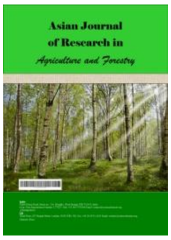

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Agromorphological Characterization of a Rubber Tree-Teak Agroforestry System in Central Côte d'Ivoire

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Faced with environmental issues, soil degradation and the scarcity of arable land, farmers are adopting several cropping practices, including agroforestry. It is in this context that a study entitled "Agromorphological characterization of a rubber tree-teak agroforestry system in central Côte d'Ivoire" was carried out in order to assess the effects of this crop combination on the agromorphological parameters of these crops.

Place and Duration of Study: The study was carried out in Lomo Sud, a village in the city of Toumodi (central Côte d'Ivoire) from February to August 2022.

Methodology: Two experiments were carried out on two plots, a rubber tree one and a teak one. On the rubber tree plot, ten treatments were defined depending on their proximity to teak. On the teak plot, seven treatments were determined depending on their proximity to rubber trees. On each plot, the experimental design was in *one tree plot design*. The parameters taken into account in the study on rubber trees were stand, girth, rubber yield and rate of tapping panel dryness. For teak, the parameters assessed were stand, girth, straightness, cylindricity, branching, pruning and health condition.

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Results: For rubber trees, the results showed that teak negatively influenced the number of rubber trees under tapping, growth and rubber yield, which were reduced by 125, 18 and 110%, respectively. For teak, the results showed that rubber trees positively influenced the growth, straightness, branching and pruning of teak.
Conclusion: The rubber tree-teak agroforestry system assessed in central Côte d'Ivoire is beneficial for teak but detrimental to rubber trees.

Keywords: Agroforestry system; rubber tree; teak; agromorphological parameters.

1. INTRODUCTION

The major agricultural development projects undertaken around the 1970s in Côte d'Ivoire led to the creation of numerous agro-industrial complexes and smallholdings throughout the Ivorian territory [1]. This development policy, although having enormously contributed to the economic development of Côte d'Ivoire, has, in contrast, reduced the Ivorian forest cover. Agriculture has long been one of the main factors in the decline of the Ivorian forest massif. The surface area of the Ivorian forest fell from 16.55 million to around 2 million hectares from 1960 to 2014; that is, a reduction in the cover rate from 78% to 13% [2] and an annual deforestation rate of 2.66% between 2000 and 2015 [3]. Indeed, according to a BNETD [4] study on land occupation and land use, it shows an area of 4.8 million ha for the coffee and cocoa binomial, 1.4 million ha for cashew, 0.6 million ha for rubber and 0.4 million for oil palm and coconut binomal.

This decrease in forest cover would be the cause of variations in rainfall due to the decrease in evapotranspiration. The effects of climate change are perceptible in the agricultural environment with variations in rainfall cycles and reductions in yields and farmers' incomes. Thus, Ivorian farmers are faced with many environmental challenges (decline in soil fertility, drop in yields, drop in farmers' incomes, surface warming) [5].

To overcome this, the Ivorian state has adopted the fifteenth Sustainable Development Goal (SDG) which reads as follows: “Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss” [6]. As from 2014, in order to be in tune with the realities of the rural environment, and to better protect biodiversity, Ivorian forest policies were revised through the adoption of a new forest code. This code incorporated innovations in the management of Ivorian forests such as community management and agroforestry [7]. Thus, so as to reduce its impact on deforestation and biodiversity loss, the Ivorian State has initiated several projects for the recovery and improvement of the forest cover through agroforestry. The promotion of agroforestry has led agro-industrial companies and individuals to engage in this practice. Agroforestry plantations based on cash crops such as cocoa, coffee and rubber tree have therefore been created. Our study, which relates to the assessment of a rubber tree-teak agroforestry system in Toumodi in central Côte d'Ivoire fits in this perspective. The general objective of this study is to contribute to the recovery of the forest cover. More specifically, this study will help:

- determine the influence of teak stands on the agronomic and sanitary parameters of the rubber tree.
- assess the effect of rubber tree on the agro-morphological, health and quality parameters of teak.

2. MATERIALS AND METHODS

2.1 Presentation of the Study Area

The study was carried out in Lomo Sud, a village in the city of Toumodi. Toumodi is a city in central Côte d’Ivoire, located at 194 km from Abidjan, with a surface area of 6809 km^2. The region of Toumodi shows a slightly uneven relief, with some plateaus (whose average altitude varies between 200 and 300 m) and chains of granite hills. Its vegetation is composed of woodland, grassland savannah and gallery forests. The climate of this region is similar to that of tropical zones. It is characterized by a dry season, a long rainy season, a short dry season and a short rainy season. The average annual precipitation varies between 1000 and 1200 mm^3. As for the temperature, it averages around 30°C. The soils of the region of Toumodi are of three types. They include ferralitic soils, clayey or sandy-humic or hydromorphic soils and soils composed of basic rocks and cuirasses [8].

2.2 Study Material

2.2.1 Plant material

The plant material consisted of clone GT1 of rubber tree (*Hevea brasiliensis*) and teak (*Tectona grandis L*) plants. Teak is a reforestation plant species. Cultivation of the rubber trees started in 2008 over a surface area of one hectare at a density of 555 plants/ha. The plants were in their sixth year of tapping at the time the data was taken.

Cultivation of the teak started in 2006 over a surface area of one hectare at a density of 1111 trees/ha.

2.2.2 Technical material

The material used in the field consisted of:

- a tape measure for measuring the girth of trees;
- forms for collecting data;
- a camera for taking pictures;
- a scale for weighing the rubber.

2.3 Methods

2.3.1 Experimental design

Two experiments were conducted on two plots, a rubber tree plot and a teak plot (Fig. 1), 5 m apart.

The trial on rubber trees included 10 treatments (Table 1). Each treatment consisted of a line of rubber trees. Treatment T1A was the closest to teak and treatment T10A was the farthest from teak.

The trial on teak included 7 treatments (Table 2). Each treatment consisted of a line of teak. Treatment T1B was the closest to rubber trees and treatment T7B was the farthest from rubber trees.

For each trial, the experimental design was in *one tree plot design* (a tree constitutes a repetition). For the trial on rubber trees, the distance per treatment varied from 5 to 32 m while for the one on teak, the distance per treatment varied from 5 to 23 m. The study was carried out from February to August 2022.

2.3.2 Parameters measured

2.3.2.1 Parameters measured on rubber trees

An inventory was carried out at each location so as to determine the number of rubber trees present and the number of missing rubber trees. Then for each rubber tree present, it was checked whether it was under tapping or not. Then, for each rubber tree under tapping, the number of years of tapping was determined by counting.

Rubber trees' girth measurements were taken once a month at 1.70 m from the ground using a tape measure (Fig. 2). Girth measurements were expressed in cm. For each rubber tree, the monthly rubber yield over six months was weighed using a scale. The yields were expressed in grams per month (g/m) (Fig. 3).

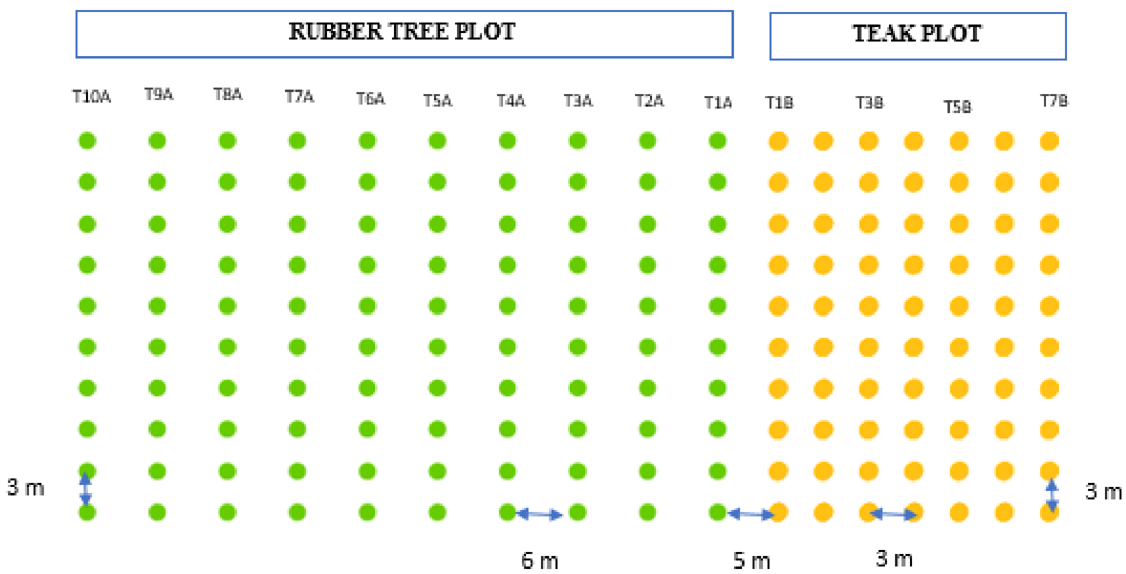

Fig. 1. Experimental design

Table 1. Characteristics of the treatments in the trial on rubber trees

Treatments	Characteristics of rubber trees	Distance from teaks
T1A	Fist line	5 m
T2A	Second line	8 m
T3A	Third line	11 m
T4A	Fourth line	14 m
T5A	Fifth line	17 m
T6A	Sixth line	20 m
T7A	Seventh line	23 m
T8A	Eighth line	26 m
T9A	Ninth line	29 m
T10A	Tenth line	32 m

Table 2. Characteristics of the treatments in the trial on teak

Treatments	Characteristics of teaks	Distance from rubber trees
T1B	Fist line	5 m
T2B	Second line	8 m
T3B	Third line	11 m
T4B	Fourth line	14 m
T5B	Fifth line	17 m
T6B	Sixth line	20 m
T7B	Seventh line	23 m

Fig. 2. Rubber trees' girth measurement

Fig. 3. Rubber yield weighing

Tapping panel dryness is a disease that is expressed by the partial or total stoppage of the flow of latex after tapping. After each tapping, the tapping panel dryness rate (TPDR) of each rubber tree was determined by the following relationship:

TPDR% = (DC / TCL) x100

With DC: Dry Cut and TCL: Total Cut Length
Cut length measurements were taken using a tape measure.
The TPDR was expressed as a percentage (%).

2.3.2.2 Parameters measured on teak

An inventory was carried out on each elementary plot in order to determine the number of teak present and the number of missing teak. Then the girth of each teak was measured using a tape measure at 1.30 m from the ground. These values were expressed in cm (Fig. 4). The quality of teak is defined as the potential capacity to be exploited with a good yield [9]. The value of a teak is seen in the first meters of the stem. Five quality parameters were assessed according to three classes of value rated from 1 to 3. These parameters were: straightness, cylindricity, branching, pruning and health condition. Straightness is the rectilinear aspect of the main stem. Cylindricity is the cylindrical appearance of the trunk. Branching was assessed in relation to the height of the main stem. Pruning was assessed in relation to the size of ramifications and the health condition was assessed in relation to the state of life of the teak [10,11] (Table 3).

2.4 Statistical Analyses

The data collected was subjected to a one-way analysis of variance (ANOVA) with XLSTAT 2022 2.1 software. This analysis made it possible to compare the plants for their agronomic, morphological and health parameters. Moreover, this analysis was used to assess the effects of each crop (rubber tree and teak) on the measured parameters of the plants. In case of significant differences at 5% threshold, Tukey's test was used to compare the means.

Fig. 4. Measurements of teak' girth

Table 3. Rating of qualitative parameters of teak [10,11]

Parameters	**Rating**		
	1	**2**	**3**
Straightness	Tree having two curvatures or more	Tree having one curvature	Straight tree without curvature
Cylindricity	Tree with two or more flat portions	Tree with one flat portion	Perfectly circular tree; no flat portion
Branching	Tree with several large branches	Tree with one large branch	Tree without large branch
Pruning	Tree having no thin branches	Tree having few thin branches	Tree having several thin branches
Health condition	Dead tree	Living but attacked tree	Living and unattacked tree

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Influence of teak on rubber trees

3.1.1.1 Density of the rubber tree stand

The results of the assessment of the number of rubber trees depending on the treatments are shown in Fig. 5. The number of rubber trees present varied from 28 to 44 and the number of missing ones from 19 to 35. Treatment T1A (closest to teak) had the lowest number of rubber trees present (28) and treatment T10A (farthest from teak) had the highest number of rubber trees present (44). Concerning missing rubber trees, treatment T1A showed the highest number (35) and treatment T10A, the lowest number (19). The number of rubber trees present increased when getting away from teak (from T1A to T10A).

3.1.1.2 Number of rubber trees under tapping

Table 4 shows the number of rubber trees under tapping depending on the treatments. The number of rubber trees under tapping varied from 13 to 36. Treatment T2A showed the lowest number of rubber trees under tapping and treatment T10A showed the highest number of rubber trees under tapping. The difference in the number of rubber trees under tapping between the rubber trees closest to teak and the rubber trees farthest from teak was +125%.

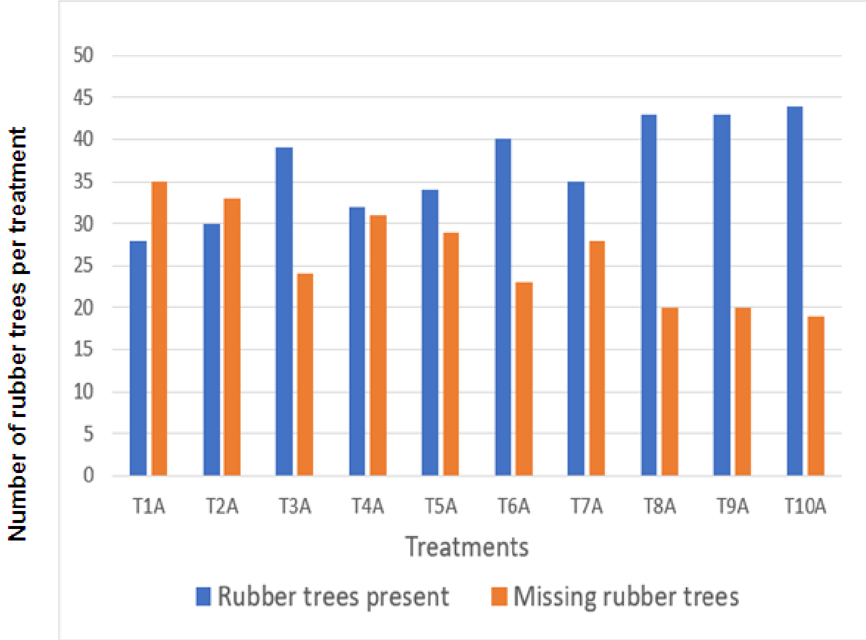

Fig. 5. Number of rubber trees inventoried depending on the treatments

Table 4. Number of rubber trees under tapping depending on treatments

Treatments	Number of rubber trees under tapping	% T1A
T1A	16	-
T2A	13	-19
T3A	23	+44
T4A	19	+19
T5A	23	+44
T6A	29	+81
T7A	23	+44
T8A	31	+94
T9A	28	+75
T10A	36	+125

%T1A: percentage of the number of rubber trees under tapping compared to treatment T1A

Table 5. Number of years the rubber trees have been tapped depending on the treatments

Treatments	Average of number of years the rubber trees have been tapped	%T1A
T1A	2.26 b	-
T2A	2.57ab	+14
T3A	2.65ab	+17
T4A	2.31ab	+2
T5A	2.47ab	+9
T6A	2.52ab	+12
T7A	2.29ab	+1
T8A	2.38ab	+5
T9A	2.37ab	+5
T10A	2.69a	+19
Significant	Yes	
P	0.001	

%T1A: Percentage of the number of years the rubber trees have been tapped compared to treatment T1A
The results assigned the same letter are not significantly different (Newman-Keuls test at 5%)

3.1.1.3 Number of years the rubber trees have been tapped

The numbers of years the rubber trees have been tapped are shown in Table 5. The numbers of years of tapping varied from 2.26 to 2.69. These results reveal a significant difference in the treatments (p=0.001). Treatment T10A showed the greatest number of years the trees have been tapped, statistically identical to those of treatments T9A, T8A, T7A, T6A, T5A, T4A, T3A and T2A. The number of years of tapping of treatment T10A is significantly higher than that of treatment T1A. Treatments TA1 to TA9 showed identical statistical number of years the rubber trees have been tapped. The difference in the number of years the rubber trees have been tapped between the rubber trees closest to teak and the rubber trees farthest from teak was +19%.

3.1.1.4 Girth of rubber trees

The average girths of the rubber trees are shown in Table 6. The girths of the rubber trees varied from 39.70 cm (T1A) to 47.58 cm (T10A). The treatments closest to the teak recorded the smallest girths and the farthest treatments recorded the largest girths. The difference in girth between the rubber trees closest to teak and the rubber trees farthest from teak was +18%.

3.1.1.5 Rubber yield

Table 7 shows the cumulative yield per month of each treatment. Rubber yields varied from 5,600 to 12,090 g/m. Treatment T10A showed a high rubber yield which was statistically identical to those of the treatments T8A and T6A and higher than those of treatments T7A, T5A, T4A, T3A,

Table 6. Girths of rubber trees depending on the treatments

Treatments	Average of girths of rubber trees (cm)	%T1A
T1A	39.70c	-
T2A	41.18bc	+4
T3A	40.81bc	+3
T4A	40.62bc	+2
T5A	44.9abc	+13
T6A	45.13abc	+14
T7A	42.92abc	+8
T8A	46.00ab	+16
T9A	46.92a	+15
T10A	47.58a	+18
Significant	Yes	
P	0.001	

%T1A: percentage of the average of girths of rubber trees compared to treatment T1A
The results assigned the same letter are not significantly different (Newman-Keuls test at 5%).

Table 7. Rubber yield in gram per month (g/m) depending on the treatments

Treatments	Rubber yield (g/m)	% T1A
T1A	5760 cde	-
T2A	3800 e	-34
T3A	8730 abc	+52
T4A	5600 de	-3
T5A	7020 cd	+22
T6A	9490 ab	+65
T7A	7720 bc	+34
T8A	10380 ab	+80
T9A	7890 abc	+37
T10A	12090 a	+110
Significant	Yes	
P	0.001	

%T1A: percentage of the rubber yield compared to treatment T1A
The results assigned the same letter are not significantly different (Newman-Keuls test at 5%)

T2A and T1A. Treatments T1A, T2A and T4A showed the lowest rubber yields. The difference in yield between the rubber trees closest to teak and the rubber trees farthest from teak was +110%.

3.1.1.6 Taping panel dryness rate

Table 8 shows the tapping panel dryness rate. Tapping panel dryness rate ranged from 12.44% to 17.68%. These results showed that there is a significant difference between the treatments (p = 0.001). In fact, treatments T1A, T3A and T8A showed the highest tapping panel dryness rates, statistically identical to that of treatment T7A and significantly higher than those of the other treatments. However, treatment T10A had the lowest tapping panel dryness rate, statistically identical to those of treatments T2A, T4A, T5A and T6A.

3.1.1.7 Correlation between parameters measured on rubber trees and their proximity to teak

Statistical analysis show that the presence of teak significantly influenced the number of rubber trees per treatment, the number of trees under tapping, the girth and the rubber yield (Table 9). Indeed, there is a strong positive correlation between the number of rubber trees and their distance from teak (0.91), a positive correlation between the number of rubber trees under tapping and their distance from teak (0.89), a positive correlation between rubber yield of rubber trees and their distance from teak (0.76) and a very strong positive correlation (0.93) between the girth of rubber trees and their distance from teak. The number of rubber trees, the girth, rubber yield and the distance from teak therefore evolve in the same direction. In other words, the closer the rubber trees are to teak, the lower the number of rubber trees, the girth and rubber yield. However, the number of years the rubber trees have been tapped and the tapping panel dryness rate were not influenced by teak.

3.1.2 Influence of rubber trees on teak

3.1.2.1 Quantitative parameters

3.1.2.1.1 Teak stand density

Teak stand densities varied between 99 and 108. Treatment T3B has the smallest stand (99 trees) and the T2B and T4B treatments the highest densities (107 and 108 trees, Fig. 6).

3.1.2.1.2 Girths of teak

Table 10 shows the girths of teak depending on the treatments. The girths of teak varied from 60.45 to 78.46 cm. Treatment T1B showed the largest girths, significantly greater than the ones of the other treatments. Treatments T2B to T7B had statistically equivalent girths. The difference in girth between the teak closest to the rubber trees (T1B) and the teak farthest from the rubber trees (T7B) was -21%.

3.1.2.2 Quality parameters of teak

3.1.2.2.1 Straightness

Fig. 7 shows the variation in the straightness of teak depending on the treatments. The teak from all the treatments (with the exception of treatment T6B) showed mainly one to two curvatures (rating 2). For treatment T6B, the number of teak with straightness rating 1 (presence of more than two curvatures) was identical to those with rating 3 (no curvature). The number of teak with rating 3 decreased from T4B treatment to treatment T7B. The farther we got from the rubber trees, the more the number of teak showing no curvature decreased.

Table 8. Tapping panel dryness rate of rubber trees depending on the treatments

Treatments	Tapping panel dryness rate (%)
T1A	17.32a
T2A	14.27bcd
T3A	17.68a
T4A	14.40bcd
T5A	13.46cd
T6A	13.95cd
T7A	15.96ab
T8A	17.08a
T9A	14.94bc
T10A	12.44d
Significant	Yes
P	0,001

The results assigned the same letter are not significantly different (Newman-Keuls test at 5%)

Table 9. Correlation between the parameters measured on rubber trees and their distance from teak

Source of variation	Average	Standard deviation	Number of observations	Correlation coefficient (r)
Number of rubber trees present	35.5	6.98	630	0.91*
Girth	43.4	10.31	630	0.93*
Yield	41.58	13.32	630	0.76*
Tapping panel dryness rate	15.15	3.85	630	0.15
Number of years the trees have been tapped	2.45	0.72	630 .00	0.13
Number of trees under tapping	24.1	7.05	630	0.89*

** Significant correlation*

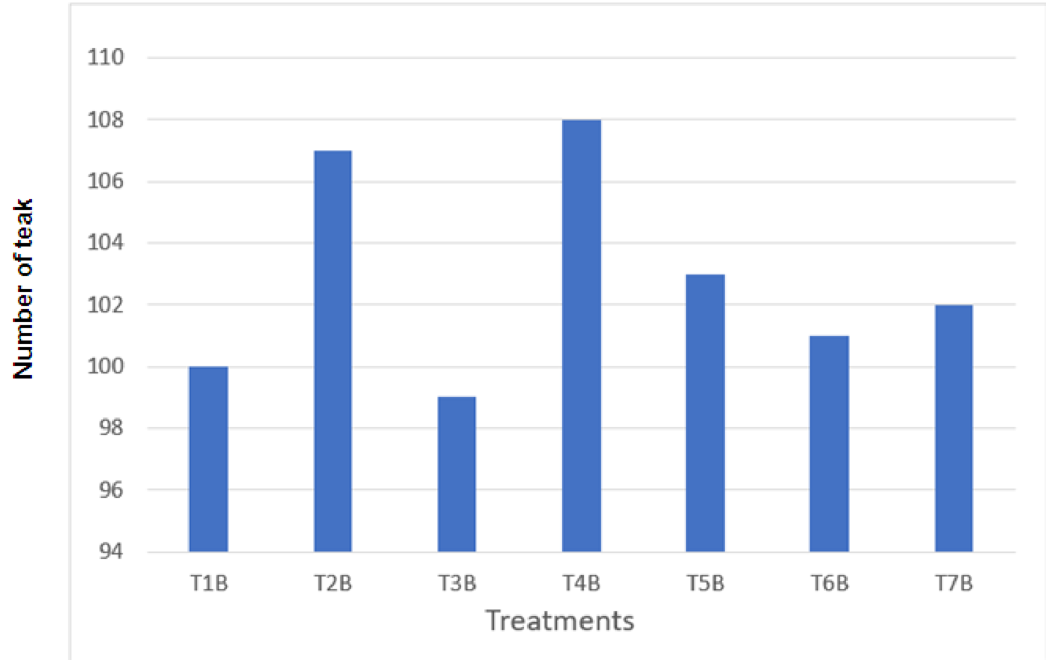

Fig. 6. Stand of teak according to the treatments

Table I0. Girths of teak depending on the treatments

Treatments	Average of girths of teak	% T1B
T1B	78.46a	-
T2B	60.47b	-23
T3B	60.78b	-23
T4B	60.89b	-22
T5B	57.91b	-26
T6B	57.64b	-27
T7B	62.38b	-21
Significant	Yes	
P	0.000	

%T1B: Percentage of the girth of the treatments depending on treatment T1B
The results assigned the same letter are not significantly different (Newman-Keuls test at 5%)

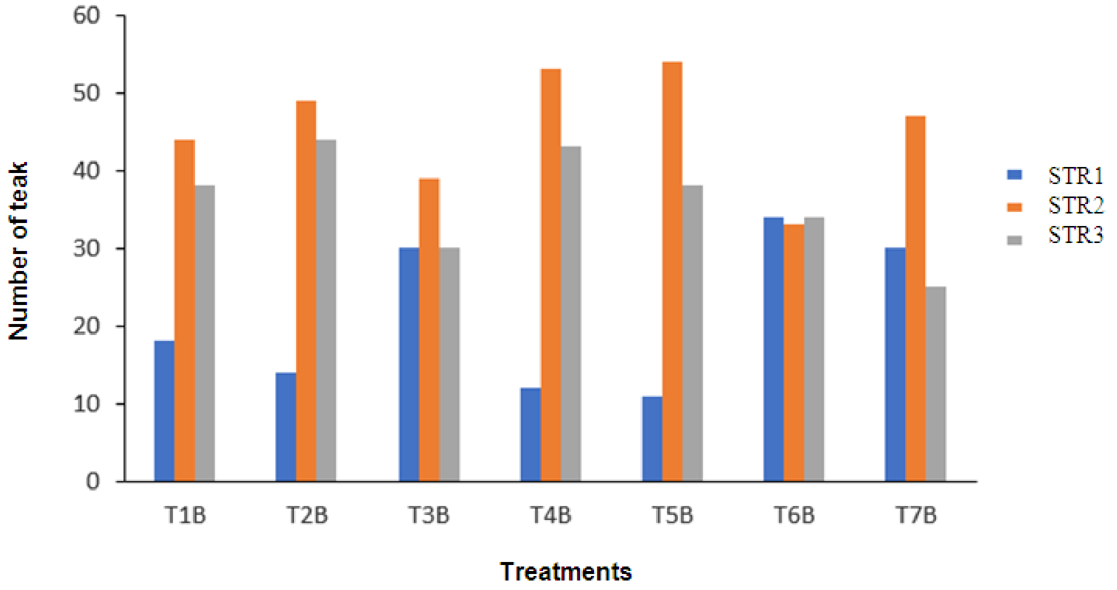

Fig. 7. Variation in straightness of teak depending on the treatments
STR1 - Straightness rating 1 (teak with more than two curvatures)
STR2 - Straightness rating 2 (teak with one or two curvatures)
STR3 - Straightness rating 3 (teak with no curvatures)

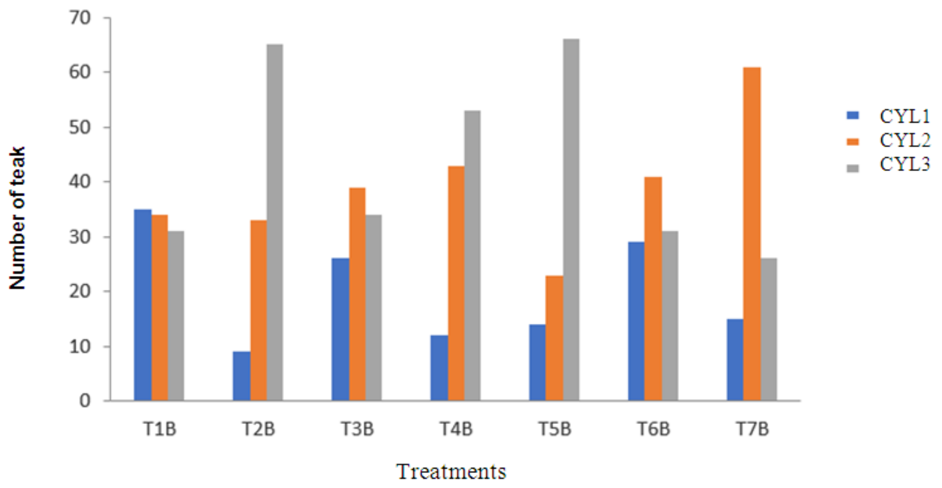

Fig. 8. Variation in the cylindricity of teak depending on the treatments
CYL1 - Cylindricity rating 1 (teak with more than two flat portions)
CYL2 - Cylindricity rating 2 (teak with a one flat portion)
CYL3 - Cylindricity rating 3 (teak showing no flat portion)

3.1.2.2.2 Cylindricity

The variations in the cylindricity of teak as a function of the treatments have been presented in Fig. 8. The teak of the treatments T2B, T4B and T5B mainly code for rating 3 (no flats). Teak from treatments T3B, T6B and T7B mainly coded for rating 2 (presence of more than two flats). T1B treatment teak coded for rating 1 (presence of several flats).

3.1.2.2.3 Branching

Fig. 9 shows the branching variations depending on the treatments. Teak from treatments T1B, T2B, T3B, T4B and T5B (closer to rubber trees) coded mainly for rating 3 (no large branches). Teak from treatments T6B and T7B (farther from rubber trees) coded more for rating 2 (one or two large branches). The closer the teak were to the rubber trees, the less they had large branches and were therefore of better quality.

3.1.2.2.4 Pruning

Fig. 10 shows the variations in pruning depending on the treatments. Teak from treatments T1B, T2B, T3B, T4B and T5B (closer to rubber trees) showed mainly rating 3 (trees with several thin branches that were easy to prune). Almost all of the teak from treatments T6B and T7B (farther from the rubber trees) had rating 2 (presence of few thin branches).

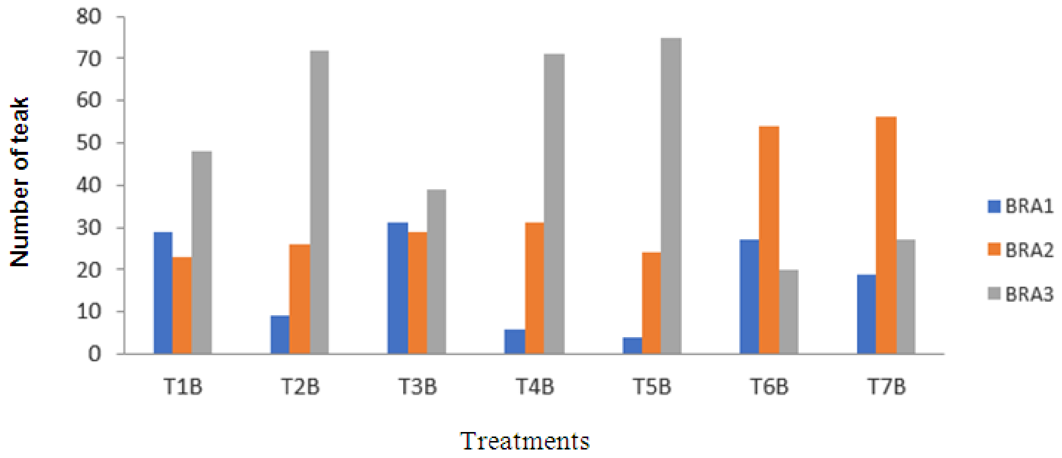

Fig. 9. Variation in the branching of teak depending on the treatments
BRA1 - Branching rating 1 (teak with several large branches)
BRA2 - Branching rating 2 (teak with one or two large branches)
BRA3 - Branching rating 3 (teak with no large branch)

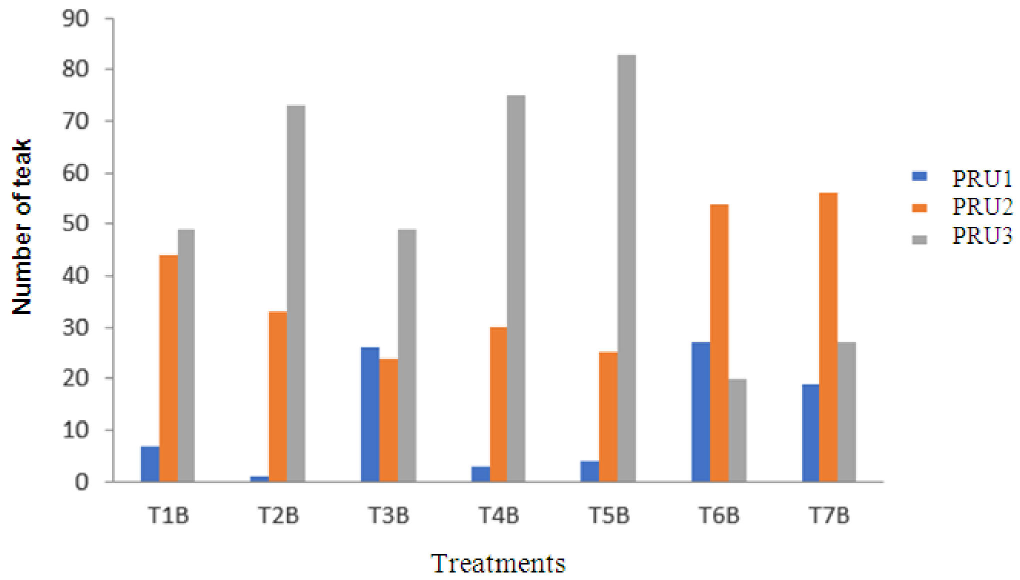

Fig. 10. Variation in teak pruning depending on the treatments
PRU1 - Pruning rating 1 (teak with no thin branche)
PRU2 - Pruning rating 2 (teak with few thin branches)
PRU3 - Pruning rating 3 (teak with several thin branches)

3.1.2.2.5 Health condition

The variations in the health condition of teak depending on the treatments are represented in Fig. 11. This graph shows that the teak of all the treatments were healthy. However, one to two trees of treatments T1B, T3B, T5B and T6B were attacked.

3.1.2.3 Correlation between parameters measured on teak and their proximity to rubber trees

Statistical tests showed that the presence of rubber trees influences the girth of teak but does not influence their total number (Table 11). There is a significant negative correlation (-0.609) between the girth of teak and their distance from rubber trees. The girth of teak decreased as we got away from rubber trees.

3.1.2.4 Relationship between quantitative, qualitative parameters and treatments

Ordination by multiple factor analysis (MFA) made it possible to relate the quantitative parameters (girth and stand of the teak), the qualitative parameters (straightness, cylindricity, branching, pruning and health condition) and the treatments (T1B, T2B, T3B, T4B, T5B, T6B and T7B). The analysis allowed the use of two axes, axis 1 (principal component 1) and axis 2 (principal component 2) with 72.32% (Fig. 12). The juxtaposition of the two graphs (circle of correlation and graph of individuals) made it possible to divide each one into four sectors (Fig. 12A and 12B). Factor 1 (46.81% of the total variance) is explained on the positive side of the axis with variables PRU1, BRA3, STR3, STR2, CYL3 and on the negative side of the axis with variables BRA1, STR1, PRU3, BRA2, CYL2. The negative side opposes straight, cylindrical teak with thin branches. This axis is called the quality axis. Factor 2 (25.54% of the total variance) is explained on the positive side of the axis by variables D3, D1, PRU2, D4, CYL1 and on the negative side of the axis by variables D2. Opposite the positive axis, teak whose girth was in the girth category D3 (80.5 to 120 cm) and D4 (120.5 to 160 cm) had few thin branches and had several flat portions. This axis is referred to as the axis with the best girth and of poor quality. The hierarchical classification made it possible to identify similar groups of stands (Fig. 13). The first class included treatment T7B. This group was made up of teak that had few large branches and flat portions. The second class included treatments T3B and T6B. This group was made up of teak that had large branches with trunks that were not straight. Moreover, the third class included treatment T1B characterized by teak that were not cylindrical and had few thin branches, but had the largest girths. Finally, the last class was made up of treatments T4B, T5B and T2B characterized by cylindrical, straight teak and having several thin branches.

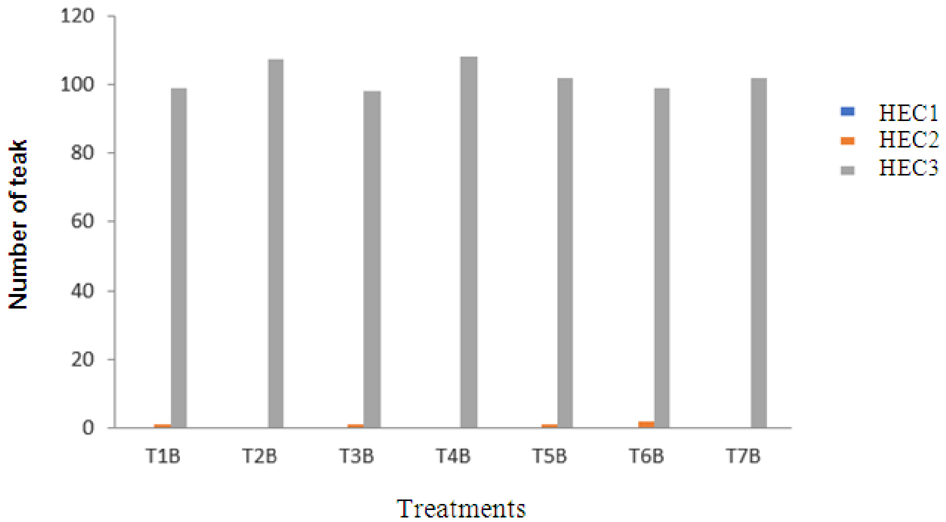

Fig. 11. Variation in the health condition of teak depending on the treatments

HEC1 - Health condition rating 1 (dead teak)

HEC2 - Health condition rating 2 (teak alive but attacked)

HEC3 - Health condition rating 3 (perfectly healthy teak)

Table 11. Correlation between quantitative parameters of teak and their distance from rubber trees

Source of variation	Average	Standard deviation	Number of observations	Correlation coefficient
Number of teaks	102.86	3.44	720	-0.045
Girth	62.64	7.18	720	-0.609

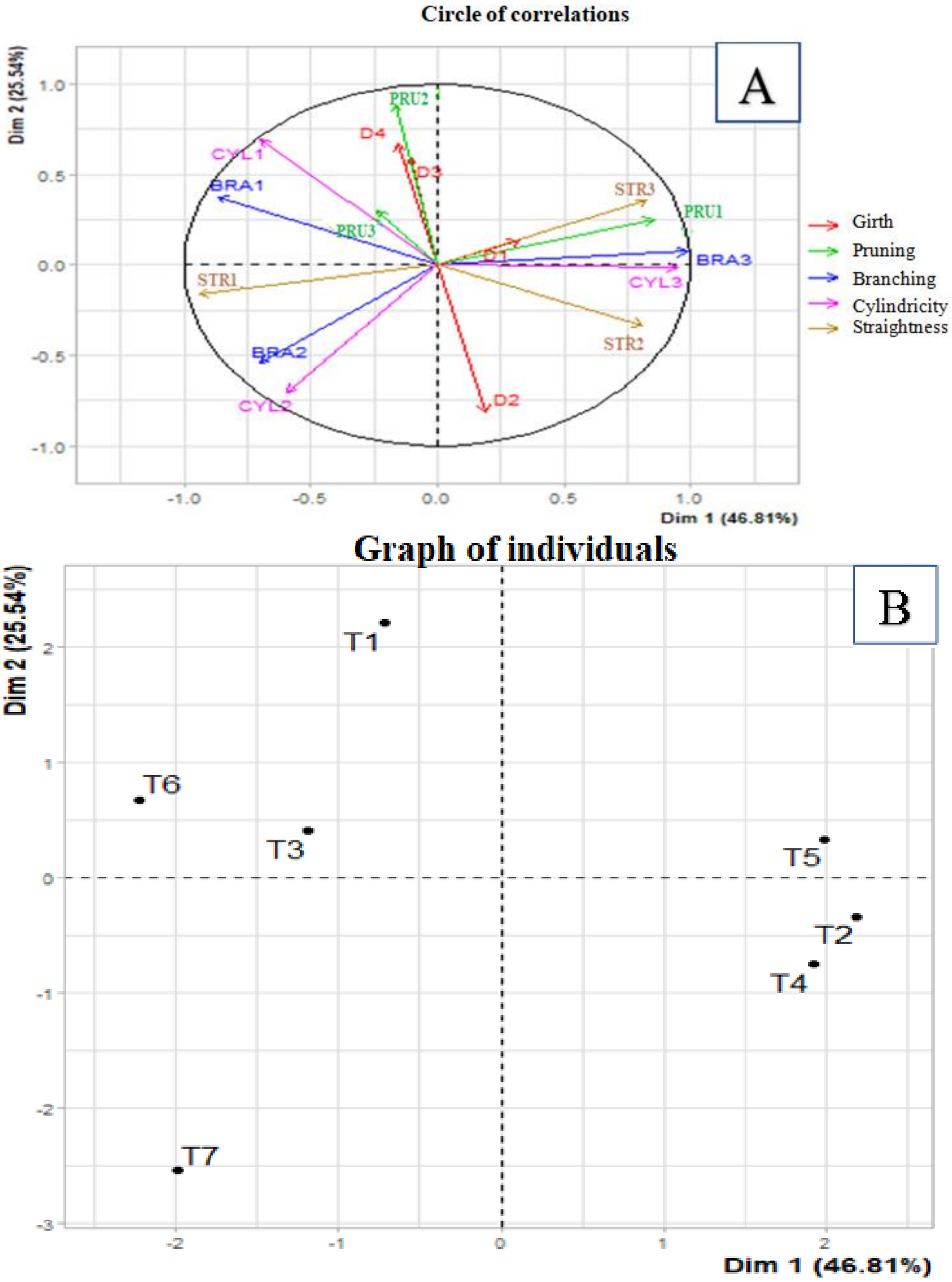

Fig. 12. Multiple factor analysis of qualitative and quantitative parameters in teak stands Circle of correlations (A); graph of individuals (B). D1: First girth category (0-40 cm); D2: Second girth category (40.5-80 cm); D3: Third girth category (80.5-120 cm); D4: Fourth girth category (120.5-160 cm)

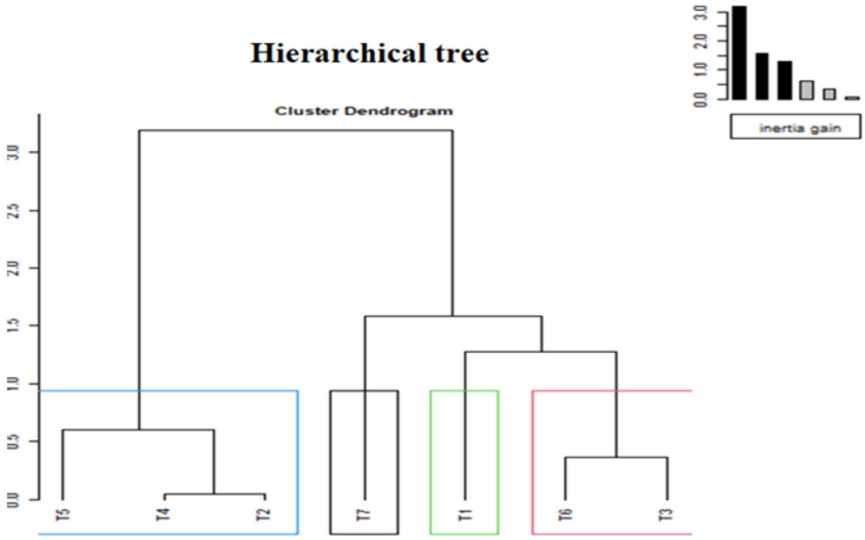

Fig. 13. Analysis of the hierarchical classification of teak treatments

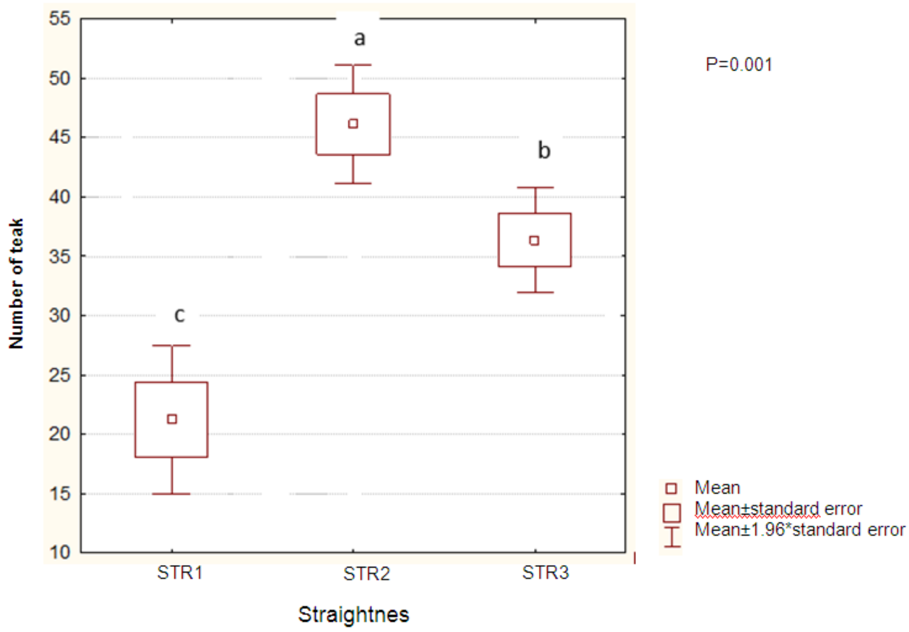

Fig. 14. Variation in the number of teak depending on straightness rating
STR1 - Straightness rating 1 (teak with more than two curvatures)
STR2 - Straightness rating 2 (teak with one or two curvatures)
STR3 - Straightness rating 3 (teak with no curvatures).

3.1.2.5 Qualities of the entire teak stand regardless of the treatments

3.1.2.5.1 Straightness

Fig. 14 shows the variation in the number of teak depending on straightness. The number of teak having straightness rating 2 was statistically higher than the number of teak having ratings 1 and 3. The number of teak having rating 1 was significantly lower than the number of teak having straightness rating 3.

3.1.2.5.2 Cylindricity

The variations in the number of teak depending on cylindricity are shown in Fig. 15. The number of teak having cylindricity rating 3 was statistically identical to the number of teak having rating 2 and significantly higher than the number of teak having rating 1. The number of teak having cylindricity rating 1 was statistically identical to the number of teak having rating 2.

3.1.2.5.3 Branching

The variations in the number of teak depending on branching are shown in Fig. 16. The number of teak having branching rating 3 was identical to those having rating 2 and was significantly higher than those having rating 1. The number of teak having rating 1 was statistically identical to those having branching rating 2.

3.1.2.5.4 Pruning

Fig. 17 shows the variations in teak depending on pruning rating. The number of teak having rating 1 was significantly higher than the number of teak having ratings 2 and 3. The number of teak having rating 2 was significantly higher than those having rating 3.

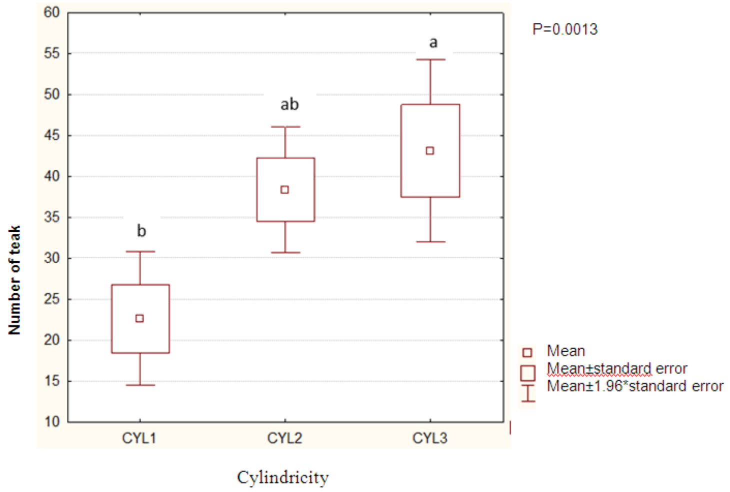

Fig. 15. Variation in the number of teak depending on cylindricity rating
CYL1 - Cylindricity rating 1 (teak with more than two flat portions)
CYL2 - Cylindricity rating 2 (teak with one flat portion)
CYL3 - Cylindricity rating 3 (teak with no flat portion)

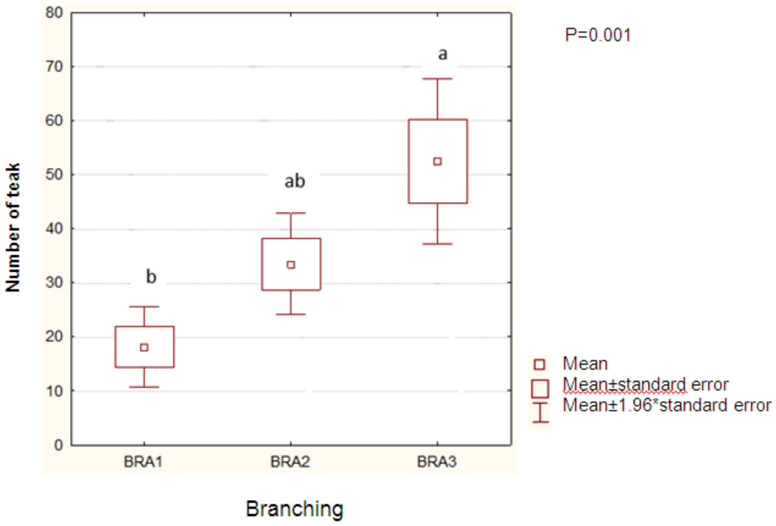

Fig. 16. Variation in the number of teak depending on branching rating
BRA1 - Branching rating 1 (teak with several large branches)
BRA2 - Branching rating 2 (teak with one or two large branches)
BRA3 - Branching rating 3 (teak with no large branch)

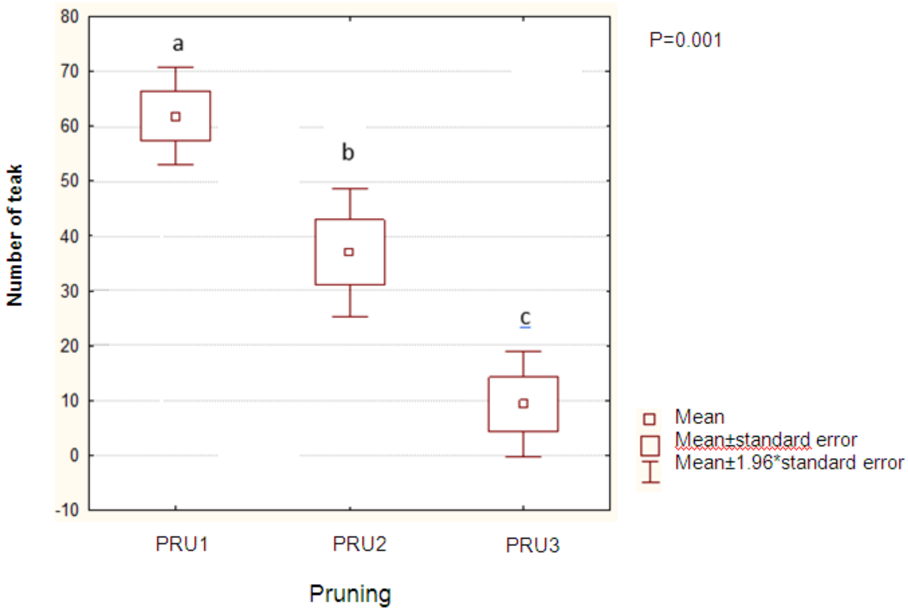

Fig. 17. Variation in the number of teak depending on pruning rating
PRU1 - Pruning rating 1 (teak with no thin branches)
PRU2 - Pruning rating 2 (teak with few thin branches)
PRU3 - Pruning rating 3 (teak with several thin branches)

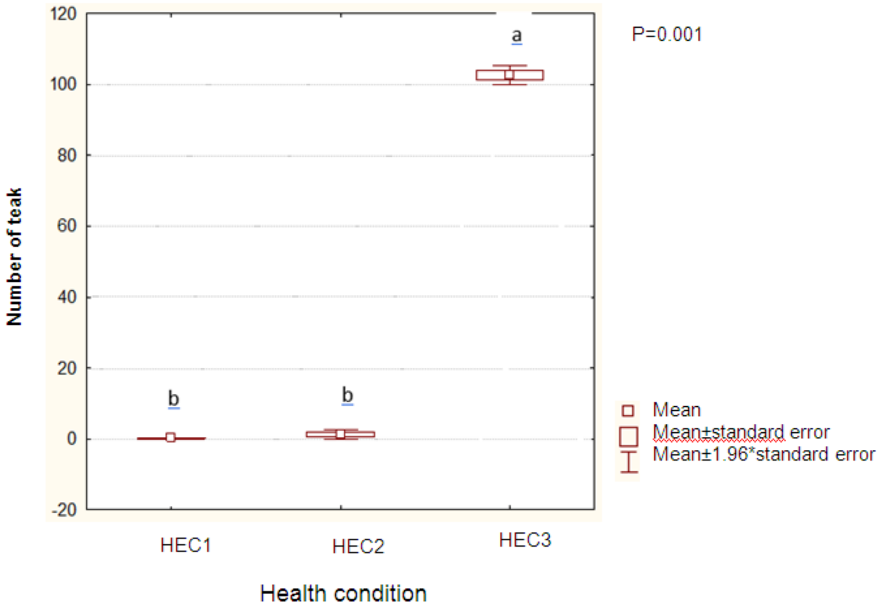

Fig. 18. Variation in the number of teak depending on health condition rating
HEC1 - Health condition rating 1 (dead teak)
HEC2 - Health condition rating 2 (teak alive but attacked)
HEC3 - Health condition rating 3 (perfectly healthy teak)

3.1.2.5.5 Health condition

Fig. 18 shows the variation in the number of teak depending on health condition. The number of teak having rating 3 was significantly higher than those having ratings 1 and 2. The number of teak having rating 2 was statistically identical to the number of teak having rating 1.

3.2 Discussion

3.2.1 Influence of teak on the agronomic and health parameters of rubber trees

The results showed a strong incidence of teak on rubber trees in this agroforestry system. Indeed, the farther we got from teak, the more the number of rubber trees under tapping increased (up to +125%). This could be explained by the shade provided by teak leaves which are wider than those of the rubber trees. Thus, the strong shade of teak prevents rubber trees close to them from accessing light in order to carry out photosynthesis, which explains their lower number [12]. Competition for light between the two plants is the main problem. Either the associated plant tolerates shade and can be planted according to a classic planting scheme (6 m x 3 m, for example), or the shade is too competitive and the classic planting design must then be modified.

Moreover, teak influence the girth and therefore the thickness growth of rubber trees. The farther we get from teak, the greater the girths of the rubber trees (up to +18%). This influence may be due to competition of rubber trees and teak for light, water and nutrients as shown by Keli *et al*. [13] in a rubber tree-based cropping system. According to these authors, at least one of the environmental parameters might be involved in these competitions (soil water, mineral elements, light).

Furthermore, the results showed that teak negatively influenced rubber yield. Indeed, the rubber trees closest to the teak induced the lowest yields and the rubber trees farthest from the teak induced the highest yields (up to +110%). This is explained by the fact that rubber trees distant from teak have a larger number of yielding trees and have larger girths. Indeed, rubber yield depends on the number of rubber trees under tapping and the size (girth) of the tapped rubber trees. The larger the girth of the rubber trees, the higher their yield [14]. These results are in agreement with those of Penot and Eschbach [15] who demonstrated in a rubber-teak agroforestry system in a smallholders environment, the need to cut teak after the fourth year, otherwise there would be a marked effect on the growth and yield of rubber trees. However, these results are contrary to those obtained by Jácome et al. [16] in Brazil in a coffee-teak agroforestry system, where an increase in coffee production was recorded after 5 years of cultivation.

Finally, concerning the tapping panel dryness and the number of years the trees have been tapped, analyses have shown that teak do not influence these parameters.

3.2.2 Influence of rubber trees on the quantitative and qualitative parameters of teak

3.2.2.1 Quantitative parameters

The results showed that the rubber trees had no effect on the stand of teak but still positively influence their girth. Indeed, the teak closest to the rubber trees had the largest girths. The presence of rubber trees therefore does not prevent teak from drawing from their environment all the elements they need for their development (light, water and minerals). Competition for these elements of the environment is therefore to the advantage of teak as shown by Penot and Eschbach [15].

3.2.2.2 Qualitative parameters

Concerning straightness, the results showed that the teak were mainly of straightness 2 (having one to two curvatures). Indeed, the teak stand has developed bent trees. This is explained by the fact that the teak have favored their growth in thickness to the detriment of their growth in height.

Moreover, the teak closest to the rubber trees were almost entirely of branching 3 (having no large branches). Rubber trees therefore do not favor the development of large branches in teak. According to the study by Dupuy and Verhaegen [17], only 1% of teak wood from Côte d'Ivoire has thin branches. However, according to our work, it possible to affirm that rubber trees have a significant influence on the branching of teak.

Furthermore, the teak closest to the rubber trees were of pruning 3 (having thin branches that are easy to prune). The development of thin teak branches is therefore favored by the presence of rubber trees. This could be due to the closed canopy of the rubber tree stand. According to Voui [18], an almost closed stand canopy certainly does not allow the development of lateral branches. This assertion is in agreement with our work, which allows us to affirm that rubber trees have a significant effect on the thinness of teak branches.

Finally, the cylindricity and health condition of teak are in no way influenced by rubber trees. According to Dupuy and Verhaegen [17] teak from Côte d'Ivoire is of good quality since it has a survival rate of 85% and is 90% healthy.

3.2.2.3 Relationship between quantitative and qualitative parameters and treatments

The results of the multiple factor analysis showed that there is a relationship between the quantitative and qualitative variables and the treatments. Good health condition was noted in all treatments. The teak of treatments T2B, T4B and T5B were of better quality. Indeed, they had both either one or two curvatures, were perfectly cylindrical (no flat portion) and did not have large branches.

4. CONCLUSION

The purpose of this study is to contribute to the reconstitution of the Ivorian forest canopy through the assessment of a rubber-teak agroforestry system.

At the end of this study, it appears that teak have a significant negative influence on the stand of rubber trees, on their growth, on the number of trees under tapping and on their rubber yield. Indeed, the presence of teak reduces the number of rubber trees under tapping by up to 125%. In addition, teak lead to a decrease of up to 18% in the girth of rubber trees. Finally, teak cause rubber yield losses of up to 110% in rubber trees. However, teak do not have a significant impact on the tapping panel dryness and the number of years the rubber trees have been tapped.

Regarding the influence of rubber trees on teak, qualitatively, it appears that rubber trees have no impact on the stand of teak but have favored a better growth in thickness of the latter. Qualitatively, the presence of rubber trees positively influences the straightness, branching and pruning of teak. Indeed, the teak close to the rubber trees have one or two curvatures (straightness 2), have no large branch (branching 3) and have several thin branches (pruning 3). However, rubber trees have no influence on the cylindricity and health of teak. The proximity of rubber trees to teak has therefore contributed to improving the quality of teak.

The rubber-teak agroforestry system has therefore proven to be beneficial for teak but detrimental for rubber trees.

To better assess the rubber-teak interaction in this agroforestry system, it would be wise to:

- extend the study to several rubber-teak agroforestry plots in several agro-ecological zones of Côte d'Ivoire;
- develop new rubber-teak agroforestry designs;
- create new clones of rubber tree or teak for a sustainable and beneficial crop combination for both crops.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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