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Identification of the host plants of *Nedotepa curta* (Homoptera: Cicadellidae), carrier of the phytoplasma responsible for the lethal yellowing disease of the coconut palm in Côte d'Ivoire

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ABSTRACT
Objectives: to identify among the species of Arecaceae and weeds tested positive for the phytoplasma responsible for the Lethal yellowing of the coconut palm in Grand-Lahou, those that are host plants of Cicadellidae *Nedotepa curta*, carrier of this phytoplasma. In addition, to assess the abundance and spatio-temporal distribution of adults on the various plants identified as hosts.
Methodology and Results: The identification of the host plants was done by a visual examination of Arecaceae and weeds in order to detect the presence of clusters, larvae, exuviae and adults of *N. curta*. The abundance and spatio-temporal distribution are made using yellow glue traps hoisted in the crown of ten plants of each Arecaceae where the presence of clusters, larvae, exuvia and adults has been detected by *N. curta*. The trap survey was done once a week for twelve months. The results identified that only Arecaceae *Cocos nucifera* and *Elaeis guineensis* as host plants for Cicadellidae *N. curta*. The long dry season shows the highest average abundances with the peak in December (22.1 ± 0.78) on *C. nucifera* and the peak in January (24.8 ± 0.52) on *E. guineensis*. Low average abundances were recorded during the main rainy season, the lowest in June on *C. nucifera* (5.3 ± 0.64) and on *E. guineensis* (8.5 ± 0.92). As for the spatio-temporal distribution of the population of *N. curta* differs according to the different months of the year.
Conclusion and Application of results: *C. nucifera* and *E. guineensis* were identified as the two host plants of *N. curta* with average abundances and a spatio-temporal distribution, which differ according to the host plant. This information makes it possible firstly to have a catalogue of *N. curta* host plants, secondly to adopt cultural by avoiding the establishment of *C. nucifera* plantations close to *E. guineensis* plantations, thirdly to understand the spread of this disease and finally to implement vector control strategies.
Keywords : Cicadellidae, *Nedotepa curta*, host plants, abundance, spatio-temporal distribution.

Identification des plantes hôtes de *Nedotepa curta* (Homoptera : Cicadellidae), porteur du phytoplasme responsable du jaunissement mortel du cocotier en Côte d'Ivoire

RÉSUMÉ

Objectifs : cette étude avait pour objectifs d'une part d'identifier parmi les espèces d'Arecaceae et d'adventices testés positifs au phytoplasme responsable du jaunissement mortel du cocotier à Grand-Lahou, celles qui sont des plantes hôtes de *Nedotepa curta,* porteur de cet phytoplasme. D'autre part, d'évaluer l'abondance et la répartition spatio-temporelle des adultes sur les différentes plantes identifiées comme hôtes.

Méthodologie et résultats : l'identification des plantes hôtes s'est faite par un examen visuel des Arecaceae et adventices afin de déceler la présence d'amas, de larves, d'exuvie et d'adulte de *N. curta*. L'abondance et la répartition spatio-temporelle sont faites à l'aide de pièges jaunes à glue hissé dans la couronne de dix plantes de chaque Arecaceae où a été décelée la présence d'amas, de larves, d'exuvie et d'adulte de *N. curta*. Le relevé des pièges s'est fait une fois par semaine durant douze mois. Les résultats ont permis d'identifier que seuls les Arecaceae *Cocos nucifera* et *Elaeis guineensis* comme plantes hôtes à la Cicadellidae *N. curta*. La grande saison sèche présentent les abondances moyennes les plus élevées avec le pic en Décembre (22,1 ± 0,78) sur *C. nucifera* et le pic en Janvier (24,8 ± 0,52) sur *E. guineensis*. Les faibles abondances moyennes ont été relevées durant la grande saison des pluies, dont la plus faible au mois de Juin sur *C. nucifera* (5,3 ± 0,64) et sur *E. guineensis* (8,5 ± 0,92). Quant à la répartition spatio-temporelle de la population de *N. curta* diffère en fonction des différents mois de l'année.

Conclusion et application des resultats: *C. nucifera* et *E. guineensis* ont été identifiés comme les deux plantes hôtes de *N. curta* avec des abondances moyennes et une répartition spatio-temporelle qui diffèrent selon la plante hôte. Ces informations permettent d'abord de disposer d'un catalogue de plantes hôtes de *N. curta*, ensuite d'adopter une lutte culturale en évitant la mise ne place de plantations de *C. nucifera* proches des plantations de *E. guineensis* et enfin de comprendre la dissemination de cette maladie et mettre en oeuvre des strategies de contrôle du vecteur.

Mots-clés : Cicadellidae, *Nedotepa curta*, plantes hôtes, abondance, répartition spatio-temporelle.

INTRODUCTION

The coconut palm (*Cocos nucifera* L.) is an important crop on the coast in Côte d'Ivoire (Assa *et al.*, 2006). It provides income and food through its nuts rich in coconut oil and milk, but also provides employment opportunities through the exploitation of copra oil, grated coconut and other fatty coconut products (Amenan *et al*., 2012). Unfortunately, coconut cultivation in Côte d'Ivoire, the leading African country to export coconut and copra oil to Europe and West Africa (Gerbaud, 2011; Kra *et al.*, 2017) is threatened by the lethal yellowing disease of the coconut palm. This systemic disease, which has spread rapidly in Grand-Lahou, has devastated more than 4,000 ha of coconut tree plantation and poses a threat to some 85,000 smallholders' coconut farmers (Arocha-Rosete *et al.*, 2017). Indeed, it is associated with phytoplasmas belonging to the group of 16SrXXII (Arocha-Rosete *et al.*, 2014), the propagation of which is generally done by stinging-sucking insects of the Homoptera species, in particular, the Cicadellidae family (Nelson 1979; Weintraub & Beanland, 2006). Thus, an epidemiological study carried out by the Plant Health Unit of Nangui Abrogoua University made it possible to identify *Nedotepa curta* as a carrier of the phytoplasma and therefore suspected of being a probable vector of this disease (Kwadjo *et al.*, 2018). *Nedotepa curta* (Homoptera: Cicadellidae) belongs to the Typhlocybinae subfamily which nymphs and adults transfer pathogenic microorganisms by feeding on it (Della guistina *et al.*, 1992). Previous work on this insect has focused on the morphological description of the adult (Dmitriev, 2016) and its development cycle (Kodjo *et al.*, 2020). In addition, alternative phytoplasma hosts play an active role in the development of epidemics (Lee *et al*., 2003; Weintraub & Beanland, 2006). In Côte d'Ivoire, the search for host plants with the phytoplasma responsible for the fatal yellowing has identified six herbaceous species *Paspalum vaginatum* (Poaceae), *Pennisetum pedicillatum* (Poaceae), *Stachytarpheta indica* (Verbenaceae), *Scoparia dulcis* (Plantaginaceae), *Phyllantus muellerianus* (Phyllanthaceae), *Diplacrum capitatum* (Cyperacea) tested positive for phytoplasma (Arocha-Rosete *et al.*, 2016). The Arecaceae *Cocos nucifera* L., *Elaesis guineensis* Jacq., *Borassus aethiopium* Mart. and *Raphia vinifera* P. Beauv. were also tested positive for a phytoplasma belonging to the group of 16SrXXII (Kra *et al.*, 2017). However, the census of host plants and estimation of the population density of vectors on these different host plants tested positive for phytoplasma would constitute the cornerstone of fundamental research on agricultural ecosystems and the main tool to implement effective control programs (Kogan and Herzog, 1980) against fatal yellowing of the coconut palm. Thus, the aim of the present study was to determine whether the Arecaceae and weed species that tested positive for phytoplasma could harbour the different stages of development of the egg, nymphs and adults of *N. curta*. This could help to understand the spread of the deadly yellowing of the coconut tree in Grand-Lahou. In addition, the abundance and fluctuation of adults of *N. curta* were determined on plants identified as hosts of this Cicadellidae.

MATERIAL AND METHODS

Study site: The present study was carried out in the department of Grand-Lahou (5° 14'39 "North latitude -5° 00'11 "West longitude), south of Côte d'Ivoire, precisely on Avikam Island. Grand-Lahou department is crossed by the Bandama River and washed by the Tiagba lagoon and the Atlantic Ocean with a 70 km coastline. The department of Grand-Lahou is located 140 kilometres from Abidjan and belongs to the "Grands-Ponts" region in the "Lagunes "district (N'Guessan *et al.*, 2019). As for Avikam Island, it is 15 kilometres from the city of Grand-Lahou at the mouth of the Bandama River (Figure 1). The choice of this area is based on the one hand on the fact that the coconut palm is a top crop in the ethnocultural group of Grand-Lahou and on the other hand, because the coconut palms in this region show symptoms of the disease coconut fatal yellowing (ProMED, 2013). The climate, of equatorial type of transition, always humid, locally called Attié climate, is characterized by four seasons : a great rainy season (April to mid-July) ; a short dry season (mid-July to September) ; a small rainy season (October to November) and a long dry season (December to March) (Bomisso, 2005). The annual duration of sunstroke varies greatly depending on the season and the average is estimated at 1762 hours (Avit *et al.*, 1999). During our study, the annual temperature ranged from 26°C to 31°C with an average of 27.5°C and the average annual rainfall was 101.73 mm of rain.

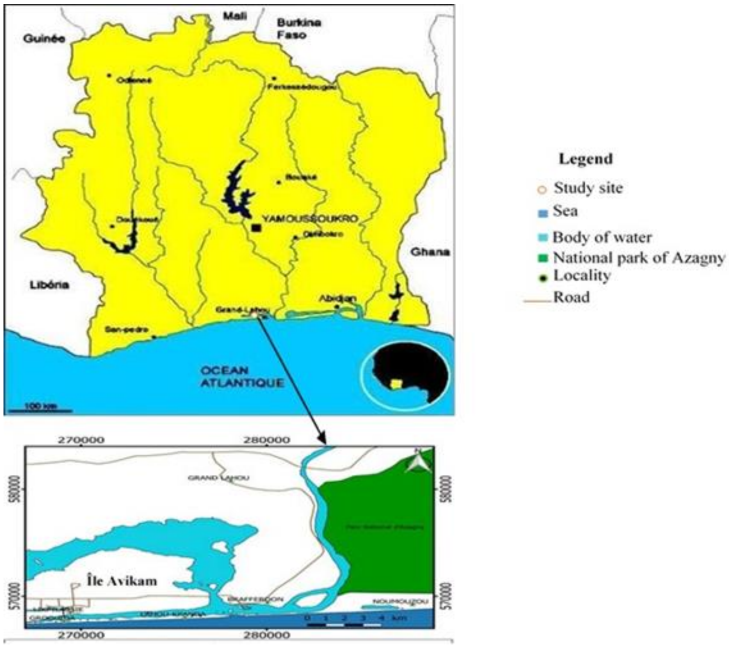

Figure 1: Geographical localisation of the study site

Identification of host plants: Through this study, intended to identify the host plants of the Homoptera *N. curta* favourable to its development in the Grand-Lahou area. Thus, three different Arecaceae families were identified mainly on Avikam Island and the six weed species tested positive for the deadly yellowing coconut phytoplasma in Côte d'Ivoire by Arocha Rosete *et al.* (2016). These are for Arecaceae: coconut tree (*Cocos nucifera* L.), oil palm tree (*Elaeis guineensis* Jacq.) and raffia (*Raphia vinifera* P. Beauv.). The weeds are *Paspalum vaginatum* (Poaceae), *Pennisetum pedicillatum* (Poaceae), *Stachytarpheta indica* (Verbenaceae), *Scoparia dulcis* (Plantaginaceae), *Phyllantus muellerianus* (Phyllanthaceae) and *Diplacrum capitatum* (Cyperacea). The identification initially consisted of a careful examination of the plants in order to detect the presence of clusters, larvae, exuviae and adults of *N. curta* on the palms of Arecaceae and weeds. Secondly, it consisted in evaluating the number of plants carrying clumps, larvae, exuviae and adults of *N. curta* as well as the position of the clusters on the leaf of the plant. Study of the density and dynamics of *Nedotepa curta* on different plants identified as hosts: For the study of the density and dynamics of *N. curta*, 10 plants from each Arecaceae where the presence of clusters, larvae, exuvia and adults of *N. curta* were detected were selected. These are the coconut tree (*Cocos nucifera* L.) and the oil palm tree (*Elaeis guineensis* Jacq.). A yellow glue trap, made of a wooden plate with glue applied to both sides, was hoisted into the crown of each Arecaceae using a rope (Figure 2). Once the trap was in the crown, the rope was tied to a point buried in the trunk of the plants. For the readings, the traps were lowered from the crown, while pulling on the rope, in the same way as a flag. The plate readings were done once a week for twelve months on the various Arecaceae host groups. At each reading, individuals of *N. curta* were counted for each selected Arecaceae. Data processing: Data processing was carried out using the software STATISTICA version 7.1. The monthly average abundances of Cicadellidae (*N. curta*) adults for each host plants were compared statistically by one-way analysis of variance (ANOVA I) at the 5% threshold. The post-hoc test, Fisher's test, was used to classify monthly averages of *N. curta* abundances. In addition, Student's T test made it possible to compare the means of the abundances of *N. curta* collected between the coconut palm and the oil palm tree.

Figure 2: Yellow sticky trap on Arecaceae

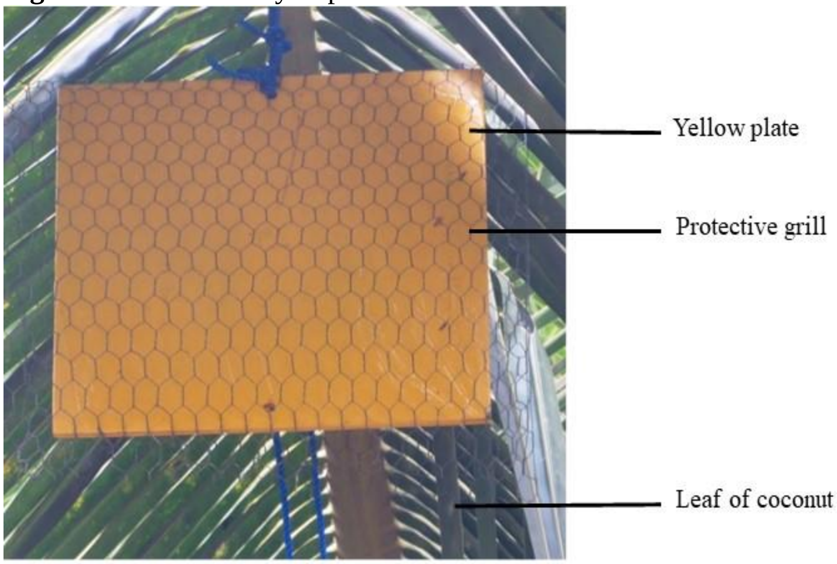

Figure 2: Yellow sticky trap on Arecaceae

RESULTS

Observation on the different Arecaceae families and herbaceous plants tested positive for phytoplasma responsible for the deadly yellowing of the coconut tree. The different stages of development of *N. curta* observed (eggs, larvae and adults) were identified only on two Arecaceae, which are the coconut palm (*Cocos nucifera*) and the oil palm tree (*Elaeis guineensis*). No stage of development was observed on raffia (*Raphia viniferai*). The eggs are laid in clusters on the underside of the leaflets of the various Arecaceae. The larvae that emerged developed around the cluster and the exuviae were left there after each molt. For the different weeds tested positive for the phytoplasma of the lethal yellowing of the coconut palm, no stage of development has been observed on the different parts of its plants (Table 1).

Table 1: Different stages of development of *Nedotepa curta* observed on the different Arecaceae and weeds

Plants types	Species	Observed elements			
		Eggs	**Larva**	**Exuviae**	**Adults**
Arecaceae	Coconut tree (*Cocos nucifera*)	X	X	X	X
	Raffia (*Raphia viniferai*)	O	O	O	O
	Oil palm tree (*Elaeis guineensis*)	X	X	X	X
Weeds	*Paspalum vaginatum*	O	O	O	O
	Pennisetum pedicillatum	O	O	O	O
	Stachytarpheta indica	O	O	O	O
	Scoparia dulcis	O	O	O	O
	Phyllantus muellerianus	O	O	O	O
	Diplacrum capitatum	O	O	O	O

X: presence O: absence

Proportion of individuals collected from sticky traps on each Arecaceae hosts: Total abundance was assessed on the two Arecaceae species, *Cocos nucifera* and *Elaeis guineensis*. In total, 3,184 individuals were collected from the two types of Arecaceae hosts including 1639 individuals (51.48% of individuals collected) on *E. guineensis* and 1545 individuals (48.52% of individuals collected) on *C. nucifera* (Figure 3).

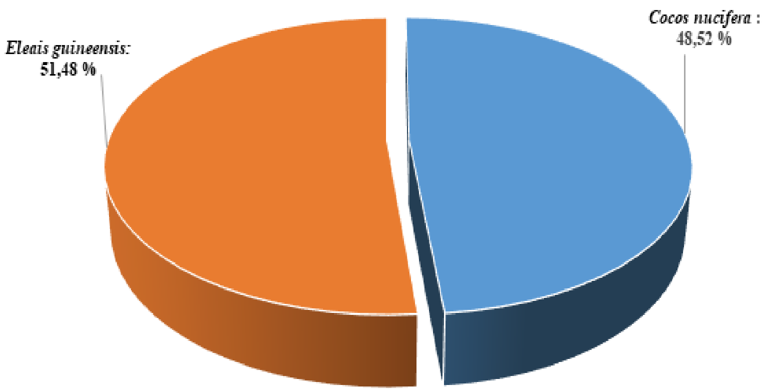

Figure 3: Proportion of individuals of *Nedotepa curta* on the Arecaceae hosts

Comparison of average abundances and spacio-temporal distribution of the population of *N. curta* between *Cocos nucifera* and *Elaeis guineensis* depending on the months of collection: Monthly abundance average of the highest *N. curta* population on *C. nucifera* was observed during the month of December (22.1 ± 0.78) and on *E. guineensis* during the month of January (24.8 ± 0.52) which are months of high temperatures. The lowest monthly average population abundances were observed during the month of June on *C. nucifera* (5.3 ± 0.64) and on *E. guineensis* (8.5 ± 0.92) which is one of the months of heavy rains. The results also indicate that the mean monthly abundance of *N. curta* shows a significant difference at different months at p = 0.001 on *C. nucifera* and at p = 0.003 on *E. guineensis* (Table 2). The results indicate that the spatio-temporal distribution of the population of *N. curta* on the two species of Arecaceae identified as hosts, which are the coconut tree (*C. nucifera*) and the oil palm tree (*E. guineensis*) shows significant differences at some months and overall with Student's T test at P <0.05. The months of June and July with the lowest abundances on *C. nucifera* and *E. guineensis* are different depending on the host plant. The months of highest abundance are also different depending on the host plants with December for *C. nucifera* and January for *E. guineensis* (Table 2).

Table 2: Monthly mean abundance and spatio-temporal distribution of *Nedotepa curta* on *Cocos nucifera* and *Elaeis guineensis*

collection months	*Cocos nucifera*	*Elaeis guineensis*
April	10,7 ± 0,47 dA	11,2 ± 0,52 cdA
May	9,0 ± 0,88 dA	10,1 ± 0,51 deA
June	5,3 ± 0,64 eA	8,5 ± 0,92 eB
July	7,2 ± 0,77 dA	9,7 ± 0,70 dB
August	13,3 ± 0,60 cA	10,6 ± 0,62 dB
September	10,9 ± 0,56 dA	12,1 ± 0,53 cdA
October	9,8 ± 0,84 dA	10,0 ± 0,80 eA
November	14,5 ± 1,02 bcA	12,4 ± 0,96 cdA
December	22,1 ± 0,78 aA	19,7 ± 0,67 bB
January	20,3 ± 0,71 aA	24,8± 0,52 aB
February	16,6 ± 0,87 bA	18,5± 0,73 bA
March	15,0 ± 0,79 bcA	16,3 ± 0,85 cA
Total	154,7 ±15,37 a	163,9 ± 13,61 b

Means followed by different lowercase letters in the same row are significantly different (p <0.05, Fisher LSD test). The means followed by different capital letters in the same row are significantly different (p <0.05, Student's T test).

Fluctuation of the population of *N. curta* between *Cocos nucifera* and *Elaeis guineensis* depending on the months of collection: The dynamics of the population of *N. curta* evolve differently depending on the months of collection on the two species of Arecaceae *C. nucifera* and *E. guineensis* (Figure 4). Strong growth is observed on *C. nucifera* during the long dry season. It takes place from October to December with 98 individuals and 221 individuals respectively, culminating in a peak in December. Strong population growth occurs on *C. nucifera* from July with 72 individuals through August with 133 individuals where it peaks. A sudden fall of the population is observed from February (166 individuals) to the end of June (51 individuals) corresponding to the rainy season. On *E. guineensis*, a population growth of *N. curta* also begins in October with 100 individuals until January with 248 individuals where it peaks. This peak is followed by a significant drop in the population. A weak and linear growth culminating in a peak in September with 121 individuals, takes place after June with 85 individuals. A slight decline in the population is observed from September to October, which marks the short rainy season. The population is high on *C. nucifera* only on *E. guineensis* during the month of August and the period from October to December. In contrast, the number of individuals is greater on *E. guineensis* than on *C. nucifera* during the periods from January to July and from September to October.

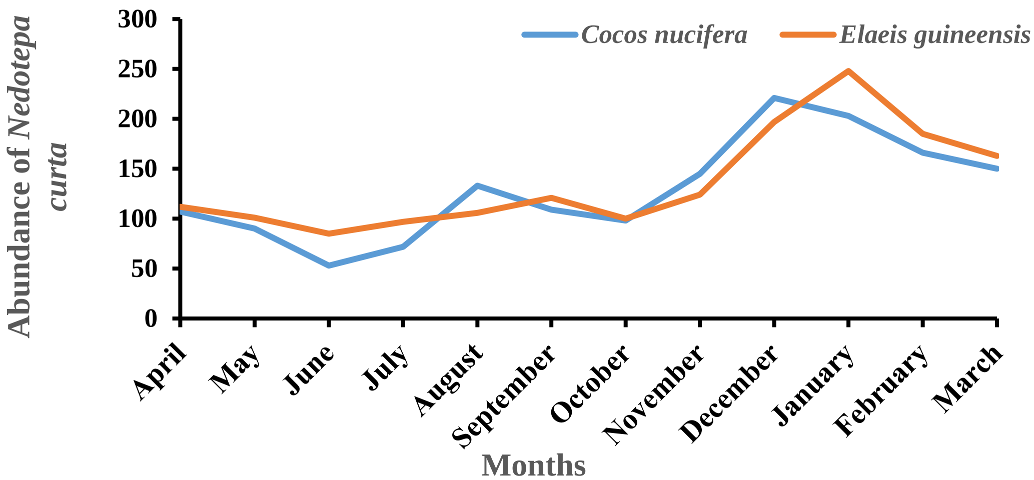

Figure 4: Fluctuation of the population of *Nedotepa curta* between *Cocos nucifera* and *Elaeis guineensis*

DISCUSSION

This study made it possible to identify among the host plants tested positive for phytoplasma responsible for the fatal yellowing of the coconut palm in Côte d'Ivoire, those that are favourable to the different stages of development of *Nedotepa curta*. Among the plants inspected, different stages of development have been identified on *Cocos nucifera* and *Elaeis guineensis*. This choice of plants would be that of adults because these two species would present characteristics favouring the development and protection of the offspring. In fact, the selection of host plants by phytophagous insects is largely determined by the adult insects, which choose the place of development of the offspring (Janz & Nylin, 1997). In addition, it has been observed that the immature stages of *N. curta* do not change host plants or location within the host plant during their development as is the case in several insect species. Therefore, the quantity and quality of food available for their development as well as the surrounding ecological conditions result from the choice of the adult-female (Awmack & Leather, 2002). In addition, the leaflets of these different Arecaceae do not have trichomes and the sap does not have toxins that can hinder the nutrition and development of the immature stages that are the larvae. Indeed, the decision of an insect to accept or reject a plant as a host is determined by the existence of direct and / or indirect defence mechanisms developed by the plant (Wallin & Raffa, 2004) such as the absence of trichomes, the toxins contained in the sap (Wool 2004 ; Fathi *et al.*, 2009). Furthermore, the lack of developmental stages in Raphia vinifera could be explained by the fact that within the same botanical family, different species can develop different means of defence against pests. In addition, this plant is present in swamps that would harbour a microenvironment unfavourable to the development and survival of this insect due to the high relative humidity and low temperature. The individual characteristics of plants as well as their close environment can therefore affect the behaviour of the phytophagous insect in the choice of the host plant. Phytophagous insects will therefore tend to avoid plants on which their performance is reduced (Poelman *et al.*, 2008; Barbosa *et al.*, 2009). Indeed, Al-Wahaibi & Morse (2009) and Chuche & Thiéry (2012) who have worked on Cicadellidae have shown that abiotic conditions, in particular temperature

and relative humidity condition their development
As a result, the low temperatures observed in swamps could subject the plant to regular opening of the stomata of the leaves, causing surface cooling (Jackson *et al*., 1981). This physiological state can be more unfavourable for the development of insects since they do not have a thermoregulatory system. The pH of the liquid in the xylem could explain the choice of host plant by *N. curta* for its development. Thus, Coudron *et al.* (2007) reported that the development and performance of the leafhopper *Homalodisca vitripennis* was affected by the pH of the xylem enzymes of cowpea and sunflower, the latter's host plants. According to its authors, a pH between 5 and 6 of the liquid in the xylem of cowpea and sunflower was optimal for cysteine proteinase in the midgut and caseinolytic activity in the salivary gland of *H. vitripennis*. In addition, Brodbeck *et al.* (1999) argued that a more balanced nutrient profile resulted in nearly 90% survival to adulthood in Cicadellidae. This suggests that coconut and oil palm tree provide the balanced nutritional profile required for the development of the larva in *N. curta*, which could not be the case with raffia. In this study, the distribution of *N. curta* egg-laying was on the underside of the leaflets, which is the privileged place of spawning of Cicadellidae. Indeed, the choice of the lower face of the leaves of the plant for egg laying would be motivated by the female's concern to put her offspring in a safe environment. Several authors show that the choice of a host plant and the location of the eggs on it are of paramount importance for the success of the offspring of laying females, especially against predators, parasitoids and inclement weather (Wheeler *et al*., 1998; Al-Wahaibi & Walker, 2000). The results of the observation on herbaceous plants tested positive for the phytoplasma responsible for the fatal yellowing of the coconut palm in Grand-Lahou showed an absence of the different stages of development of *N. curta*. This could suggest that these plants are more of a source of food for adults than a site for egg-laying and nymph development. Indeed, Brodbeck *et al.* (2007) and Mizell *et al.* (2008) state that in Cicadellidae H. vitripennis, there is no egg-laying on the full range of plant species on which the insect feeds due to the dietary requirements of nymphs which differ from that of adults. Abiotic factors play a vital role in the behaviour of insects (Xiaofei & Hui, 2009).
Thus, the seasonal change could have major effects on the abundance and dynamics of many species of phytophagous insects on their different host plants. During the study, individuals of N. curta were more abundant on Cocos nucifera and Elaeis guineensis during the period from December to March which marks the great dry season during which the temperatures are high. Indeed, insects are organisms ectotherms (poikilotherms) and therefore have a very low capacity to regulate their body temperature, so that ambient temperature determines all biological activities (Brown *et al.* 2004) ; resulting in significant changes in their development, survival, reproduction and behaviour as reported by the authors Bale (2002) ; Angilletta *et al*., (2004) and Parmesan (2006). Also, the abundance of many species of phytophagous pests must be synchronized with the phenology of the host plant to allow access to a favourable food, refuge or oviposition site, survival or reproduction optimal (Candau, 2008). In fact, during dry seasons, plants experience an increase in carbohydrates which would make them more attractive to insects (Ziska & Réunion, 2007).

CONCLUSION AND APPLICATION OF RESULTS

This study on the search for host plants for *Nedotepa curta* identified *Cocos nucifera* and *Elaeis guineensis* as the two host plants of *N. curta*. Weeds that test positive for the phytoplasma responsible for the fatal yellowing of coconut palms do not harbour any developmental stages of *N. curta*. Peak average abundance of *N. curta* was observed in December on *C. nucifera* and in January on *E. guineensis*. The lowest average abundances were recorded in June on *C. nucifera* and on *E. guineensis*. This information makes it possible firstly to have a catalogue of *N. curta* host plants, secondly to adopt cultural by avoiding the establishment of *C. nucifera* plantations close to *E. guineensis* plantations, thirdly to understand the spread of this disease and finally to implement vector control strategies.

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