



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

Yadom Y. F. R. Kouakou^{1*}, Kouamé Daniel Kra¹ and Hortense Atta Diallo¹

¹Unité Santé des Plantes, Université Nangui Abrogoua, 02 BP 801 Abidjan 02, Côte d'Ivoire.

Authors' contributions

This work was carried out in collaboration with all authors. Author YYFRK designed the study, performed the statistical analysis and wrote the manuscript. Authors KDK and HAD managed the analyses of the study. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2020/v32i1130342

Editor(s):

(1) Dr. Fatemeh Nejatizadeh, Islamic Azad University, Iran.

Reviewers:

(1) Nadia Sufyan, IFTM University, India.

(2) Davabhai Jethabhai Patel, B. A. College of Agriculture, India.

Complete Peer review History: <http://www.sdiarticle4.com/review-history/60199>

Original Research Article

Received 10 June 2020
Accepted 15 August 2020
Published 22 August 2020

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 g 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* spp., *Pratylenchus coffeae* and *Xiphinema* were the nematodes associated with the symptoms. *Pratylenchus coffeae* was strongly involved in the development of cracks ($r = 0.75$) and dry rot ($r = 0.86$) then *Meloidogyne* spp. in that of galls ($r = 0.78$). *Pratylenchus coffeae* and *Meloidogyne* spp. 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.

*Corresponding author: E-mail: yadomregis@yahoo.fr;

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. MATERIALS 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°C. 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°C [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°C [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°C [17]. Tanda's plot was established on a land which was a three-year *Parkia biglobosa* and *Imperata cylindrica* fallow.

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 (*Florida*, *Bète bête*, *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 m².

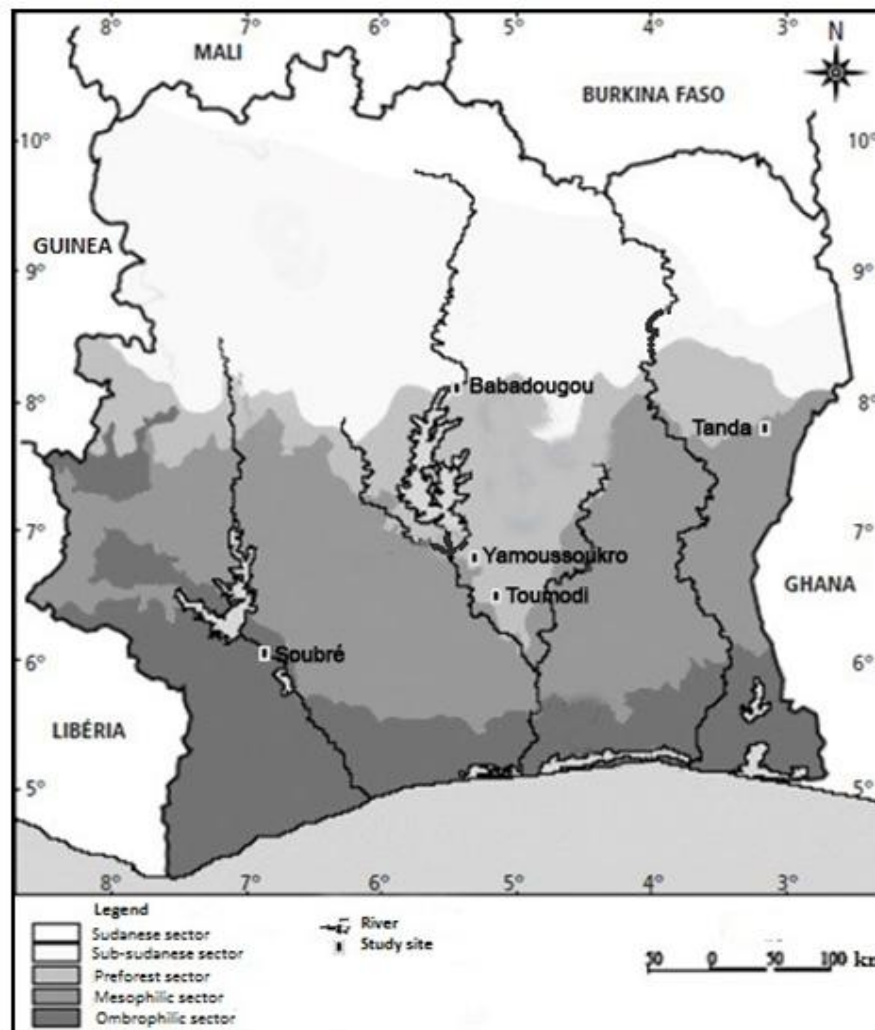


Fig. 1. Geographical location of the study sites in Côte d'Ivoire

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).

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 g 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-aliqouts of nematodes were removed and mounted on a counting plate under an optical microscope (AmScope) so as to describe the individuals observed. The extracted nematodes were identified using the morphological identification keys of [20,21,22] at genus level.

The most abundant and widespread genera of nematodes present in both yam soils and tubers were selected for molecular identification. From each locality, 10 individuals of each nematode genus were handpicked and transferred into 200 µl Eppendorf tubes containing 20 µl of sterile water. DNA extraction was done as described by [23]

The extracted DNAs were amplified by polymerase chain reaction (PCR) according to the [24] protocol. The universal primers D2A/D3B (5'-ACA AGT ACC GTG AGG GAA AGT TG-3'/5'-TCG GAA GGA ACC AGC TAC TA-3', Inqaba Biotechnologies, South Africa) were used for PCR [25]. PCR products were separated by gel electrophoresis and visualized using a UV-transilluminator (E-BOX VX5).

After electrophoresis, positive PCR products were sequenced by the Eurofins-Cochin sequencing service, France. DNA sequences obtained were compared to their homologous sequences of the GenBank database using BLAST to identify the nematode species extracted from yam tubers.

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.

$$ANI_i = \frac{1}{n} \sum (NI_i) \quad (1)$$

ANI_i: Average number of individuals of genus *i* /100 g of soil samples or 100 g of yam peel

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

Ni : Number of individuals of genus i in 100 ml of nematode solution
 n : Number of repetitions

$$RFi = \frac{Ni}{TNI} \times 100 \quad (2)$$

RFi : Relative frequency of a genus i
 Ni : 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 g 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 $\log_{10}(x+1)$ and $\arcsin\sqrt{(p/100)}$ functions respectively before carrying out the statistical analyses [26]. 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).

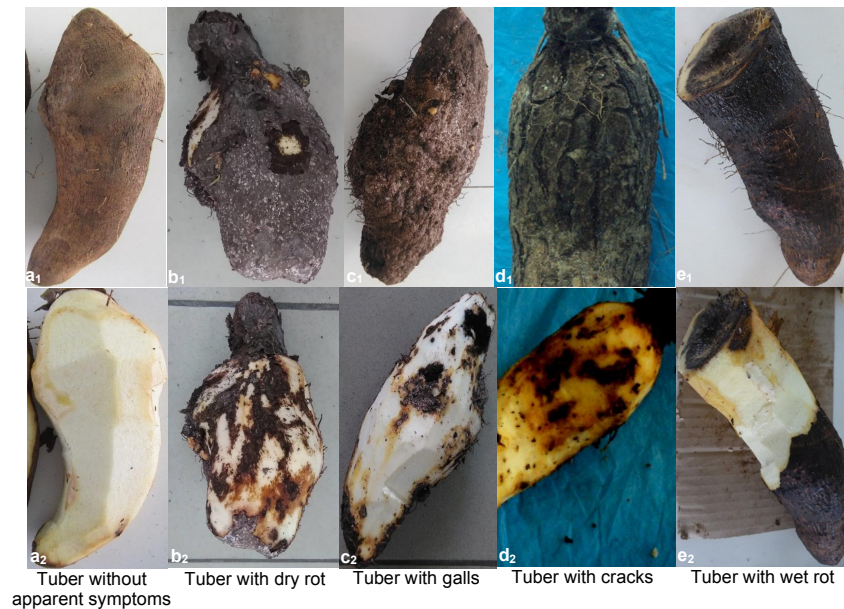


Fig. 2. Yam tubers exhibiting various symptoms

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 (Fig. 3). These included *Criconebella*, *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. 4). 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.

Isolates of *Pratylenchus* extracted from yam peels of all localities are *Pratylenchus coffeae*.

Meanwhile, isolates of *Meloidogyne* extracted from yam peels of Babadougou and Soubré are respectively *Meloidogyne arenaria* and *M. javanica*. Finally, isolate of *Meloidogyne* extracted from yam peels of Tanda could not be identified at species level.

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 coffeae* was mainly extracted from Babadougou and Tanda yam peels with respective relative frequencies of 64.46 and 55.17%. As for *Meloidogyne* spp. and *Globodera*, they were respectively the main nematodes extracted from Soubré and Toumodi yam peels with relative frequencies of 75 and 66.67%.



Fig. 3. Main genera of nematodes extracted from yam cultivation soils

Table 2. Relative frequencies of nematodes extracted from yam cultivation soil

Identified nematodes	Localities			
	Babadougou	Soubré	Tanda	Toumodi
<i>Criconemella</i>	0.72 ± 0.49c	0.51 ± 0.51d	0.29 ± 0.25d	0.07 ± 0.07d
<i>Helicotylenchus</i>	2.30 ± 0.98c	8.21 ± 4.84c	0.11 ± 0.04d	2.89 ± 1.90d
<i>Hoplolaimus</i>	15.33 ± 7.81b	6.10 ± 3.00c	1.52 ± 0.22d	2.14 ± 1.52d
<i>Globodera</i>	5.25 ± 1.80bc	0.16 ± 0.12d	23.58 ± 1.64b	21.46 ± 4.47a
<i>Meloidogyne</i>	7.82 ± 1.99bc	13.28 ± 3.27b	44.48 ± 25.92a	15.76 ± 6.48b
<i>Pratylenchus</i>	52.66 ± 29.2a	34.39 ± 11.09a	15.52 ± 1.93c	23.69 ± 10.0a
<i>Radopholus</i>	5.92 ± 3.91bc	0.48 ± 0.32d	3.98 ± 1.89d	4.16 ± 2.84d
<i>Tylenchorhynchus</i>	5.42 ± 1.68bc	10.40 ± 2.09bc	4.67 ± 1.43d	11.29 ± 2.24c
<i>Xiphinema</i>	3.07 ± 1.19c	10.91 ± 3.91bc	0.04 ± 0.04d	13.70 ± 4.41b
<i>Peltamigratus</i>	0	0.61 ± 0.61d	1.27 ± 0.91d	0.05 ± 0.05d
<i>Scutellonema</i>	0.45 ± 0.45c	1.90 ± 1.90d	0	2.09 ± 1.98d
<i>Tylenchulus</i>	0.42 ± 0.31c	0.84 ± 0.70d	0.47 ± 0.29d	0
<i>Gracilacus</i>	0.63 ± 0.21c	0	0	0.99 ± 0.76d
<i>Longidorus</i>	0	0.65 ± 0.37d	0	1.62 ± 0.91d
<i>Rotylenchulus</i>	0	11.56 ± 11.30bc	4.09 ± 2.21d	0
<i>Paratrichodorus</i>	0	0	0	0.07 ± 0.07d
<i>P</i>	.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



Fig. 4. Main genera of nematodes extracted from yam peels

S: Stylet, V: Vulva

Table 3. Relative frequencies of nematodes extracted from yam tubers

Identified nematodes	Localities			
	Babadougou	Soubré	Tanda	Toumodi
<i>Globodera</i>	16.27 ± 3.00 ^b	0	0	66.67 ± 6.22 ^a
<i>Meloidogyne</i> spp.	13.25 ± 1.47 ^b	75.00 ± 4.75 ^a	34.48 ± 5.71 ^b	0
<i>Pratylenchus coffeae</i>	64.46 ± 3.45 ^a	25.00 ± 5.41 ^b	55.17 ± 5.77 ^a	33.33 ± 3.87 ^b
<i>Xiphinema</i>	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 (Figs. 5 and 6). 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.

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 coffeae* 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* spp. increased significantly with the severity of galls; which was materialized by a strong positive correlation of 0.78.

3.4.2 Fluctuation of nematode numbers during yam crop cycle

The numbers of *Globodera*, *Meloidogyne* spp., *Pratylenchus coffeae* and *Xiphinema* fluctuated in soils and tubers depending on the development stages of yam tubers (Fig. 7). Only *Globodera* numbers in Babadougou, *Meloidogyne* spp. and *Pratylenchus coffeae* increased during yam crop cycle, unlike *Xiphinema*.

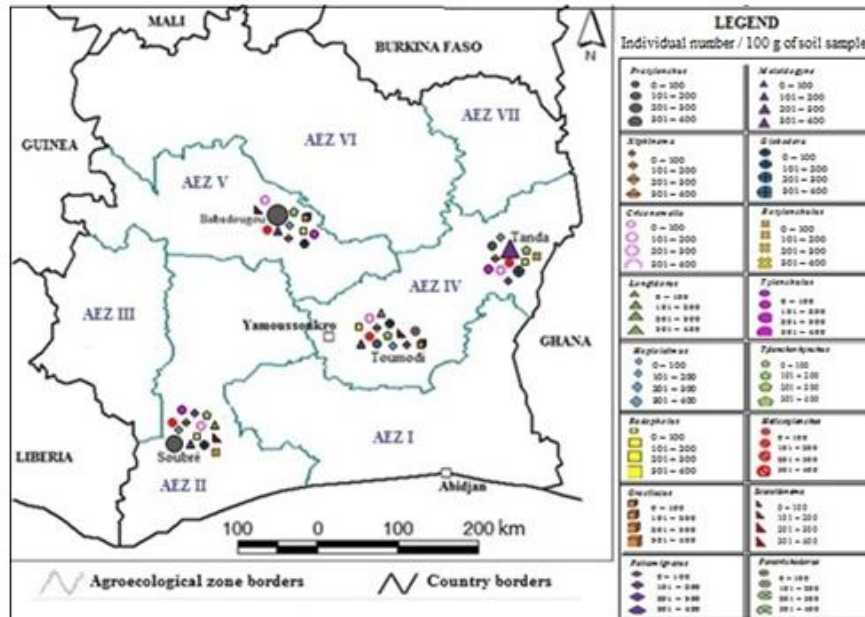


Fig. 5. Distribution map of nematodes extracted from soils in yam cultivation areas in Côte d'Ivoire

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

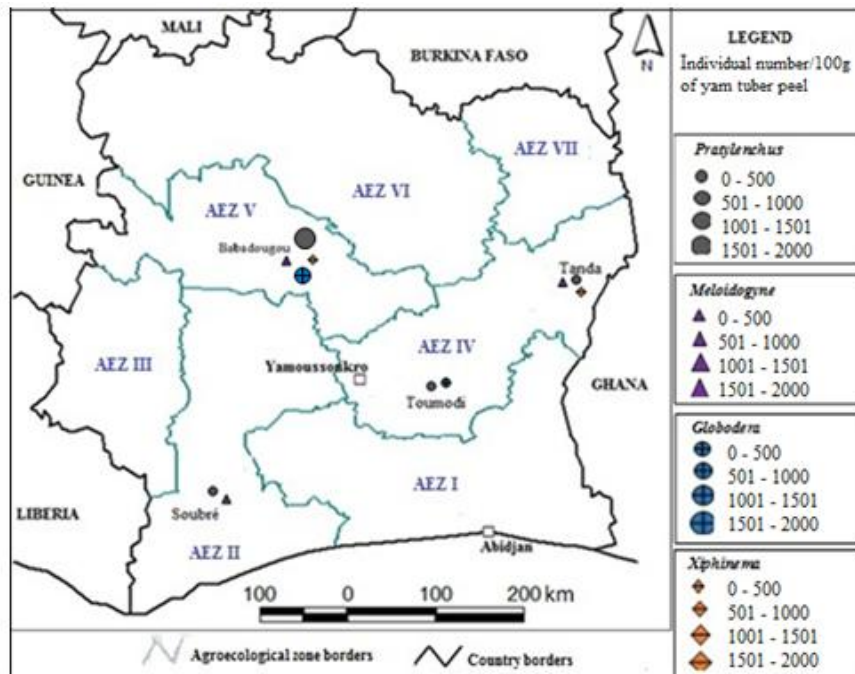


Fig. 6. Distribution map of nematodes extracted from yam tubers in cultivation areas in Côte d'Ivoire

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

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

Symptoms	Nematodes			
	<i>Pratylenchus coffeae</i>	<i>Meloidogyne</i> spp.	<i>Globodera</i>	<i>Xiphinema</i>
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

Before the 3rd month of cultivation, only *Globodera* numbers in Tanda were the most significant, increasing from 69 to 421 individuals /100 g of soil (Fig. 7A). From 3 months, this number started decreasing significantly, down to less than 120 individuals /100 g 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 100 individuals /100 g of soil or 100 g of peels whatever the development stages of yam tubers.

The numbers of *Meloidogyne* spp. significantly increased in cultivation soils and developing tubers in the different localities (Fig. 7B). These numbers increased from less than 20 individuals before seed planting to the interval 138 to 440 individuals /100 g of soil or 100 g of peels in the 9th month depending on the localities. However, the number of *Meloidogyne* sp. in Tanda soils, after reaching a peak of 857 individuals /100 g of soil, fell to 69 individuals /100 g of soil in the 9th month.

Concerning *Pratylenchus coffeae*, the numbers in cultivation soils and tubers increased significantly, switching from less than 100 individuals before yam seed planting to the interval between 100 and 2 200 individuals /100 g of soil or 100 g of yam peels in the 9th month depending on the localities (Fig. 7C). In addition, the number of *Pratylenchus coffeae* in Babadougou cultivation soils, after a peak of 998 individuals /100 g of soil, fell to 575 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 g of soil or 100 g of peel whatever the development stages of the tubers in the different localities (Fig. 7D).

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 coffeae* 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* spp. 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.

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

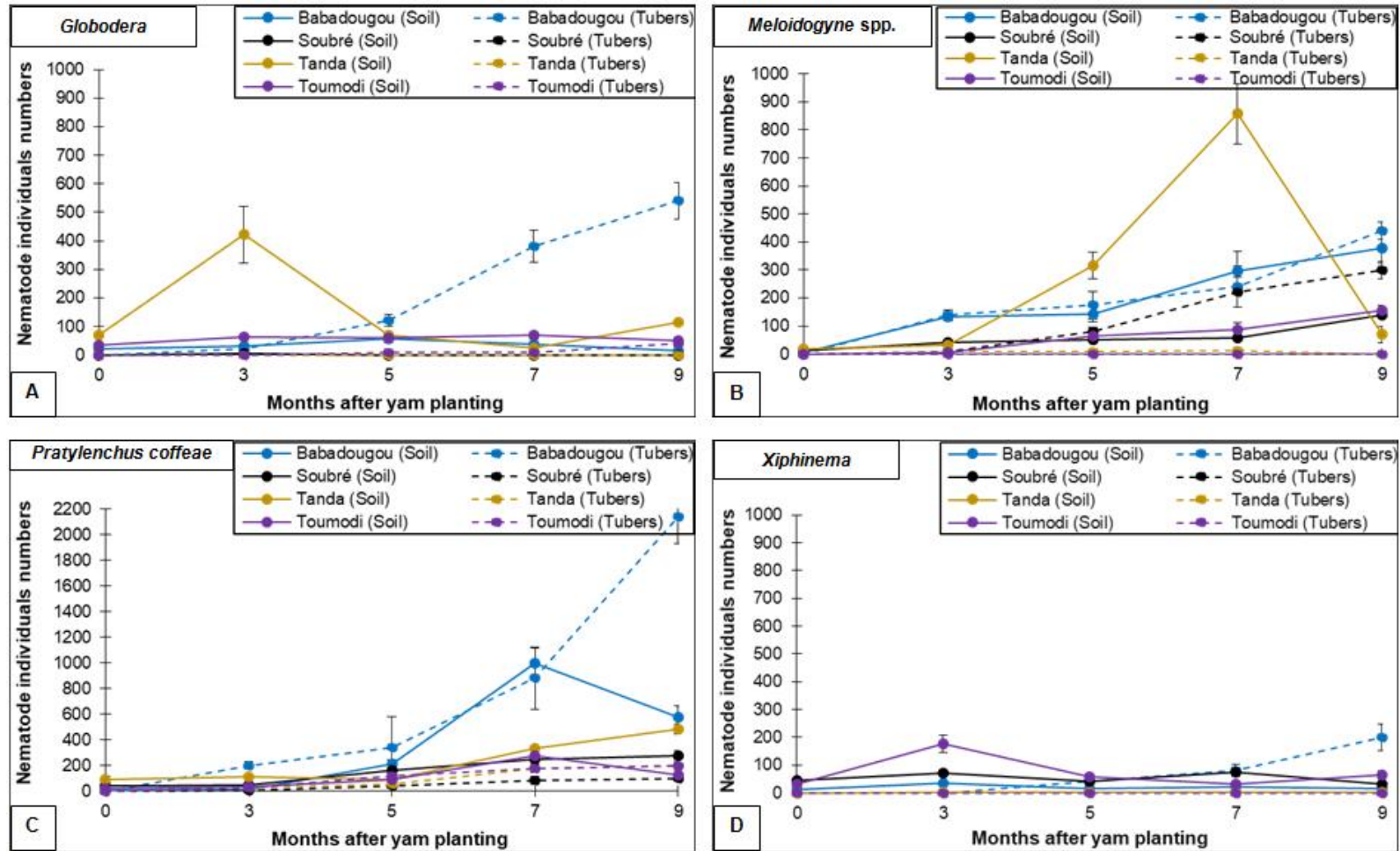


Fig. 7. Dynamics of nematode populations in soils and tubers during the yam crop cycle in production areas

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			
		<i>Globodera</i>	<i>Meloidogyne</i> spp.	<i>Pratylenchus coffeae</i>	<i>Xiphinema</i>
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

cells [27]. 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 [28].

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 [29], 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 [30]. The change in the composition of plant species might directly modify the composition of phytopathogenic nematodes [31]. According to [32], the development of particular plant species increases the abundance of nematode species specific to these plants.

In contrast, regarding yam tubers, only *Globodera*, *Meloidogyne* spp., *Pratylenchus coffeae* 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 [33]. 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 [34]. Yam tubers are excellent sources of sugar and water [35]. 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 coffeae* increased with the severity of cracks and dry rot, while those of *Meloidogyne* spp. increased with the severity of galls. This strong increase shows that *Pratylenchus coffeae* individuals are strongly involved in the development of dry rot and cracks, and *Meloidogyne* spp. 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 [36].

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, [37] 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 [29] 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* spp. and *Pratylenchus coffeae* 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. [38] 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 [39], 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 coffeae* and *Meloidogyne* spp. 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 coffeae* populations are strongly involved in the development of cracks and dry rot, while *Meloidogyne* spp. ones are involved in the development of yam galls. Such infected tubers of yam should not be used for planting by farmers. The numbers of *Pratylenchus coffeae* and *Meloidogyne* spp. 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 coffeae* and *Meloidogyne* spp. populations on yam production, cost effective control measures should worked out by the scientists for benefits of farmers. Finally, treatments with chemical or non-chemical nematicides are recommended before initiation of tuberization, that is, as from seed planting.

ACKNOWLEDGEMENTS

This work was carried out thanks to the technical and financial support from the Interprofessional Fund for Agricultural Research and Consultancy (FIRCA) and the West African Agricultural Productivity Program (WAAPP).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Nweke FI, Ugwu BO, Asadu CLA, Ay P. Production costs in the yam-based cropping systems of south-western Nigeria. 6th ed., Resource and Crop Management Division: IITA; 1991.
2. Treche S. Valeur nutritionnelle des ignames. In Berthaud J, Bricas N, Marchand JL, editors. L'igname, plante séculaire et culture d'avenir, ed. Montpellier: CIRAD; 1998. French.
3. Chukwu GO, Ikwelle MC. Yam: Threats to its Sustainability in Nigeria. NRCRI News. 2000;17(1):1-7.
4. Korada RR, Naskar SK, Edison S. Insect pests and their management in yam production and storage: A world review. International Journal of Pest Management. 2010;56(4):337-349.
5. Ettien JB, Tschannen A. Evaluation de nouvelles variétés d'igname en Côte d'Ivoire: Bilan de trois ans d'expérience avec des génotypes améliorés par l'IITA, Actes du Colloque, Garoua; 2003. French.

6. Faostat. Food and Agricultural Organization Statistics Database. Available:<http://faostat.fao.org> Accessed 03 May 2019.
7. Doumbia S, Koko L, Aman SA. L'introduction et la diffusion de la variété d'igname C18 en région centre de Côte d'Ivoire. *Journal of Applied Biosciences*. 2014;80:7121-7130. French.
8. Doumbia S, Touré M, Mahyao A. Commercialisation de l'igname en Côte d'Ivoire: Etat actuel et perspectives d'évaluation. *Cahiers Agricultures*. 2006; 15(3):273-277. French.
9. Bridge J, Coyne DL, Kwoseh CK. Nematodes parasites of tropical root and tuber crops (excluding potatoes). In: Luc M, Sikora RA, Bridge J, editors. *Plant parasitic nematodes in subtropical and tropical agriculture*. 2nd ed. Wallingford: CAB International; 2005.
10. Quénéhervé P. Les nématodes de l'igname, Actes du Séminaire International Cirad-Inra-Orstom-Coraf. Montpellier; 1997. French.
11. Kouakou YYFR, Kra KD, Atta Diallo H. Plant parasitic nematodes associated with deformation and degradation symptoms of yam tubers (*Dioscorea* spp.) in Côte d'Ivoire. *International Journal of Agriculture Sciences*. 2016;8(54):2906-2911.
12. Adebite AA, Saka JO, Agbaje GO, Owolade OF, Olaiifa GO, Lawal A, Ojo ST. Survey of plant-parasitic nematodes associated with yams in Edo, Ekiti and Oyo states of Nigeria. *African Journal of Agricultural Research*. 2006;1(4):125-130.
13. Koffi YS. Cotton production and food security in Mankono north-central Côte d'Ivoire. *Indian Streams Research Journal*. 2013;3(6):1-5.
14. Bitty EA, Kadjo B, Bene JCK, Kouassi PK. Bushmeat survey an indicator of wildlife disappearance in Soubre Region, Côte d'Ivoire. *Livestock Research for Rural Development*. 2014; 26:54. Available:<http://www.lrrd.org/lrrd26/3/bitt26054.html> Accessed 15 May 2016.
15. N'Zi JC, Koua AP, Kouassi KD, Kahia J, Kouassi JL, N'Guetta ASP, Kouamé C. Effect of inoculating seeds with *Bradyrhizobium japonicum* on the agronomic performance of five varieties of soybean (*Glycine max*) in Côte d'Ivoire. *African Journal of Agricultural Research*. 2015;10(37):3671-3677.
16. Tié TB, Diby LN, Seyo E, Assa A. Estimating soil available nitrogen with a hot H₂O₂/KCl extraction. *Scientific Research and Essays*. 2010;5(12):1455-1462.
17. Ahoussi KE, Youan TM, Loko S, Adja MG, Lasm T, Jourda JP. Étude hydrogéochimique des eaux des aquifères de fractures du socle Paléoprotérozoïque du Nord-Est de la Côte d'Ivoire: Cas de la région de Bondoukou. *Afrique Science*. 2012;8(3):51-68. French.
18. Plowright R, Kwoseh C. Identification of resistance to major nematode pests of yams (*Dioscorea* spp.) in West Africa R6694 (ZA0021). Crop Protection Programme, Final technical report; 2000.
19. Coyne DL, Nicol JM, Claudius-Cole B. Les nématodes des plantes: Un guide pratique des techniques de terrain et de laboratoire. Cotonou, Institut International d'Agriculture Tropicale (IITA); 2010. French.
20. Hunt DJ, Luc M, Manzanilla-López RH. Identification, morphology and biology of plant parasitic nematodes. In Luc M, Sikora RA, Bridge J, editors. *Plant parasitic nematodes in subtropical and tropical agriculture*, 2nd ed. Wallingford: CAB International; 2005.
21. Castillo P, Vovlas N, editors. *Pratylenchus* (Nematoda: Pratylenchidae): Diagnosis, biology, pathogenicity and management. 6th volume. *Nematology monographs and perspectives*: Brill Leiden-Boston; 2007.
22. Mekete T, Dababat A, Sekora N, Akyazi F, Abebe E. Identification key for agriculturally important plant-parasitic nematodes prepared for the International Nematode Diagnosis and Identification. A manual for nematology, Mexico: DF CIMMYT; 2012.
23. Liu GK, Chen J, Xiao S, Zhang SS, Pan DM. Development of species-specific PCR primers and sensitive detection of the *Tylenchulus semipenetrans* in China. *Agricultural Sciences in China*. 2011; 10(2):252-258.
24. Tenente GCMV, De Ley P, Tandingan DLI, Karssen G, Vanfleteren JR. Sequence analysis of the D2/D3 region of the large subunit rDNA from different *Meloidogyne* isolates. *Nematropica*. 2004;34(1):1-12.
25. De Ley P, Felix MA, Frisse LM, Nadler SA, Sternberg PW, Thomas WK. Molecular and morphological characterisation of two reproductively isolated species with mirror-image anatomy (Nematoda: ephalobidae). *Nematology*. 1999;1(6):591-612.

26. Jayaraman K. Manuel de statistique pour la recherche forestière. Organisation des Nations Unies pour l'Alimentation et l'Agriculture; 1999. French.
27. Gheysen G, Mitchum MG. How nematodes manipulate plant development pathways for infection. *Current Opinion in Plant Biology*. 2011;14(4):415-421.
28. Bartlem DG, Jones MGK, Hammes UZ. Vascularization and nutrient delivery at root-knot nematode feeding sites in host roots. *Journal of Experimental Botany*. 2013;65(7):1789-1798.
29. Adediran JA, Adegbite AA, Akinlosotu TA, Agbaje GO, Taiwo LB, Owolade OF, Oluwatosin GA. Evaluation of fallow and cover crops for nematode suppression in three agroecologies of south western Nigeria. *African Journal of Biotechnology*. 2005;4(10):1034-1039.
30. Van der Putten WH, Van der Stoel CD. Plant parasitic nematodes and spatio-temporal variation in natural vegetation. *Applied Soil Ecology*. 1998;10(3):253-262.
31. Yeates GW, Bongers T. Nematode diversity in agroecosystems. *Agriculture Ecosystems and Environment*. 1999;74(1-3):113-135.
32. De Deyn GB, Raaijmakers CE, Van Ruijven J, Berendse F, Van der Putten WH. Plant species identity and diversity effects on different trophic levels of nematodes in the soil food web. *Oikos*. 2004;106(3):576-586.
33. Dinh PTY, Knoblauch M, Elling AA. Nondestructive imaging of plant-parasitic nematode development and host response to nematode pathogenesis. *hytopathology*. 2014;104(5):497-506.
34. Bleve-Zacheo T, Melillo MT, Castagnone-Sereno P. The contribution of biotechnology to root-knot nematode control in tomato plants. *Pest Technology*. 2007;1(1):1-16.
35. Dania VO, Fadina OO, Ayodele M, Lava Kumar P. Efficacy of *Oryza sativa* husk and *Quercus phillyraeoides* extracts for the in vitro and in vivo control of fungal rot disease of white yam (*Dioscorea rotundata* Poir). *SpringerPlus*. 2014;3(711): 1-7.
36. Mudioppe J, Coyne DL, Adipala E, Talwana HAL. Damage to yam (*Dioscorea* spp.) by root-knot nematode (*Meloidogyne* spp.) under field and storage conditions in Uganda. *Nematropica*. (2012);42(1):137-145.
37. Quénéhervé P, Chabrier C, Auwerkerken A, Topart P, Martiny B, Marie-Luce S. Status of weeds as reservoirs of plant parasitic nematodes in banana fields in Martinique. *Crop Protection*. 2006;25(8): 860-867.
38. Ndiaye A. Influence de facteurs abiotiques et biotiques sur la multiplication et la morphologie de quelques Nématodes phytoparasites de la région soudano-sahélienne. Université Cheikh Anta Diop, Dakar; 1994. French.
39. Kouakou AM, Zohouri GP, Dumont R, Yapi-Gnaoré V. Bien cultiver l'igname en Côte d'Ivoire, Centre National de Recherche Agronomique, Fiche technique; 2005. French.

© 2020 Kouakou et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
<http://www.sdiarticle4.com/review-history/60199>