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Cutting height as a competition control factor in teak (*Tectona grandis* L.f) plantations in southern Benin

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A R T I C L E I N F O

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A B S T R A C T

The effect of stump sprouts on the growth of trees in the main plantation under system of even-aged forest was investigated in this study. In this context, eight plantations taking into account the age, the number of thinning and the type of soil were selected. In order to assess the practices related to cutting height, a survey was carried out in each plantation. In each plantation, at least, two square plots measuring 50 × 50 m (one containing trees with less stump sprouts and the other containing trees with stump sprouts) were installed. The density of stump sprouts and filler trees had a detrimental effect on the growth of trees in the main plantation. Competition for resources was the main cause. The density of stumps and those of filler trees within a radius of 5 m around each future tree were estimated at 3 stumps and 3 filler trees respectively. The distance between the future trees and the stump sprouts or the filler trees was estimated at around 3 m. The search for an appropriate cutting level, spacing of trees and compliance with recommendations related to silvicultural practices are among other solutions to limit this competition.

1. Introduction

Sustainable forest management relies in part on our ability to predict the evolution of different stands, in terms of composition, structure, production and wood quality, depending on site conditions and different silvicultural scenarios [1,2]. However, the state of forests in Sub-Saharan Africa such as structure, composition, regeneration are not well known [1], thus limiting the implementation of sustainable forest management strategies, which also requires the renewal of standing potential and the management of new stands using appropriate silvicultural techniques. Thus, in the case of plantations carried out under even-aged forest regime, for better management of these plantations, it is a question of knowing the influence of stump sprouts on the growth of trees resulting from natural regeneration.

Teak has been the priority species in reforestation programs for many years due to its unique feature [3]. In fact, teak is a high economic valued wood in the international market [4,5] with several benefits that are used for furniture, shipbuilding, indoor and

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outdoor equipment [6–8]. The area of teak forests was estimated at 4.35 million Ha and covers 69 countries [9]. Despite the lack of recent statistics, the total area of teak plantations in Benin covers 40,000 ha (both public and private) including 20,000 ha of State plantations [10]. The management of teak plantations is complex due to variations in environmental, social and economic conditions [11]. In Benin, the government and the private sector have different practices in his silviculture. Three techniques are mainly used for the renewal of teak plantations: natural or assisted regeneration, the use of stumps and the use of stump sprouts. The private sector makes more use of stump sprouts given the short rotation coppice regime used by them. The Office National du Bois (ONAB), which owns the largest teak plantations, has chosen to use the natural assisted regeneration technique since 1989 to renew its plantations (Lutz, 1991) [12] under even-aged forest regime. However, there are several factors that limit the growth of natural regeneration of teak where the rain is among the most important one. The breaking of rains, especially at the time of seed germination may lead to seed abortion as water is among the important factors governing cell turgor, hydrolysis and photosynthesis [12]. In addition to this factor, stump sprouts resulting from clear cutting or thinning of plantations constitute another handicap for the management of plantations towards a system of even-aged forest. Teak is indeed a species whose strains have a great ability to produce stump sprouts. These sprouts therefore enter into competition with the residual trees of the main plantation in a system of even-aged forest if they are not eliminated. According to Ref. [13], the individual growth of a tree for a given species and type of environment is dependent on many factors: climatic effects, natural or anthropogenic disturbances, effects of age and size of the tree, the micro-environment, the

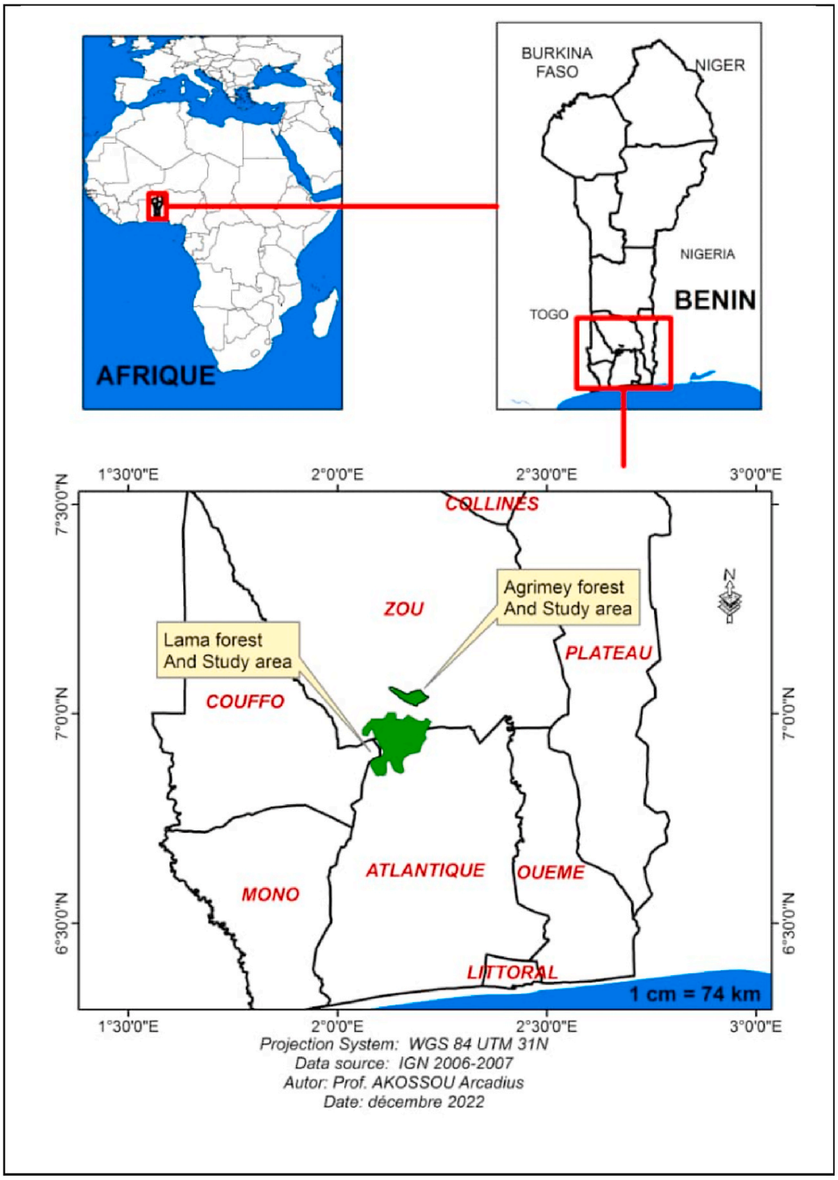

Fig. 1. Study area.

individual genetic factor as well as the local inter- or intra-specific competition that the tree undergoes. The effect of competition is often mentioned in the literature as a major effect of variation in size and growth [14,15]. This competition is all the more intense when the spacing between the plants is small at the time of the establishment of the plantation. So, competition between trees was related to the density of stands, where their closeness can increase the competition between them [16]. The increase in planting density significantly affected the diameter of the canopy [17] and the diameter of tree [5,17–19] but decreased bole height [17]. Thus, the spacing was an important aspect of increasing forest yield both forest productivity and forest economic value [5,20,21]. It can also interact with clones to provide various wood properties [22] by affecting the quality [23]. It indicated that the wide spacing would probably increase the tree's wood volume, and carbon sequestration, but it can decrease the wood quality [24].

Teak was intolerant of competition between trees [5]. The presence of stump sprouts, which are not eliminated after coppicing in plantations under even-aged forest regime, further reinforces this competition. In a plantation under even-aged forest regime, resulting from natural or assisted regeneration, the option of stumps without rejection would be the most appropriate. The thrust of stump sprouts after cutting depends on several factors, the most important of which are the species, the time of year when the cut took place, the size of the stumps and finally, the quality of the station in close connection with tree vigor [25,26]. These factors influence the abundance, growth, quality and longevity of stump sprouts [27]. In addition, the regeneration capacity of the plantation after coppicing depends on the cutting height (Ake, 2005; Soro, 2007) [28].

The presence of stump sprouts in the plantation under even-aged forest regime therefore creates competition between future trees and stump sprouts or other trees in the plantation. Taking this competition into account is of great importance in forestry in general and in particular for the management of a plantation under even-aged forest regime. This research aims to evaluate the effect of stump sprouts on the growth of future trees in teak plantation under even-aged forest regime in Benin.

2. Material and methods

2.1. Study area

The research focuses on six national teak plantations of ONAB resulting from natural regeneration in the forest sectors of Agrimey and Lama (Toffo, Massi, Koto and Akpè) and on two private plantations in the Agrimey area (Fig. 1). These sectors were located in the Atlantic and Zou department at latitudes of 6°49′ and 7°4′ North and longitudes of 2°05′ and 2°22′ East. The plantations benefit a subequatorial type climate in transition towards tropical climates (Sudanian or Sudano-Guinean) characterized by an average annual rainfall varying from 1100 mm to 1200 mm. The average temperature ranges from 27 °C to 28 °C. The bar land, which occupies the southern portion of the zone, is part of the series of weakly desaturated ferralitic soils [29]. The vertisols, which surround the southern region of the teak groves to the northwest, bear most of the Lama's plantations (Toffo, Massi, Koto and Akpè). In the Guineo-Sudanian zone, the fundamental soil unit of the teak groves, particularly those of Agrimey, belongs to the class of leached tropical ferruginous soils with concretions. It is characterized by underlying horizons more or less loaded with ferruginous and sometimes indurated concretions [30].

2.2. Data collection

2.2.1. Choice of plantations and experimental design

In each sector (Agrimey, Toffo and Lama) two teak plantations of different ages (8 years and 18 years) were clear cut or thinned and selected for the study. Two other private plantations were also selected in the area of the Agrimey sector. Each plantation in one sector had its correspondence in the other three sectors in terms of age. Three soil types namely ferruginous, ferralitic and vertisol were retained for the study. The experimental unit was a square plot measuring 50 m × 50 m. The number of plots per plantation was a function of its surface, but did not exceed three. Among the plots installed, one was considered as a control plot (plot containing fewer stumps). In the ONAB plantations, the trees were initially installed at a spacing of 2.5 m × 2.5 m, whereas, in private plantations the spacing of 2 m × 2 m was maintained. Table 1 presents the characteristics of these plantations in relation to the parameters studied.

2.2.2. Inventory of cutting heights during clear cuts and thinning

In each selected plantation, the line transect method was carried out by traversing all the lines between the rows of trees in the plantation. This enables to have an overview of the distribution of strains and stump sprouts. Following this phase, at least, one plot

Table 1
Mean values and in brackets standard deviation of the dendrometric characteristics of the sampled plots.

Soil type	Age (year)	Number of thinning	Diameter (cm)	Total height (m)	Bark thickness (cm)
Vertisol (ONAB)	8	1	14.05 (0.23)	9.58 (0.05)	0.34 (0.02)
	18	2	24.58 (0.16)	20.34 (0.26)	1.01 (0.01)
Ferralitic (ONAB)	8	1	15.34 (0.12)	9.28 (0.08)	0.35 (0.01)
	18	2	23.65 (0.17)	18.15 (0.20)	1.03 (0.01)
Ferruginous (ONAB)	8	1	15.71 (0.11)	9.98 (0.05)	1.00 (0.00)
	18	2	14.17 (0.11)	18.15 (0.06)	1.05 (0.01)
Ferruginous (private)	8	1	13.78 (1.55)	11.90 (1.00)	0.85 (0.16)
	18	2	16.21 (1.25)	18.58 (1.25)	0.94 (0.28)

was installed in an area where there is a strong presence of stump sprouts, and another considered as a control plot was installed in an area where the presence of stumps is practically non-existent. An inventory of all the stump sprouts (height of the stump, number of stump sprouts, diameter at breast height (DBH) and height of the largest stump sprouts) was carried out.

2.2.3. Effect of stump sprouts on dendrometric parameters of trees in the main plantation

In order to assess the effect of the presence of stump sprouts on the growth of the trees of the main plantation, the dendrometric characteristics (height, diameter at breast height, thickness of the bark of each tree of teak) were collected on the observation plots and the control plot of each plantation. Similarly, the quality of each tree was assessed by simple observation.

2.2.4. Study of the competition between stump sprouts, filler trees and future trees

The study of competition between stump sprouts and other trees in the plantation consisted of collecting the geographical coordinates of each filler tree, each stump sprouts and each future tree. In this study, a tree is considered as a filler tree if it is dominated and is likely to be thinned later. A future tree is a dominant tree. For the latter case, the trees used to calculate the dominant height (100 largest trees per hectare) were retained. The plot having an area of 50 $m^2 \times 50$ $m^2 = 2500$ m^2, then the 25 trees with the largest diameters on the plot were considered as future trees.

Within a radius of 3 and 5 m around each future tree, the characteristics of each stump sprouts and filler tree present were recorded. It's about the distance from the future tree, the number of stump sprouts, the number of filler trees, the height of each stump sprouts, the height of each filler tree, the average height and diameter of largest stump sprout.

2.3. Data analysis

First, a synthesis was carried out on the data resulting from the inventory of the stump sprouts. Then, the effect of growth conditions (age and type of soil) on stump sprouts characteristics (stump height, number of sprouts, diameter and height of the largest stump sprouts) was evaluated by the method of variance analysis (ANOVA), which followed by the method of Student-Newman-Keuls' multiple comparison of means. The influence of stump sprouts on the growth of trees in the main plantation was evaluated using Student's *t*-test, comparing dendrometric characteristics. A distribution map of the different categories of trees (stump sprouts, filler trees and future trees) was produced on each plot from the geographical coordinates of each tree. This distribution enable to assess the

Table 2
Mean values, standard deviation, minimum and maximum values of stump height, number of stump sprouts per stump and diameter of large stump sprouts, per plantation.

Settings	Age	Soil type	Mean[a]	Standard error	Variation coefficient	Minimum	Maximum
Height of the stump (cm)	8	Ferralitic	16.02b	0.38	41.18	4.00	30.00
		Ferruginous	16.67b	0.73	45.83	5.00	60.00
		Private	5.79c	0.11	26.65	2.00	8.00
		Vertisol	19.31a	0.41	17.05	10.00	25.00
	18	Ferralitic	14.30y	0.85	52.36	2.00	30.00
		Ferruginous	16.38a	0.63	43.80	2.00	30.00
		Private	5.77b	0.14	23.14	3.00	8.00
		Vertisol	16.34a	0.59	40.70	5.00	30.00
Number of sprouts per stump	8	Ferralitic	2b	0	66	0	6
		Ferruginous	2bc	0	90	0	6
		Private	3a	0	38	1	5
		Vertisol	2c	0	104	0	6
	18	Ferralitic	2c	0	75	0	5
		Ferruginous	4a	0	49	0	7
		Private	3b	0	34	1	4
		Vertisol	3b	0	38	1	6
Diameter of the big stump sprout (cm)	8	Ferralitic	4.14b	0.16	67.54	0.00	21.00
		Ferruginous	2.55c	0.26	106.40	0.00	15.00
		Private	5.56a	0.14	35.97	2.00	10.00
		Vertisol	4.02b	0.55	109.93	0.00	20.00
	18	Ferralitic	4.13c	0.31	65.30	0.00	12.00
		Ferruginous	5.41b	0.33	68.40	0.00	15.00
		Private	7.07a	0.23	30.05	3.00	14.00
		Vertisol	5.12b	0.13	28.03	2.00	10.00
Height of the big stump sprout (m)	8	Ferralitic	5.08a	0.17	59.01	0.00	19.00
		Ferruginous	3.16c	0.28	92.99	0.00	15.00
		Private	4.52 ab	0.08	24.38	2.00	8.00
		Vertisol	4.02bc	0.54	108.78	0.00	20.00
	18	Ferralitic	3.70b	0.36	84.43	0.00	15.00
		Ferruginous	5.97a	0.30	55.94	0.00	14.00
		Private	6.56a	0.19	27.24	4.00	11.00
		Vertisol	6.19a	0.31	56.48	2.00	20.00

[a] The means denoted by different small letters show significant difference at the 5% level.

competition between future trees and stump sprouts or filler trees. Thus, the characteristics of stump sprouts and filler trees present within a radius of 3 m and 5 m around each future tree were determined. Competition was studied using the index proposed by Ref. [31]. This index was chosen because it is easy to use and also gives very good results than more complex indices [32]. The Hegyi competition index is defined by the following Equation (1):

$$IC_i = \sum_{j=1}^{n} \left[\frac{DBH_j / DBH_i}{r_{ij}^2} \right] \quad (1)$$

where DBH_j represents the diameter of the jth competitor tree, DBH_i the diameter of the ith subject tree (future tree), r_{ij}^2 is the linear distance between the ith subject and the jth competitor. Competing trees that enter into the calculation of the index are limited by a distance from the subject tree (3 and 5 m).

3. Results

3.1. Silvicultural practices related to cutting level

The characteristics linked to the stump sprouts counted during the inventory were highly variable (Table 2). The cutting heights varied from 2 to 60 cm. They were lower in the private plantations (on average they were 5.77 and 5.79 cm respectively in the 8- and 18-year-old plantations), whereas the 8-year-old ONAB plantation located on vertisol presented the highest value (19.31 cm on average). The number of sprouts per stump was also variable (0–6 sprouts per stump). The lowest values (2 sprouts per stump on average) were counted in the ONAB plantations (the 8-year-old plantation located on vertisol and the 18-year-old plantation located on ferralitic soil). The highest values were observed on ferruginous soil (on average of 3 in the 8-year-old private plantations and 4 in the 18-year-old ONAB plantation). The diameter and the height of the stump sprouts were also very variable (0–20 cm for the diameter and 0–20 m for the height). For illustration, Fig. 2 showed some cutting levels (Fig. 2a–c) as well as a mixture of stump sprout, filler trees and future trees (Fig. 2d).

Fig. 2. Management of cutting level and stump sprouts: (a), (b) and (c), different cutting levels with stump sprout, (d) mixture of stump sprout, filler trees and future trees.

3.2. Influence of stump sprouts on the growth of trees in the main plantation

Comparison of dendrometric characteristics of trees present in the plots with fewer stump sprouts (control plots) to those of the trees located in the plots with stump sprouts within the same plantation (Table 3) showed that the characteristics (diameter at breast height, bole height, total height and bark thickness) of trees present in plots with fewer stump sprouts were significantly higher in most cases than those of trees in presence of stump sprouts. For example, in the 8-year-old plantation located on vertisol, the average diameter was 18.2 cm for the control plot against a diameter of 15 cm in the plot containing stump sprouts. It follows that the trees growth was more pronounced in the absence of stump sprouts.

3.3. Competition between stump sprouts, filler trees and future trees

The spatial distribution of trees and stumps (Figs. 3 and 4) showed a strong presence of stump sprouts and filler trees around the future trees. A detailed analysis within a radius of 3 m and 5 m around future trees was presented in Tables 4 and 5. For a radius of 3 m around a future tree, on average two stump sprouts and two filler trees were present in most cases (depending on soil type and age of planting). Stump sprouts and filler trees were on average located at a distance of 2 m from the future tree. The calculated values of the Hegyi index to assess competition with stump sprouts were between 0.33 and 1.27 and those calculated with filler trees were between 0.61 and 1.69. When the radius increases to 5 m around the future tree, the number of stump sprouts varied from 2 to 5 and those of the filler trees was from 2 to 10. The values of the Hegyi index varied from 0 0.18 to 1.46 in the case of stump sprouts and 0.69 to 2.84 in the case of filler trees. For each of the ages considered (8 years and 18 years), Figs. 3 and 4 showed, on the one hand, the spatial distribution within each plot of stump sprouts, filler trees and future trees on vertisols (Figs. 3a and 4a), on ferralitic soils (Figs. 3b and 4b) and on ferruginous soils (Figs. 3c and 4c) in ONAB plantations and, on the other hand, those obtained on ferruginous soils of private plantations (Figs. 3d and 4d).

4. Discussion

4.1. Inventory of silvicultural practices related to cutting level

The characteristics of the stumps resulting from the clear cuts or thinning showed great variability of the heights of cut of the trees irrespective of the soil types and the age of the plantation. The cutting heights varying from 2 cm to 60 cm, showed that the recommendations made for the cuts (cutting level of 10 cm) were not respected. A significant number of stump sprouts were also encountered during the inventory phase. For example, in the plantations located on vertisols, more than 362 and 127 stump sprouts were counted respectively on the 18-year-old and 8-year-old plantations. The importance of this number of stump sprouts could be linked to a lack of maintenance. Cutting heights were lower in private plantations than in ONAB plantations. This showed that silvicultural recommendations related to cutting practices were relatively more respected in private plantations. The number of sprouts per stump was, on the contrary, relatively higher in private plantations. Since private plantations are small in size and the regime practiced is coppice, the search for a vigorous stump sprouts leads these farmers to allow several sprouts to develop on the stump before proceeding to remove the less vigorous ones. The thrust of stump sprouts after cutting depends on several factors, the most important of which are the species, the time of year when the cut took place, the size of the stumps and finally, the quality of the station in close

Table 3
Dendrometric characteristics of trees present in plots without stumps and those of trees located in plots with stumps.

Soil type	Age	Plot	Diameter (cm)	Bole height (m)	Total height (m)	Bark thickness (cm)
Vertisol (ONAB)	8	Control plot	18.2a		16.0a	0.7a
		Plot with stump	15.0b		12.2b	0.6b
	18	Control plot	26.3a	14.8a	27.6a	1.0a
		Plot with stump 1	24.9 ab	12.7b	25.0b	0.9b
		Plot with stump 2	24.5b	11.5c	24.9b	0.9b
ferralitic (ONAB)	8	Control plot	16.0a		15.0a	0.6a
		Plot with stump 1	15.5a		12.8b	0.6 ab
		Plot with stump 2	14.7b		12.5b	0.6b
	18	Control plot	24.8a	13.4a	26.8a	0.9a
		Plot with stump	22.1b	12.7a	23.9b	0.8b
Ferruginous (ONAB)	8	Control plot	18.0a		15.6a	0.8a
		Plot with stump 1	16.2b		13.2b	0.7a
		Plot with stump 2	15.2c		13.0b	0.6b
	18	Control plot	26.2a	14.3a	26.3a	1.1a
		Plot with stump 1	24.3b	13.5 ab	25.2b	0.9b
		Plot with stump 2	23.7b	13.3b	24.0c	0.7c
Ferruginous (private)	8	Control plot	16.1a		12.9a	0.9a
		Plot with stump	13.4b		11.7b	0.8b
	18	Control plot	17.4a	11.1a	19.3a	1.1a
		Plot with stump	15.9b	9.8b	18.4b	0.9b

The means in the columns denoted by different small letters show significant difference at the 5% level.

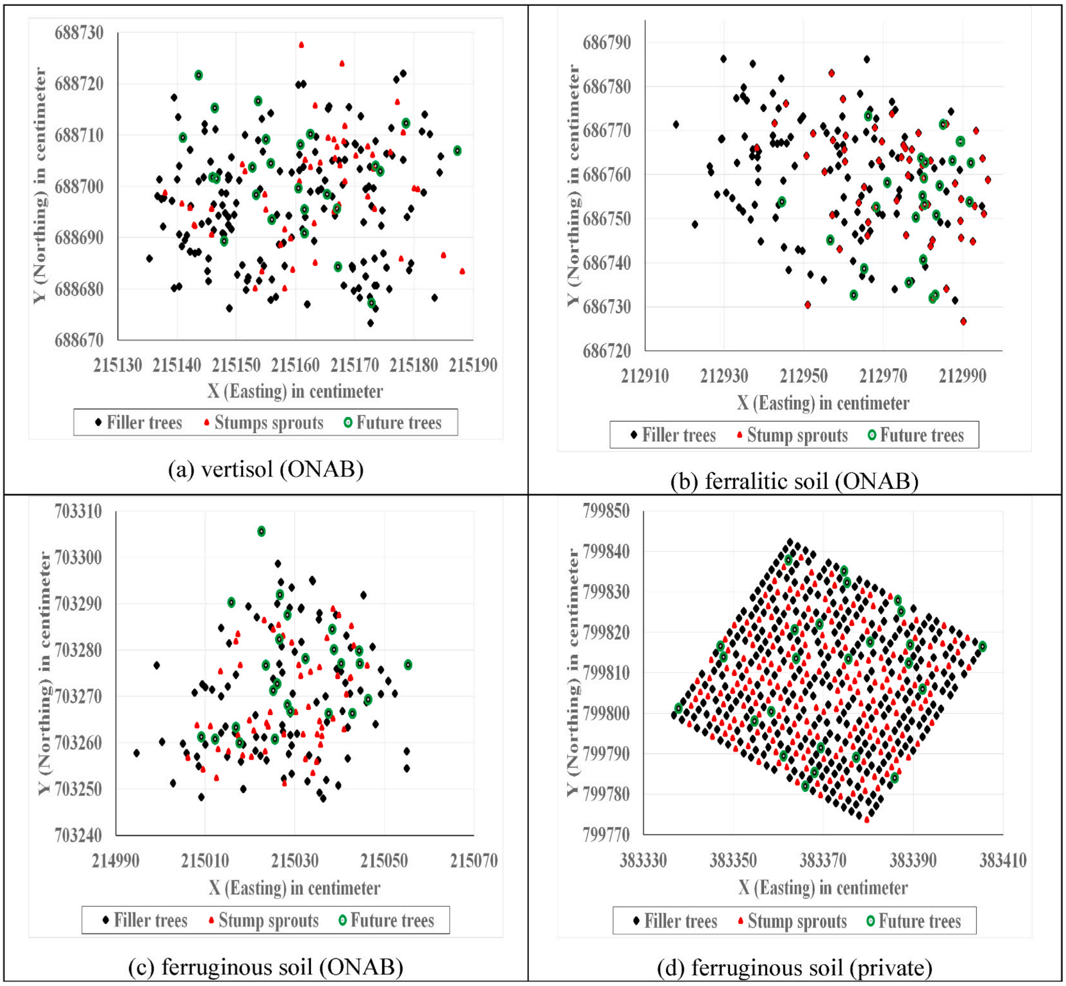

Fig. 3. Spatial distribution (X and Y geographic coordinates in centimeter) within each plot of stump sprouts, filler trees and future trees in 8 years old plantations of (a) vertisol, (b) ferralitic, (c) ferruginous soil of ONAB and (d) ferruginous soil of private.

connection with tree vigor [25,26,28]. These factors influence the abundance, growth, quality and longevity of stump sprouts [27]. In addition, the regeneration capacity of the plantation after coppicing depends on the cutting height (Ake, 2005; Soro, 2007) [28,33,34]. The fact that teak is a species whose stumps have a great ability to sprout, cutting levels explains the importance of the number of sprouts per stump, which can reach 7 sprouts/stump. According to Ref. [33], the number of stumps sprouts in teak increases inversely with cutting height and stumps of 5–10 cm in cutting height often show the maximum number of sprouts which can vary from 5 to 7 sprouts [35] or 7 to 9 sprouts per stump with a cutting level of 10 cm [34]. Ref. [28] found that the maximum number of sprouts was found at a stump height of 10–20 cm from ground level.

The primary advantages of coppicing are that it is easy, offers a low cost of establishment and accelerates early growth [28,36] and thus, is widely practiced in many private plantations. Early growth from a coppice is usually faster than early growth from seed, allowing for quick re-establishment of a teak plantation. However, because the coppice roots often develop only on one side of the tree, the trees may be less resistant to wind than trees from seed [37]. Trees from coppice are also vulnerable to rot originating from the stump and more often develop hollow stems at the base. A solution to improve root system development and reduce the possibility of hollow stems, cut the stumps as close to the ground as possible [37].

As ONAB's objective is to conduct plantations under a regime of even-aged forest, resulting from natural or assisted regeneration, the search for a height of cut that minimizes stump sprouts is necessary. This will enable to overcome, on the one hand, the problem of lack of maintenance and, on the other hand, the problem of competition between the stump sprouts and the trees of the main plantation.

4.2. Impact of the presence of stump sprouts on the growth of future trees

Natural regeneration or stump planting offers several advantages such as being able to be transported over considerable distances

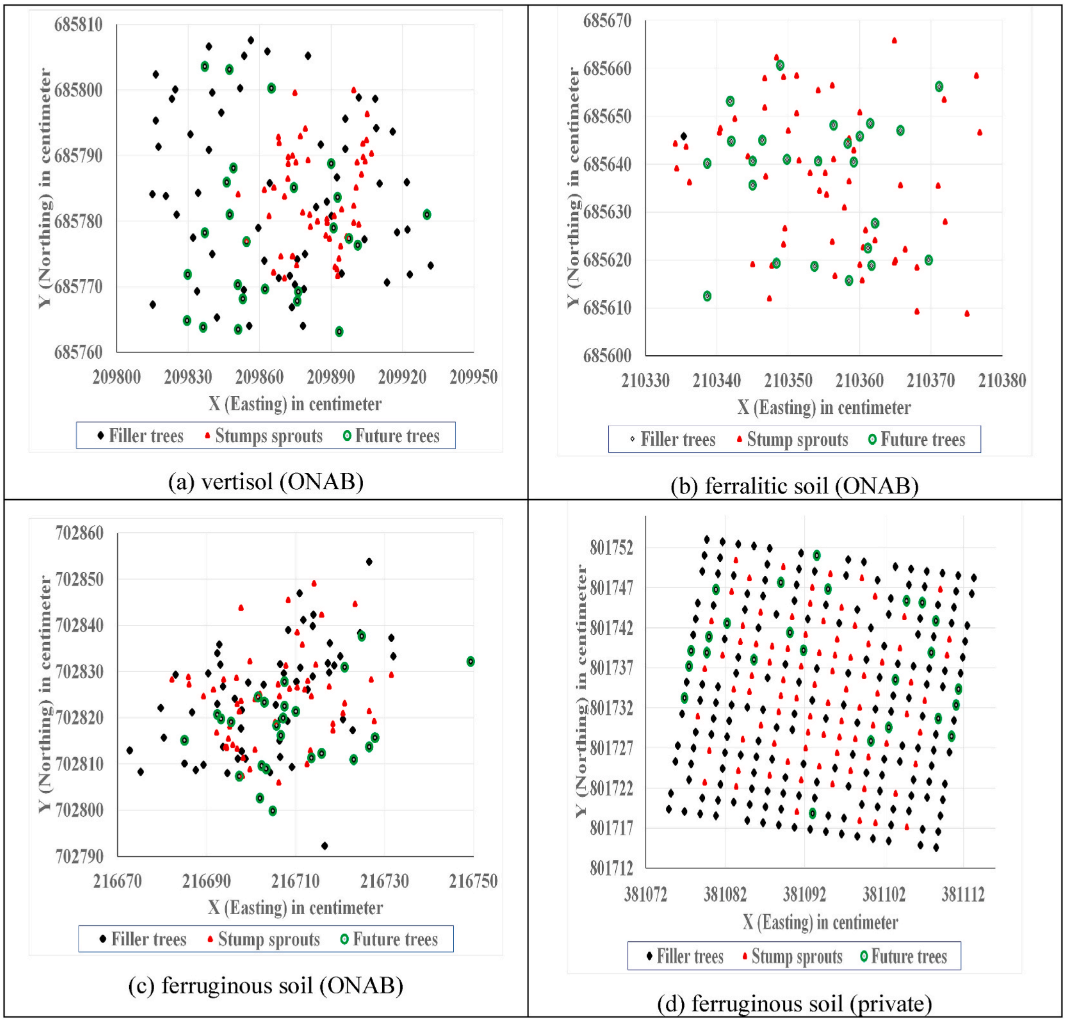

Fig. 4. Spatial distribution (X and Y geographic coordinates in centimeter) within each plot of stump sprouts, filler trees and future trees in 18 years old plantations of (a) vertisol, (b) ferralitic, (c) ferruginous soil of ONAB and (d) ferruginous soil of private.

while maintaining the viability of the stump and being easy and quick to plant; therefore, this technique is used in several countries (Thaiutsa, 1999) [38,39]. Furthermore, the significant increase in the net increase of future plants following thinning has been demonstrated by several studies (Center for Forest Studies, Research and Training, 2015) [40–43]. Although thinning have a significant effect on the growth of residual teak stems and for wood production, the stump sprouts from thinning become potential competitors to these trees if the stump sprouts were not eliminated. The evaluation of competition between the trees of the main plantation and the stump sprouts showed the negative effect of the presence of the stump sprouts on the growth of the trees of the main plantation. In fact, as the results showed, the growth of trees in the main plantation is better in the absence of stumps. Competition between stump sprouts and future trees is due to the fact that the stump sprouts have already a well-developed root system, whereas the young seedlings resulting directly from regeneration are called upon to build up their root system over time to have access to the resources necessary for their growth (light, water and nutrients). The presence of stump sprouts therefore constitutes a handicap to access to these resources necessary for their growth. This is also true for older trees. The analysis of the spatial distribution of all trees (future trees, stump sprouts and filler trees) on each plot showed a high density of stumps and filler trees around the future trees (two stumps and two filler trees for the 3 m distance from the future tree, up to 2 to 5 stumps and 2 to 10 filler trees when the distance is 5 m). The density of these sprouts and filler trees at a short distance around the future trees shows the existence of strong competition for resources. This was confirmed by the values of the Hegyi index obtained. The values of the index are greater than 1/3 in the case of a radius of 3 m and greater than 1/5 when the radius is 5 m. For better growth of future trees in teak plantations, it therefore appears to minimize this competition by reducing the density of stumps and filler trees around future trees. This could involve determining a cutting height or a technique to minimize or have stumps without sprouts. Controlling the spacing between seedlings when establishing plantations is also a solution, as this will limit competition. Indeed, in clonal teak planting, adjusting spacing is one of the silvicultural techniques for optimizing their growth [16]. Fast-growing tree species, i.e. selected clonal teak, will produce high

Table 4
Average characteristics of stump sprouts and filler trees located within 3 m of each future tree.

Soiltype	Age	Distanceofthestumpfromthefuturetree(m)	Stumpheight(cm)	Numberofstumpsprouts	Diameteroflargeststumpsprout(cm)	Totalheightoflargeststumpsprout(m)	Numberofstump	Hegyiindex	Distanceofneighboringtreesfromthefuturetree(m)	Diameterofneighboringtrees(cm)	Diameteroffuturetrees	Totalheightofneighboringtrees(m)	Heightoffuturetrees	Numberofneighboringtrees	Hegyiindex
Vertisol	8 years	1.95 (0.63)	20.28 (3.03)	1.51 (1.54)	5.48 (5.68)	5.42 (5.69)	2	0.33 (0.49)	2.10 (0.45)	14.97b (1.62)	19.32a (0.75)	12.64a (1.52)	12.80a (2.08)	3	1.27 (0.90
	18 years old	1.80 (1.01)	18.25 (7.48)	3.90 (0.22)	4.90 (1.52)	7.25 (2.35)	2	1.27 (0.85)	2.13 (0.56)	24.24b (1.32)	28.28a (1.97)	26.07a (1.44)	24.89a (4.62)	2	0.61 (0.40)
ferralitic	8 years	1.66 (0.71)	16.38 (4.61)	2.52 (1.53)	3.60 (2.17)	4.25 (2.32)	2	0.25 (0.27)	1.98 (0.44)	15.28b (1.98)	19.92a (3.16)	13.64b (2.71)	17.71a (2.82)	2	0.84 (0.53)
	18 years old	2.31 (1.34)	11.33 (6.59)	1.65 (1.05)	4.10 (2.16)	3.19 (2.04)	2	0.75 (0.47)	2.08 (0.62)	25.33b (4.09)	26.56a (2.80)	25.06a (1.35)	24.28a (1.77)	2	1.25 (1.12)
Ferruginous (ONAB)	8 years	2.18 (0.54)	14.69 (5.39)	2.05 (1.51)	2.93 (2.50)	3.57 (2.73)	1	0.10 (0.08)	1.98 (0.44)	15.28b (1.98)	18.00a (1.35)	13.63b (2.71)	15.76a (3.33)	2	0.84 (0.53)
	18 years old	1.99 (0.62)	13.68 (4.59)	3.92 (1.72)	5.06 (3.08)	5.58 (2.68)	2	1.13 (0.93)	2.08 (0.62)	25.33b (4.09)	28.80a (3.05)	25.06a (1.35)	24.92a (1.81)	2	1.25 (1.12)
Ferruginous (private)	8 years	2.44 (0.31)	6.08 (1.41)	2.93 (0.83)	5.53 (1.66)	4.55 (0.87)	2	0.34 (0.18)	2.40 (0.20)	13.64b (0.68)	15.12a (0.33)	11.84a (0.42)	12.02a (0.64)	4	1.39 (0.44)
	18 years old	2.36 (0.34)	6.00 (0.88)	2.76 (0.66)	7.04 (1.71)	6.49 (1.65)	2	0.85 (0.50)	2.46 (0.18)	16.20b (0.69)	18.52a (1.26)	18.65a (0.64)	18.60a (1.12)	5	1.69 (0.50)

Table 5
Average characteristics of stumps and filler trees located within 5 m of each future tree.

Soiltype	Age	Distanceofthestumpfromthefuturetree(m))	Stumpheight(cm)	Numberofstumpspouts	Diameteroflargeststumpsprout(cm)	Totalheightoflargeststumpsprout(m)	Numberofstump	Hegyiindex	Distancebetweenfillertreesandfuturetree(m)	Diameterofneighboringtrees(cm)	Diameteroffuturetrees	Totalheightofneighboringtrees(m)	Heightoffuturetrees	Numberofneighboringtrees	Hegyiindex
Vertisol	8 years	3.36	19.89	1.37	4.03	3.91	2	0.29	3.36	14.92	19.32a	12.27	12.80a	7	1.99
		(1.59)	(2.72)	(1.08)	(3.49)	(3.47)		(0.44)	(0.43)	(1.23)	(0.75)	(0.68)	(2.08)		(1.16)
	18 years old	3.48	17.56	3.50	4.86	5.36	3	1.13	3.77	25.62	28.28a	25.43	24.89a	2	0.69
		(1.25)	(6.19)	(0.62)	(1.09)	(0.86)		(1.01)	(0.74)	(3.24)	(1.97)	(1.68)	(4.62)		(0.65)
ferralitic	8 years	3.17	16.50	2.25	3.92	4.67	4	0.31	3.46	15.20	19.92a	13.29	17.71a	5	1.44
		(0.91)	(5.02)	(1.28)	(1.91)	(2.21)		(0.31)	(0.36)	(1.20)	(3.16)	(1.51)	(2.82)		(0.66)
	18 years old	3.39	10.70	1.78	4.25	3.45	3	0.94	3.10	24.78	26.56a	25.10	24.28a	4	1.37
		(1.06)	(4.68)	(0.93)	(1.97)	(2.19)		(0.63)	(0.84)	(2.32)	(2.80)	(0.65)	(1.77)		(1.28)
Ferruginous (ONAB)	8 years	3.56	18.94	2.33	3.53	4.04	3	0.18	3.46	15.20	18.00a	13.29	15.76a	5	1.44
		(0.65)	(7.98)	(1.25)	(1.68)	(1.82)		(0.11)	(0.36)	(1.20)	(1.35)	(1.51)	(3.33)		(0.66)
	18 years old	3.31	15.34	4.30	5.29	5.97	5	1.45	3.10	24.78	28.80a	25.10	24.92a	4	1.37
		(0.58)	(2.56)	(0.93)	(1.89)	(1.77)		(1.06)	(0.84)	(2.32)	(3.05)	(0.65)	(1.81)		(1.28)
Ferruginous (private)	8 years	3.35	6.10	2.87	5.53	4.37	5	0.59	3.51	13.55	15.12a	11.82	12.02a	9	2.49
		(0.46)	(1.02)	(0.59)	(1.25)	(0.56)		(0.30)	(0.20)	(0.42)	(0.33)	(0.27)	(0.64)		(0.67)
	18 years old	3.56	5.89	2.74	6.85	6.38	5	1.46	3.46	16.11	18.52a	18.65	18.60a	10	2.84
		(0.35)	(0.45)	(0.26)	(1.38)	(1.20)		(0.99)	(0.18)	(0.42)	(1.26)	(0.54)	(1.12)		(0.74)

productivity, but they require the most suitable plant types and spacing arrangements [44]. The diameter increased with the wider spacing due to a lower stand density [45]. Wide spacing produces a larger DBH [17], and an initial stand density has a more substantial influence on tree diameter than height [46]. The wider spacing could increase crown, and root density due to less competition among trees in the forest area [17,18].

5. Conclusion

This work recommends the threshold of less than 10 cm tree cutting height above the ground as good silvicultural practices for the better management of teak plantations in Benin. Appropriate cutting level and compliance with the recommendations related to silvicultural practices could be solutions to limit competitions and allow good growth of future trees in the main plantation. This has resulted in a significant presence of stump sprouts that are not often pruned. These stump sprouts and filler trees thus exert strong competition on the resources available for the growth of future trees.

Author contribution statement

Soufianou Arzouma; Roméo Gbaguidi: Conceived and designed the experiments; Performed the experiments; Wrote the paper.
Gauthier Ayélo: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.
Adoté HG Akueson: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data.
Arcadius Yves Justin Akossou: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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