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ORIGINAL PAPER

Impact of an invasive alien plant species *Lantana camara L.* (Verbenaceae) on floristic diversity and soil physicochemical properties of coconut groves from Southeastern Côte d'Ivoire

Impact d'une plante exotique envahissante *Lantana camara L.* (Verbenaceae) sur la diversité floristique et les propriétés physicochimiques des sols des cultures de coco du Sud-Est de la Côte d'Ivoire

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Résumé Les espèces végétales exotiques envahissantes constituent une menace pour la biodiversité des plantations. L'objectif principal de cette étude est d'améliorer les connaissances sur *Lantana camara*. Pour cela, des échantillons de plantes et de sols ont été collectés dans des cocoteraies envahies et non envahies afin d'analyser l'impact de *L. camara* sur la diversité floristique et les propriétés physico-chimiques du sol. Des indices de diversité, des fréquences relatives, des contributions spécifiques ont été calculés et un diagramme d'infestation a été réalisé. Les résultats montrent que la flore des cocoteraies envahies est moins diversifiée que celle des cocoteraies non envahies. Dans les cocoteraies envahies, *L. camara* est très régulière et agressive avec une fréquence relative de 96,5 p.c. et une contribution spécifique de 9,2. Le diagramme d'infestation montre que l'espèce a un potentiel de nuisance élevé. Les sols sont caractérisés par une texture sableuse. Les sols sous les cocoteraies envahies sont plus acides et plus riches en azote total. En revanche, les sols des cocoteraies non envahies sont moins acides et plus riches en potassium assimilable. Ces résultats reflètent le potentiel nocif de cette espèce. Des mesures de gestion doivent être mises en place pour freiner son invasion en Côte d'Ivoire.

Mots clés : Espèce exotique envahissante, Diagramme d'infestation, Diversité floristique, Propriétés physico-chimiques du sol, *Lantana camara*, Côte d'Ivoire.

Abstract Invasive alien plant species are threats to biodiversity of plantations. The main objective of this study was to improve knowledge on *Lantana camara*. Plant and soil samples were collected in invaded and non-invaded coconut groves to analyse the impact of *L. camara* on floristic diversity and soil physicochemical properties. Indices of diversity, relative frequencies and, specific contributions were calculated and, an infestation diagram was realized. The results showed that flora of invaded coconut groves had less diversified than that of non-invaded coconut groves. In invaded coconut groves, L. camara was very regular and aggressive with a relative frequency of 96.5 p.c. and a specific contribution of 9.2. The infestation diagram showed its high potential of nuisance. Soils had sandy, those beneath coconut groves had more acidic and richer in nitrogen, while those under the uninvaded counterpart had less acid and richer in potassium. These results reflect the noxious potential of this species. Management measures must be developed to curb its invasion in Côte d'Ivoire.

Key words : Alien Invasive species Infestation diagram, Floristic diversity, Soil physicochemical properties, *Lantana camara*, Côte d'Ivoire.

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Introduction

The phenomenon of biological invasion is the consequence of the extension of anthropogenic activities (Hulme *et al*., 2008). Currently, 17 p.c. of the terrestrial surface area and 16 p.c. of biodiversity hotspots appear to be extremely vulnerable to biological invasions (Early *et al*., 2016). Climate and land-use changes imposed by human activities are among the main factors facilitating biological invasion (Pyšek *et al*., 2010). Biological invasion refers to a process in which an alien species invades a new habitat and establishes its population. This invasion can be facilitated by human activity or occurred in natural way (Richardson and Pysek, 2008). According to Richardson *et al*. (2000), alien species are considered invasive when, having crossed successive barriers that limit their reproduction, naturalization, and dispersal; they undergo a significant phase of expansion in their new area of introduction. These species are animals, plants or other organisms introduced by humans into distinct environments that threaten ecosystems, native habitats, or species with negative environmental and/or economic and/or health consequences (IUCN, 2000). Worldwide, there is an overabundance of invasive alien species (IAS) such as *Chromolaena odorata* (L.) R.M. King & H. Rob. (Asteraceae), *Hopea odorata* Roxb. (Dipterocarpaceae), *Lantana camara* L. (Verbenaceae), *Tithonia diversifolia* (Hemsl.) (Sharma et Raghubanshi, 2011; Tiébré *et al*., 2012, 2014, 2015, 2018; Akaffou *et al*., 2019; Pagny *et al*., 2020) that affect ecological processes and cause a loss of native ecosystem biodiversity (McNeely, 2001). This includes a myriad of impacts such as alteration of ecosystem processes (Devine and Fei, 2011), decline in the abundance and richness of native flora (Capers *et al*., 2009), the alteration of community structure (Sanders *et al*., 2003) and modification of physical and chemical properties of soils (Aravind *et al*., 2010).

Among these species, *Lantana camara* is native to tropical and subtropical America and one of the 100 most harmful invasive species in the world (IUCN, 2000). It is a perennial evergreen shrub that spreads rapidly by its abundant seed and shallow crown buds. This species is strongly odorous, with a height of 2 to 5 m (Nanjappa *et al*., 2005). Furthermore, Species Information Network identifies *L. camara* among the top ten invasive species worldwide (GISIN, 2011). In Africa, *Lantana camara* is currently present in 34 countries (CABI, 2019). It has been introduced into several countries through its ornamental seeds and spread through birds (Ghisalberti, 2000). This species encroaches on agricultural land, reduces grazing capacity and is a threat to many crops (Baars and Heystek 2003). Also, its include loss in biodiversity i.e., a reduction in native species diversity and extinctions. *Lantana camara* causes the fall of soil fertility and alteration of ecosystem processes (Sharma et Raghubanshi, 2011).

Given the many negative impacts of these invasive species on ecosystems and the sustainability of ecosystem services, their control has become a priority for biodiversity conservation planners and country governments (Smith *et al*., 2006). Numerous studies have therefore been carried out to analyze the impact of *Lantana camara* on flora and soil. For example, in worldwide, the work of Gooden *et al*. (2009) in Australia have shown the impact of this species on native plant communities. Studies of Osunkoya and Perrett (2011) highlighted the effects of *L. camara* invasion on the physico-chemical properties the soil from Australia. In addition, Dobhal *et al*. (2011) assessed the impact of *L. camara* invasion on four large woody shrubs along the Nayar River of the Pauri Garhwal in Uttarakh and the Himalayas (India). Also, in India, Mandal and Joshi (2014) showed the role on habitat types and soil physico-chemical properties. In Africa, Witt (2010) have shown the impact of its proliferation on forage species in Kenya. Simba *et al*. (2013) has highlighted the impact of *L. camara* on soil properties from in the Nairobi National Park. The method used in these studies compares the invaded and uninvaded plots of *Lantana camara*. Indeed, the richness, abundance and composition of plants were analyzed along mountain ranges in areas not invaded and invaded by *Lantana camara* (Gooden *et al*., 2009). Dobhal *et al*. (2011) assessed the impact of *Lantana camara* on plant frequency and abundance in uninvaded and invaded quadrats in Pauri Garhwal. In their studies, Mandal and Joshi (2014) analyzed the physico-chemical properties of soil in the Don Valley in quadrats heavily and less invaded by *Lantana camara*. The physico-chemical properties of soils in Nairobi National Park were analysed by taking samples from sites invaded and non-invaded by *Lantana camara* (Simba *et al*., 2013). Osunkoya and Perrett (2011) compared soil physicochemical properties under invaded and non invaded vegetation across four sites west of Brisbane, SE Australia. In these studies, uninvaded plots were used as controls (Gooden *et al*., 2009; Dobhal *et al*., 2011; Osunkoya et Perrett, 2011; Simba *et al*., 2013; Mandal et Joshi, 2014).

In Côte d'Ivoire, *L. camara* was introduced by horticulture (Neuba *et al.*, 2014). Currently, this species occupies 20 p.c. of the national territory, i.e. an area of 65,782.40 km² (Pagny *et al.*, 2020). It proliferates in some localities such as Alépé, Bongouanou, Dimbokro, Gagnoa, Grand-Bassam, Issia and in many coconut plantations in the southeast (Kassi *et al.*, 2010; Maroun, 2017; Tiébré *et al.*, 2018). To date, studies on this species have focused on its perception by riparian populations and its current and future distribution in Côte d'Ivoire (Tiébré *et al.*, 2018; Pagny *et al.*, 2020). Despite the studies carried out and the fact that *Lantana camara* causes damage to invaded ecosystems, work linking its impact on flora and soil has not yet been conducted (Tiébré *et al.*, 2018). For accessing the impact of this species on floristic diversity and soil management the following questions were stated: what is the degree of congestion of coconuts plantations invaded by *L. camara*? What is the impact of the invasion on the flora and physicochemical properties of the soil of coconut groves? To address these concerns, the main objective of this study was to improve knowledge of the invasion of *L. camara*. Specifically, this involved (1) determining the degree of *L. camara* proliferation in coconut groves, (2) assessing the floristic diversity and the soil composition of invaded plantations.

Materials And Methods

Study area

The department of Grand-Bassam is in the umbrophile sector between 5° 2' and 5° 4' North and between 4° 40' and 4° 55' West (Guillaumet and Adjanohoun 1971). It has a subequatorial climate rhythmed by 4 seasons. Considering the most recent data from 2009 to 2017, provided by SODEXAM for the South Comoe region, there are two rainy seasons, a large season from March to mid-July and a small season from October to November. Then, two dry seasons, the big one from December to February and the small season starts from August to September. The average annual rainfall exceeds 1800 mm (Mévanly 2018). The vegetation of the region belongs to the coastal area of the Guinean estate (Guillaumet and Adjanohoun 1971), characterized by the presence of evergreen forests, coastal forests, coastal thickets, swamp forests and mangroves. This vegetation is now severely degraded due to human activities that are mainly agriculture, crafts, fishing, livestock, and tourism (Mévanly, 2018). As for wildlife, it is home to many animal species, including palearctic and migratory birds (Nicolle *et al.*, 1987). The department of Grand-Bassam has ferralitic, hydromorphic and sandy soils (Zan-Bi, 2014). That corresponds to Acrisol (AC), Gleysol (GL) and Arenosol (AR) according to FAO classification (FAO, 2015). The soils of littoral are low-developed sandy soils superior à 80 p.c. , mainly composed of quaternary sands, very low natural fertility, degraded and very poor in mineral elements. These soils are 96.42 p.c. , coarse sands (200-2000 μm), pH (4.6), carbon (0.37 p.c.), nitrogen (0.02 mg/100g), potassium (mg/100g), exchangeable cations and very low cationic exchange capacity (1.09 cmol (+) kg-1). Soil organic matter content is 0.41 p.c. , i.e. less than 1 p.c. (Lekadou, 2009). This study was carried out at three sites. These are the PK 5, PK 8 and the Station Marc Delorme of the National Centre for Agricultural Research of Côte d'Ivoire (CNRA). Those sites were chosen according to the level of invasion of the coconut plantations by *Lantana camara* (Figure 1). Coconut groves have been established since the 1950s and 1960s (Lekadou, 2009). The areas of plantations varied from 1 to 5 ha for the sites PK 5 and PK 8 and to 210 ha for the CNRA plantation (Assa *et al.*, 2006). The latter contained 30 varieties of the Assinie collection of "grand" coconuts (Lekadou, 2009). Coconut groves considered to be invaded were those containing many populations of *Lantana camara*. Uninvaded coconut groves were remarkable either by the rare tufts of *L. camara* or no individuals of the species. In each site, invaded and uninvaded plots were identified. Uninvaded plots were used as control such as Gooden *et al.* (2009); Dobhal *et al.* (2011); Osunkoya and Perrett (2011); Simba *et al.* (2013); Mandal et Joshi (2014). In total, three invaded sites and two uninvaded sites were identified.

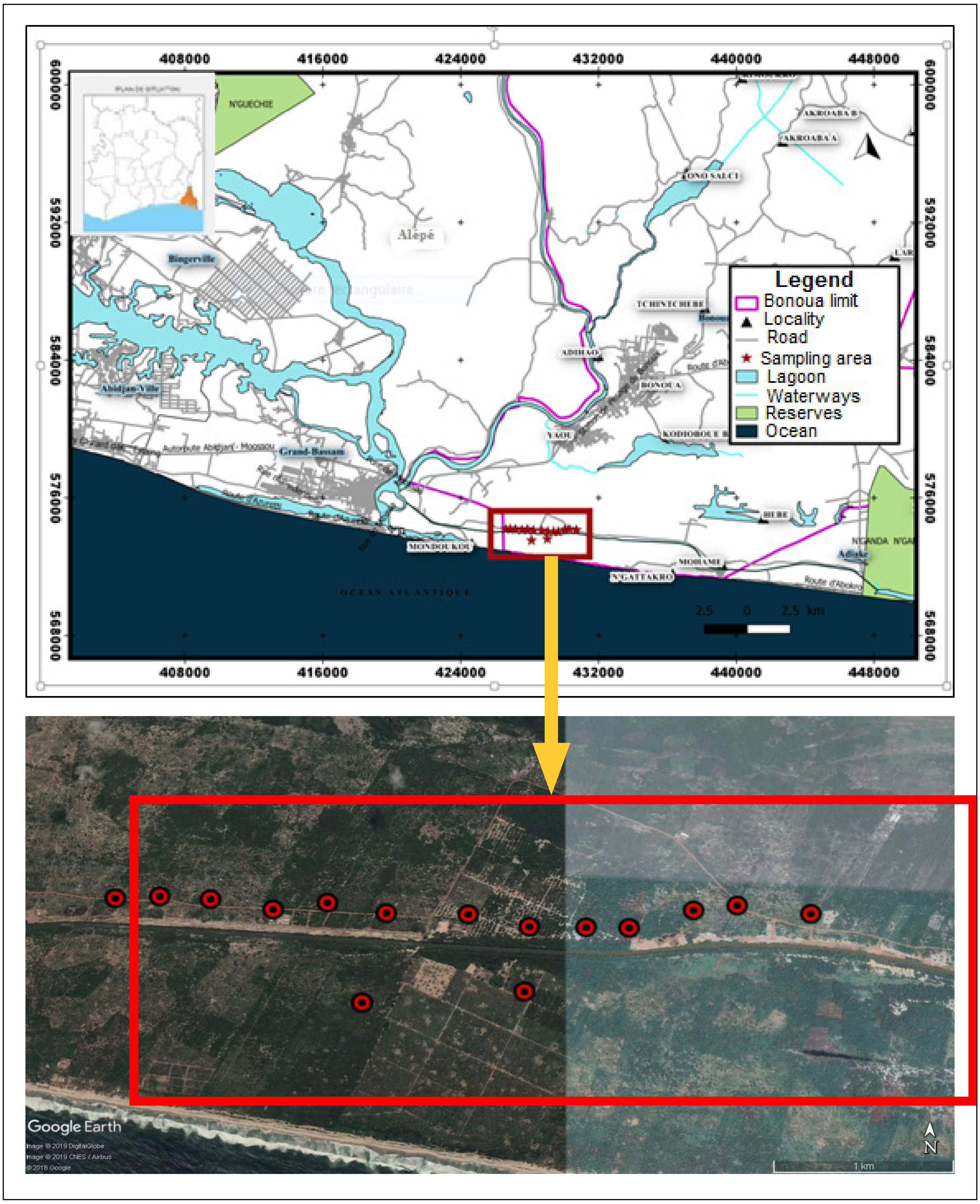

Figure 1: Location map of study area and sampling sites

Description of the vegetation

For the description of vegetation, three strata were defined according to morphological types with reference to the work of Raunkier (1934). These strata were: Herbaceous stratum containing annual and perennial herbaceous plants that were Therophytes (Th), Hemicryptophytes (H), Chamephytes (Ch) and Geophytes (G) which height below 0.25 m; Shrub stratum composed of a low shrub stratum with the Nanophanerophytes (np) which height was between 0. 25 to 2 m and high shrub stratum with the MicroPhanerophyte (mp) which height was between 2 to 8 m; Tree stratum corresponding to Mesophanerophytes (mP) which height was between 8 to 30 m and MegaPhanerophytes (MP) which height is over 30 m.

Collection of floristic data

Twenty-two (22) transects (North-South and East-West) were identified in the three sites. Each transect was subdivided into contiguous plots of 100 m^2 (10 m x 10 m), for a total of 220 plots. On each plot floristic, data were collected by the surface survey method (Duvigneaud, 1949; Yoka et *al.*, 2013). All species were identified. Those that could not be identified in the field were put in herbarium and later identification at the National Floristic Centre of Côte d'Ivoire. Species recovery was subjectively assessed on the abundance-dominance of Van Der Maarel (1979) (Table I).

Table 1: Abundance-dominance coefficient according Van der Maarel (1979)

(Van Der Maarel, 1979) AD	Definition	Average recovery (p.c.)
1	1 individual	1
2	2 individuals	2
3	Dr ≤ 5 p.c.	3.5
4	5 < Dr ≤ 10 p.c.	7.5
5	10 < Dr ≤ 15 p.c.	12.5
6	15 < Dr ≤ 25 p.c.	20
7	25 < Dr ≤ 50 p.c.	37.5
8	50 < Dr ≤ 75 p.c.	62.5
9	Dr > 75 p.c.	87.5

Legend: Dr: Relative abundance; AD: Abundance-Dominance Coefficient

Richness and floristic composition

The floristic richness of coconuts plantations at each site was determined by the number of species, genera, and families (Aké-Assi, 1984). The identification of the plant species was done using the identification key of Lebrun and Stork (1991; 1997); Hawthorne (1995). The family names followed the APG IV (2016). The specific diversity of each site was determined by the Shannon-Weaver diversity index (1948) according to the following formula: with H': Shannon diversity index; pi = n/r, where n represented the recovery of species i in the relevant statement and r represented the total sum of the recovery of the species in the statement. The floristic homogeneity at each site was assessed based on the Pielou equitability index (1966), which is derived from the Shannon-Weaver index. This index describes the distribution of the different species of a population and has mathematical expression: E = H' / ln S where H' represented the Shannon index, S had been the total number of species of a given biotope, and ln S represented the maximum diversity of the biotope. The invasive alien species were identified from IUCN (2014); Neuba *et al.* (2014); Noba *et al.* (2017); Dogba *et al.* (2018); Akaffou *et al.* (2019).

Regularity of species

The relative frequency (Fr) is a value that reflects the regularity of the distribution of a species in a plant community (Daget and Poissonet 1969). It was calculated according the formula: Fr = Fa (e) / N with Fa (e): absolute frequency of each species and N: number of plots. To classify the relative frequency of species, Raunkiaer (1905) defined 5 groups of frequent species: Class I included very infrequent species with a relative frequency between 0 and 20 per cent. Class II included irregular species with a relative frequency between 21 and 40 per cent. Classes III, IV and V included regular, very regular and particularly regular species with frequencies between 41 and 60 p.c., 61 and 80 p.c., and 81 and 100 p.c., respectively.

Aggressiveness of species

The specific contribution is a value that reflects the aggressiveness of species in a plant community (Daget and Poissonet 1969). This specific contribution was obtained from the formula : Cs (e) = [Fs (e) / $^{n}_{1}$ FS (e)] x 100 where FS (e) represented the specific frequency of the species (e) and $^{n}_{1}$ FS (e) represented the sum of the frequencies of all species. For classifying the aggressiveness of species, Daget and Poissonet (1969) adopted the following classification: Cs(e) < 1: non-productive species; species with a more or less negligible depressive effect on plants; 1 ≤ Cs(e) < 4: unproductive species with a relatively high depressive effect on plants and aggressive; Cs (e) ≥ 4: very productive species with a particularly high depressive effect and very aggressive on other plants.

Degree of infestation

The degree of infestation of *Lantana camara* and other species were graphically highlighted by an infestation diagram. This diagram was based on the relative frequencies and the mean abundance of a species (Le Bourgeois et Guillerm, 1995). The mean abundance was obtained following formula (Kazi *et al.*, 2010) : AD moy(e) = Σ AD(e) / Nrel(e) where AD(e) represented the mean of the species abundance/dominance indices and Nrel(e) represented the number of plots where the species was present. The infestation diagram allows differentiating groups of species according to their degree of infestation (Le Bourgeois et Guillerm, 1995; Diomandé *et al.*, 2018). Thus, nine groups of species can be discriminated: Group 1 (G1) contained the major general species that were both very frequent (Fr > 0.5) and very abundant (AD moy. > 1.5). They were the most harmful species that could colonize all ecological environments and had the potential for significant invasion; Group 2 (G 2) was composed of general potential species, very frequent (Fr > 0.5) and very abundant (1.25 < AD moy. < 1.5). They were very ubiquitous species; whose infestation was generally less than that of general major species; Group 3 (G 3) contained very frequent general species (Fr > 0.5), but never abundant (mean AD < 1.25). They were ubiquitous species found in almost all environments; Group 4 (G 4) corresponded to major regional species, very frequent (Fr > 0.5) but never abundant (A D moy. < 1.50). They were ubiquitous species but did not pose any problem in the current phytotechnical context. These species to be monitored because of their wide distribution during cultivation practices. They were species whose presence is linked to a regional ecological factor. It was the original vegetation or agricultural environment; Group 5 (G 5) contained potential regional species. They were very abundant (AD moy. > 1.5) and moderately frequent (0.2 < Fr < 0.5) with a wide ecological range whose presence were linked to a regional ecological factor (soil, climate, topography); Group 6 (G 6) consisted of regional species, moderately frequent (0.2 < Fr < 0.5) and less abundance (AD moy. < 0.5). They had an average ecological range but were not a constraint due to their limited abundance. However, they could be used as indicators of regional ecological conditions; Group 7 (G 7) consisted of the major local species, very abundant (1.25 < AD moy. < 1.5) and moderately frequent (0.2 < Fr < 0.5). They had a narrow ecological range and became an important agronomic constraint on the cultivated parcels in the forest or savannah zone; Group 8 (G 8) were local potential species, infrequent (Fr 0.2) and occasionally showed less average dominance indices (1.25 < AD moy. < 1.5). They had a narrow ecological range; Group 9 (G 9) consisted of minor species infrequent (Fr < 0.2) and unabundant (AD moy. < 1.25). They were rare, foreign, or pioneering species. They were not harmful to crops. However, the fields should be cleared of these species, especially because of the competition they can engage with the culture for the occupation of space.

Soil sampling and analyses

The soil samples were taken in each plot using an auger at the corner and in the centre at a depth of 0 - 20 cm. The five soil samples were mixed and put into a bag to form a composite sample (Abobi *et al.*, 2014). A total of fifteen (15) composite soil samples were taken. They were then air-dried and sieved with a 2 mm sieve for physicochemical analysis in the laboratory. The water pH was obtained with electrode measurements according to NF-ISO 10390. The concentrations of hydrogen ions (H^+) were determined from the measurement of the soil solution (the water of the soil and its dissolved substances) when measuring soil water pH (McCauley *et al.*, 2017). The method of Walkley and Black (1934) was used for the determination of carbon. Total nitrogen was determined by the Kjeldhal method (Bremner and Mulvaney, 1982). Available phosphorus was determined by the Bray 2 method (Okalebo *et al.*, 2002). Cation exchange capacity was determined by extraction (percolation) in a 1N ammonium acetate-buffered medium, pH 7.0 to saturate the soil with NH_4^+ cations in a mechanical vacuum extractor (Van Ranst *et al.*, 1999). Available magnesium, potassium and sodium were determined in the acetic extract by atomic absorption spectrophotometry (Bertalot *et al.*, 2013). Samples used for texture analysis were dispersed with sodium carbonate solution (Na_2CO_3) and hexametaphosphate sodium and pre-treated according to the ISO11464 method. Particle size analyses of clay and silt were carried out using the Robinson pipette method (AFNOR-NF X 31-107 standard), (Verger, 1976) with a Texsol24B sedimentation machine (LCA Instruments, France). The sand fraction was obtained by wet sieving at 200 µm. These analyses were carried out at the Institute National Polytechnic Félix Houphouët-Boigny of Côte d'Ivoire.

Statistical analysis

Floristic data were submitted to the non-parametric Kruskal-Wallis test to compare water pH, carbon (C), total nitrogen (Nt), available phosphorus (mg P per g of soil), available magnesium (Mg^{2+}) and sodium (Na^+) (Alignier, 2011). Whenever the calculated probability was significant, Dunn's test was used to compare the means in pairs to assess significant differences. Comparison of the means of C/N, cation exchange capacity (CEC), available calcium (Ca^{2+}) and available potassium (K^+) was performed by the Anova test followed by the Tukey pairwise comparison test (Alignier, 2011).

Multiple factor analysis (MFA) was used to describe groups of individuals based on qualitative and quantitative variables (Pagès, 2002). In this study, the qualitative variable was *Lantana camara* cover and the quantitative variables were floristic data (specific richness, Shannon diversity index, Piélou equitability index, specific contribution) and soil physicochemical parameters (clay, silt, sand, water pH, C, Nt, C/Nt , available P (mg P per g of soil), CEC, available Ca2+, available Mg2+, available K+ and Na+). All analyses were performed using XLSTAT software version 2014.5.03 and R Version 3.2.

Results

Vegetation of coconut groves

Vegetation of uninvaded coconut groves was structured in 3 strata: an herbaceous, shrubby and tree stratum. The rarely mowed undergrowth was distinguished by a tree covered layer with an average height of 9 m and a cover of 15-25 p.c. dominated by *Leptoderris ledermannii* Harms (Fabaceae). It also included species with lianaceous characteristics such as *Ancistrocladus barteri* Scott-Elliot (Ancistrocladaceae). A shrub stratum with an average height of 4 m was then encountered. This stratum was subdivided into a low shrub stratum with characteristic species such as *Acroceras zizanoides* (Kunth) Dandy, *Borreria verticillata* (L.) G.Mey. (Rubiaceae), *Triumfetta rhomboidea* Jacq. (Malvaceae), *Waltheria indica* L. (Malvaceae) and a high shrub stratum characterized by *Alchornea cordifolia* (S. & Th.) Mûll. Arg. Macbr (Euphorbiaceae), *Baphia nitida* Lodd (Fabaceae), *Rauvolfia vomitoria* Afzel. (Apocynaceae) and *Chrysobalanus icaco* L. subsp. *Icaco* L. (Chrysobalanaceae) which was the most dominant species. The herbaceous stratum with an average height of 1 m had a low coverage of 5-15 p.c. It included perennial herbs such as *Andropogon auriculatus* Stapf (Poaceae), *Emilia coccinea* (Sims) G.Don (Compositae), *Cucumis sativus* L. (Cucurbitaceae), *Cyperus sphacelatus* Rottb. (Cyperaceae) and perennial grasses including *Catharanthus roseus* (L.) G. Don (Apocynaceae), *Centrosema pubescens* Benth. (Fabaceae), *Chrysopogon aciculatus* Trin. (Poaceae) and *Heterotis rotundifolia* Smith (Melastomataceae). The dominant species of this herbaceous stratum was *Andropogon auriculatus*.

In case of an invasion by *Lantana camara*, the undergrowth of the coconut groves was regularly mowed. This undergrowth was characterized by a low shrub layer with a wide cover and dominated by *Lantana camara*. Shrubs such as *Acroceras zizanoides* (Kunth) Dandy, *Borreria verticillata* (L.) G.Mey., *Ouratea glaberima* (P. Beauv.) Engl. were founded in places. We also observed *Dalbergia afzeliana* G., a lianescent species. Sometimes a high shrub stratum developed with rare individuals planted liked *Acacia mangium* Willd. The herbaceous stratum, with an average height of 1 m, included annual herbaceous plants such as *Oldenlandia affinis* (Roem. & Schult.) DC. and perennial herbaceous plants as *Diodia rubricosa* Hiern.

Some species remained present in invaded and uninvaded coconut groves of *Lantana camara*. They were: *Acacia mangium, Acroceras zizanioides, Agelaea pentagyna, Albertisia scandens, Alchornea cordifolia, Ancistrocladus abbreviatus, Andropogon auriculatus, Baphia nitida, Borreria verticillata, Calopogonium mucunoides, Chromolaena odorata, Chrysobalanus icaco, Oldenlandia affinis* and *Waltheria indica*. Among these plants, *Calopogonium mucunoides* and *Chromolaena odorata* were highly invasive species in Côte d'Ivoire. Other species present in uninvaded coconut groves disappeared during the invasion. These plants included: *Albertisia cordifolia, Clerodendrum splendens, Eucalyptus camaldulensis, Eugenia whytei, Ficus trichopoda, Pentodon pentandrus, Perotis indica, Phyllanthus pentandrus, Pouzolzia guineensis, Rauvolfia vomitoria, Secamone afzelei, Sesamum radiatum, Stachytarpheta cayennensis, Tricalysia discolor, Zanthoxylum Zanthoxyloides*. Some of the species that appeared during the invasion were: :*Axonopus compressus, Boerhavia diffusa, Cassia occidentalis, Desmodium ascendens, Eragrostis domingensis, Fimbristylis ferruginea, Imperata cylindrica, Micrograma owariensis, Mimosa pudica, Panicum repens, Pennisetum pedicellatum, Pteridium aquilinum, Phyllantus amarus, Sauvagesia erecta, Schrankia leptocarpa, Scoparia dulcis, Sterculia tragacantha, Tapinanthus bangwensis, Triclisia patens, Vernonia cinerea*. There were not invasive plants among the species that appeared or disappeared during the invasion of *Lantana camara*.

Floristic diversity and physicochemical properties of soil

A total of 120 species were inventoried. Ninety-four (94) species were found in uninvaded coconut groves and sixty-two in invaded coconut groves. These species were divided into 101 genera and 41 families. The important families were Poaceae (13 species), Cyperaceae (12 species), Fabaceae (11 species) and Rubiaceae (10 species). The mean number of species was varied from 13.5 ± 3.4 in uninvaded coconut groves to 10.4 ± 2 in invaded ones. Statistical analyses showed a significant difference (K = 34.9; P < 0.05) (Table II). The highest mean value of Shannon index was obtained in uninvaded coconut groves (1.4 ± 0.4). The lowest value was obtained in invaded coconut groves (0.8 ± 0.4). The difference between these mean values was statistically significant (K = 80.5; P < 0.05) (Table III). The Piélou equitability index of uninvaded coconut groves (0.8 ± 0.4) differed significantly from that of invaded coconut groves (0.6 ± 0.05) (K = 115.7; P < 0.05) (Table III).

In invaded coconut groves, *L. camara* was more frequent (96.5 p.c.) and more aggressive (9.2) (Table IV). In uninvaded coconut groves, *Lantana camara* came in the 29th position with a relative frequency equal to 4 p.c. and a specific contribution equal to 1 (Table IV). Infestation diagram showed that the Group 1 was composed of *Lantana camara* which was very frequent (Fr > 0.5) and very abundant (AD moy. > 1.5), (Figure 2). Soil texture did not show significant differences (Table V). Studied soils had sandy texture with > 95% of sand, around 2% of silt and 1% of clay. Three soils variables showed significant differences in mean concentrations. They were water pH (K = 11.6; P < 0.05), total nitrogen (K = 12.9; P < 0.05) and available potassium (F =17.1; P < 0.0001). Average soil water pH varied from 5.1 ± 0.05 in uninvaded coconut groves to 3.5 ± 0.2 in invaded coconut groves. Average of total nitrogen varied from 0.032 ± 0.004 mg / 100g in uninvaded coconut groves to 0.14 ± 0.009 mg / 100g in invaded coconut groves. Average of available potassium varied from 0.097 ± 0.001 mg / 100g in uninvaded coconut groves to 0.092 ± 0.001 mg / 100g in invaded coconut groves. The other chemical parameters did not show significant differences among invaded and uninvaded plots (Table VI).

Multiple Factor Analysis (MFA) showed that the three axes explained 77.52 p.c. variance information (Figure 3). First and second axes restored 63.85 p.c. variance information and third axis 13.67 p.c. Factor map showed two groups of coconut groves. Group 1 described in the positive and negative of axis 1 was composed of uninvaded coconut groves with low *Lantana camara* coverage. These groves were characterized by high floristic diversity and high richness of soil chemicals such as available phosphorus, sodium, available potassium, cation exchange capacity and available magnesium. Group 2 described in the positive and negative plan of axis 2 contained invaded coconut groves where *Lantana camara* coverage was high. They were characterized by high specific contribution, low floristic diversity and richness of soil chemical elements. Soil was correlated with total nitrogen, carbon, carbon/ nitrogen ratio.

Table 2: Parameters of floristic richness of study sites

Study sites	Number of species	Average number of species
Invaded coconut groves	62	10.4 ± 2.1^{a}
Non invaded coconut groves	94	13.5 ± 3.4^{b}
Entire study area	120	11.15 ± 6^{ab}
Statistical test	K = 34.9 ; P < 0.05	

The values with same letters within a column are not significantly different.

Table 3: Specific diversity indices of different biotopes

Study sites	Average Shannon Index/Plot	Average Pielou Index/Plot
Invaded coconut groves	0.8 ± 0,4^{a}	0.6 ± 0,05^{a}
Non-invaded coconut groves	1.4 ± 0,4^{b}	0.9 ± 0,1^{b}
Statistical test	K = 80.5 ; P < 0,05	K =115.7 ; P < 0.05

The values with same letters within a column are not significantly different.

Table 4: Relative frequencies and specific contributions of species surveyed at different study sites

	Invaded coconut groves						Non-invaded coconut groves				
N°	Species	Fr	N°	Species	Cs	N°	Species	Fr	N°	Species	Cs
1	*Lantana camara*	**96.5**	**1**	*Lantana camara*	**9.2**	**1**	*Andropogon auriculatus*	90	1	*Andropogon auriculatus*	6
2	*Oldenlandia affinis*	60.6	2	*Oldenlandia affinis*	5.8	2	*Chrysobalanus icaco*	74	2	*Chrysobalanus icaco*	5
3	*Acacia mangium*	59.4	3	*Acacia mangium*	5.7	3	*Acacia mangium*	60	3	*Acacia mangium*	4.1
4	*Diodia rubricosa*	58.8	4	*Diodia rubricosa*	5.6	4	*Zanthoxylum Zanthoxyloides*	60	4	*Zanthoxylum Zanthoxyloides*	4.1
5	*Andropogon auriculatus*	58.2	5	*Andropogon auriculatus*	5.6	5	*Leptoderris ledermannii*	58	5	*Leptoderris ledermannii*	4
6	*Chromolaena odorata*	58.2	6	*Chromolaena odorata*	5.6	6	*Cassytha filiformis*	58	6	*Cassytha filiformis*	4
7	*Borreria verticillata*	57.6	7	*Borreria verticillata*	5.5	7	*Nephrolepis biserrata*	58	7	*Nephrolepis biserrata*	4
8	*Triumfetta rhomboidea*	55.9	8	*Triumfetta rhomboidea*	5.3	8	*Alchornea cordifolia*	56	8	*Alchornea cordifolia*	4
			9	*Rauvolfia vomitoria*	4.4	9	*Chromolaena odorata*	54	9	*Chromolaena odorata*	4
			10	*Catharanthus roseus*	4.1	10	*Borreria verticillata*	54	10	*Borreria verticillata*	4
			11	*Waltheria indica*	4.1	11	*Machaerium lunatum*	54	11	*Machaerium lunatum*	4
			12	*Baphia nitida*	3.7	12	*Heterotis rotundifolia*	52	12	*Heterotis rotundifolia*	3.5
			13	*Chrysobalanus icaco*	3.1	13	*Baphia nitida*	50	13	*Baphia nitida*	3.4
			14	*Centrosema pubescens*	3	14	*Croton hirtus*	50	14	*Croton hirtus*	3.4
			15	*Acroceras zizanioides*	2.5	-			15	*Diodia rubricosa*	3
			16	*Heterotis rotundifolia*	1.7	-			16	*Ouratea flava*	1.3
			17	*Alchornea cordifolia*	1.6	-			17	*Scoparia dulcis*	1.2
			18	*Chrysopogon aciculatus*	1.5	-			18	*Albertisia scandens*	1.2
			19	*Phoenix reclinata*	1.1	-			19	*Clerodendrum splendens*	1.2
			20	*Croton hirtus*	1	-			20	*Macaranga barteri*	1.2
			21	*Mariscus dubius*	1	-			21	*Ancistrocladus abbreviatus*	1
						-			-		
						-			-		
						29	*Lantana camara*	**14**	**29**	*Lantana camara*	**1**

Legend: Fr : Relative frequencies ; Cs : Specific contributions

Table V: Summary statistics of the soil chemical variables by biotope

Soil variables	Invaded coconut groves				Non-invaded coconut groves				Statistical test
	Average	Ec-t	CV	Eten	Average	Ec-t	CV	Eten	
pH_eau	3.5a	0.2	5.7	0.5	5.1b	0.05	1	0.1	K = 10.6 ; P < 0.05
C (g/kg)	0.5a	0.3	60	1	0.3a	0.003	1	0.07	K = 0.12 ; P > 0.05
Nt(mg/100g)	0.14a	0.009	6.4	6.4	0.02b	0.004	12.5	0.01	K = 11.74 ; P < 0.05
P (mg/100g)	32.2a	2.1	6.5	7	44a	27.5	62.5	69	K = 0.7 ; P > 0.05
Mg2+ (mg/100g)	0.5a	0.2	40	0.6	0.5a	0.2	40	0.4	K = 0.087 ; P > 0.05
Na+ (mg/100g)	0.09a	0.08	88.9	0.22	0.2a	0.1	50	0.4	K = 2.7 ; P > 0.05
C/Nt	11.4a	0.5	4.4	2.2	10.8a	0.6	5.5	2.7	F = 0.6 ; P > 0.001
CEC (mEq /100g)	1.7a	2	117.6	115.6	1.8a	2.2	122.2	0.9	F = 0.3 ; P > 0.001
Ca2+ (mg/100g)	0.6a	0.8	133.3	0.2	0.6a	0,8	133.3	0.3	F = 0.001; P > 0.001
K+ (mg/100g)	0.092a	0.001	1.09	1.08	0.097b	0.001	1.03	1.03	F = 5.9 ; P < 0.001
Clay	0.8a	0.4	50	0.7	1.25a	0.9	72	1.7	K = 0.8 ; P > 0.05
Silt	1.9a	0.5	26.3	1.1	2.04a	1.4	68.6	2.8	K = 1.14 ; P > 0.05
Sand	97.3a	0.5	0.5	0.6	96.7a	1.7	1.7	1.2	K = 3.8 ; P > 0.05

Legend: Ec-t: Standard deviation; CV: Coefficient of variation; Eten: Extent; C: Carbon; Nt: Total nitrogen; P: Available phosphorus; Mg2+: Available magnesium; Na+: Available sodium; C/Nt: Carbon/ Total nitrogen; CEC: Exchangeable bases; Ca2+: Available calcium; K+: Available potassium. The same letter in exposing in a row indicates no significant difference between the variables. Comparisons between variables were made using an ANOVA test to a factor followed by the Tukey test.

Table VI: Statistics of soil parameters with significant differences in inventoried biotopes

Soil parameters	Invaded coconut groves	Non-invaded coconut groves	Test statistics
pH_eau	3.5 ± 0.2^{a}	5.1 ± 0.05^{b}	K = 10.6 ; P < 0.05
Nt (mg/100g)	0.14 ± 0.009^{a}	0.032 ± 0.004^{b}	K = 11.74 ; P < 0.05
K+ (mg/100g)	0.092 ± 0.001^{a}	0.097 ± 0.001^{b}	F = 5.9; P < 0.001

Legend: The values with same letters within a column are not significantly different. Comparisons between soil variables were made using an ANOVA at a factor followed by the Tukey-HSD test for potassium. Comparisons between soil variables were made using a Kruskal-Wallis test followed by the Dunn test for water pH and nitrogen. *** P 0.05 for pH water. *** P 0.05 for nitrogen.

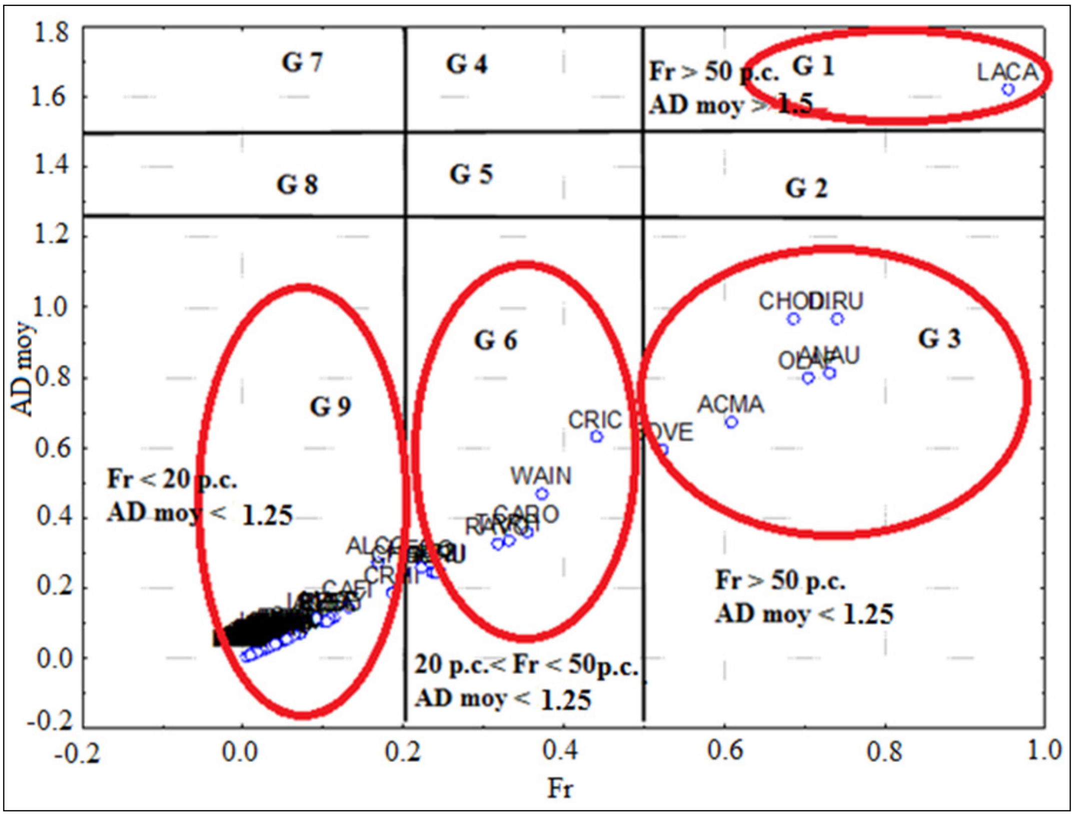

Figure 2: Infestation diagram showing the invasiveness of species at all study sites

Legend: The four letters represent the species names (the first two letters represent the beginning of the genus and the last two letters represent the beginning of the species-specific epithet). **AD moy**: Mean abundance-dominance; **Fr**: Relative frequency

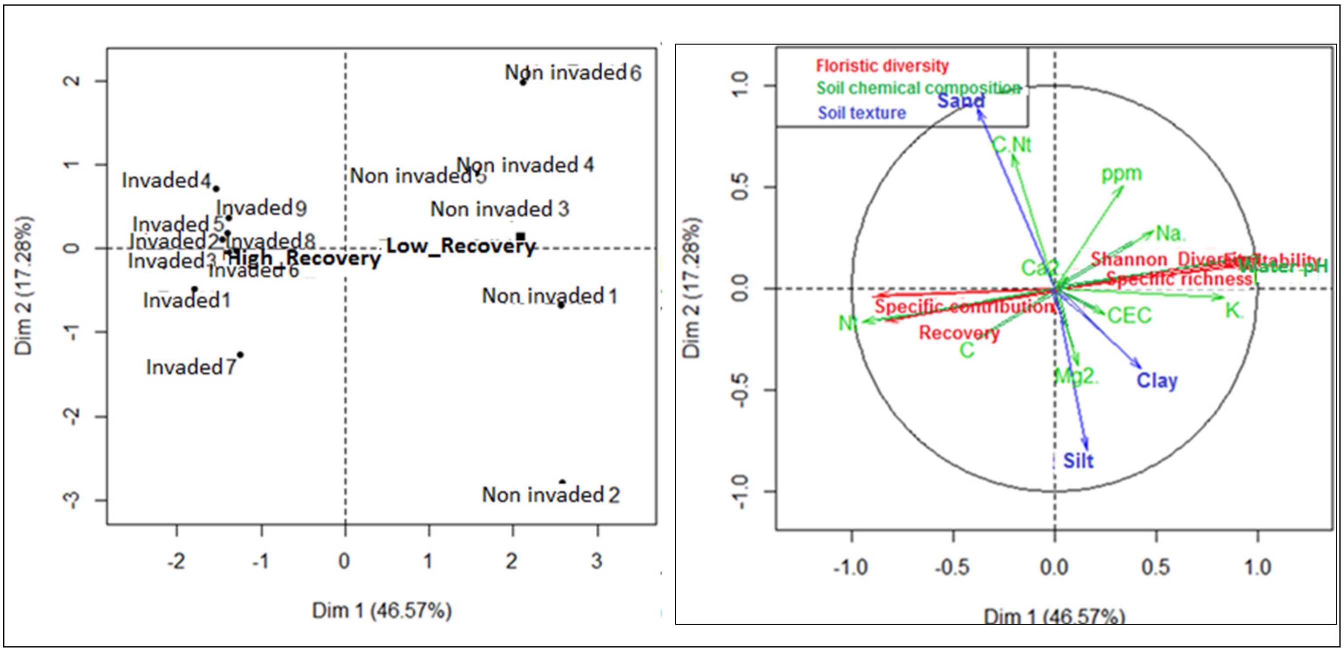

Figure 3: Factorial map and correlation circle of quantitative and qualitative variables used in the AFM

Legend: Dim: Dimensions; C: Carbon; Nt: Total Nitrogen; C.Nt: Carbon/Total Nitrogen; ppm: Available Phosphorus; CEC: Exchangeable Bases; Ca2: Available Calcium; Mag2: Available Magnesium; K: Available Potassium; Na: Available Sodium.

Discussion

A stratum is a set of plants, of a given height, participating in the vertical organization of plant communities (Géhu, 2006). In the present study, a low cover of shrub and tree strata was observed in the coconut groves plantations. These industrial plantations are regularly mowed to facilitate access to the coconut groves. This anthropogenic action provides a good herbaceous conditions conducive to their development (Atta *et al.*, 2010). Adou Yao *et al.* (2011) point out the fact that the maintenance of coconut plantations requires complete clearing to allow the rapid development of seedlings. These disturbances were confirmed by the presence of lianaceous species reflecting disturbed environment (Kouamé, 1998). The abundance of *Lantana camara* in this shrub stratum was related to the ecology of the environment. Sharma *et al.* (2005) point out that invasive species are very present in highly anthropized environments. They also demonstrated that the production of abundant seeds throughout the year allows them having a highly competitive power over native species. Tiébré *et al.* (2018) also reported the proliferation of *Lantana camara* in coconut groves of Mondoukou and Assouindé.

This study also showed that some plant species were resilient to *L. camara* invasion. This could be due to their competitiveness (Djaha *et al.*, 2009). Indeed, species such as *Acacia mangium*, *Calopogonium mucunoides* and *Chromolaena odorata* are alien species that adapted and the two latter have become invasive in Côte d'Ivoire (Maroun, 2017 ; Tiébré and Gnanazan, 2018 ; Akaffou *et al.*, 2019). On the other hand, the disappearance of species in the presence of *L. camara* may be related to their low competitiveness and the shade created by the tufts of *L. camara*. Indeed, the shade created by the foliage contributes to the elimination of herbaceous and other heliophilic species from the flora (Mwoleka, 2019). In addition, the appearance of certain plant species in the presence of *L. camara* can be explained by a spontaneous appearance. This is the case of *Sterculia tragacantha*. Gnahoua *et al.* (2003) have shown that this species appears spontaneously in regenerating environments after repeated disturbances.

In this study the impact of *Lantana camara* on the floristic diversity and physicochemical properties of soil was highlighted by comparing invaded and uninvaded plots, the latter being used as control. This method was already used by Gooden *et al.* (2009); Dobhal *et al.* (2010); Osunkoya et Perrett (2011); Simba *et al.* (2013); Mandal et Joshi (2014) to analyse the impact of alien invasive species. The results showed that invaded coconut groves (62 species) had fewer species than uninvaded ones (94 species). Invaded coconut groves had fewer species than non-invaded coconut groves. Mwoleka (2019) also showed that areas invaded by *Lantana camara* in Bumanya, Bulima and Wampeewo in Uganda had fewer species than uninvaded. In the study of Mwoleka (2019), the number of species increased from 47 to 19 in Bumanya, from 52 to 20 in Bulima and from 57 to 19 in Wampeewo. High specific contribution of *Lantana camara* was also revealed by Senarathne *et al.* (2003) in coconut groves in Fiji, Trinidad, New Hebrides and Sri Lanka. According to Daget and Poissonet (1969), this reflects the depressive effect of *Lantana camara* on other species. In addition, Sharma *et al.* (2005) indicated that the depressant effect came from the high seed production, homeostatic form and phenotypic plasticity of this species. In this study, plant diversity decreased in the invaded coconut groves. Similar results were found by Zende (2016) in Victoria Falls National Park and Imire Ranch in Zimbabwe. This species produces and releases phenolic acids, flavonoids, terpenes and terpenoids that are known to be inhibitors of plant growth (Pysek *et al.*, 2004). These compounds change soil chemical composition and inhibit plant growth in invaded sites. This affirmation is according with Novel weapons hypothesis which states that certain plants can produce and release biochemical substances that have a negative effect on neighbouring plants by inhibiting their development (growth, germination). The result is a reduction of diversity plants in invaded areas. This study also indicated an inequitable distribution of plants in invaded coconut groves. The same results were revealed by Sax and Gaines (2003). For these authors, invasive alien species cause homogenization when they are dominant in the ecosystem. Results of infestation diagram showed that *Lantana camara* was the most harmful plant in coconut groves. Same results were found by Nanjappa *et al.* (2005) in coconut groves of Rji and Trinidad. *Lantana camara* produces allelochemical compounds that affect the roots, stem, and leave of coconut plants (Chaudhary and Bhansali, 2002). Also, these compounds destroy the viability of the seeds and prevents the growth of coconut plants (Chaudhary and Bhansali, 2002). The presence of thorns on *Lantana camara* prevents coconut collection and causes yield losses (Day *et al.*, 2003).

Soil mineral analysis showed differences between water pH, total nitrogen and available potassium concentration in invaded and non-invaded coconut groves. These results are identical to those of Simba *et al.* (2013) and mean that they are important for the growth of *L. camara*. Water pH represents the level of acidity or alkalinity of a given soil (Ndoum, 2010). In this study, water pH became lower in invaded sites than non-invaded sites. This was also observed by Ehrenfeld (2003) and means that soil became more acidic during the invasion of *L. camara*. According to Adéchina (2017) acidity can affect the activity of nitrifying bacteria. Acidic soils are toxic, inhibit plant growth and are less fertile for crops. Nitrogen is an essential nutrient for vegetative growth of plants (F.A.O., 2003). As reported by Simba *et al.* (2013) *Lantana camara* being a highly branched species with a lot of leaf biomass. In the current study, the nutrient concentrations of *Lantana camara* leaves were not measured. However, Jama *et al.* (2000) observed concentrations of 2.8% N and 2.1% K in *Lantana camara* leaves. Our study showed that total nitrogen concentration was higher in soil of invaded sites. These results are similar to those of Mandal and Joshi (2014) that deduced that the increase in nitrogen could be explained by the presence of *Lantana camara*. Indeed, this species drops a large amount of litter under its canopy. After litter decomposition, total nitrogen rate increases in the soil. Wang *et al.* (2015) demonstrated that an increase in total nitrogen allows *Lantana camara* to better express its invasiveness. In addition, it has been demonstrated that high soil nitrogen contents favour the proliferation of invasive plants to the detriment of native plants (Laungani and Knops, 2009). In this study, other alien species have been observed in the presence of *Lantana camara*. There were *Acacia mangium*, *Calopogonium mucunoides* and *Chromolaena odorata. Acacia mangium* was introduced in the coconut groves of southeast Côte d'Ivoire since 1986 for soil nitrogen and organic matter improvement. This species, invasive in other countries (Koutika and Richardson, 2019), is not invasive in Côte d'Ivoire. *Calopogonium mucunoides* and *Chromolaena odorata* are two highly invasive species in Côte d'Ivoire (Akaffou *et al.*, 2019). In the current study, available potassium decreased in the invaded sites. These results are similar to those of Simba *et al.* (2013) in Kenya. According to Thomas and Ellison (2000), *Lantana camara* need available potassium for flowering and seed production (12,000 fruits containing 1 to 2 seeds). This positively affect the growth and spread of *Lantana camara* (Simba *et al.*, 2013).

Conclusion

The floristic inventory listed 120 plants, divided into 101 genera and 41 families in coconut groves of Southeast Côte d'Ivoire. *Lantana camara* is the most common species in coconut groves and is aggressive to native species. The low shrub stratum in the invaded coconut groves is dominated by *Lantana camara* and the study highlights the resilience, disappearance, and appearance of certain species. This proliferation causes a loss of specific diversity and a remarkably high nuisance potential. The soils of the invaded coconut groves are more acidic, poor in minerals and floristic diversity. On the other hand, the soils of uninvaded coconut groves are rich in mineral elements and show a high floristic diversity. This indicates that *L. camara* modifies the chemical properties of the soil. It is therefore necessary to develop strategies to control this invasive alien species.

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