product which is not treated with nematicides during its cultivation. In addition, there is no national schedule for the control of yam pathogen nematodes. All these factors favor the development of yam nematode populations in cultivation soils and then in yam roots and tubers; which could result in significant production losses. In addition, any method for controlling these yam nematodes requires knowledge of the kinetics of nematode populations in cultivation soils and tubers depending on the phenological stages of yams. Therefore, this study aims at studying the dynamics of yam pathogen nematode populations depending on yam development stages in production areas in Côte d'Ivoire.

2. MATERIAL AND METHODS

2.1. Study sites

The study was carried out in four yam producing localities in Côte d'Ivoire: Babadougou in North central, Soubré in Southwestern, Toumodi in Central and Tanda in Northeastern Côte d'Ivoire (Fig. 1) with the following agroecological characteristics.

The climate of Babadougou area is of South Sudanese type with a rainy season (April to October) and a dry season (November to March). Annual rainfall varies between 1200 and 1400 mm [13]. Annual temperatures range from 23.9 to 28.1 ℃. The plots used in that area were *Chromolaena odorata*, *Imperata cylindrica* and *Panicum maximum* five-year fallows.

In Soubré, the climate is humid tropical with two rainy seasons (March to July and September to November) and two dry seasons: August and December to February [14]. Annual rainfall in that area varies between 968 and 1767 mm and annual temperatures range from 23 to 36 ℃ [15]. The precedent crops of the plots in that area were fallows with a three-year floristic composition of *Chromolaena odorata* and cassava (*Manihot esculenta*).

The Toumodi area is a transition between forest and savannah with a humid tropical climate characterized by two rainy seasons (March to June and September to October) and two dry seasons (July to August and November to February). Annual rainfall varies between 1000 and 1200 mm with annual temperatures ranging from 26 to 29.5 ℃ [16]. The Toumodi plots were fallows dominated by three-year *Chromolaena odorata* and *Imperata cylindrica*.

The climate of Tanda area is of humid tropical type with two rainy seasons (April to June and September to October) and two dry seasons (July to August and November to March). Annual rainfall varies between 800 and 1400 mm. Annual temperatures vary between 24 and 29 ℃ [17]. Tanda's plot was established on a land which was a three-year *Parkia biglobosa* and *Imperata cylindrica* fallow.

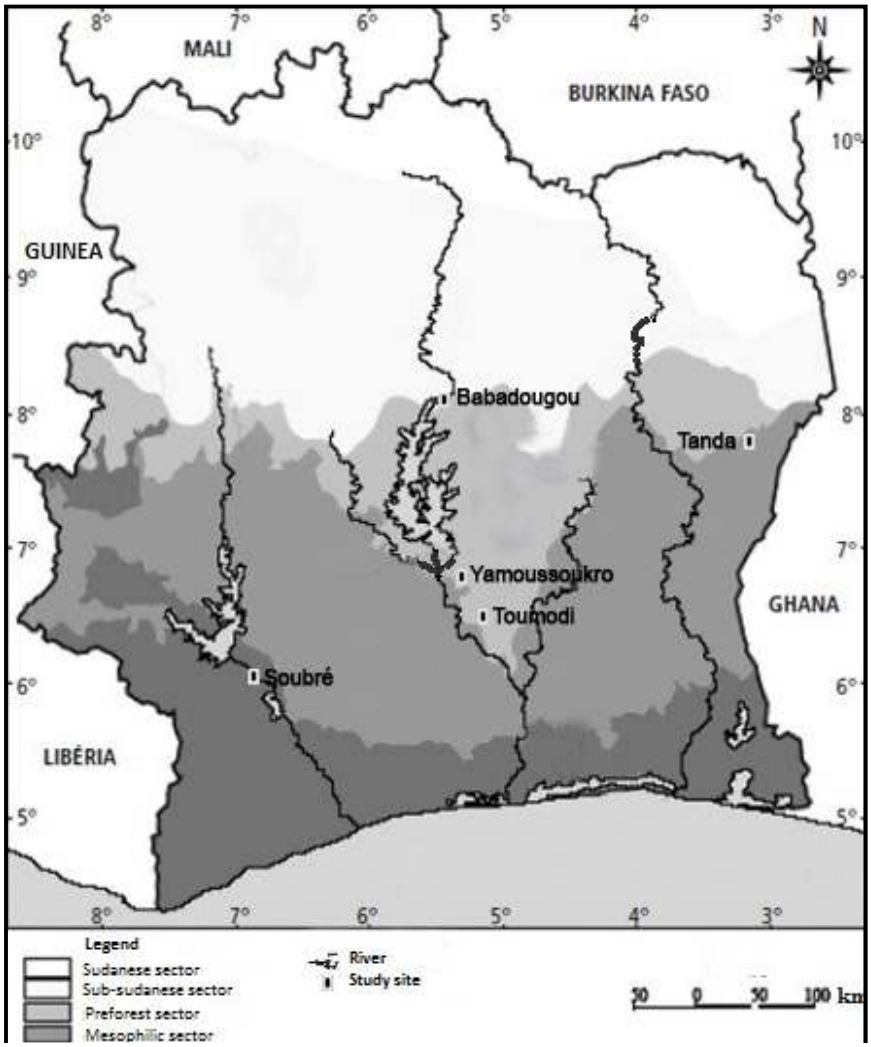

Fig. 1. Geographical location of the study sites in Côte d'Ivoire

2.2. Pathogenic activities of yam nematodes

2.2.1. Establishment of experimental plots

The experimental plots were established for two consecutive years in the localities of Babadougou, Soubré and Toumodi and one year in that of Tanda. In each locality, a 49 m × 22 m plot was demarcated, cleared and subdivided into three blocks. Each block was divided into eight sub-blocks of 6 m × 5 m each.

In this study, two improved varieties (TDa 00/90 and C18) and five local varieties (*Florido*, *Bètè bètè*, *Adaguié*, *Sapian* and *Woro*) of water yam (*Dioscorea alata* L.), whose cultivation extends over nine months were used. The tubers of these varieties were supplied by the National Center for Agronomic Research (CNRA) to serve as seeds in the cultivation trials. The yam varieties were cultivated in mounds using the Fisher block design with three repetitions. Mound density per plot was 576 mounds / 1078 m^2.

2.2.2. Inventory of symptoms on yam tubers

Yam tubers from the experimental plots of each study site were harvested after 9 months of cultivation. The harvested tubers were observed and the symptoms of nematode damage were described.

2.2.3. Severity of symptoms

Infested yam tubers were classified per symptom. Thus, for each symptom observed on the tuber, its severity was noted according to [18] improved severity scale from 0 to 4 (Table 1).

Table 1. Improved severity scale according to the symptoms observed on yam tubers and their significance

Severity Score	Infested surface rate (%)	Galls	Dry or wet rot	Cracks
0	0	None	None	None
1	1 to 25	Mild	Mild	Mild
2	26 to 50	Moderate	Moderate	Moderate
3	51 to 75	Severe	Severe	Severe
4	76 to 100	Very severe	Very severe	Very severe

2.3. Extraction and identification of yam nematodes

2.3.1. Collection of soil and tuber samples

Soil samples were collected during seed planting (no cultivation), in the 3rd month (initiation of tuberization), 5th month (tuber filling beginning), 7th month (end of tuber filling) and 9th month (end of yam development cycle) at 30 cm deep in the mounds. Sixty soil samples weighing approximately 500 g each were taken randomly from each plot on each collection date.

Tuber samples were collected in the 3rd, 5th, 7th and 9th months of cultivation. In the 3rd, 5th and 7th months of cultivation, five plants randomly selected from each sub-block were carefully dug up. The root system of the plant and the adhering soil were collected and put together in sachets so as to maintain the humidity of the plant organs. In the 9th month, after harvest, three to ten symptomatic tubers were collected randomly.

The severity scores of the symptoms observed on the tubers collected were indicated. After each collection, the samples were packaged in polyethylene bags before being sent to the Phytopathology Laboratory of the Université Nangui Abrogoua, Abidjan, Côte d'Ivoire for nematode extraction.

2.3.2. Extraction of nematodes

The soil samples taken from each plot on a given date were mixed so as to form a composite sample. The nematodes were extracted from 100 ml of soil samples using the Whitehead tray method [19]. Five repetitions were made per composite sample.

Tubers were grouped depending on the symptoms and assigned severity scores. The tubers of each group (same symptom and same severity score) were peeled and cut into pieces of approximately 5 mm × 5 mm. The nematodes were extracted from 100 g of yam peels using

the Baermann maceration method [19]. Five repetitions were made for each composite sample prepared.

2.3.3. Identification of nematodes

For each composite sample of soil and yam peel, the nematodes were extracted from 100 ml of water. Three 5 ml-aliquots of nematodes were removed and mounted on a counting plate under an optical microscope (AmScope) so as to describe the individuals observed. The genera of nematodes were identified using the morphological identification keys of [20, 21, 22].

2.3.4. Quantification of identified nematodes

The numbers and relative frequencies of individuals of each genus of nematodes identified were calculated according to the following formulas.

$$\mathrm{ANI}i = \frac{1}{\mathrm{n}}\sum(\mathrm{NI}i) \quad (1)$$

ANI*i*: Average number of individuals of genus *i* /100 ml of soil samples or 100 g of yam peel
NI*i*: Number of individuals of genus *i* in 100 ml of nematode solution
n: Number of repetitions

$$\mathrm{RF}i = \frac{\mathrm{NI}i}{\mathrm{TNI}} \times 100 \quad (2)$$

RF*i*: Relative frequency of a genus *i*
NI*i*: Number of individuals of a genus *i*
TNI: Total number of individuals of all genera extracted

2.4. Mapping of nematodes distribution

The geographic coordinates of the study sites were recorded with GPS (Garmin GPSMAP 64). Maps of nematode distribution in cultivation soils and yam tubers in Côte d'Ivoire were produced using ArcView 3.2 software.

2.5. Study of the correlation between yam evolution and nematode populations

2.5.1. Relationship between symptom severity and the population of associated nematodes

The relationship between symptom severity and the population of associated nematodes was established by determining the Pearson correlation coefficient r using Statistica 7.1 software. Thus, the number of individuals in each population of nematodes associated with a symptom *i* was determined based on the severity scores for such symptom observed on the tubers.

2.5.2. Evolution of nematode populations in soils and yam tubers

Nematodes associated with symptoms observed on yam tubers were considered in this study. Their numbers in 100 ml of soil sample and in 100 g of yam peel were determined at the five phenological stages of the roots and tubers of *Dioscorea alata* yam respectively.

2.5.3. Relationship between nematode populations and the age of yam plants

The relationship between nematode populations and the age of developing yam plants was established by determining the Pearson correlation coefficient r using Statistica 7.1 software. To this end, the number of individuals of each population of nematodes extracted on the one hand from cultivation soils and on the other hand from collected tubers was determined depending on the development stages of the tubers of cultivated yam plants.

2.6. Statistical analyses

Data analysis was done using Statistica 7.1 software. The numbers and relative frequencies of nematodes were transformed by the log10(x+1) and arcsin$\sqrt{(p/100)}$ functions respectively before carrying out the statistical analyses [23]. The purpose of these transformations was to stabilize the variances in numbers and nematode relative frequencies because they did not meet the conditions for applying the normality of distribution and homogeneity of variances. In the event of a significant difference between the average number of nematodes on the one hand, and between the average relative frequencies of nematodes on the other hand, at 5% threshold, the Fisher LSD (Least Significant Difference) test was used to obtain homogeneous groups.

3. RESULTS

3.1. Pathogenic activities of nematodes

3.1.1. Symptoms observed on yam tubers

Several symptoms were observed on freshly harvested yam tubers in production areas in Côte d'Ivoire. These included cracks and galls then dry and wet rot (Fig. 2).

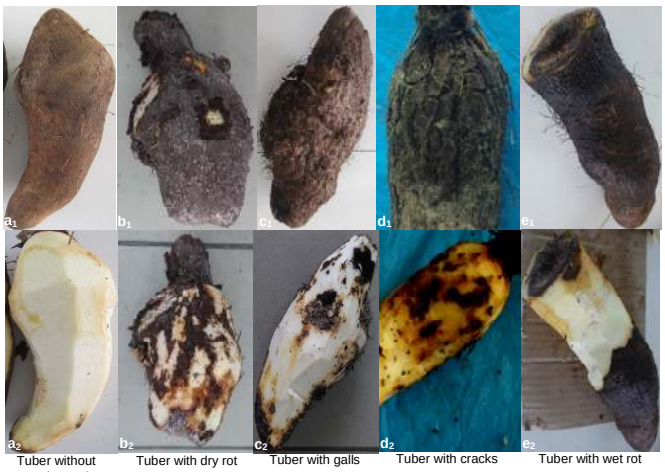

Fig. 2. Yam tubers exhibiting various symptoms

3.2. Identified nematodes

3.2.1. Nematodes extracted from yam cultivation soil samples

Various genera of nematodes were extracted from soil samples. A total of 16 genera of nematodes were extracted from soil samples during the yam crop cycle. These included *Criconemella*, *Globodera*, *Gracilacus*, *Helicotylenchus*, *Hoplolaimus*, *Longidorus*, *Meloidogyne*, *Paratrichodorus*, *Peltamigratus*, *Pratylenchus*, *Radopholus*, *Rotylenchulus*, *Scutellonema*, *Tylenchorhynchus*, *Tylenchulus* and *Xiphinema*. Twelve genera of nematodes were extracted from each of the Babadougou and Tanda soil samples, compared to 14 genera in those of Soubré and Toumodi.

3.2.2. Nematodes extracted from yam peels

Four genera of nematodes, namely, *Globodera*, *Meloidogyne*, *Pratylenchus* and *Xiphinema* were extracted from yam peels (Fig. 3). These four genera were extracted from Babadougou yam peels, against three (*Globodera*, *Meloidogyne* and *Pratylenchus*) for Tanda yam peels, two (*Meloidogyne* and *Pratylenchus*) for Soubré ones then two (*Globodera* and *Pratylenchus*) for those of Toumodi.

Fig. 3. Main genera of nematodes extracted from yam peels

3.2.3. Relative frequencies of nematodes from yam cultivation soils

In each locality, relative frequencies of nematode from yam cultivation soils were statistically different (Table 2). *Pratylenchus* was the main nematode extracted from soil samples from Babadougou, Soubré and Toumodi with respective relative frequencies of 52.66; 34.39 and 23.69%. However, *Meloidogyne* was the main nematode extracted from Tanda soil samples with a relative frequency of 44.48%.

3.2.4. Relative frequencies of nematodes from yam peels

Nematodes extracted from yam peels from each locality had different relative frequencies (Table 3). *Pratylenchus* was mainly extracted from Babadougou and Tanda yam peels with respective relative frequencies of 64.46 and 55.17%. As for *Meloidogyne* and *Globodera*, they were respectively the main nematodes extracted from Soubré and Toumodi yam peels with relative frequencies of 75 and 66.67%.

Table 2. Extraction rate of nematodes extracted from soil samples from each locality

Identified nematodes	Localities			
	Babadougou	Soubré	Tanda	Toumodi
Criconemella	0.72 ± 0.49**c**	0.51 ± 0.51**d**	0.29 ± 0.25**d**	0.07 ± 0.07**d**

Helicotylenchus	2.30 ± 0.98**c**	8.21 ± 4.84**c**	0.11 ± 0.04**d**	2.89 ± 1.90**d**
Hoplolaimus	15.33 ± 7.81**b**	6.10 ± 3.00**c**	1.52 ± 0.22**d**	2.14 ± 1.52**d**
Globodera	5.25 ± 1.80**bc**	0.16 ± 0.12**d**	23.58 ± 1.64**b**	21.46 ± 4.47**a**
Meloidogyne	7.82 ± 1.99**bc**	13.28 ± 3.27**b**	44.48 ± 25.92**a**	15.76 ± 6.48**b**
Pratylenchus	52.66 ± 29.2**a**	34.39 ± 11.09**a**	15.52 ± 1.93**c**	23.69 ± 10.0**a**
Radopholus	5.92 ± 3.91**bc**	0.48 ± 0.32**d**	3.98 ± 1.89**d**	4.16 ± 2.84**d**
Tylenchorhynchus	5.42 ± 1.68**bc**	10.40 ± 2.09**bc**	4.67 ± 1.43**d**	11.29 ± 2.24**c**
Xiphinema	3.07 ± 1.19**c**	10.91 ± 3.91**bc**	0.04 ± 0.04**d**	13.70 ± 4.41**b**
Peltamigratus	0	0.61 ± 0.61**d**	1.27 ± 0.91**d**	0.05 ± 0.05**d**
Scutellonema	0.45 ± 0.45**c**	1.90 ± 1.90**d**	0	2.09 ± 1.98**d**
Tylenchulus	0.42 ± 0.31**c**	0.84 ± 0.70**d**	0.47 ± 0.29**d**	0
Gracilacus	0.63 ± 0.21**c**	0	0	0.99 ± 0.76**d**
Longidorus	0	0.65 ± 0.37**d**	0	1.62 ± 0.91**d**
Rotylenchulus	0	11.56 ± 11.30**bc**	4.09 ± 2.21**d**	0
Paratrichodorus	0	0	0	0.07 ± 0.07**d**
P	*.001*	*.000*	*.000*	*.000*

The values with the same letter in each column are statistically identical at 5 % threshold according to Fisher LSD test, P: Probability value

Table 3. Extraction rate of nematodes extracted from yam tubers from each locality

Identified nematodes	Localities			
	Babadougou	Soubré	Tanda	Toumodi
Globodera	16.27 ± 3.00**b**	0	0	66.67 ± 6.22**a**
Meloidogyne	13.25 ± 1.47**b**	75.00 ± 4.75**a**	34.48 ± 5.71**b**	0
Pratylenchus	64.46 ± 3.45**a**	25.00 ± 5.41**b**	55.17 ± 5.77**a**	33.33 ± 3.87**b**
Xiphinema	6.02 ± 0.82**c**	0	10.35 ± 1.24**c**	0
P	*.000*	*.000*	*.001*	*.005*

The values with the same letter in each column are statistically identical at 5 % threshold according to Fisher LSD test, P: Probability value

3.3. Nematodes distribution in yam cultivation areas

The composition of nematode communities in soils and yam peels varied little depending on yam cultivation areas (Fig. 4 and 5). Nine genera of nematodes, including *Criconemella*, *Globodera*, *Helicotylenchus*, *Hoplolaimus*, *Meloidogyne*, *Pratylenchus*, *Radopholus*, *Tylenchorhynchus* and *Xiphinema* were extracted from soil samples from the study sites. Regarding tubers, only *Pratylenchus* was extracted from peels from all the study sites.

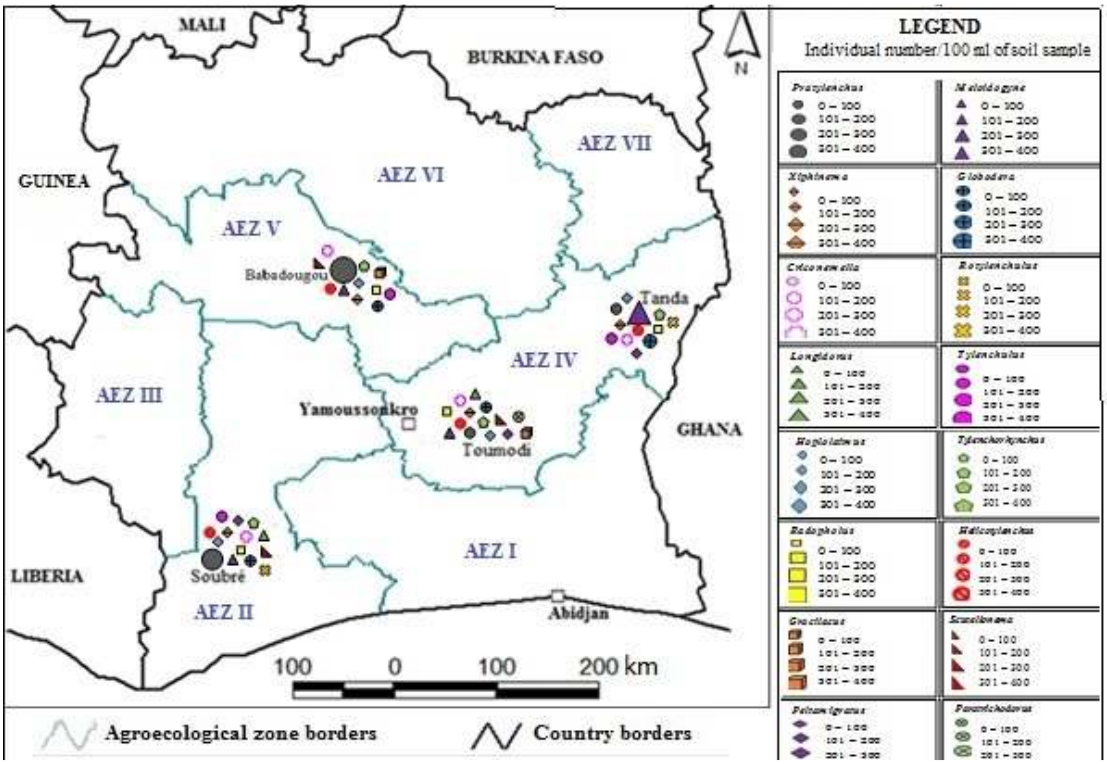

Fig. 4. Distribution map of nematodes extracted from soils in yam cultivation areas in Côte d'Ivoire

***AEZ**: Agroecological zone, **I:** Southern dense humid forest zone, **II**: Western dense humid forest zone, **III**: Western semi-mountainous forest zone, **IV**: Semi-deciduous dense forest zone, **V**: Transitional forest zone, **VI**: Wet tropical savannah zone, **VII**: Dry tropical savannah zone*

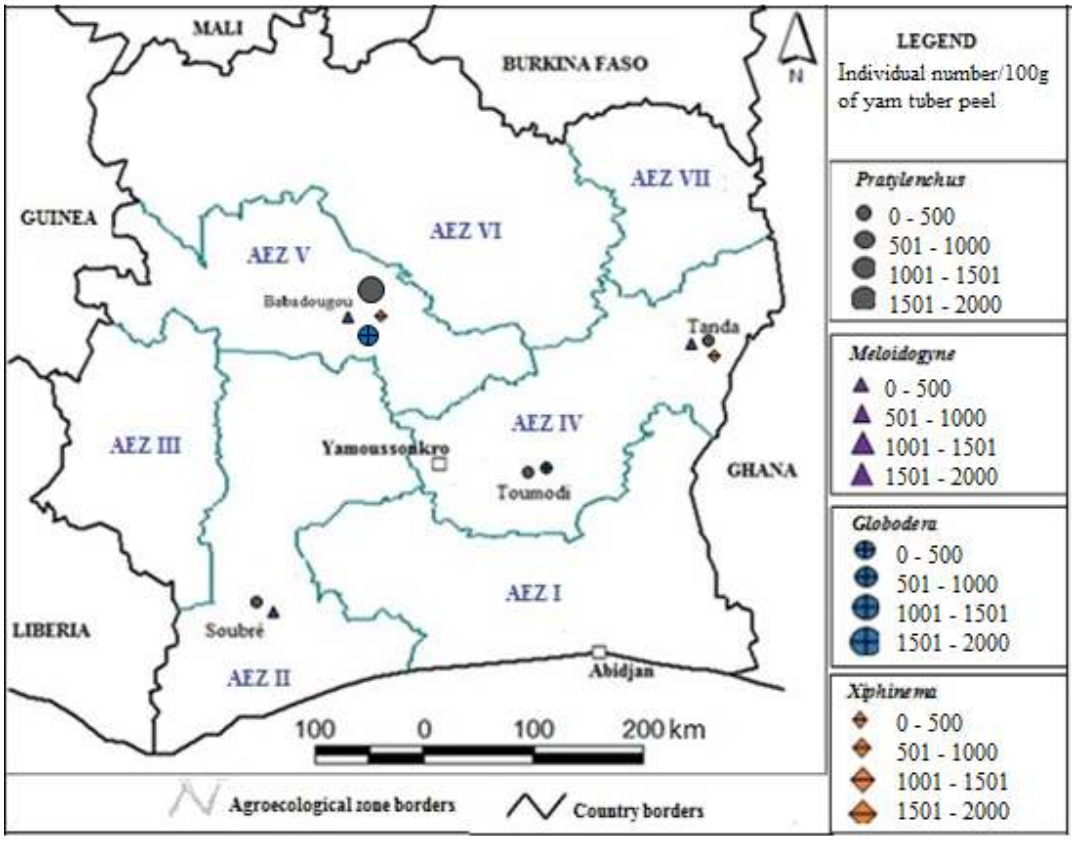

Fig. 5. Distribution map of nematodes extracted from yam tubers in cultivation areas in Côte d'Ivoire

***AEZ**: Agroecological zone, **I**: Southern dense humid forest zone, **II**: Western dense humid forest zone, **III**: Western semi-mountainous forest zone, **IV**: Semi-deciduous dense forest zone, **V**: Transitional forest zone, **VI**: Wet tropical savannah zone, **VII**: Dry tropical savannah zone*

3.4. Evolution of nematode populations in soils and yam tubers

3.4.1. Correlation between symptom severity and populations of associated nematodes

The symptoms observed on yam tubers were galls, cracks and then dry and wet rot. The study of the relationship between symptom severity and the population of associated nematodes revealed a variation in correlation coefficients (Table 4). Only the numbers of *Pratylenchus* individuals increased significantly with the severity of crack and dry rot. This was reflected by strong positive correlations of 0.75 and 0.86 respectively (Table 4). Similarly, only the numbers of *Meloidogyne* increased significantly with the severity of galls; which was materialized by a strong positive correlation of 0.78.

Table 4. Correlation coefficients between the severity of symptoms observed on yam tubers and the populations of associated nematodes

Symptoms	Nematodes			
	Pratylenchus	*Meloidogyne*	*Globodera*	*Xiphinema*
Dry rot	**0.86***** (.000)	0.11ns (.815)	0.21ns (.723)	−
Cracks	**0.75**** (.005)	0.09ns (.902)	−	0.06ns (.901)
Galls	0.21ns (.722)	**0.78***** (.000)	−	−
Wet rot	0.26ns (.716)	−	0.19ns (.753)	−

**P* < .05, ***P* < .01, ****P* < 0,001, *ns: Not significant correlation;*
Data in parentheses are *P* values;
-: The correlation cannot be determined because the nematodes concerned were not associated with these symptoms

3.4.2. Fluctuation of nematode numbers during yam crop cycle

The numbers of *Globodera*, *Meloidogyne*, *Pratylenchus* and *Xiphinema* fluctuated in soils and tubers depending on the development stages of yam tubers (Fig. 6). Only *Globodera* numbers in Babadougou, *Meloidogyne* and *Pratylenchus* increased during yam crop cycle, unlike *Xiphinema*.

Before the 3rd month of cultivation, only *Globodera* numbers in Tanda were the most significant, increasing from 60 to 370 individuals /100 ml of soil (Fig. 6A). From 3 months, this number started decreasing significantly, down to less than 100 individuals /100 ml of soil in the 9th month. Meanwhile, the number of *Globodera* in the yam tubers collected in Babadougou started increasing from 20 to 540 individuals /100 g of peels in the 9th month. In contrast, the size of *Globodera* populations in the soils and tubers of Soubré and Toumodi remained relatively constant with less than 60 individuals /100 ml of soil or 100 g of peels whatever the development stages of yam tubers.

The numbers of *Meloidogyne* significantly increased in cultivation soils and developing tubers in the different localities (Fig. 6B). These numbers increased from less than 10 individuals before seed planting to the interval 121 to 440 individuals /100 ml of soil or 100 g of peels in the 9th month depending on the localities. However, the number of *Meloidogyne* in Tanda soils, after reaching a peak of 754 individuals /100 ml of soil, fell to 60 individuals /100 ml of soil in the 9th month.

Concerning *Pratylenchus*, the numbers in cultivation soils and tubers increased significantly, switching from less than 80 individuals before yam seed planting to the interval between 200 and 2 200 individuals /100 ml of soil or 100 g of yam peels in the 9th month depending on the localities (Fig. 6C). In addition, the number of *Pratylenchus* in Babadougou cultivation soils, after a peak of 878 individuals / 100 ml of soil, fell to 506 individuals in the 9th month. Meanwhile, its number increased exponentially in tubers to the point of reaching 2 140 individuals / 100 g of peel in the 9th month.

The numbers of *Xiphinema* remained relatively constant in soils and yam tubers with less than 200 individuals / 100 ml of soil or 100 g of peel whatever the development stages of the tubers in the different localities (Fig. 6D).

3.4.3. Correlation between numbers of nematodes and age of yam plants

Correlation coefficients ranging from -0.29 to 0.98 were recorded between the numbers of the different nematode populations and the age of the yam plants (Table 5). In cultivation soils and yam tubers, regardless of the locality, only the numbers of *Pratylenchus* increased with the age of yam plants. This increase was reflected by strong, highly significant positive correlations ranging between 0.68 and 0.97.

Similar results were noted in *Meloidogyne* with correlation coefficients ranging from 0.89 to 0.98, except in Tanda where weak positive correlations, namely 0,10 and 0.42 were noted between the number of individuals in the cultivation soil and in yam tubers and the age of yam plants.

Furthermore, concerning *Globodera* and *Xiphinema*, only their numbers in developing yam tubers in the sole locality of Babadougou increased with the age of yam plants with strong positive correlations of 0.93 and 0.88.

Table 5. Correlation coefficients between the numbers of nematodes in cultivation soils and yam tubers in the different localities and the age of yam plants

Substrates	Localities	Nematodes			
		Globodera	*Meloidogyne*	*Pratylenchus*	*Xiphinema*
Soil	Babadougou	-0.06ns (.926)	**0.98**** (.004)	**0.78*** (.035)	-0.12ns (.852)
	Soubré	-0.29ns (.638)	**0.89*** (.041)	**0.95*** (.011)	-0.13ns (.829)
	Tanda	-0.24ns (.697)	0.42ns (.480)	**0.86*** (.043)	0.09ns (.847)
	Toumodi	0.46ns (.534)	**0.95*** (.013)	**0.68*** (.048)	-0.13ns (.834)
Tubers	Babadougou	**0.93*** (.022)	**0.96*** (.009)	**0.88*** (.047)	**0.88*** (.047)
	Soubré	-	**0.94*** (.018)	**0.96*** (.011)	-
	Tanda	-	0.10ns (.870)	**0.94*** (.019)	0.11ns (.813)
	Toumodi	0,23ns (.685)	**-**	**0,97**** (.006)	-

**P* < .05, ***P* < .01, ****P* < 0,001, *ns: Not significant correlation;*
Data in parentheses are P values;
-: The correlation cannot be determined because the nematodes concerned were not extracted from yam peels in this locality

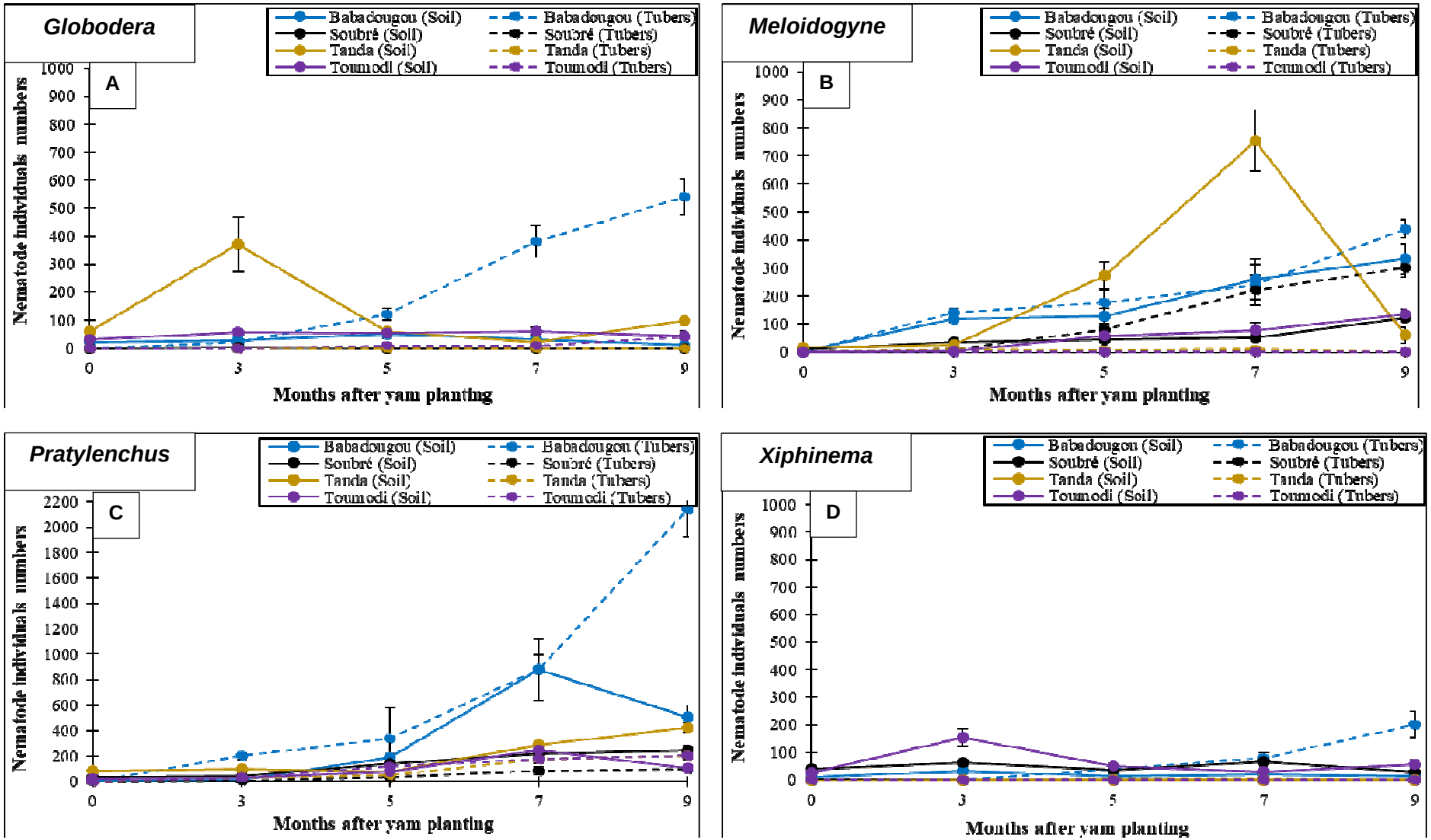

Fig. 6. Dynamics of nematode populations in soils and tubers during the yam crop cycle in production areas

4. DISCUSSION

Various symptoms, such as galls, cracks and dry and wet rot were observed on yam tubers. The development of various symptoms would be due to the activity of several species of nematodes with various modes of infestation. Migratory endoparasitic nematodes use intracellular routes through mechanical and chemical actions, creating necroses on the tubers. As for sedentary endoparasitic nematodes, they migrate through intercellular spaces by means of enzymatic digestion of the middle lamella of the host cells [24]. Once inside the host, these nematodes select host target cells and turn them into giant cells. These giant cells increase in size and operate for the benefit of nematodes. Meanwhile, the cells surrounding the giant cells divide rapidly, causing localized swelling, hence the typical symptom of galls [25].

Moreover, the use of the Whitehead tray method revealed the presence of 16 genera including: *Criconemella*, *Globodera*, *Gracilacus*, *Helicotylenchus*, *Hoplolaimus*, *Longidorus*, *Meloidogyne*, *Paratrichodorus*, *Peltamigratus*, *Pratylenchus*, *Radopholus*, *Rotylenchulus*, *Scutellonema*, *Tylenchorhynchus*, *Tylenchulus* and *Xiphinema* in yam cultivation soils. The diversity of nematodes in yam cultivation soils would be due to the influence of the climate and vegetation on the sites before the trials were set up. According to [26], soil, climate and vegetation are important factors influencing the composition of nematode communities in soils. Indeed, fallow plots, in the different areas used for yam cultivation, had flora composed of several plant species. Phytopathogenic nematodes, feeding on living roots, can be specific to a host plant [27]. The change in the composition of plant species might directly modify the composition of phytopathogenic nematodes [28]. According to [29], the development of particular plant species increases the abundance of nematode species specific to these plants.

In contrast, regarding yam tubers, only *Globodera*, *Meloidogyne*, *Pratylenchus* and *Xiphinema* were extracted from peels. Their presence in tubers would be due to their phytoparasitic lifestyle. Indeed, phytoparasitic nematodes are obligate biotrophic organisms that live only at the expense of a host plant [30]. Part of their life cycle takes place in the roots and tubers of host plants. Thus, water and mineral salts drawn and sugars synthesized by plants are diverted by phytoparasitic nematodes during their development [31]. Yam tubers are excellent sources of sugar and water [32]. The nematodes there would find an environment favorable to their feeding and reproduction, consequently, to induce symptoms on yam tubers.

Furthermore, the correlation study revealed that the numbers of *Pratylenchus* increased with the severity of cracks and dry rot, while those of *Meloidogyne* increased with the severity of galls. This strong increase shows that *Pratylenchus* individuals are strongly involved in the development of dry rot and cracks, and *Meloidogyne* ones in the development of yam galls. These results support the words of [9] reporting that *Pratylenchus coffeae* is also responsible for yam cracks and dry rot. *Meloidogyne* spp. is responsible for yam galls in Uganda [33].

This study also revealed that the numbers of nematodes in soils and tubers fluctuated depending on the phenological stages of developing yam tubers. In addition, before yam seed planting, the numbers of the different nematode populations were relatively low, compared to other periods, in soils. This low number might be due to the scarcity of resources necessary for nematode reproduction and development. In fact, the precedent crops of the sites were three to five-year fallows with flora, mainly composed of *Chromolaena odorata*, *Panicum maximum* and *Imperata cylindrica*.

These plant species would not be suitable hosts for pathogenic yam nematodes. Indeed, [34] did not find, in Martinique, nematodes such as *Pratylenchus*, *Meloidogyne*, etc. in the roots of *Panicum maximum* plants. In addition, fallow plots of *Chromolaena odorata* established by [26] for three years in the localities of Ilora, Ibadan and Ikenne in Southwestern Nigeria significantly reduced the numbers of *Pratylenchus* sp., *Helicotylenchus* sp. and *Meloidogyne* sp. in soils.

Despite what has been mentioned above, the numbers of *Globodera* in Babadougou, on the one hand, then *Meloidogyne* and *Pratylenchus* in cultivation soils and yam tubers of all areas on the other hand, increased significantly with the age of yam plants. This increase is greater from initiation stage to tuberization. These results show that yam is a suitable host for these nematode populations. Indeed, the increase in the biomass of underground organs (roots and tubers) of yam plants might constitute important nutritional resources for these nematode populations. [35] showed that the more the host plant develops, the higher its root system is significant and the better nematodes get fixation sites and resources favorable to their development. According to [36], the crop cycle of water yam is nine months, while the life cycle of *Meloidogyne* and *Pratylenchus*, under favorable conditions, is three to four weeks [20]. This situation might allow the development of several generations of these nematode populations; which would favor, therefore significant pathogenic activities, depending on their modes of infestation in yam tubers, from hence the development of dry rot, cracks and galls on the tubers of freshly harvested yams. Thus, when the numbers of *Pratylenchus* and *Meloidogyne* individuals increase in cultivation soils, they are more so in developing yam tubers. Under these conditions, a preventive treatment with a synthetic or non-synthetic nematicide before the initiation of tuberization, that is, from seed planting, would be possible. Thus, certainly a part of the nematicide might penetrate the seeds and potentially end up in developing tubers, but there might be little risk of contamination with residues in the tubers harvested intended for consumption.

5. CONCLUSION

Galls, cracks and dry rot observed on freshly harvested yam tubers in production areas are characteristic of nematode infestation. *Pratylenchus* populations are strongly involved in the development of cracks and dry rot, while *Meloidogyne* ones are involved in the development of yam galls. The numbers of *Pratylenchus* and *Meloidogyne* increase in cultivation soils and developing yam tubers with the age of yams. Thus, producers could draw inspiration therefrom in order to set up a schedule for yam nematode control. Thus, in order to reduce the impact of *Pratylenchus* and *Meloidogyne* populations on yam production, treatments with synthetic or non-synthetic nematicides are recommended before initiation of tuberization, that is, as from seed planting.

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Fig. 1. Geographical location of the study sites in Côte d'Ivoire
Fig. 2. Yam tubers exhibiting various symptoms
Fig. 3. Main genera of nematodes extracted from yam peels
Fig. 4. Distribution map of nematodes extracted from soils in yam cultivation areas in Côte d'Ivoire
Fig. 5. Distribution map of nematodes extracted from yam tubers in cultivation areas in Côte d'Ivoire
Fig. 6. Dynamics of nematode populations in soils and tubers during the yam crop cycle in production areas