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Effects of silvicultural practices on physical quality of stump sprouts of *Tectona grandis* L. f. (Verbenaceae) in association with *Gmelina arborea* Roxb. (Verbenaceae) and *Cedrela odorata* L. (Meliaceae) in classified forest of Bouaflé (Centre-Ouest, Côte d'Ivoire)

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Abstract

In Côte d'Ivoire, woody forest resources have been declining for several decades, mainly due to agriculture. In order to counteract this phenomenon, reforestation with *Tectona grandis* (teak) appears to be a sustainable alternative. The objective is to produce good quality teak wood that can be used to restore the wood potential. In classified forest of Bouaflé, a silvicultural trial was installed to analyse the physical characteristics of teak stump sprouts in pure and mixed stands. Using a Fisher block design, three silvicultural practices were compared according to the physical quality (straightness, branching, health status) of woody stands. The silvicultural treatments were: T1 (pure *Tectona grandis*), T2 (700 *Tectona grandis* + 411 Gmelina arborea) and T3 (400 *Tectona grandis* + 400 *Gmelina arborea* + 400 *Cedrela odorata*). The physical analysis was based on a three-dimensional rating according to three value classes marked 1, 2 and 3. After cinq years of vegetation, the results showed that monospecific stands (T1), with 77.58% healthy trees developed the largest basal area (2.67 m^2/ha). This corresponded to 23.36 m^3/ha of exploitable wood. The most stable trees with fine branches were developed in multi-species plots T2. Finally, we note that multispecies plots (T3) favoured the straightest trees.

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Introduction

The tropical rainforests of west Africa, despite their diversity and high endemism, are among the most threatened ecosystems on the planet (Myers *et al.*, 2000; Archard *et al.*, 2002). Agriculture-related activities still constitute the means of subsistence for about 60% of the active population. In West Africa, agriculture plays an important role in the economic development of countries. On average, it accounts for 70% of total employment, 40% of exported goods and one-third of GDP (FAO, 2015).

In Côte d'Ivoire, 84% of the forest area has disappeared and is now estimated at 1.38 million hectares (Koné, 2015). Illegal activities such as agricultural clearing and overexploitation of forests play an important role in the reduction of forest cover (Ruf and Schroth, 2004). In order to sustain forest resources and mitigate the impact of deforestation, a network of protected areas, consisting of parks, reserves and classified forests has been created (Koné *et al.*, 2012). These protected areas constitute natural spaces capable of preserving and supplying the forestry industry with the main tree species, but also being sources of supply of harvested products for the local populations (Zoro Bi and Kouakou, 2004; Kouassi *et al.*, 2014). Today, the most important deforestation areas are located in classified forests where the annual rate reached 4.2% over the period 2000-2015 (Koné, 2018).

In order to curb this scourge, alternative solutions consisting of recreating monospecific stands of timber, firewood and service wood remain appropriate. Thus, more than 171,000 ha of artificial forests consisting mainly of *Tectonagrandis*, *Gmelina arborea*, *Terminalia superba* and *Cedrelaodorata* have been created. Teak, with over 41%, has become the most important reforestation species in Côte d'Ivoire (Koné *et al.*, 2010). It has many qualities in its wood, including high ecological plasticity, excellent technical properties, strong initial growth in plantations, tolerance to bush fires and high commercial value. This makes teak a species of choice for industrial reforestation (Krékoumou, 2010).

However, in an increasingly competitive international timber market and taking into account consumer demands, the physical quality of teak remains a major concern for foresters in Côte d'Ivoire. This involves improving the conformation of the stems (straightness, cylindricity), branching (size of branches, pruning) and above all the health of the wood. Such results can only be obtained properly if the silviculturist takes into account and applies suitable densities that can have a considerable effect on branch size (Zhang and Chauret, 2001). Finally, numerous studies, notably those of Voui (2014) and Zhang and Chauret (2001), have shown that teak adapts well to other species, notably, woody species (*Gmelina arborea*, *Cedrelaodorata*, *Terminalia superba*) and herbaceous species (*Zea mays*, *Arachis hypogaea*, *Phaseolus vulgaris*), constituting viable systems.

The aim is to rapidly create a forest environment favourable to growth while limiting the development of competing for herbaceous vegetation. The aim is also to create an attractive trunk shape and to limit the development of branching in order to obtain the best possible quality logs (Balandier and Marquier, 1998).

In the classified forest of Bouaflé (centre-west Côte d'Ivoire), teak reforestation has been the subject of several silvicultural techniques: density, regeneration, cropping associations, thinning, and depressing. Thus, behavioural trials in monospecific or multispecific mode have made it possible to determine the best components capable of producing vigorous and good-quality trees. We hypothesize that silvicultural techniques consisting of monospecific and multispecific stands with two or three species improve the physical quality of teak shoots.

The objective is to produce teak wood in quantity and quality, thus providing a marketable and exploitable wood potential. Specifically, the aim is to analyse the effect of silvicultural practices on the physical performance of teak shoots in the classified forest of Bouaflé.

Material and methods

Study area

The study was carried out in the classified forest of Bouaflé, located in the centre-west of Côte d'Ivoire. It is located between 6°46′ and 6°55′ North Latitude and between 6°04′ and 6°15′ West Longitude (SODEFOR, 2014) (Fig. 1). It is in the domain of mesophilic forests (Guillaumet and Adjanohoun, 1971; Monnier, 1983) and covers an area of 20 350 ha. The dense semi-deciduous forest vegetation is dominated by Celtis Sp and *Triplochiton scleroxylon* (Aubréville, 1959).

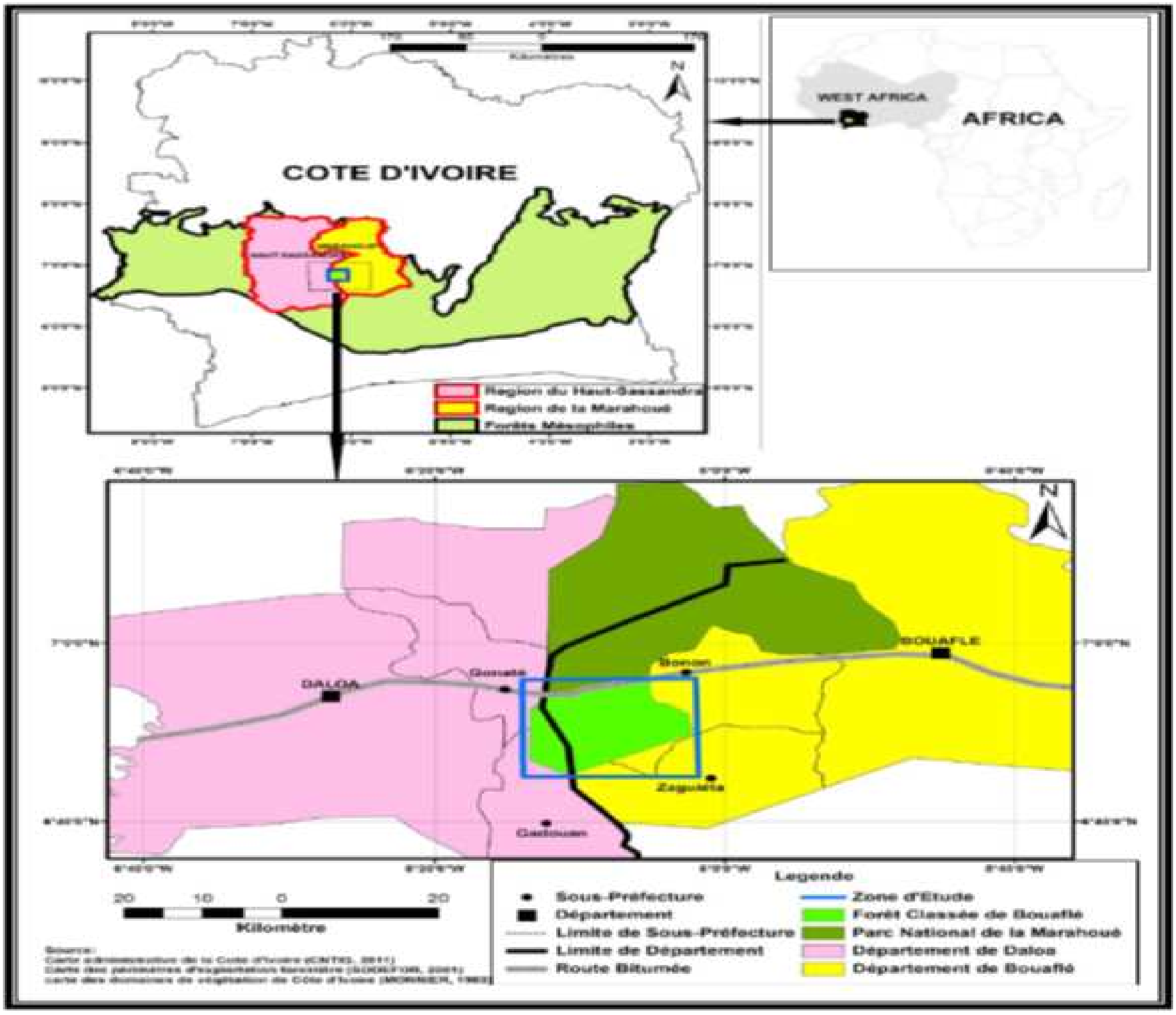

Fig. 1. Geographical location of Bouaflé Classified forest.

The soils are ferralitic and moderately desaturated with a humus horizon that is thin but rich in organic matter, weakly acidic and well structured (Perraud, 1971). The climate is sub-equatorial Atrean. The average annual temperature and rainfall from 1999 to 2019 are 20.3°C and 223 mm respectively (Tah, 2019).

Data collection set-up

Three treatments relating to silvicultural system types were tested in a block design (Fig. 2). Each block comprised one treatment or system. The treatments were labeled as T_1, T_2 and T_3. Each treatment was repeated four times. The elementary plots measured 25 m x 25 m, giving an elementary area of 625 m^2. A 5 m wide strip was left on each side to avoid the border effect.

Within the treatment T_1 (pure teak), the initial spacing was 3 m x 3m, i.e. a density of 1111 plants/ha. The pure *Tectonagrandis* stand consisted of stump sprouts and natural seedlings. Treatment T_2 consisted of 700 plants of *Tectonagrandis* + 411 plants of*Gmelina arborea*, giving a density of 1111 plants/ha. The system consisted of both stump sprouts and natural seedlings of *Tectonagrandis* + *Gmelina arborea*. Treatment T_3 consisted of 400 plants of *Tectonagrandis*+ 400 plants of *Gmelina arborea* + 400 plants of *Cedrelaodorata*. Thus, within the three-species multi-species stand a density of 1200 plants/ha was established. The characteristics of the different stands are given in Table 1.

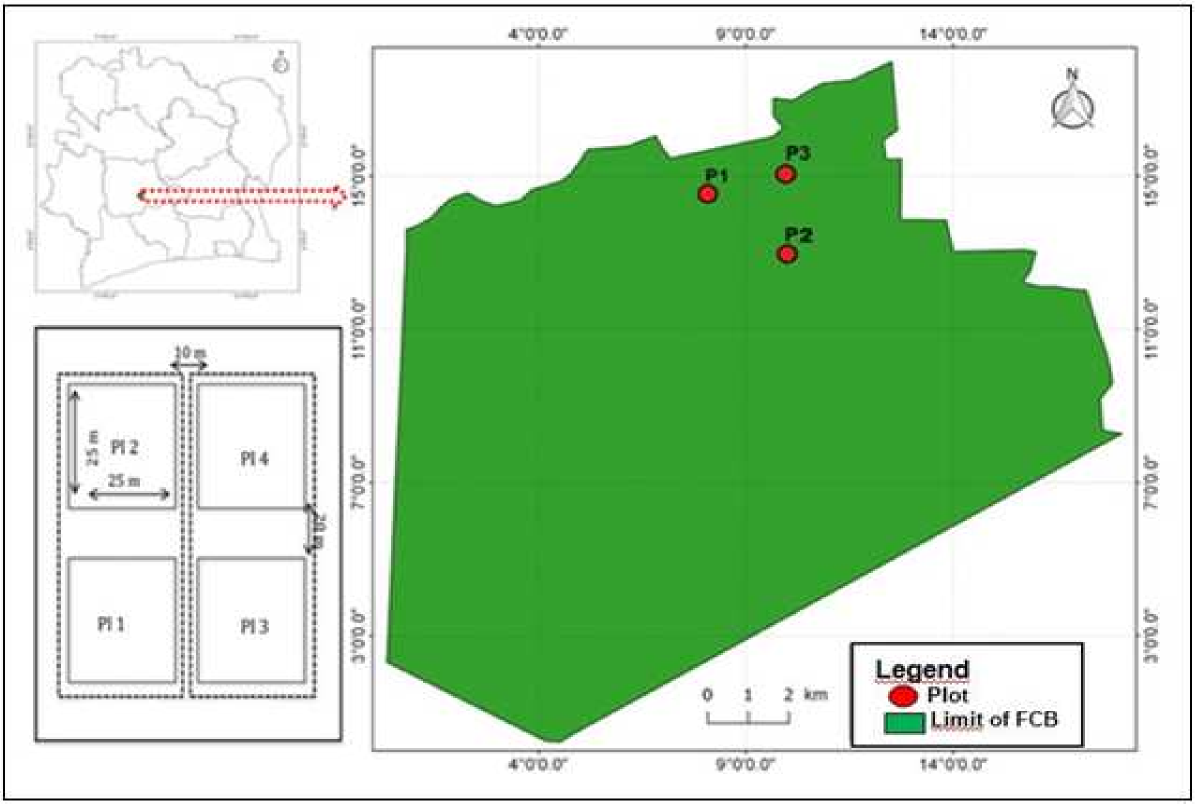

Fig. 2. Data collection device, P-Plot; PL-Sub-plot; FCB-Classified forest of Bouaflé.

Management of regenerated teak stands

All of the woody stands had been clear-cut five years earlier. When the stands were regenerated, the stumps that had been rejected were refreshed flush with a chainsaw in order to initiate new shoots. Natural seedlings shoots were also taken into account in order to maintain the optimal density of about 1100 to 1200 plants/ha. In fact, the stump sprouts were sometimes subject to wind breakage and competition between sprouts from the same stump and different stumps, thus reducing the stand density. During the evolution of the stands, shoot removal and maintenance work was carried out to improve the growth of the shoots. After five years of vegetation, physical quality assessments were carried out on the teak shoots. The qualitative data concerned the straightness, branching and health status of the shoots.

Data analysis

Branching factor (I)

This is an index characterizing the stability of the tree and is defined as the ratio of the average height to the average diameter at breast height (dbh) of the teak stand.

The index varies between three intervals: if I ≤ 80, then the stand is stable; if 80 ≤ I ≤ 100, the trees are unstable; if I ≥ 100, the trees are very unstable and the risk of windthrow is very high (Voui *et al.*, 2015).

The slenderness factor (I) is calculated as follows:

$$I = \frac{H_t}{Dt} \qquad (1)$$

Ht and Dt being the total height and diameter of the average basal area tree of the stand.

Basal area of woody stands

Basal area is the sum of the cross-sections of all trees in a survey assuming cutting at breast height which indicates the degree of infill of a forest. It is an indicator used for forest stand studies. It is also an index of land use and makes it possible to follow the evolution of a stand over time. As a control tool in silviculture, it allows better management of thinning. It thus reflects the degree of competition within the forest stand and constitutes an indirect measure of ground lighting conditions (REDD+, 2021). It can also be used as a descriptor of different stand development stages. It allows rapid comparison between different stands. It is calculated by considering the following formula:

$$G = \frac{\pi}{4}\sum_{i=1}^{n} Dm^2 \qquad (2)$$

With G-stand basal area and Dm-average diameter in cm

Physical quality of teak stump sprouts

The quality of standing trees is defined as the capacity (potential) to be exploited with a good yield (Djimbi and Fouqué, 1998). The estimation of standing trees thus makes it possible to improve the operational character of the inventory for the various actors in the timber sector. It provides useful data for commercial negotiations between the forest owner and the logger (FAO, 1981). Three qualitative parameters were assessed according to three value classes rated from 1 to 3, with grade 1 corresponding to the best quality sought, grade 2 to average quality or some minor defects and grade 3 to poor quality or very important defects (Yedmel, 2004; Voui, 2014). These parameters are straightness, branching and health status (Table 2). These three-dimensional ratings were assessed by at least two people positioned at perpendicular angles to examine each individual in both planes. For a given stand, these two people made all the quotations from the beginning to the end of the inventory work (Kadio *et al.*, 2006). These variables have an ordered character because the modalities were defined according to the same logic. They could therefore be considered as ordered qualitative variables or quantitative indices because the scores 1, 2 and 3 code in order a morphological characteristic that is a priori less and less favourable for the use of exploited wood (Lanly and Lépitre, 1970; Voui, 2014).

Statistical analysis of the data

The analysis of variance was performed on the means of the parameters evaluated. But long before that, the data were tested for normality (Shapiro *et al.*, 1968) and homogeneity of variance (Brown and Forsythe, 1974). The hypothesis tested by the analysis of variance (ANOVA) was that of zero difference between treatments, H_0: $T_1 = T_2 = .T_n$. If the F-test was significant, then the null hypothesis is rejected and a post-hoc test (Turkey test) is performed to determine the treatments between which these differences exist for the trait studied. The significance level chosen for the analyses was 5%. The degree of freedom was n-k, where n and k represent the number of observations and groups. Analysis of variance with one classification criterion was used in the study. This criterion concerned the following silvicultural practices: T_1 (stand of pure*Tectonagrandis*), T_2 (*Tectonagrandis+ Gmelina arborea stand*) and T_3 (multispecies stand of *Tectonagrandis+ Gmelina arborea+ Cedrelaodorata*). They were used to assess differences in quality averages (straightness, branching, health status). This analysis was carried out using STATISTICA software version 7.1.

Results

Basal area and teak wood production

In all stands, the average basal area calculated was 2.49 ± 0.55 m^2/ha, giving a total volume of 19.90 ± 1.01 m^3/ha of exploitable wood. This area varied between 1.78 ± 0.25 m^2/ha and 2.67 ± 0.34 m^2/ha. The monospecific silvicultural technique T_1 generated the largest basal area with a value of 2.67 ± 0.34 m^2/ha. The basal area generated by the stands from the T_3 treatment was the lowest with a mean value of 1.78 ± 0.25 m^2/ha. The analysis of variance showed a significant difference between basal areas (*F = 3.835; P = 0.04998*) for the silvicultural techniques applied to the teak stand (Fig. 3).

Table 1. Characteristics of reforested stands in Bouaflé classified forest.

Type of reforestation	Stand type	Characteristics of the stand
monospecific	*Tectona grandis*	Year of creation : 2016 N° Bloc : 3 Area : 32 ha
multispecies	- *Tectona grandis* - *Gmelinaarborea*	Year of creation : 2016 N° Bloc: 82 Area : 10 ha
	- *Tectona grandis* - *Gmelinaarborea* - *Cedrela odorata*	Year of creation : 2016 N° Bloc : 81 Area : 14 ha

Pruning of regenerated teak stands

The stability of teak stump sprouts was studied using the corresponding pruning factors. The analysis was carried out according to the three silvicultural practices. The average slenderness factor was evaluated at 87.67 ± 3.90. The highest index was 96.38 ± 1.24. This was achieved in the T_2 multispecies stands. In these stands the trees were stable. The lowest stability index, with a value of 79.03 ± 5.16, was noted in the T_1 monospecific plots. Silvicultural practice T_1 produced the most stable trees.

In contrast, multispecies silvicultural practices T_2 and T3 produced unstable trees (Table 3). Stability indices were significantly different between silvicultural treatments (*F = 6.861; P = 0.00154*).

Table 2. Scoring of qualitative parameters.

Parameters	Cotation		
	1	2	3
Straightness (RE)	Straight tree without bend (RE1)	Tree with a bend (RE2)	Tree with two or more bends (RE3)
Branching (BR)	Tree with very thin lower branches (BR1)	Tree with a large low branch (BR2)	Tree with more than two large low branches (BR3)
Health status(ETS)	Living, unaffectedtree (ETS1)	Tree alive but under attack ETS2)	Dead tree(ETS3)

Physical quality of regenerated teak stands

In Fig.4, the qualitative behaviour of the individuals was analyzed according to the silvicultural treatments. In terms of straightness, 59.35% of the individuals developed straight shafts without bending (Fig. 4 A). In the same plots, trees with very thin low branches were represented at 87.79% (Fig. 4 B).

Finally, more than 79% of the rated stems were healthy and not attacked in the different plots (Fig. 4 C). It is noted that more than half of the inventoried trees were rated with a score of 1. Therefore, a one criteria analysis of variance was performed to assess the influence of silvicultural treatments on the best quality of the trees searched for (Figs. 5, 6 and 7).

Effect of silvicultural practices on the shape of teak shoots

The average straightness was achieved at 69.25 ± 2.78%. It varied from 64.60 ± 1.25% to 73.05 ± 3.27 (Fig. 5). The T_3 silvicultural treatment had the highest number of trees with straight boles while the T_1 treatment had the lowest number. However, the change in the number of trees between silvicultural treatments was not significant (*F = 2.046; P = 0.1852*).

Effect of silvicultural practices on branching of teak shoots

On average, 87.27% of the teak stands had very thin lower branches. Branch thinness ranged from 86.65 ±

2.06 to 88.20 ± 2.48% (Fig. 6). The highest proportion of trees with thin branches was observed in silvicultural treatment T_2 and the lowest in monospecific stands T_1. Silvicultural treatments were not significantly different for teak branch thinness (*$F = 0.122$; $P = 0.8865$*).

Table 3. Effect of silvicultural treatments on the stability of teak stands.

Treatments	Average± standard deviation	Class of index	Stand status
T_1	$79{,}03 \pm 5{,}16^{a}$	I < 80	stable
T_2	$96{,}38 \pm 1{,}24^{b}$	80 < I < 100	unstable
T_3	$88{,}49 \pm 2{,}98^{ab}$	80 < I < 100	unstable

T_1-Stand of pure *Tectonagrandis*; T_2-*Tectona grandis* + *Gmelina arborea*; T_3-*Tectona grandis* + *Gmelina arborea* + *Cedrelaodorata*; I-Stability Index (Slenderness Factor); Means followed by the same letter are not significantly different according to Tukey's HSD test of means comparison at α = 0.05.

Effect of silvicultural practices on the health status of teak cuttings

Regarding the health status of the stands, on average 80.50% of the trees were healthy. Their proportions varied from 77.58 ± 4.45 to 83.21 ± 3.12% (Fig. 7). The silvicultural treatment T_1 had the highest number of healthy individuals with 77.58 ± 4.45% while T_3 had the lowest proportion with 83.21±3.12%. There was no significant difference between silvicultural practices for health status (*$F = 0.3917$; $P = 0.6869$*).

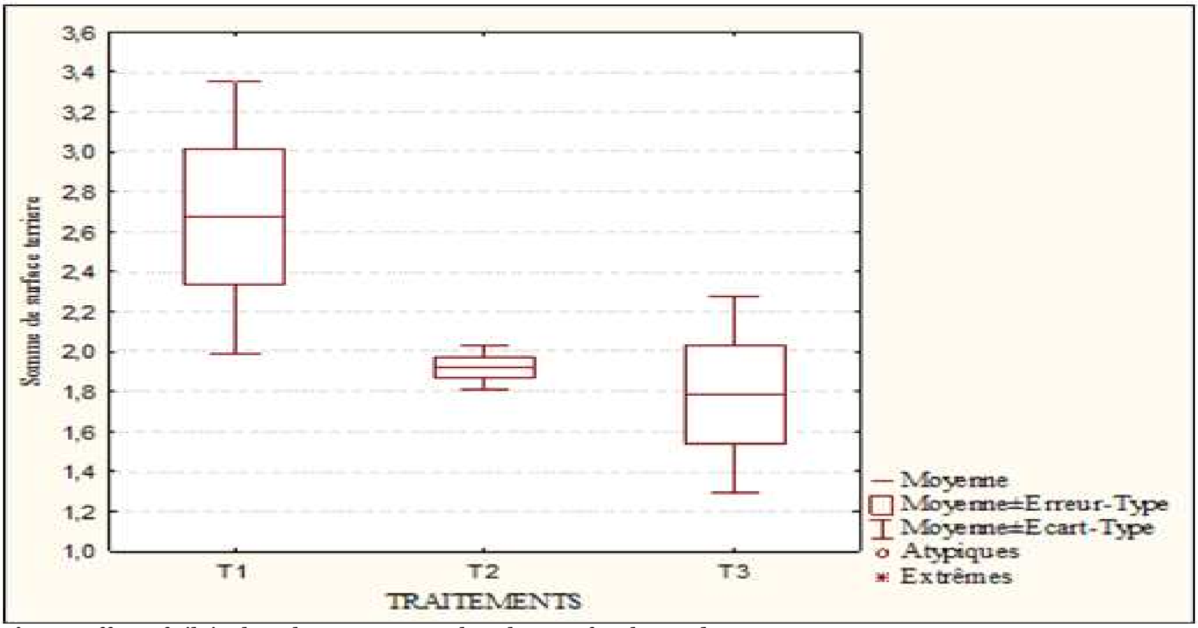

Fig. 3. Effect of silvicultural treatments on basal area of teak stands.

T_1-Stand of pure *Tectonagrandis*; T_2-*Tectona grandis* + *Gmelina arborea*; T_3-*Tectona grandis* + *Gmelina arborea* + *Cedrelaodorata*; Means followed by the same letter are not significantly different according to Tukey's HSD test of means comparison at α = 0.05.

Discussion

The basal area resulting from monospecific stands is higher than that from the multi-species plots. The high basal area value in pure teak stands would be justified by a higher density compared to multi-species plots. The basal area value reflects the degree of competition within the forest stand and is an indirect measure of the light conditions on the ground. It allows a quick comparison between different stands.

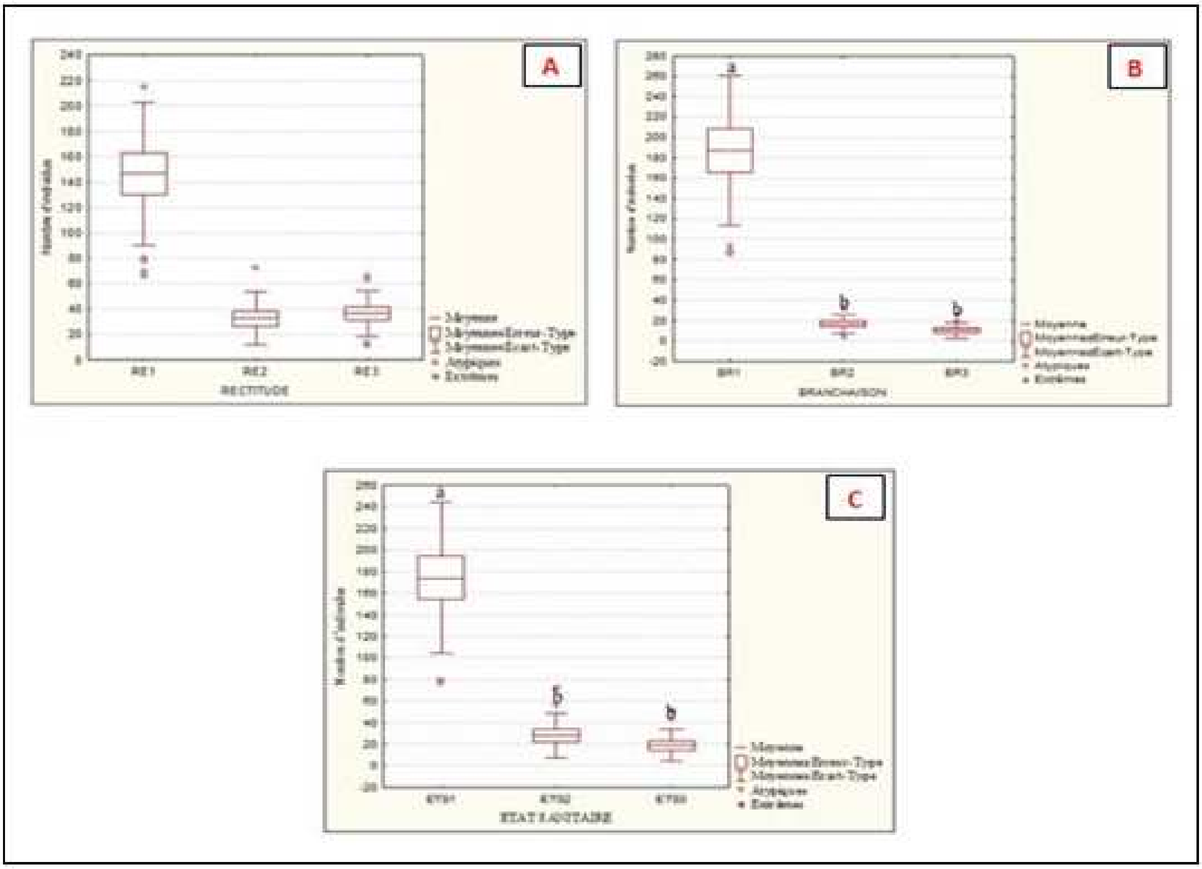

Fig. 4. Variation in the number of individuals (trees) according to the qualitative variables.
A-Variation in the number of individuals as a function of straightness; B-Variation in the number of individuals as a function of branching; C-Variation in the number of individuals as function of health status. RE-Rescertainty; BR-Branching; ETS-Health status; Means followed by the same letter are not significantly different according to Tukey's HSD test of means comparison at α = 0.05.

A slowdown in growth indicates saturation of the plantation's production capacity and leads to silvicultural intervention (CTFT, 1989). Some research has resulted in higher land area values than our work at older ages. Thus, it is possible to use the basal area as a descriptor of different stages of stand development. The work of Fuhr *et al.* (1998) showed that the total basal area of stands increases with age and stabilizes at around 40 years of age at around 45 m^2/ha. Compared to the norms prescribed by Trainer *et al.* (2003), the basal area resulting from our trials is much lower (2.49 m^2/ha). The norm according to the same authors varies between 15 and 21 m^2/ha. Beyond the upper limit, thinning should be carried out. The big difference is due to an excessive age difference since these authors present their norm for stands between 25 and 35 years old. In monospecific stands, the trees are less slender and have good stability. This is due to a greater increase in diameter at the expense of shoot height.

In addition, a high number of species leads to higher competition for nutrients. Intra-and interspecific competition could lead to a nutrient deficit, which results in stunted tree growth in multispecies stands. Lower species numbers reduce nutrient competition and competition for light between individuals, thus promoting growth in diameter and height of offshoots. In this respect, Zobel and Van Buijtenen (1989) point out that as competition for nutrients increases, tree growth decreases; wide spacing of trees favours rapid growth, whereas overly dense stands tend to produce smaller trees. Similarly, according to Zhang and Chauret (2001) in China, trunk diameter, crown size and branch diameter increase with decreasing stand density.

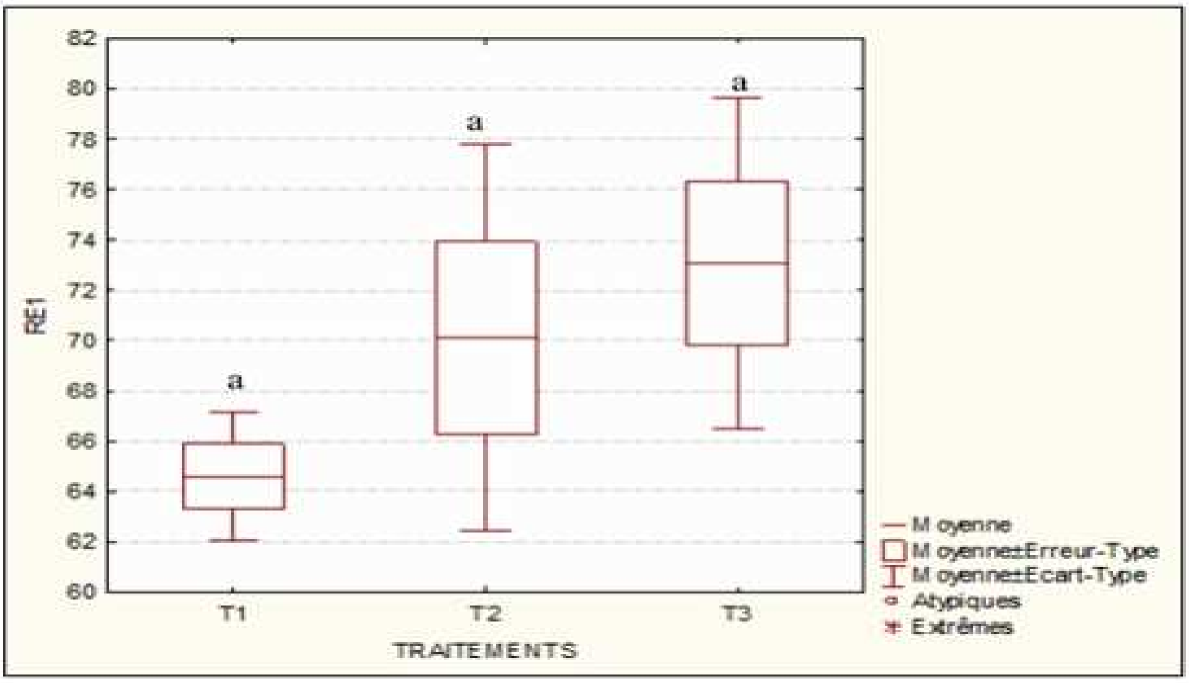

Fig. 5. Effect of silvicultural treatments on the straightness of teak trees.

T_1-Stand of pure *Tectonagrandis*; T_2-*Tectona grandis* + *Gmelina arborea*; T_3-*Tectona grandis* + *Gmelina arborea* + *Cedrelaodorata*; RE-Straightness.

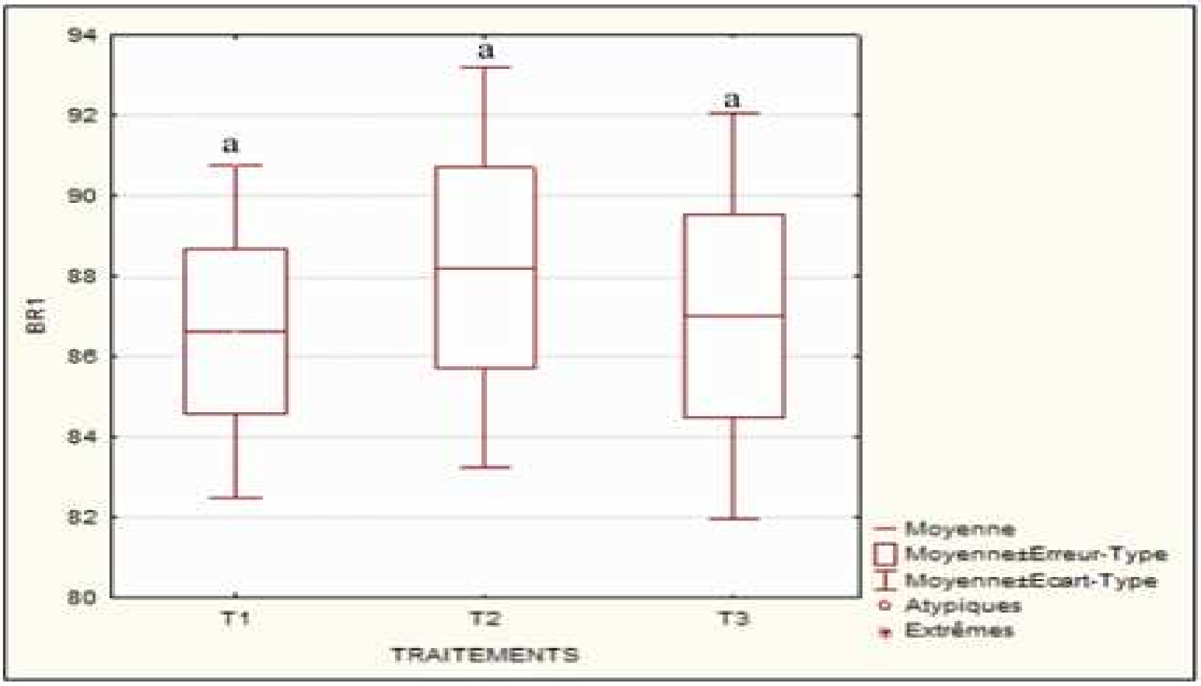

Fig. 6. Effect of silvicultural treatments on branching of teak trees.

T_1- Stand of pure *Tectonagrandis*; T_2-*Tectona grandis* + *Gmelina arborea*; T_3-*Tectona grandis* + *Gmelina arborea* + *Cedrelaodorata*; BR-Branching.

The study showed that the silvicultural treatments did not influence the bole shape, branching and health status of the regenerated teak stands. Overall, the majority of trees from the different stands developed a straight bole with very thin lower branches and a high proportion of healthy trees. This suggests that a genetically fixed trait of teak is at the origin of this. Indeed, most of the teak species introduced into Côte d'Ivoire come from South-East Asian countries. These species have been tested for provenance and progeny and have led to the analysis of intraspecific variability and the mass selection of remarkable individuals. Further analysis could also help us to find out more about them, as the stands on which we have worked are still morphologically young (5 years old). Several authors, including Zhang and Chauret (2001), have obtained similar results for *Picea marina*. The author indicates that density has a considerable effect on branch size.

Thus, at the stand level, a low density would result in a larger average diameter, a wider crown and larger branches. He adds that for the same diameter class, trees from a high density will have smaller branches.

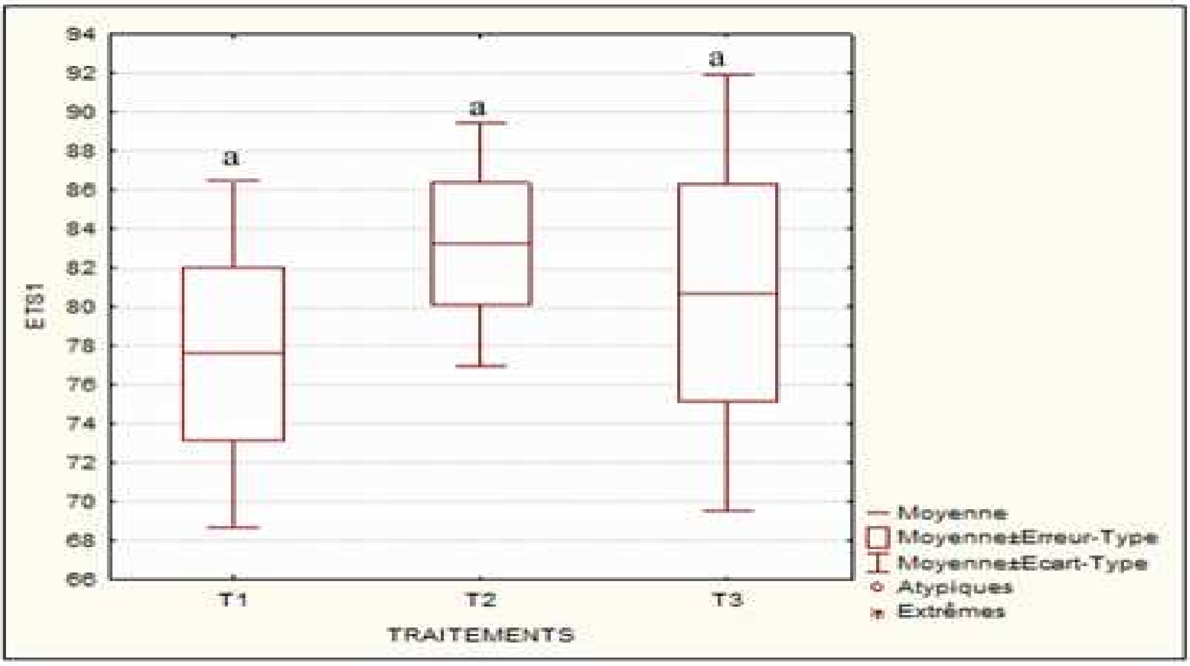

Fig. 7. Effect of silvicultural treatments on the health status of teak trees.
T_1-Stand of pure *Tectonagrandis*; T_2-*Tectona grandis* + *Gmelina arborea*; T_3-*Tectona grandis* + *Gmelina arborea* + *Cedrelaodorata*; ETS- Health status.

Conclusion

The study thus presented not only made it possible to characterize certain physical qualities sought by the timber industry (straightness, branching and health status) but also to analyse the stability of regenerated stands. It also confirmed that teak rejects vigorously from the stump.

It is thus noted that monospecific silvicultural practices develop stable and healthy stands that are free of disease attacks. Also, multispecific silvicultural practices with two species (*Tectonagrandis* + *Gmelina arborea*) and three species (*Tectonagrandis* + *Gmelina arborea* + *Cedrelaodorata*) promote not only straight shafts but also natural pruning by producing very fine low branches.

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