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RESEARCH ARTICLE

DISTRIBUTION AND DYNAMICS OF NEMATODE POPULATIONS ASSOCIATED WITH CASSAVA (*Manihot esculenta* Crantz) CULTIVATION IN TWO MAIN PRODUCTION AREAS IN CÔTE D'IVOIRE

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Abstract

Plant parasitic nematodes associated with cassava cultivation in Côte d'Ivoire have received very little public attention. This study aims at updating information on nematodes associated with cassava. Surveys were carried out in cassava fields in five localities spread over two agroecological zones so as to collect cassava soil and root samples. The nematodes were extracted, identified, quantified and their distribution mapped. Sixteen nematode genera were extracted from cultivation soils, six of which including *Gracilacus*, *Helicotylenchus*, *Meloidogyne*, *Pratylenchus*, *Radopholus* and *Tylenchulus* were extracted from cassava roots. *Gracilacus* and *Meloidogyne* were extracted from cassava roots from all localities. Local and improved cassava varieties were infected with nematodes. *Gracilacus* was mainly extracted from cassava roots in Adzopé, Agboville and Dabou at frequencies ranging from 48.43 to 56.58%. *Meloidogyne* and *Pratylenchus* were the main nematodes extracted from cultivation soils in Gagnoa (46.81%) and Yamoussoukro (78.15%) respectively. The numbers of *Gracilacus* in Adzopé, Agboville and Dabou, *Meloidogyne* in Agboville, Dabou and Gagnoa, *Pratylenchus* in Dabou and Yamoussoukro and *Radopholus* in Adzopé increased in cultivation soils with the age of cassava plants.

Introduction:-

Cassava (*Manihot esculenta* Crantz) is one of the most important root and tuber plants in the world. It is cultivated for its edible tuberous roots, rich in starch which is appreciated by nutritionists thanks to its excellent digestibility (Kouassi *et al*., 2010). Cassava provides food security for millions of people in Africa. It contributes to improving the economy of producing countries (Amani *et al*., 2005) through its processing into various products (Abu *et al*., 2006; Apea-Bah *et al*., 2009) such as cossettes, gari, attiéké and tapioca (Amani *et al*., 2007). It is also a source of income for millions of African, Asian and Latin American farmers (Guillaume-Gentil, 2015). Cassava is the second food crop in Côte d'Ivoire, after yam, with 5.37 million tons of tuberous roots yielded in 2017 (Faostat, 2017).

Despite all of the above, cassava is a plant whose cultivation is subject to enormous parasitic constraints, including plant parasitic nematode ones. Studies on cassava parasitic nematodes are scarce compared to those of other root and tuber crops such as yam (Asimiea *et al.*, 2015). However, several nematode species are associated with cassava in different production areas around the world (Bridge *et al.*, 2005). The most important nematode species, which infect cassava in Africa, are *Meloidogyne incognita*, *Meloidogyne javanica* and *Pratylenchus brachyurus*

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(Akinsanya and Afolami, 2018). Coyne *et al*. (2012) found that root-knot nematodes are responsible for 87-98% of greenhouse yield losses in Uganda. Recently, studies in Nigeria revealed the presence and recurrence of *Gracilacus* in cassava roots (Asimiea *et al*., 2015; Taminola *et al.,* 2016; Taminola *et al.,* 2018). In addition, these nematodes interact with other plant parasitic organisms to induce disease complexes (Bridge *et al*., 2005).

In Côte d'Ivoire, cassava is cultivated in about 80% of the territory (N'zué *et al.,* 2004). This cassava cultivation area covers a diversity of soil types (ferruginous, ferralitic, etc.), agroecological zones (dense humid forest zones, transition forest zone and humid and dry tropical savannah zones, etc.), climates (equatorial, humid tropical, South Sudanese, etc.) and vegetation (dense forests, mesophilic forests, shrub savannas, etc.). Like other cassava-producing countries, studies of plant parasitic nematodes associated with cassava in Côte d'Ivoire have received very little scientific attention to date. This inattention results in the lack of information on plant parasitic nematodes infecting cassava, on the distribution and dynamics of their populations in cultivation soils depending on the phenological stages of the plant. Thus, this study aims at updating the available information on plant parasitic nematodes associated with cassava through inventory of nematodes, determination of their frequencies and distribution and then the fluctuation of their populations depending on the phenological stages of cassava plants in two main production areas.

Materials and methods:-

Description of study sites:

This study was carried out in cassava fields in five localities belonging to two agroecological zones. Adzopé, Agboville, Dabou and Gagnoa belong to the dense humid forest zone in the south characterized by rainfall ranging between 1 400 and 2 500 mm/year with an annual average temperature of 29 °C. However, Yamoussoukro is located in the dense humid semi-deciduous forest zone characterized by rainfall varying from 1 300 to 1 750 mm/year with an annual average temperature of 23.5 °C (Bolou *et al.,* 2016). In order to know the distribution and dynamics of nematode populations associated with cassava cultivation, their inventory in production areas was necessary.

Inventory of nematodes associated with cassava cultivation:

Phytosanitary surveys:

The cassava fields surveyed were set up by the Plant Health Unit of the University Nangui Abrogoua (Abidjan, Côte d'Ivoire), as part of the project "Development of methods for cassava disease and pest control" registered under number WAAPP/PPAAO 058/CS/PPAAO/2012 of the West African Agricultural Productivity Program. Three to four cassava varieties (two improved varieties and one or two local varieties) were cultivated depending on the localities (Table 1).

Phytosanitary surveys were carried out in the period from May 2013 to May 2014 at different phenological stages of the crop: cassava planting (beginning of the season), 3rd month (beginning of canopy development), 5th month (end of canopy development), 7th month (intense transfer of carbohydrates to the roots) and 12th month (plant dormancy or end of cassava development cycle). These phytosanitary surveys made it possible to collect cassava soil and root samples.

Table 1:- Cassava varieties cultivated on the fields surveyed depending on the zones.

Localities	**Cassava varieties**			
	Improved varieties		**Local varieties**	
Adzopé	Bocou 1	TMS 4(2)1425	Yacé	Mamawa
Agboville	Bocou 1	Bocou 3	Kadi	Akpêkpênondjê
Dabou	Bocou 1	TMS 4(2)1425	Sapel	Péri péri
Gagnoa	Bocou 1	Bocou 3	Zabia	-
Yamoussoukro	Bocou 1	TMS 4(2)1425	Yavo	Bonoua

Collection of cassava root and cultivation soil samples:

Soil sample collection was carried out at the aforementioned periods during phytosanitary surveys. About 200 g of the soil sample was taken from about 20 cm deep at the base of each cassava plant. Sixty soil samples were taken from each field at each collection. Cassava roots were collected in the 12th month, when the tuberous roots were harvested. Ten tuberous roots of each cassava variety were collected. Samples were packaged in sterile polyethylene bags and taken to the laboratory for nematode extraction.

Nematode extraction:
Cultivation soil samples were mixed in a tank to form a composite sample. Nematodes were extracted from 100 ml of soil sample by the Whitehead tray method (Coyne *et al.* 2010). Five repetitions were made per composite sample. Root samples from each plot were grouped per variety. Root samples were cut into explants of approximately 5 mm × 5 mm. Nematodes were extracted from 5 g of root explants by Baermann maceration method (Coyne *et al*., 2010). Five repetitions were also made for each composite sample prepared. The extracted nematodes were identified.

Nematode identification:
For each composite soil or root explant sample, the nematodes were concentrated in 100 ml of water. Three 5-ml aliquots were taken and mounted on an optical microscope counting plate (AmScope) to identify the individuals observed. Nematodes were identified at the genus level by the morphological identification keys of Hunt *et al.* (2005), Castillo and Vovlas (2007) and Mekete *et al.* (2012). After nematode identification, their distribution mapping was necessary.

Nematode distribution mapping in cassava production areas:
The geographical coordinates of the fields were recorded using GPS (Garmin GPSMAP 64). Distribution maps of cassava soil and root plant parasitic nematodes in Côte d'Ivoire were produced using ArcView 3.2 software. After mapping, knowledge of the main nematodes was necessary, hence their quantification in cassava soils and roots.

Quantification of identified nematodes:
The numbers then the relative and absolute frequencies of each nematode genus identified were calculated according to the following formulas.

$$\mathrm{ANi} = \frac{1}{\mathrm{n}} \sum(\mathrm{ni}) \times 20$$

ANi: Average number of individuals of a genus i
ni: Number of individuals in genus i in 100 ml of soil samples or 5 g of root explants
n: Number of repetitions performed

$$\mathrm{RFr}\ (\%) = \frac{\mathrm{NIi}}{\mathrm{TNI}} \times 100$$

RFr (%): Relative frequency of a genus i
NIi: Number of individuals of a genus i
TNI: Total number of individuals of all extracted genera

$$\mathrm{AFr}\ (\%) = \frac{\mathrm{NSi}}{\mathrm{TNS}} \times 100$$

AFr (%): Absolute frequency of a genus i
NSi: Number of samples containing the genus i
TNS: Total number of samples collected

In order to know the relationship between nematode population and plant age, the study of nematode population dynamics depending on cassava plant phenological stages was necessary and carried out.

Nematode population dynamics during cassava crop cycle:
Evolution of nematode numbers depending on cassava plant age:
Nematodes extracted from cassava tuberous roots from each locality were considered for this study. Thus, their number in 100 ml of cultivation soil sample were determined depending on the five phenological stages of the cassava plants considered.

Relationship between nematode populations and cassava plant age:
The relationship between nematode populations and the age of developing cassava plant was established by determining Pearson's r correlation coefficient. To this end, the number of individuals of nematode populations extracted from cultivation soils was determined depending on cassava plant phenological stages.

Statistical analyses:

The data collected during this study was analyzed with Statistica 7.1 software. The numbers and relative frequencies of nematodes were transformed respectively by the $\log_{10}(x+1)$ and $\arcsin\sqrt{p/100}$ functions before proceeding to statistical analyses (Jayaraman, 1999). In the event of a significant difference between the average numbers of nematodes on the one hand, and between the average relative frequencies of nematodes on the other hand at 5% level, Fisher's LSD test was used so as to get homogeneous groups.

Results:-

Phytopathogenic nematodes identified:

Nematodes extracted from cassava cultivation soils:

Fourteen nematode genera were extracted from soil samples. These included *Criconemella*, *Globodera*, *Gracilacus*, *Helicotylenchus*, *Hoplolaimus*, *Longidorus*, *Meloidogyne*, *Paratrichodorus*, *Pratylenchus*, *Radopholus*, *Scutellonema*, *Tylenchorhynchus*, *Tylenchulus* and *Xiphinema*. Of these, twelve genera were extracted from each soil sample of Adzopé and Yamoussoukro and eleven genera from each of Agboville and Dabou ones, compared to ten genera from Gagnoa ones.

Nematodes extracted from cassava tuberous roots:

Six nematode genera, namely *Gracilacus*, *Helicotylenchus*, *Meloidogyne*, *Pratylenchus*, *Radopholus* and *Tylenchulus* were extracted from cassava roots (Figure 1). Five genera were extracted from cassava roots in Yamoussoukro, against four genera in Gagnoa ones, three genera from each of Adzopé and Dabou ones. Finally, two nematodes genera were extracted from cassava roots collected in Agboville.

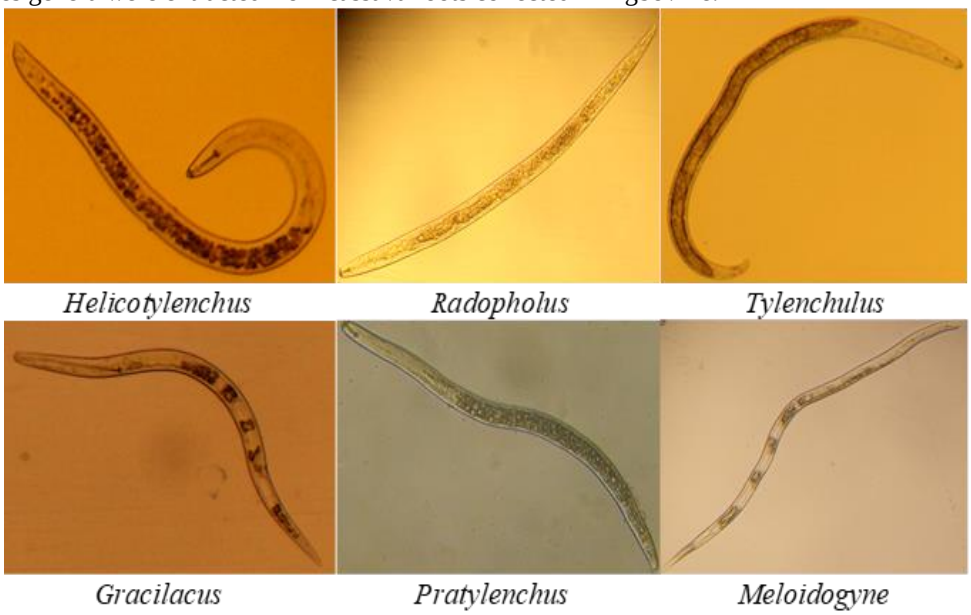

Figure 1:- Nematodes extracted from cassava tuberous roots.

Nematode distribution in cassava cultivation areas:

Not all nematode genera were present in cassava soil and root samples from all cassava fields surveyed **(Figures 2 and 3)**. In total, eight nematode genera *Gracilacus*, *Helicotylenchus*, *Longidorus*, *Meloidogyne*, *Pratylenchus*, *Radopholus*, *Tylenchorhynchus* and *Xiphinema* were extracted from soil samples from all the cassava fields surveyed. Only *Gracilacus* and *Meloidogyne* were extracted from cassava root samples collected from all the fields surveyed.

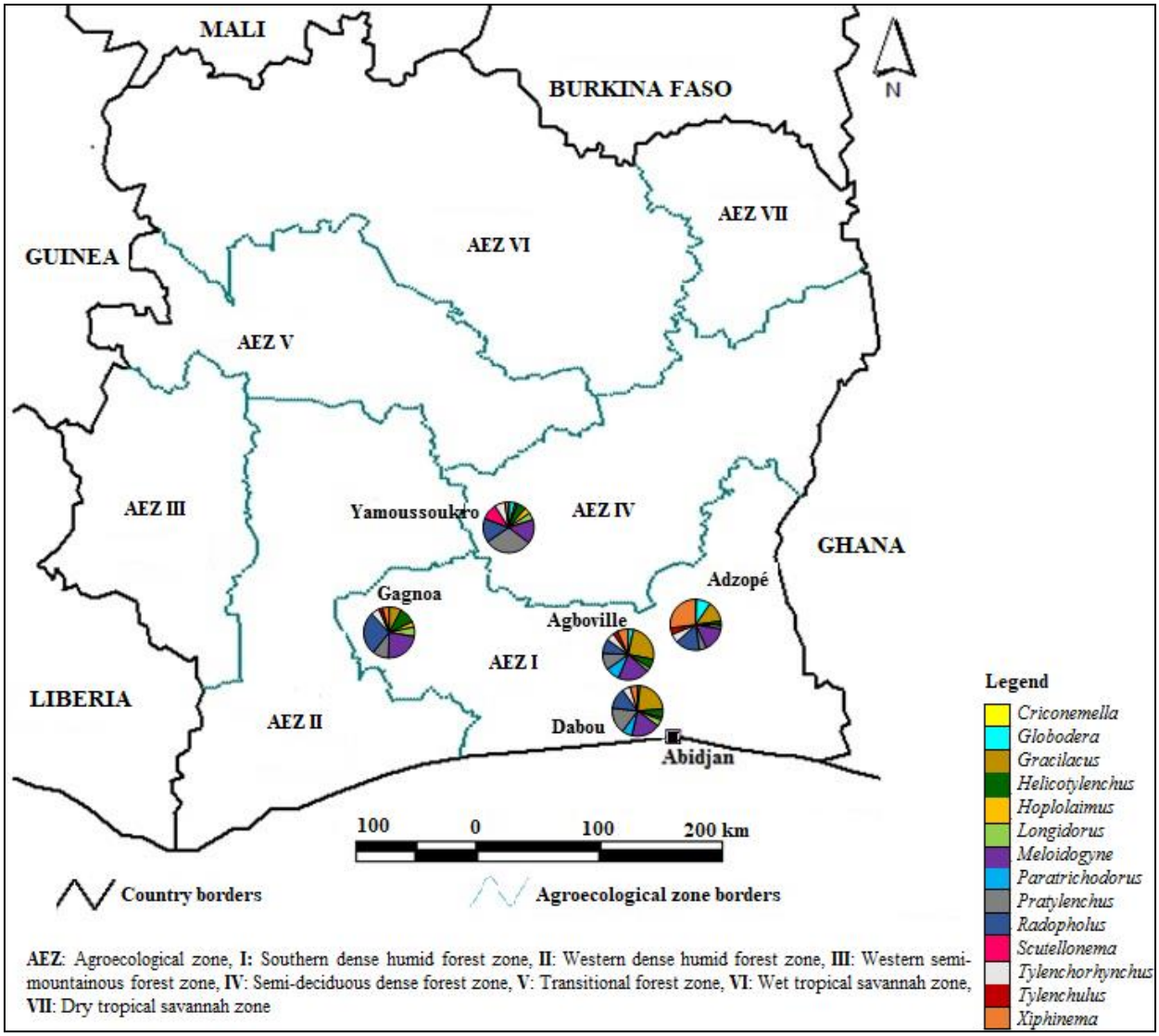

Figure 2:- Map of distribution and relative frequencies of nematodes extracted from cultivation soils in agroecological zones.

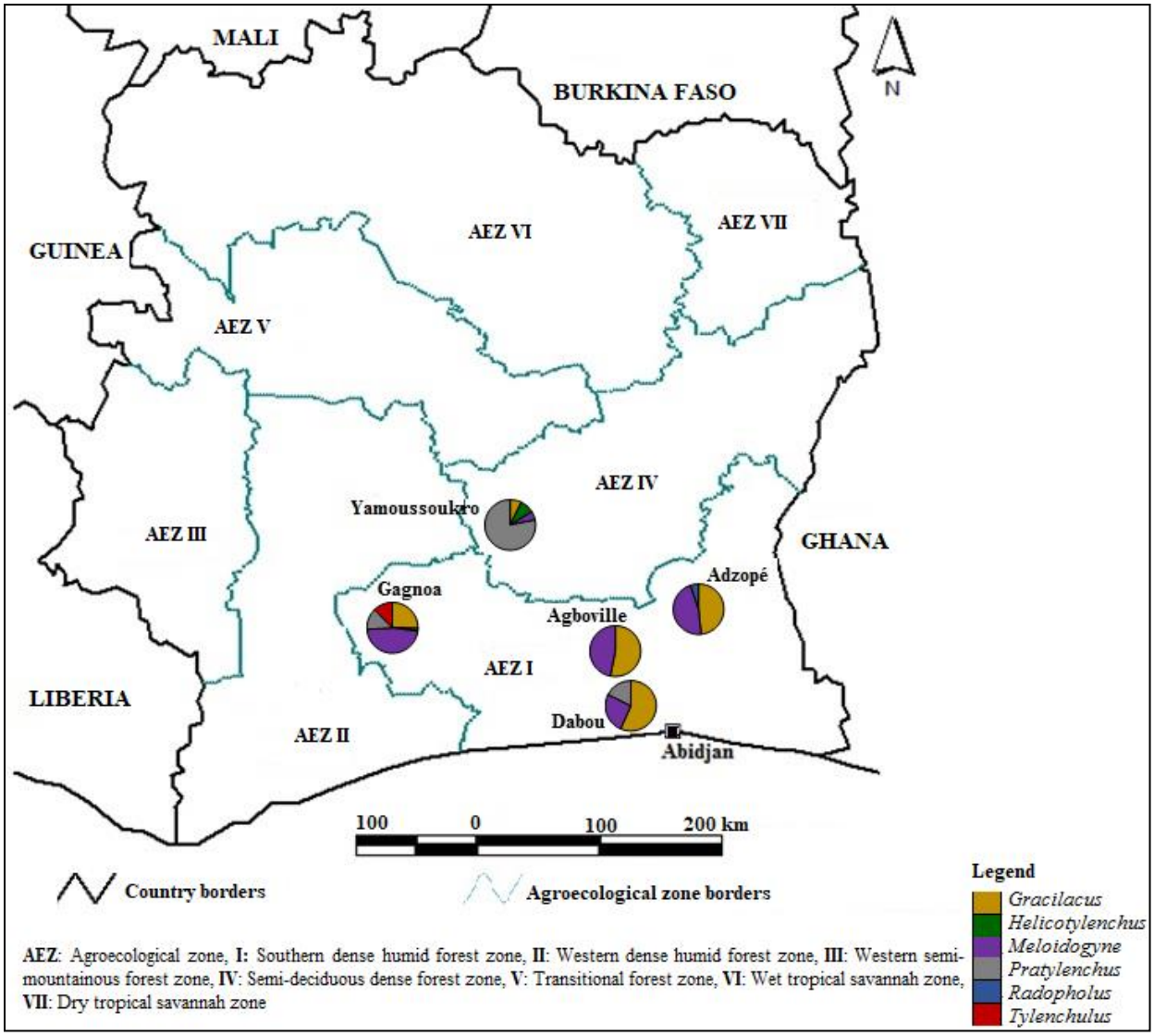

Figure 3:- Map of distribution and relative frequencies of nematodes extractedfrom cassava roots in agroecological zones.

Nematode quantification:

Absolute frequencies of nematodes:

The absolute frequencies of nematodes in cassava soils and roots varied depending on the nematode genera (Table 2). *Gracilacus*, *Meloidogyne* and *Pratylenchus* were found in all soil samples collected and *Radopholus* in 96% of soil samples. However, *Scutellonema* was found in only 4% of soil samples. In roots, *Gracilacus* and *Meloidogyne* were found in all samples, compared to only 15.79% for *Tylenchulus*.

Relative frequencies of nematodes:

The relative frequencies of nematodes varied in cassava soil and root samples according to genera (Tables 3 and 4). A significant difference was noted between the relative frequencies of nematode genera ($P < 0.05$). Thus, *Xiphinema* was the main nematode extracted from Adzopé soil samples with a relative frequency of 27.02%. *Gracilacus*, was mainly extracted from Agboville and Dabou soil samples with relative frequencies of 24.67 and 22.1%, respectively. In Gagnoa, the main nematode extracted from soil samples was *Radopholus* with a relative frequency of 27.23%. Finally, in the Yamoussoukro field, *Pratylenchus* was mainly extracted from soil samples with a relative frequency of 29.97%.

Gracilacus was the main nematode genus extracted from both cassava root samples collected at Adzopé, Agboville and Dabou with relative frequencies of 48.43, 53.16 and 56.58%, respectively. *Meloidogyne* was mainly extracted from Adzopé, Agboville and Gagnoa cassava roots with relative frequencies of 46.34 and 46.81%, respectively. Finally, the main nematode extracted from cassava roots collected in Yamoussoukro was *Pratylenchus* with a relative frequency of 78.15%.

Table 2:- Absolute frequencies of nematodes extracted from cassava soil and root samples.

Plant parasitic nematodes	Types of sample	
	Soils	Roots
Criconemella	8	0
Globodera	52	0
Gracilacus	100	100
Helicotylenchus	80	36.84
Hoplolaimus	40	0
Longidorus	56	0
Meloidogyne	100	100
Paratrichodorus	8	0
Pratylenchus	100	57.89
Radopholus	96	21.05
Scutellonema	4	0
Tylenchorhynchus	64	0
Tylenchulus	24	15.79
Xiphinema	56	0

Table 3:- Relative frequencies of nematodes extracted from cassava cultivation soil samples.

Plant parasitic nematodes	Localities				
	Adzopé	Agboville	Dabou	Gagnoa	Yamoussoukro
Criconemella	0.37 ± 0.12**d**	0	0	0	0.41 ± 0.21**d**
Globodera	9.22 ± 2.8**bc**	3.42 ± 0.27**c**	1.67 ± 0.11**d**	0	3.73 ± 0.22**cd**
Gracilacus	13.2 ± 2.51**b**	24.7 ± 1.42**a**	22.1 ± 4.59**a**	7.93 ± 2.76**c**	1.68 ± 0.33**d**
Helicotylenchus	2.31 ± 0.32**d**	5.82 ± 1.57**bc**	5.60 ± 0.89**c**	10.3 ± 2.77**c**	5.71 ± 2.40**cd**
Hoplolaimus	0.37 ± 0.15**d**	0	1.56 ± 0.59**d**	3.34 ± 0.48**c**	3.90 ± 5.20**cd**
Longidorus	2.31 ± 0.03**d**	2.46 ± 0.29**c**	4.17 ± 1.68**c**	6.02 ± 5.18**c**	4.60 ± 5.38**cd**
Meloidogyne	15.44 ± 4.5**b**	19.9 ± 4.71**a**	18.5 ± 3.16**b**	22.9 ± 4.1**b**	15.42 ± 1.11**b**
Paratrichodorus	0	8.91 ± 0.38**b**	6.50 ± 0.71**c**	0	0
Pratylenchus	4.59 ± 1.14**c**	10.5 ± 2.22**b**	16.7 ± 2.85**b**	10.27 ± 3.7**c**	29.97 ± 4.2**a**
Radopholus	15.5 ± 4.51**b**	9.16 ± 2.38**b**	13.2 ± 3.43**b**	27.3 ± 10.9**a**	15.25 ± 4.52**b**
Scutellonema	0	0	0	0	10.31 ± 2.51**c**
Tylenchorhynchus	5.62 ± 2.40**c**	5.21 ± 0.5**bc**	5.20 ± 1.12**c**	5.46 ± 5.02**c**	6.74 ± 1.72**cd**
Tylenchulus	4.15 ± 1.06**c**	2.98 ± 0.43**c**	0	2.34 ± 0.38**c**	0
Xiphinema	27.02 ± 7.51**a**	6.93 ± 1.2**bc**	4.75 ± 0.91**c**	4.23 ± 1.02**c**	2.28 ± 1.51**cd**
P	*< 0.05*	*< 0.05*	*< 0.05*	*< 0.05*	*< 0.05*

In each column, values with the same letter are statistically identical at 5% level according to Fisher's LSD test. P: Value of the probability

Table 4:- Relative frequencies of nematodes extracted from cassava root samples.

Plant parasitic nematodes	Localities				
	Adzopé	Agboville	Dabou	Gagnoa	Yamoussoukro
Gracilacus	48.43 ± 8.99**a**	53.16 ± 4.31**a**	56.58 ± 3.11**a**	25.30 ± 4.73**b**	7.11 ± 0.32**b**
Helicotylenchus	0	0	0	1.86 ± 0.53**d**	9.14 ± 2.26**b**
Meloidogyne	46.34 ± 7.76**a**	46.84 ± 8.62**a**	25.84 ± 1.99**b**	46.81 ± 8.34**a**	5.60 ± 0.60**b**
Pratylenchus	0	0	17.58 ± 2.27**c**	13.69 ± 5.53**c**	78.15 ± 2.89**a**
Radopholus	5.23 ± 1.52**b**	0	0	0	0
Tylenchulus	0	0	0	12.34 ± 1.47**c**	0

P	*< 0.05*	*> 0.05*	*< 0.05*	*< 0.05*	*< 0.05*

In each column, values with the same letter are statistically identical at 5% level according to Fisher's LSD test, P: Value of the probability

Number of nematodes depending on cassava varieties:

The roots of different cassava varieties were infected with nematodes (**Table 5**). Their number varied significantly depending on cassava varieties (*P <0.05*). Nematodes in Adzopé were most significant in Bocou 1 and Kadi with 11 to 13 individuals. Nematodes were more abundant in Mamawa than the other varieties in Agboville where 46 individuals were noted. In Dabou, the number of nematodes was higher in Sapel than the other varieties with 18 individuals. The number of nematodes was statistically equal regardless of cassava varieties cultivated in Gagnoa with 7 to 12 individuals noted. Finally, the number of nematodes was higher in Bocou 1 and Yavo than the other varieties with 12 and 13 individuals respectively.

Table 5:- Number of nematodes depending on cultivated cassava varieties.

Cassava varieties	**Localities**				
	Adzopé	**Agboville**	**Dabou**	**Gagnoa**	**Yamoussoukro**
Bocou 1	11 ± 3**a**	22 ± 3**b**	11 ± 3**b**	9 ± 3**a**	12 ± 5**a**
Bocou 3	7 ± 2**b**	0	0	7 ± 2**a**	0
TMS 4(2)1425	0	11 ± 2**c**	8 ± 3**c**	0	6 ± 3**b**
Akpêkpênondjê	6 ± 2**b**	0	0	0	0
Bonoua	0	0	0	0	7 ± 3**b**
Kadi	13 ± 4**a**	0	0	0	0
Mamawa	0	46 ± 5**a**	0	0	0
Péri péri	0	0	7 ± 2**c**	0	0
Sapel	0	0	18 ± 5**a**	0	0
Yacé	0	30 ± 5**b**	0	0	0
Yavo	0	0	0	0	13 ± 6**a**
Zabia	0	0	0	12 ± 3**a**	0
P	*< 0.05*	*< 0.05*	*< 0.05*	*> 0.05*	*< 0.05*

In each column, values with the same letter are statistically identical at 5% level according to Fisher's LSD test, P: Value of the probability

Evolution of nematode populations in cassava cultivation soils:

Fluctuation of the number of nematodes depending on cassava plant age:

Apart from *Helicotylenchus* and *Tylenchulus* the number of *Gracilacus*, *Meloidogyne*, *Pratylenchus* and *Radopholus*, fluctuated strongly in cultivation soils depending on cassava plant development stages whatever the localities (Figure 4).

The number of *Gracilacus* in the different localities was relatively constant in the soils between planting period and the 3rd cultivation month with less than 50 individuals/100 ml of soil (Figure 4A). However, from the 3rd to the 12th cultivation month, the number of *Gracilacus* increased from 46 to 433 individuals/100 ml of soil in Adzopé, Agboville and Dabou. Meanwhile, the number of *Gracilacus* in Gagnoa and Yamoussoukro soils were relatively low and constant with less than 50 individuals/100 of soil.

Before the 3rd cultivation month, the number of *Meloidogyne* in Adzopé, Agboville and Gagnoa were the highest, switching from 19 to 188 individuals/100 ml of soil depending on the localities (Figure 4B). During this period, the number of *Meloidogyne* in Dabou and Yamoussoukro were low and constant with less than 100 individuals/100 ml of soil. On the other hand, from the 3rd month of cultivation, the number of *Meloidogyne* in cultivation soils of all localities, except Adzopé ones, increased with cassava plant age until the roots were harvested. At the same time, the number of *Meloidogyne* in Adzopé soils remained relatively constant, oscillating between 93 and 100 individuals/100 ml of soil.

From planting period to the 3rd cultivation month of cassava, the number of *Pratylenchus* in Dabou, Gagnoa and Yamoussoukro significantly increased from 10 to 83 individuals/100 ml of cassava cultivation soil (Figure 4C). During this period, the number of *Pratylenchus* in Adzopé and Agboville was constant and stood at less than 30

individuals/100 ml of soil. From the 3rd month, the number of *Pratylenchus* in Dabou, Gagnoa and Yamoussoukro soils was the highest. This number increased from 51 to 318 individuals/100 ml of soil by the 12th month. Meanwhile, the number of *Pratylenchus* in Adzopé and Agboville remained constant and low with less than 30 individuals/100 ml of soil.

Radopholus populations in all localities except Adzopé ranged from 10 to 100 individuals/100 ml of soil during cassava crop cycle (Figure 4D). However, in Adzopé, the number of *Radopholus* increased from 7 to 220 individuals/100 ml of soil between the planting period and the 5th month of cassava cultivation. From the 5th month, the number of *Radopholus* in Adzopé, although higher than the one in other localities, remained relatively constant until the end of cassava crop cycle.

Finally, the number of *Helicotylenchus* and *Tylenchulus*, remained relatively constant in cassava soils in the different localities (Figure 4E-F). The number of *Helicotylenchus* and *Tylenchulus* stood respectively at less than 100 and 30 individuals/100 ml of soil regardless of the location and the phenological stage of cassava plants.

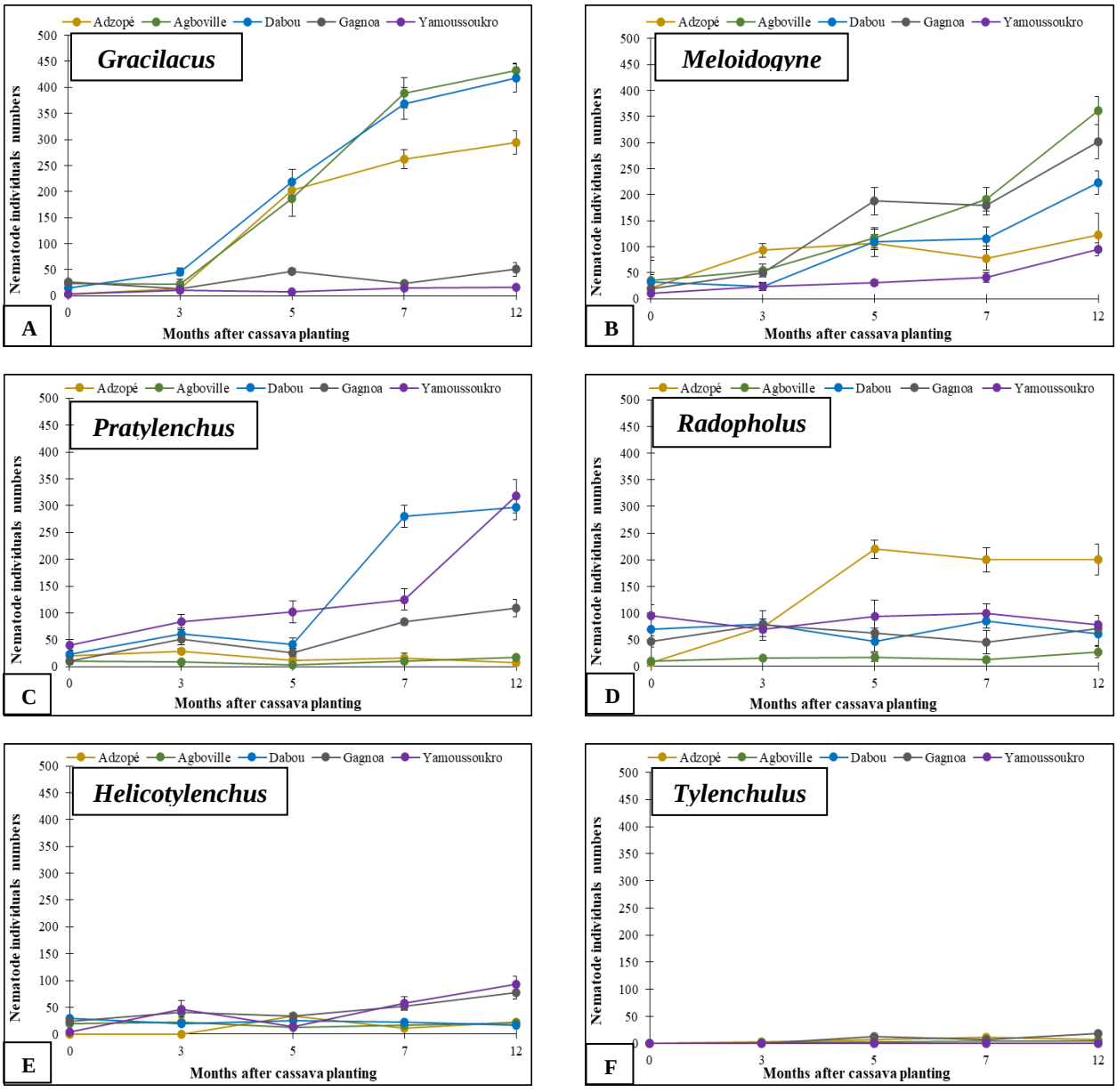

Figure 4:-Fluctuation in the number of nematodes in cultivation soils depending on cassava plant phenologicalstages in different localities of Côte d'Ivoire

Correlation between the numbers of nematodes and the age of cassava plants:
Correlation coefficients ranging from -0.47 to 0.98 were recorded between the number of different nematode populations and cassava plant age (Table 6). Only the number of *Meloidogyne* increased with the age of cassava plants in all localities. This increase was characterized by strong and very highly significant positive correlations between 0.77 and 0.98.

Similar results were noted in *Gracilacus* and *Pratylenchus* in Adzopé, Agboville and Dabou respectively with correlation coefficients ranging from 0.90 to 0.93 then in Dabou, Gagnoa and Yamoussoukro with correlation coefficients varying from 0.71 to 0.95. As for *Helicotylenchus* and *Radopholus*, only their number in cassava cultivation soils in Gagnoa, Yamoussoukro and Adzopé respectively increased with the age of cassava plants with correlation coefficients ranging from 0.75 to 0.88. Finally, the number of *Tylenchulus* in cassava cultivation soils barely correlated with cassava plant age in different locations. This lack of correlation was characterized by correlation coefficients ranging from 0.01 to 0.09.

Table 6:- Correlation coefficients between the number of nematodes in cultivation soils and cassava plant age in the different localities.

Plant parasitic nematodes	Localities				
	Adzopé	Agboville	Dabou	Gagnoa	Yamoussoukro
Meloidogyne	0.79* (0.012)	0.98** (0.004)	0.95* (0.012)	0.96** (0.010)	0.77* (0.017)
Gracilacus	0.90* (0.039)	0.91* (0.028)	0.93* (0.020)	0.31ns (0.574)	0.26ns (0.642)
Pratylenchus	-0.30ns (0.189)	0.17ns (0.711)	0.87* (0.041)	0.71* (0.031)	0.95* (0.013)
Helicotylenchus	0.56ns (0.322)	0.00ns (0.996)	-0.47ns (0.114)	0.75* (0.012)	0.88* (0.049)
Radopholus	0.79* (0.021)	0.11ns (0.721)	-0.18ns (0.768)	0.28ns (0.643)	-0.17ns (0.765)
Tylenchulus	0.01ns (0.881)	0.09ns (0.721)	-	0.08ns (0.874)	-

** ; *: Significant correlations respectively at 1 and 5% levels; ns = Non significant correlation,
Number in parenthesis is value of the probability.

Discussion:-

The Whitehead tray method used in this study revealed more than ten nematode genera found in cassava cultivation soils in each locality. These included *Criconemella*, *Gracilacus*, *Helicotylenchus*, *Hoplolaimus*, *Longidorus*, *Meloidogyne*, *Pratylenchus*, *Radopholus*, *Scutellonema*, *Tylenchorhynchus*, *Tylenchulus* and *Xiphinema*. The diversity of nematode genera in cultivation soils could be explained by several factors including the type of vegetation at the study sites before the establishment of cassava fields. Indeed, plant parasitic nematodes, feeding on underground organs of living plants, can be specific to a host plant (Van der Putten and Van der Stoel, 1998). A change in the composition of plant species at a site could directly alter the composition of plant parasitic nematode communities (Yeates and Bongers, 1999). According to De Deyn *et al.* (2004), the development of a plant species increases the abundance of nematode species specific to that plant. This could justify the presence of several nematode genera in cassava cultivation soils in production areas. The results of this study corroborate those of Ekine *et al.* (2018) who extracted about twenty nematode genera from cassava cultivation soil samples in Rivers State, Nigeria.

The preceding cropping of the plots where the cassava fields had been set up were fallow lands whose floristic composition was, mainly, *Chromolaena odorata*, *Commelina diffusa*, *Euphorbia heterophylla*, *Panicum maximum*, *Imperata cylindrica* and *Musa acuminate* plants. According to Quénéhervé *et al.* (2006), *Commelina diffusa*, *Euphorbia heterophylla*, *Musa acuminata* and *Panicum maximum* plant roots host several nematode species, which are *Helicotylenchus* spp., *Hoplolaimus seinhorsti*, *Pratylenchus* spp., *Radopholus similis* and *Rotylenchulus reniformis* in banana tree plantations in Martinique. Thus, being biotrophic organisms, cutting and stumping these plant species could force the nematodes to infect developing cassava plants in the plots of this study. After twelve months of cultivation, *Gracilacus*, *Helicotylenchus*, *Meloidogyne*, *Pratylenchus*, *Radopholus* and *Tylenchulus* were the nematodes extracted from the cassava roots collected. *Gracilacus*, *Helicotylenchus*, *Meloidogyne*, *Pratylenchus* and *Tylenchulus* have been reported in recent years in the roots of cultivated cassava plants in Rivers State, Nigeria (Taminola *et al.,* 2016; Taminola *et al.,* 2018; Ekine *et al.,* 2018).

Nematode distribution mapping shows that *Gracilacus, Helicotylenchus, Longidorus, Meloidogyne, Pratylenchus, Radopholus, Tylenchorhynchus* and *Xiphinema* on the one hand, *Gracilacus* and *Meloidogyne* on the other hand were respectively found in cassava soil and root samples from all study sites. Moreover, *Gracilacus*, *Meloidogyne* and *Pratylenchus* were the most prominent nematodes in cassava roots with relative frequencies higher than 45% depending on the localities. The prominence of *Meloidogyne* and *Pratylenchus* may be due to their polyphagous and cosmopolitan characters in tropical areas (Jones *et al*., 2013). They are among the main pathogenic nematodes of plants such as bananas, pineapples and market garden crops in the southern half of Côte d'Ivoire. Being a widely cultivated plant in this part of the country, cassava could be a suitable host for these nematodes, hence their strong presence in roots. In addition, being endoparasitic nematodes, they could interact with other pathogens, in particular fungi and bacteria to cause disease complexes (Bridge *et al.,* 2005). Moreover, the prominence of *Gracilacus*, in cassava roots, in this study, shows that cassava could be sensitive to it, and therefore a suitable host. Indeed, *Gracilacus* is an ectoparasitic nematode, occasionally, found in mint with a longer stylet (Taminola *et al*., 2018). Young *Gracilacus* female vermiform plugs their long, sturdy stylet into root tissue and remain attached to the root surface by the stylet (Taminola *et al.* 2018). The nematode feeds on epidermal, cortical and parenchymal cells and induces cell wall thickening (Asimiea *et al.,* 2015). This decade, *Gracilacus* is reported to be prominent in cassava roots in Nigeria. (Taminola *et al.,* 2018). This is the first time that *Gracilacus* has been reported in cassava roots in Côte d'Ivoire.

The cassava varieties cultivated in each locality host nematodes in different numbers. This difference in numbers might be due to a difference in concentrations of phytochemical compound such as hydrogen cyanide (HCN) with nematicidal activities in cassava roots. Indeed, when cassava roots are damaged, enzymes hydrolyze glucosides and release HCN (Chitwood, 2002; Khalil, 2014) which is more concentrated in root phelloderm (Famurewa *et al.*, 2014). Hydrogen cyanide is a compound with proven nematicidal properties (Kang *et al.,* 2018). In fact, the nematicidal activity of hydrogen cyanide might be due to the loss of mitochondrial function by cytochrome c oxidase inhibition (Zdor, 2015). The Hydrogen cyanide nematicidal activity might also be due to inhibition of electron transport and disruption of energy supply to nematode cells, resulting in their death (Abd El-Rahman *et al.,* 2019). Guédé *et al.* (2013) found that hydrogen cyanide contents in roots vary depending on cassava varieties. Thus, Mégnanou *et al.* (2009) showed that cyanide contents vary between 5.1 and 20.4 mg/100 g of root dry matter among nine local and improved cassava varieties cultivated in Côte d'Ivoire. These results confirm those of Akinsanya and Afolami (2019) indicating a difference in behavior of seven cassava varieties towards *Meloidogyne incognita* infestation in Nigeria.

Furthermore, the number of nematodes extracted from the roots fluctuated depending on cassava plant phenological stages in the surveyed field. However, the general trend observed was the increase in the number of these nematodes during cassava plant development cycle. This increase would be due to the availability of nutritional resources necessary for the development of these nematodes. Indeed, the more the host plant develops, the more important its root system is and the nematodes have more fixation sites and resources favorable to their development (Ndiaye, 1994). Cassava crop cycle duration is between 11 and 20 months, while the one of these nematodes is between 3 and 5 weeks under favorable conditions. This situation might have enabled the development of several generations of different nematode populations in roots and cultivated soils. This strong presence of nematodes could lead to significant pathogenic activities of the latter on the roots. In addition, they might interact with other plant pathogens to induce the development of disease complexes in cassava roots.

Conclusion:-

This pioneering work shows that several genera of nematodes infect cassava cultivated in Côte d'Ivoire. Cassava plants of improved and local cultivated varieties are hosts of plant parasitic nematodes. *Gracilacus, Meloidogyne* and *Pratylenchus*, besides being cosmopolitan, are most prominent in the roots. Their numbers increase, considerably, in soils with the age of cultivated cassava plants. Thus, in view of the above, several studies are planned, in particular, the pathogenicity of *Gracilacus*, *Meloidogyne* and *Pratylenchus* and the development of effective control methods against these nematodes in order to further boost cassava yield.

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References:-

1. Abd El-Rahman A. F., Shaheen H. A., Abd El-Aziz R. M. & Ibrahim D. S. S. (2019). Influence of hydrogen yanide-producing rhizobacteria in controlling the crown gall and root-knot nematode, *Meloidogyneincognita*, *Egyptian Journal of Biological Pest Control*, 29(41): 1-11.
2. Abu J. O., Badifu G. I. O. &Akpapunan M. A. (2006). Effect of crude palm-oil inclusion on some physico-chemical properties of gari, a fermented cassava food product, *Journal of Food Science and Technology*, 24: 73-79.
3. Akinsanya A. K. &Afolami S. O. (2018).Effect of seven elite cassava (*Manihot esculenta*crantz) varieties to infection by *Meloidogyne*spp. and other nematodes in the field, *Nematropica*,48: 50-58.
4. Akinsanya A. K. &Afolami S. O. (2019).Screen house response of seven elite cassava (*Manihotesculenta*Crantz) varieties to *Meloidogyneincognita*infection, *Nematropica*,49: 91-98.
5. Amani N. G., Kamenan A., Rolland-Sabaté A. & Colonna P. (2005).Stability of yam starch gels during processing, *African Journal of Biotechnology*, 4(1): 94-101.
6. Amani G., Nindjin, C., N'zué B., Tschannen A & Aka D. (2007). Potentialités de la transformation du manioc (*Manihotesculenta*Crantz) en Afrique de l'Ouest. Actes du 1er Atelier International, Abidjan, côte d'Ivoire, pp48–79.
7. Apea-Bah F. B., Oduro I., Ellis W.O. &Safo-Kantanka O. (2009).Principal components analysis and age at harvest effect on quality of gari from four elite cassava varieties in Ghana, *African Journal of Biotechnology*, 8(9): 1943-1949.
8. Asimiea O. A., Tanimola A. A. & Boma P. B-M. (2015).Nematode pests of cassava (*Manihotesculenta* Crantz) in three local government areas of Rivers State in Nigeria, *Journal of Applied Science & Agriculture*, 10(6): 68-77.
9. Bolou Bi B. A., Abo K., Doumbouya M., Kouamé K. G., Kassi K.F., Tuo S., Nahoua K., Kouassi N. P. &Koné D. (2016). Analysis of sclerotinia expression due to *Sclerotiumrolfsii*fungus in market gardening crops in the different agroecological zones of Côte d'Ivoire, *Journal of Agriculture and Ecology Research International*, 6(3): 1-12.
10. Bridge J., Coyne D. L. & Kwoseh C. K. (2005). Chapter 7: Nematodes parasites of tropical root and tuber crops (excluding potatoes), 221-258inLuc M., Sikora R. A. & Bridge J. Plant parasitic nematodes in subtropical and tropical agriculture, 2nd édition, CAB International, Wallingford, Royaume Uni, 871 pages.
11. Castillo P. & Vovlas N. (2007).*Pratylenchus* (Nematoda: Pratylenchidae): Diagnosis, biology, pathogenicity and management, Nematology monographs and perspectives, volume 6, Brill Leiden-Boston, Pays-Bas, 550 pages.
12. Chitwood D. J. (2002). Phytochemical based strategies for nematode control, *AnnualReviewofPhytopathology*, 40: 221-249.
13. Coyne D. L., Nicol J. M. & Claudius-Cole B. (2010). Les nématodes des plantes : Un guide pratique des techniques de terrain et de laboratoire, Institut International d'Agriculture Tropicale, Cotonou, Benin, 93 pages.
14. Coyne D. L., Kagoda F. &Mbiru E. (2012). Rapid screening technique for assessing resistance to *Meloidogyne*species in cassava, *NematologiaMediterranea*, 40: 111-117.
15. De Deyn G. B., Raaijmakers C. E., Van Ruijven J., Berendse F. & Van der Putten W. H. (2004). Plant species identity and diversity effects on different trophic levels of nematodes in the soil food web, *Oikos*, 106:576-586.
16. Ekine E. G., Gboeloh L. B. B. &Elele K.(2018). Plant parasitic nematodes of cassava, *Manihotesculenta* cultivated in Ahoada East local government area in Rivers State, Nigeria, *AppliedScienceReports*,21(2): 38-42.
17. Famurewa J. A. V. &Emuekele P. O. (2014). Cyanide reduction pattern of cassava (*Manihotesculenta*) as affected by variety and air velocity using fluidized bed dryer, *African Journal Food Science and Technology*, 5: 75-80.
18. Faostat (2017). Food and Agricultural Organization Statistics Database. http://faostat.fao.org/,accessed 03 march 2019.
19. Guédé S. S., Traoré S. & Brou K. (2013).Assessment of cyanide content in cassava (*Manihotesculenta* Crantz) varieties and derived products from Senegal, *International Journal of Nutrition and Food Sciences*, 2(5): 225-231.
20. Guillaume-Gentil A. (2015). Cassava: The root crop of the century. SPORE: The magazine for agricultural and rural development in ACP countries, n°176, 28 pages.
21. Hunt D. J., Luc M. & Manzanilla-López R. H. (2005). Chapter 2: Identification, morphology and biology of plant parasitic nematodes, 11-52inLuc M., Sikora R. A. & Bridge J. Plant parasitic nematodes in subtropical and tropical agriculture, 2nd édition, CAB International, Wallingford, Royaume Uni, 871 pages.

22. JayaramanK. (1999).Manuel de statistique pour la recherche forestière, Organisation des Nations Unies pour l'Alimentation et l'Agriculture, 242 pages.
23. Jones J. T., Haegeman A., Danchin E. G. J., Gaur H. S., Helder J., Jones M. G. K., Kikuchi T., Manzanilla-López R., Palomares-Rius J. E., Wesemael W. M. L. & Perry R. N. (2013). Top 10 plant-parasitic nematodes in molecular plant pathology, *Molecular Plant Pathology*, 14: 946-961.
24. Kang B. R., Anderson A. J. & Kim Y. C. (2018). Hydrogen cyanide produced by *Pseudomonaschlororaphis* O6 exhibits nematicidal activity against *Meloidogynehapla*, *Plant Pathology Journal*, 34 (1): 35-43.
25. Khalil M. S. (2014). Bright future with nematicidal phytochemicals, *BiologyandMedecine*, 6 (2): 1-3.
26. Kouassi S. K., Mégnanou R-M., Akpa E. E., Djedji C., N'zué B. &Niamke L. S. (2010). Physicochemical and biochemical characteristics evaluation of seven improve cassava (*Manihotesculenta*Crantz) varieties of Côte d'Ivoire, *African Journal of Biotechnolog*y,9 (41): 6860-6866.
27. Mégnanou R-M., Kouassi S. K., Akpa E. E., Djedji C., N'zué B. &Niamké Lamine S. (2009).Physico-chemical and biochemical characteristics of improved cassava varieties in Cote d'Ivoire, *Journal of Animal & Plant Sciences*, 5 (2): 507-514.
28. Mekete T., Dababat A., Sekora N., Akyazi F. & Abebe E. (2012). Identification key for agriculturally important plant-parasitic nematodes prepared for the International Nematode Diagnosis and Identification Course 2012, A manual for nematology, Mexico, DF: CIMMYT, 39 pages.
29. Ndiaye A. (1994). Influence de facteurs abiotiques et biotiques sur la multiplication et la morphologie de quelques Nématodes phytoparasites de la région soudano-sahélienne. Doctorat de 3e cycle, Université Cheikh Anta Diop, Dakar, Sénégal, 82 pages.
30. N'Zué B., Zohouri P. G. & Sangaré A. (2004). Performances agronomiques de quelques variétés de manioc (Manihot esculenta Crantz) dans trois zones agroclimatiques de la Côte d'Ivoire, *Agronomie Africaine*, 16 (2): 1-7.
31. Quénéhervé P., Chabrier C., Auwerkerken A., Topart P., Martiny B. & Marie-Luce S. (2006). Status of weeds as reservoirs of plant parasitic nematodes in banana fields in Martinique, *CropProtection*, 25: 860-867.
32. Tanimola A. A., Asimiea A. O. & Peter H. I. (2018). Emergence of *Gracilacus* species as one of the key plant-parasitic nematodes associated with cassava in East Senatorial District, Rivers State, Nigeria, *International Journal of Development Research*, 8 (2): 18962-18968.
33. Tanimola A A., Wokoma E. C. & Brown I-I. (2016). Plant parasitic nematodes associated with cassava in the west senatorial district of Rivers State, Nigeria, RUFORUM Working Document Series14 (1): 559-566.
34. Van der Putten W. H. & Van der Stoel C. D. (1998). Plant parasitic nematodes and spatio-temporal variation in natural vegetation, *Applied Soil Ecology*,10: 253-262.
35. Yeates G. W. & Bongers T. (1999). Nematode diversity in agroecosystems, *AgricultureEcosystemsandEnvironment*, 74:113-135.
36. Zdor R. E. (2015). Bacterial cyanogenesis: impact on biotic interactions, *Journal of Applied Microbiology*,118: 267-274.