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Diversity of Agroforestry Systems Associated with Vegetable Plots in the Municipality of Thionck-Essyl (Bignona Department, Senegal)

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Abstract

In Senegal, as in the sub-Saharan zone, tree and shrub species are generally introduced into the fields and thus constitute an integral part of agricultural, forestry, and pastoral production systems called agroforestry systems. With a view to better management of these systems, this study aimed to contribute to a better understanding of these agrarian systems in Lower Casamance. To this end, surveys of woody vegetation were conducted in seven (07) of the 14 market garden blocks in the commune of Thionck-Essyl. On the basis of a survey rate of 25% in relation to the surface area, 15 square plots of 2500 m^2 each were installed. The woody flora of these agroforestry systems included 31 species divided into 25 genera belonging to 14 botanical families. The basal area, the cover rate, and the observed density of woody plants are respectively 6 $m^2 \cdot ha^{-1}$; 46% and 67% individuals ha^{-1}. The most frequent species in these agroforestry systems are *Elaeis guineensis* Jacq. (85%), *Citrus sinensis* (L.) Osbeck (71%) and *Mangifera indica* L. (71%). The dominant height class is [2 - 4 m] with 23% of the woody stand in these agroforestry systems. The horizontal structure is characterized by a good representation of individuals with a diameter between 5 and 15 cm (31%). This study constitutes the basis of information necessary for more rational management of these agrarian systems so important in the life of the populations of the commune of Thionck-Essyl.

Keywords

Characterization, Agroforestry Systems, Thionck-Essyl, Market Gardening Plots

1. Introduction

In sub-Saharan natural landscapes, tree and shrub species are generally intro-

duced into the field and thus form an integral part of agricultural, forestry, and pastoral production systems. This is an ancient land use system practiced in West Africa for generations, including a discontinuous, low-density woody component. These forested farmlands, as described by [1], have been given the name agroforestry parks [2].

In Senegal, different types of agroforestry parks have been identified based on the dominant woody species, including *Faidherbia albida* (Delile) A. Chev. parks in the Serer country, *Vachellia tortilis* (Frossk) Galasso & Banfi. parks in northern Senegal, *Cordyla pinnata* (A. Rich.) Milne-Redh. parks in the groundnut basin, *Parkia biglobosa* (Jacq.) R. Br. ex G. Don parks, *Borassus akeassii* Bayton, Ouédr a. & Guinkoparks, and *Elaeis guineensis* parks in the Lower Casamance, etc. Of all these types of parks, the *Faidherbia albida* park has been the most studied because of its good distribution in Africa and its clear and visible effect on agricultural production [3].

In Lower Casamance, local people have always maintained or planted forest species in their fields in association with crops and/or livestock. Depending on the arrangement of these trees in the fields in association with crops, different agroforestry systems can be distinguished. In the Commune of Thionck-essyl, in addition to rice and groundnuts, farmers, particularly women, engage in market gardening with the cultivation of tomatoes, okra, bitter eggplant, chili, etc. [4].

These agroforestry systems offer both ecological and socio-economic benefits to the farmers who use them. These benefits include the provision of food for humans and animals, provision of wood for energy, pharmacopoeia, protection, and conservation of soils against water and wind erosion, etc. [5].

However, these systems that provide many services to producers are subject to climatic hazards related to climate change and anthropogenic pressure thus affecting their productive potential. It is therefore urgent to conduct studies on these systems in order to establish their current status.

Thus, while some studies have been conducted on agroforestry parks in Lower Casamance, notably the characterization of agroforestry parks in the districts of Tendouck [6] and Tenghory [7] and the characterization of *Elaeis guineensis*-parks in Lower Casamance [8], this agrarian system associated with market gardening plots remains poorly studied.

It is in this context that this study is conducted with the aim of contributing to a better knowledge of the state of agroforestry systems associated with market gardening in the department of Bignona.

2. Material and Methods

2.1. Presentation of the study area

The commune of Thionck-Essyl (12˚47'08" North and 16˚31'18" West) belonging to the arrondissement of Tendouck (**Figure 1**) is located in Lower Casamance. It belongs to the coastal South Sudanese climate domain [9].

The mean annual rainfall over the 1991-2021 series is 1300 mm (**Figure 2**).

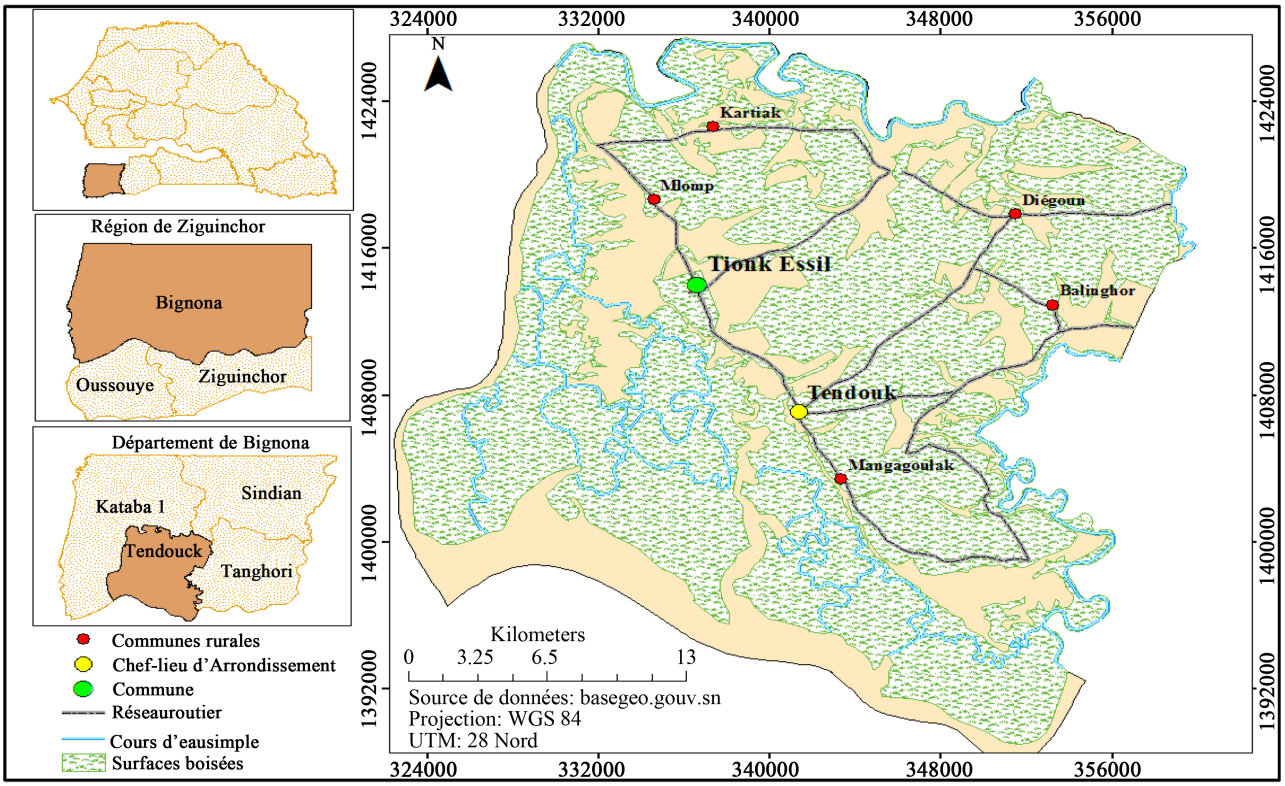

Figure 1. Location map of the municipality of Thionck-essyl. Source: [6].

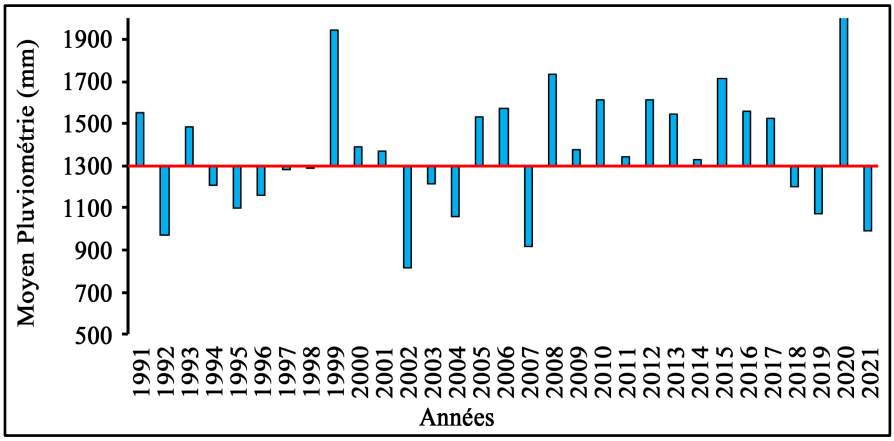

Figure 2. Variation in rainfall from 1991 to 2021 in lower casamance recorded at the ziguinchor regional weather station. Source: [10].

The means of the minimum and maximum monthly temperatures recorded at the Ziguinchor meteorological station are 21.5˚C and 35˚C, respectively, during the 1990 to 2016 series [7].

The terrain is relatively flat and has several types of soils distributed over two main areas: the continental shelf, and the flooded lands of the rice-growing valleys and mangrove forests.

The land of the continental shelf, has two types of soils: leached tropical ferruginous soils and low to medium desaturated ferralitic soils [11] cited by [2].

2.2. Methods Used

Surveys of Woody Vegetation

For the study of woody vegetation in agroforestry systems associated with market gardening plots in the commune of Thionck-Essyl, a sample of seven (07) market gardening blocks corresponding to seven (07) of the fourteen (14) sub-districts of the commune was selected, *i.e.*, a sampling rate of 50%. In Niaganane, two of the four blocks were selected, in Daga two of the four blocks were selected, in Kamanar all three blocks of the sub-district were selected and in Batine none of the three blocks were selected because they were not functional.

In each market garden block selected, square plots of 2500 m^2 each were installed, based on a sampling rate of 25% in relation to the area of each market garden block. Thus, 15 plots were installed in the seven (07) market gardening blocks selected in the sample (Table 1).

For each individual inventoried, the dendrometric parameters were measured. Thus:

- The diameter of the trunk is measured at 1.30 m height using a forestry compass to evaluate the basal area, and establish the horizontal structure of the stand;
- Mean crown diameter is measured with a metric tape in two directions (North-South and East-West) to determine woody cover;
- Tree height is measured with a SUUNTO dendrometer to establish vertical structure.

Trees with a diameter of less than 5 cm at 1.30 m are considered regenerated [12].

The floristic list was established on the basis of the flora of Senegal [13]. Synonyms were updated on the basis of the Enumeration of Flowering Plants of Tropical Africa [14].

2.3. Data Processing and Analysis

The data collected was entered into the Excel 2007 spreadsheet program, which

Table 1. Distribution of plots according to the different vegetable blocks.

Neighborhoods with functional vegetable blocks	Sub-neighborhoods (sample)	Number of plots
Niaganane	Boutame	3
	Gaffanta	1
Daga	Gandong	1
	Bougotir	4
Kamanar	Saaba	2
	Baronkol	1
	Bouloube	3
	Total	**15**

NB: Each sub-neighborhood corresponds to a vegetable block.

was used to create the graphs and tables. The XLSTAT software, version 2014 was used to perform the Principal Component Analysis (PCA). A number of formulas were used to calculate the vegetation parameters:

Specific richness: the total specific richness (S) is the total number of species that the considered stand has in a given ecosystem [15] cited by Ngom [16]. Average specificrichness is the average number of species per survey for a given sample.

The frequency of presence is a method that consists of assessing the distribution of species across surveys. The frequency of presence provides information on the distribution of a species in a stand. It is expressed in %, and is estimated by the following formula:

$$F = \frac{Nr_i}{Nr} \times 100$$

where F = frequency of occurrence expressed as a percentage (%);

Nr_i = number of plots where the species i was found and Nr = total number of plots.

The observed density: it is the number of individuals per unit area (ha). It is the ratio of the total number of individuals in the sample (N) by the sampled area (S).

$$D = \frac{N}{S}$$

Basal area is the basal area of the tree measured at the base of the tree trunk. It is expressed in square meters per hectare ($m^2 \cdot ha^{-1}$). It is therefore obtained from the following formula:

$$S_t = \frac{\sum \pi \left(\frac{d_{1.3}}{2}\right)^2}{S_E}$$

With S_t = basal area; $d_{1.3}$ = diameter in m of the trunk at 1.3 m; S_E = area of the sample considered in ha.

The cover is the area covered by the vertical projection of the tree crown on the ground. It is calculated in square meters per ha.

$$C = \frac{\sum \pi \left(\frac{dmh}{2}\right)^2}{S_E}$$

With C = woody cover; dmh = mean crown diameter in m; S = area of the sample considered in ha.

The Shannon Weaver index (H') considers both abundance, and species richness and is used to assess the distribution of individuals according to species. It is between 0 and 4.5. The index is minimum when all individuals belong to the same species. It is maximum when each individual represents a distinct species [17]. It can be expressed in bits and its formula is:

$$H' = -\sum p_i \log_2 p_i$$

p_i is the frequency of species i H' is minimal (equal to 0) if all individuals in the stand belong to the same species.

The Pielou equitability index (E) measures the distribution of individuals within species, independently of specific richness. Its value varies from 0 (particular dominance of one of the species) to 1 (equidistribution of individuals within species) [16]. It is given by the following formula:

$$E = H'/H'_{\max}$$

$H'_{\max} = \log_2 S$ (S = total number of species).

The stand regeneration rate (SRR) is given by the percentage ratio of the total number of seedlings to the total stand size.

$$\text{SRR} = \frac{\text{Total number of seedlings}}{\text{Total stand size}} \times 100$$

3. Results

3.1. Floristic Composition of Agroforestry Systems

The plant community of the agroforestry systems associated with the vegetable plots is rich in 31 woody species divided into 25 genera from 14 botanical families (**Table 2**).

The most represented families are Fabaceae, Rutaceae, Moraceae, and Meliaceae with respectively 25%, 12%, 12%, and 9% of the inventoried species.

According to the vegetable blocks, the greatest floristic diversity is observed in the vegetable block of Boutame (Bt) with 19 species distributed in 18 genera and 10 botanical families. The vegetable blocks with the least floristic diversity are those of Gaffanta (Ga) and Gandong (Gd) (**Table 3**).

3.2. Frequency Analysis

The analysis of the table below shows that in the agroforestry systems associated with vegetable plots, the most frequent woody species are: *Elaeis guineensis* (85%), *Mangifera indica*, *Citrus limon*, and *Citrus sinensis* with 71% each.

3.3. Structural Characteristics of Agroforestry Systems Associated with Vegetable Plots

- **Basal area**

The basal area is 45 $m^2 \cdot ha^{-1}$ in the agroforestry systems associated with market garden plots in the Commune of Thionck-Essyl. It is higher in the agroforestry systems associated with the market garden plots of Boutame (28 m^2/ha), Gaffanta (17 m^2/ha) and Baronkol (7 m^2/ha). *Mangifera indica* is the dominant species in these different vegetable plots with 3.65, 4 and 4.12 $m^2 \cdot ha^{-1}$/ha respectively (**Table 4**).

- **Woody cover**

The woody cover rate is 47% in the agroforestry systems associated with market

Table 2. Floristic composition of agroforestry systems associated vegetable plots in the municipality of Thionck-Essyl.

			Vegetables blocks						
Families	**genera**	**Species**	**Bt**	**Ga**	**Gd**	**Bg**	**Sa**	**Br**	**Bl**
Anacardiaceae	*Mangifera*	*Mangifera indica* L.	+	+	−	−	+	+	−
Arecaceae	*Borassus*	*Borassus akeassii* Bay, Ouedr. & Guinko..	+	−	+	−	+	−	−
	Elaeis	*Elaeis guineensis* Jacq.	+	+	+	−	+	+	+
Bombacaceae	*Ceiba*	*Ceiba pentandra* (L.) Gaerth.	−	−	−	−	−	−	+
Fabaceae	*Danielia*	*Danielia oliveri* Benn.	+	−	−	−	−	−	−
	Dialium	*Dialium guineense* (Willd)	+	−	−	−	+	−	−
	Parkia	*Parkia biglobosa* (Jacq.) Benth.	+	−	−	−	−	−	−
	Sena	*Sena sieberiana* Dc.	−	−	−	+	−	−	−
	Erythrophleum	*Erythrophleum suaveolens* (Guill. & Perr.)	+	−	−	−	−	−	−
	Pterocarpus	*Pterocarpu serinaceus* Poir.	+	−	−	−	−	−	−
	Erythrina	*Erythrina senegalensis* L.	+	−	−	−	−	−	−
	Tamarindus	*Tamarindus indica* L.	+	−	−	−	−	−	−
Euphorbiaceae	*Anthostema*	*Anthostema senegalense* A. Juss.	−	−	−	+	−	+	−
Combretaceae	*Combrétum*	*Combretum micrantum* G. Don	−	−	−	+	−	−	−
Crysobalanacees	*Neocarya*	*Neocarya macrophylla Dc.*	+	−	−	−	−	−	+
	Parinari	*Parinari excelsa* Sabine.	−	−	−	−	−	−	+
Lamiaceae	*Vitex*	*Vitex doniana* Sweet	+	−	−	−	−	−	−
Meliaceae	*Azadirachta*	*Azadirachta indica A.* Juss.	+	−	−	−	−	−	−
	Carapa	*Carapa procera* Dc.	−	−	−	−	−	+	−
	Khaya	*Khaya senegalensis* (Desr.) A. Juss.	+	−	−	−	−	−	−
Moraceae	*Ficus*	*Ficus elastica* Roxb.	−	−	−	+	−	−	−
		Ficus gnaphalocarpa (Miq.) Steud.	−	−	+	−	−	−	+
		Ficus ottoniaefolia Miq.	−	−	+	−	−	−	+
		Ficus sur Forssk.	+	−	−	−	−	−	−
Rubiaceae	*Morinda*	*Morinda citrifolia*	−	−	−	−	+	+	−
Rutaceae	*Citrus*	*Citrus aurantium* L.	−	−	−	−	+	+	−
		Citrus limon (L.) Burm. F.	+	−	+	−	−	−	+
		Citrus reticulata L.	−	+	−	−	−	+	−
		Citrus sinensis (L.) Osbeck	+	+	−	−	+	+	+
Sapindaceae	*Aphania*	*Aphania senegalensis* (Jus) Radlk.	+	−	−	−	−	−	−
Ulmaceae	*Celtis*	*Celtis toka* Forssk.	+	−	−	−	−	−	−

Legend: Bt: Boutame, Ga: Gaffanta, Gd: Gandong, Bg: Bougotir, Sa: Saaba, Br: Baronkol, Bl: Bouloube. Present = + and Absent = −.

Table 3. Frequency of presence of woody species according to vegetable blocks in the municipality of Thionck-Essyl.

Species	Frenquency (%)
Anthostema senegalense A. Juss.	14
Aphania senegalensis (Juss.) Radlk.	14
Azadirachta indica A. Juss.	29
Borassus akeassii. Bayton, Ouedr. & Guino.	43
Carapa procera Dc.	29
Sena sieberiana DC.	14
Ceiba pentandra (L.) Gaerth.	29
Celtis toka Forssk.	14
Citrus aurantium L.	43
Citrus limon (*L.*) *Burm.* F.	71
Citrus reticulata L.	57
Citrus sinensis (L.) Osbeck	71
Combretum micrantum G. Don	29
Danielia oliveri Benn.	14
Dialium guineense (Willd)	14
Elaeis guineensis Jacq.	85
Erythrina senegalensis L.	14
Erythrophleum suaveolens (Guill. & Perr.)	14
Ficus elastica Roxb.	29
Ficus gnaphalocarpa (Miq.) Steud.	29
Ficus ottoniaefolia Miq.	14
Ficus sur Forssk.	14
Khaya senegalensis (Desr.) A. Juss.	29
Mangifera indica L.	71
Morinda citrifolia L.	14
Neocarya macrophylla Dc.	29
Parinari excelsa Sabine.	14
Parkia biglobosa (Jacq.) Benth.	14
Pterocarpus erinaceus Poir.	14
Tamarindus indica L.	14
Vitex doniana Sweet	14

gardening in the commune. It is highest in Boutame (91%), Gaffanta (63%) and Baronkol (55%). In the agroforestry systems associated with market gardening plots in Boutame and Gaffanta, the species that contributes the most to the cover is *Mangifera indica* with 52.38% and 45.8% respectively (Table 4).

Table 4. Characteristics of woody vegetation in agroforestry systems according to vegetable blocks.

	Vegetable blocks						
Parameters	**Boutame**	**Gaffanta**	**Gandong**	**Bougotir**	**Saaba**	**Baronkol**	**Bouloube**
Specific Richness	19	4	4	13	9	6	8
Basal area (m^2/ha)	8	17	4	4	3	7	2
Woody cover (%)	91	63	21	32	31	55	31
Shannon Index (Bits)	2.15	1.68	0.45	2.49	2.24	2.39	2.58
Pielou Index	0.58	0.76	0.73	0.75	0.81	0.92	0.87
Regeneration rate (%)	46	20	92	35	30	4	36
Density (individuals/ha)	99	120	44	40	78	112	40

- **Observed density**

The observed density of woody species is 67 individuals ha^{-1} in the agroforestry systems associated with market garden plots in the Commune of Thionck-essyl, and is higher in the market garden plots of Gaffanta (120 plants/ha), Baronkol (112 plants/ha) and Boutame (99 plants/ha) (Table 4). The woody species with the highest densities in these vegetable plots were *Mangifera indica* (36 individuals/ha) and *Elaeisguineensis* (53 individuals/ha), respectively.

- **Specific diversity**

Shannon's diversity index takes into account not only the specificrichness but also the abundance of each species and is independent of the sample size. Thus, the Pielou Index is more appropriate for comparing stands with different specificrichness.

It appears that the species diversity is quite high in all the market garden blocks with a Pielou Index that exceeds 0.5 everywhere. This diversity is higher in Baronkol (H' = 2.39 bits; E = 0.92) and lower in Boutame (H' = 2.15; E = 0.58 (Table 4).

- **Regeneration rate of woody vegetation in agroforestry systems**

The regeneration rate of woody vegetation in the vegetable plots of the municipality is 38%. It is highest in the vegetables plots of Gandong (92%), Boutame (46%) and Bouloube (36%) (Table 4).

3.4. Structural Typology of Agroforestry Systems

The Principal Component Analysis (PCA) gives a total inertia of 71.64% (41.60% for the F1 axis and 30.03% for the F2 axis) which is sufficient for a good representation of the information contained in the matrix (Table 5).

Figure 3 represents the typology of agroforestry systems associated with market gardening plots in the Commune of Thionck-Essyl, based on the characteristics of woody vegetation, it allowed us to identify three groups according to the F1 × F2 factorial plan.

Thus we distinguish:

- Group A or agroforestry systems represented by the market garden plots of Bouloube, Saaba, Bougotir and Baronkol. These agroforestry systems are characterized by high specific diversity.

Table 5. Eigenvalues and inertia of the first four factorial axes.

	F1	F2	F3	F4
Eigenvalues	2.912	2.102	1.699	0.214
Inertia (%)	41.605	30.033	24.273	3.058
Cumulative inertia (%)	41.605	71.637	95.911	98.969

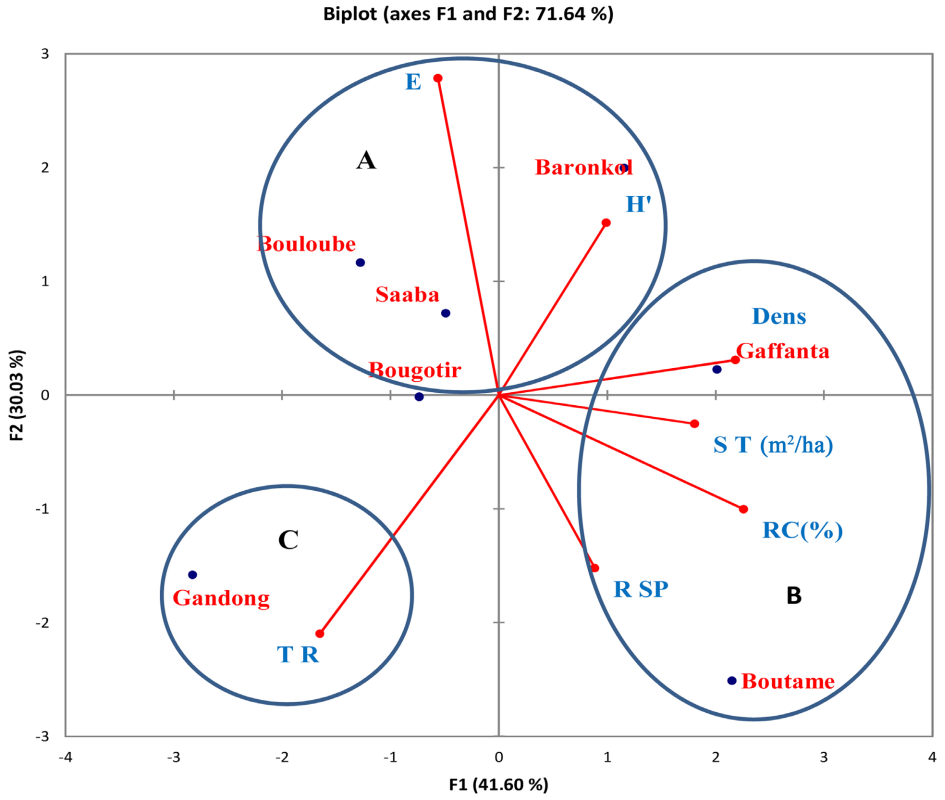

Figure 3. Characteristics of agroforestry systems associated with vegetable plots. Legend: E = Pielou Index; H' = Shannon Index; Dens = density; S T = basal area; R C = cover rate; R SP = species richness; T R = regeneration rate.

- Group B or agroforestry systems represented by the market garden plots of Gaffanta and Boutame, characterized by a high density, basal area, cover rate, and species richness.
- And finally group C or the agroforestry systems represented by the market garden plot of Gandong, characterized by a high regeneration rate.

There was a strong correlation between density and basal area (r = 0.78), between density and cover rate (0.75) and between cover rate and basal area (0.61). This means that in the commune of ThionckEssyl, agroforestry systems associated with market gardening beara high density of woody vegetation. Their trees have a high basal area and cover. And the parks with trees of a high basal area have a high coverage rate. There was also an inverse correlation between species diversity and regeneration rate, meaning that when the regeneration rate of agroforestry systems is high, the diversity is low.

3.5. Demographic Structure of the Woody Stand in Agroforestry Systems Associated with Market Gardening

- **Vertical structure**

The vertical structure of agroforestry systems associated with market gardening plots is characterized by a predominance of individuals between 2 and 4 m in height (23%), followed by individuals between 12 and 14 m in height (18%). Individuals over 16 m in height are poorly represented with 8% of the stand (Figure 4).

- **Horizontal structure**

The results showed that the dominant diameter class in the agroforestry systems is [5 - 15 cm] with 31% of the individuals in the stand (Figure 5). This is followed by the classes [25 - 35] and [35 - 45 cm], each with 19% of individuals. Individuals with a diameter greater than 55 cm are poorly represented (4%).

4. Discussion

The objective of this work is to characterize the agroforestry systems at the level of the vegetable plots of the Municipality of Thionck-Essyl. In these agrarian

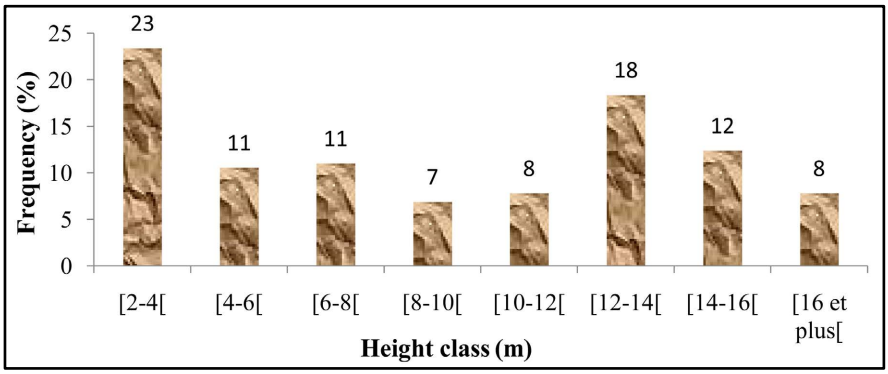

Figure 4. Distribution by height classes of individuals in the woody stand of agroforestry systems associated with vegetable plots.

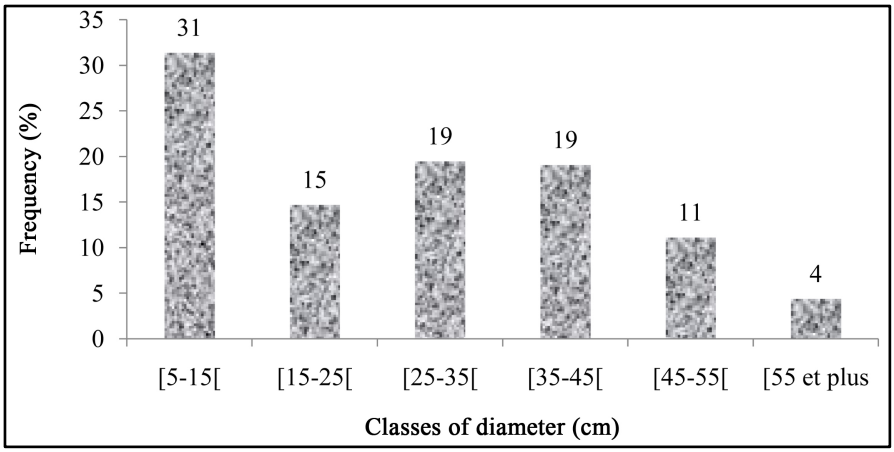

Figure 5. Distribution by diameter classes of individuals in the woody stand of agroforestry systems associated with vegetable plots.

systems, the flora is rich of 31 woody species distributed in 25 genera belonging to 14 botanical families. The most represented families are *Fabaceae*, *Rutaceae*, *Moraceae,* and *Meliaceae* with respectively 25%, 12%, 12%, and 9% of inventoried species.

These results are similar to those of [18] who found 32 species distributed in 29 genera belonging to 17 botanical families in agroforestry parks in the commune of Diegoune and those of [19] who found 32 species distributed in 26 genera and belonging to 14 botanical families in agroforestry parks in the commune of Sindian in the department of Bignona. This could be explained by the fact that these three Municipalities (Diegoune, Sindian, and Thionck-Essyl) are in the same eco-geographic zone which is the lower Casamance.

The basal area is 6 m^2/ha. It is higher in the market garden plots of Boutame (17 m^2/ha), Gaffanta (28 m^2/ha), and Baronkol (7 m^2/ha). These results are very low compared to those found by [20] in the fields of the Nema terroir where the average basal area is 67.9 m^2/ha.

The mean woody cover rate is 47%. It is higher in agroforestry systems associated with vegetable plots in Boutame (91%). In these systems, the species that contribute most to the cover is *Mangifera indica*. This represents a handicap because the shade of the mango trees prevents cultivation under the canopy [21]. In addition, the decomposition of mango leaves is slow even if composted.

The actual density of woody species in agroforestry systems at the vegetable plot level is 67 individuals/ha. This density is relatively high compared to that obtained by [6] in the agroforestry parks of the Tendouck district in Lower Casamance, which is 41.55 individuals/ha.

The regeneration rate of the woody stand in agroforestry systems associated with market gardening plots is 38%. This rate is low compared to that obtained by [7] who recorded a regeneration rate of 95.8% in agroforestry parks in the Tenghory district of Lower Casamance. This low regeneration rate reflects difficulties related to low recruitment of seedlings as stated by [22]. Indeed, the latter are eliminated during clearing and land preparation activities for the establishment of vegetable crops.

The distribution of individuals by height classes is very variable (**Figure 4**). Indeed, the classes [2; 4[, [12; 14[and [14; 16[largely dominate with respectively 23%, 18% and 12% of the individuals of the woody stand. These three classes are followed by [4; 6] and [6; 8], each representing 11%. These results show that these agroforestry systems are made up of relatively young individuals. This result is consistent with that obtained in the Commune of Tendouck by [23] who states that *Parkia biglobosa* displays a rather young stand with 77.24% of the individuals ranging in height from 8 to 18 m.

The horizontal structure is characterized by the predominance of individuals with a diameter between 5 and 15 cm. This reflects the youthfulness of the woody stand in the parks. Individuals belonging to the intermediate classes are also well represented, which indicates good recruitment of young individuals to the

adult classes. The low representation of individuals with a diameter greater than 55 cm could be explained by their cutting by producers to reduce competition with crops.

5. Conclusions

This study has established the characteristics of agroforestry systems associated with vegetable plots in the municipality of Thionck-essyl. The woody flora of these agrarian systems is rich in 31 woody species divided into 25 genera from 14 botanical families. The most represented families are *Fabaceae*, *Rutaceae*, *Moraceae*, and *Meliaceae*. The most frequent woody species in these systems are *Elaeis guineensis* (85%), *Mangifera indica* (71%), and *Citrus sinensis* (71%).

The cover rate, basal area, and stand density are respectively 46%, 67.9 m^2/ha, and 67 individuals/ha. As for the regeneration rate of the woody vegetation, it is 38%. The vertical structure of the woody stand of the parks is characterized by a predominance of individuals of the class [2; 4] with 23% of the individuals of the woody stand and the horizontal structure by a predominance of individuals of diameter between 5 and 15 cm (31%).

It would therefore be appropriate to continue the study of these agroforestry systems by addressing certain aspects such as the socio-economic interest of woody species associated with market garden plots and the influence of their density on the productivity of vegetable crops.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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