WHICH ABIOTIC FACTORS HAVE THE MOST INFLUENCE ON THE GROWTH OF TREES IN BENINESE COPPICE TEAK STANDS?

Armand Sèdami Igor YÊVIDÉ[1*], Jean Cossi GANGLO[1], Romain Lucas GLÈLÈ KAKAÏ[2], and Charles DE CARNNIÈRE[3]

Received date: July 03, 2014 Revised date: September 30, 2014 Accepted date: October 08, 2014

Abstract

Coppice teak stands are widely established by farmers in Benin as a means to diversify their livelihoods. The aim of this study was to assess the relationships between soil properties and growth performance characteristics of coppice teak stands so as to identify the main ecological parameters which control the species' growth. Samples from 29 plantations covering various plant communities were selected in the commune of Tori-Bossito located in the Atlantic department. The methodology used was based on the assessment of biological diversity indexes of plant communities, the appraisal of soil tactile texture followed by physic-chemical analysis in the laboratory, and calculation of the trees' growth parameters. These data were used to perform a principal component analysis and an analysis of correlation to evaluate the relationship between abiotic and biotic factors. Results have revealed the soil clay content as the main factor linked to the growth of coppice teak stands. The increase of the amount of clay in the soil contributes to a reduction in the soil porosity and, as a result, the decrease of the species' growth. In addition to findings from former studies on Beninese coppice teak stands, the current results are guidelines to help farmers improve their management practices.

Keywords: Coppice teak plantations, soil properties, undergrowth plant communities, dendrometric characteristics, Tori-Bossito, Benin

Introduction

Forests in Benin cover about 2351000 ha (FAO, 2009) and represent the most important wood and non-wood products' supply of the country. Unfortunately, an area of 50000 ha is lost every year because of human pressure through agriculture and resource mismanagement (FAO, 2011).

The Beninese government has initiated

[1] *Laboratory of Forest Sciences, Faculty of Agronomic Sciences, University of Abomey-Calavi, 01 BP 526, Cotonou, Bénin. E-mail: yias01@yahoo.fr or armandyevide@gmail.com*

[2] *Laboratory of Applied Ecology, Faculty of Agronomic Sciences, University of Abomey-Calavi, 01 BP 526, Cotonou, Bénin.*

[3] *Université Libre de Bruxelles, Ecole Interfacultaire de Bbioingénieurs, Service d'Ecologie du Paysage et Systèmes de Production Végétale, Avenue F. D. Roosevelt 50 CP 169, B-1050 Bruxelles, Belgium.*

* *Corresponding author*

reforestation programs to mitigate the loss of natural forests as well as to contribute to meet the growing population's needs for forest products. Also, for some decades, the farmers' interest in agroforestry and forestry has increased and they have been involved in the production of forest species such as teak (Tectona grandis L.f) stands in short rotation under a coppice regime.

Native to Southeast Asia (Behaghel, 1999), teak is a valued species planted worldwide; in America (Panama, Costa Rica, Brazil…), Asia (India, Laos, Myanmar, Indonesia…), and Africa (Tanzania, Côte d'Ivoire, Ghana, Togo, Benin, Nigeria…). The species was introduced into Benin in 1916 (Ganglo *et al.*, 1999). Nowadays, it covers more than 17000 ha in state plantations. Many research works have been undertaken in Beninese state teak plantations. These studies were focused on the impact of soil richness on the species' growth and have concluded that a high content of calcium, phosphorus, carbon, and nitrogen, the carbon-to-nitrogen (C/N) ratio, and the cation exchange capacity (CEC), are favorable for teak growth (CTFT, 1969). Catinot (1970) suggested that shallow soils and a weak water retention capacity were mainly responsible for teak stem deformation. Over recent decades, relationships between undergrowth vegetation and plantation productivity have been clearly underlined (Ganglo *et al.*, 1999; Ganglo, 2005; Ganglo *et al.*, 2006; Noumon *et al.*, 2009).

Studies have been carried out also on private teak plantations since 2002 and have contributed to the characterization of plantations and plantations owners (Quenum, 2002; Yêvidé *et al.*, 2011a; Atindogbe *et al.*, 2012); have described ecological and structural characteristics of plant communities found under the plantations (Yêvidé *et al.*, 2011a); have assessed the economic value of the products and how benefits are distributed among members of the chain, as well as determining the degree of consumers' satisfaction with respect to the product quality (Aoudji *et al.*, 2011, 2012); and have assessed the impact of factors like age, density, and plant communities on the species' growth as well as provided a primary growth model for the coppice teak stands (Yêvidé *et al.*, 2011b, 2014). As the main refinement of the research so far undertaken on the ecological and structural characteristics of coppice teak stands in Benin, this study aims to assess the relationships between the soil's properties (texture, acidity, organic matter, content…) and the growth performance characteristics of the stands so as to identify the main ecological parameters which control teak growth.

Materials and Methods

Study Area

The study was carried out in the commune of Tori-Bossito, located in the Atlantic department in the south of Benin between 6°18' and 6°58' north latitude and 1°56' and 2°30' east longitude (Figure 1). The area is mainly characterized by ferralitic and hydromorphic soils (Volkoff and Willaime, 1976). The mean annual rainfall is around 1140 mm and the mean daily temperature varies between 25.8°C and 29.1°C. Because of agriculture, the natural vegetation has been degraded and nowadays fallows and croplands dominate the landscape.

Sampling, Data Collection, and Analysis

Nine plant communities from 29 plantations of at least 1 acre (0.4 ha) each have been used for the study. The entire area of each plantation has been used to access the plantation's plant community species richness (S) and compute the Shannon Wiener diversity index (H) as well as the Pielou evenness index (E) through the following formula:

$H = -\sum P_i \log_2 (P_i)$ with $P_i = r_i / r$ where r_i is the abundance and dominance coefficient of the undergrowth species i and r is the overall abundance and dominance coefficient of all undergrowth species in the plantation. Further, $E = H/H_{max}$ with $H_{max} = \log_2 (S)$ where S is the overall number of undergrowth species.

Two square plots of 100 m^2 were established in each plantation and allowed the counting of more than a dozen trees as recommended by Duplat and Perrote (1981). The circumference at breast height (Ci) of all shoots was measured as well as the shoots' height (*Hi*) of the 10 first stumps and the height of the biggest tree in the plot (*Hd*). The following parameters were computed:

- mean quadratic diameter $Dg = \sqrt{\sum(Ci/\pi)^2/n}$ where *n* is the number of shoots
- mean height $Hg = \sum Hi/n'$ where *n'* is the number of the shoots' measured height.
- basal area $G = \sum\left(Ci^2/4\pi\right)$
- annual average increment in: height (*AAIH* = *Hg*/*AgeR*); diameter (*AAID* = *Dg*/*AgeR*); and basal area (*AAIG* = *G*/*AgeR*) where *AgeR* is the shoot age obtained through interviews with plantation owners.

The plantation slope was recorded and in 1 of the 2 plots, the tactile texture of the soil was appreciated manually at intervals of 10 cm from the surface to 50 cm in depth. Textures were recorded on the basis of the relative rates of sand, silt, and clay contained in the soil. The first 30 cm of the soil was sampled and labeled for analysis in the Soil Sciences Laboratory of the Faculty of Agronomic Sciences, University of Abomey-Calavi. The pH measurements (pH_{water} and pH_{KCl}) were determined with a pH-meter whose electrodes were immersed into a solution of 20 g of soil and 50 mL of distilled water ($pHpH_{water}$) and in a suspension of soil in a basal standard solution of potassium chloride (pH_{KCl}). The granulometric analysis for identification of the sand, silt, and clay rates was made by the method of Robinson's pipette. The carbon rate was determined by Walkley and Black's method, and the organic matter (OM) rate was calculated by multiplying the carbon rate (%C) with the coefficient 1.72 (OM = 1.72 * %C). The CEC was determined by the dosage of exchangeable cations.

To describe the relationship between abiotic and biotic factors, principal component analysis (PCA) was firstly performed on biotic variables of the plant communities in order

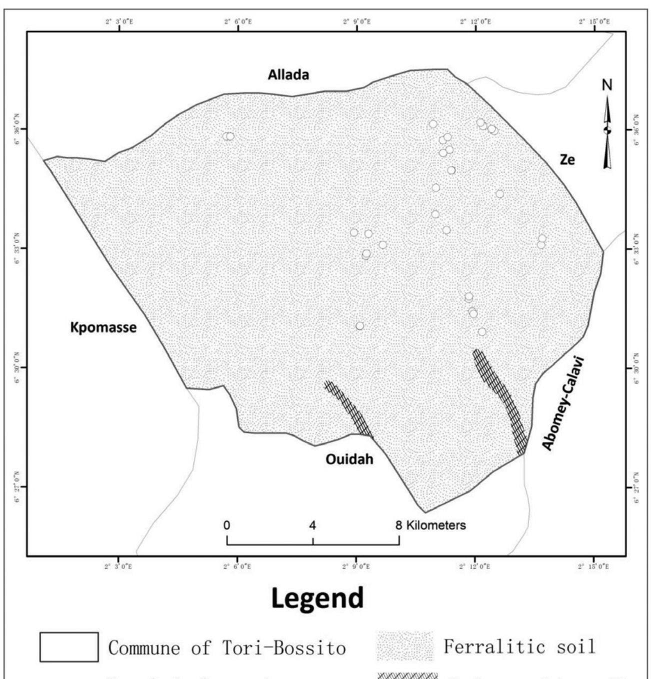

Figure 1. Geographic location of the commune of Tori-Bossito

to obtain uncorrelated components. Then, the Pearson correlation coefficients were computed between the principal components extracted and the abiotic factors. Analyses were done with SAS version 9.2.

Results and Discussion

Characteristics of Undergrowth Plant Communities and Teak Stands

Described in Table 1, the studied plant communities had, in general, more than 30 species except the *Chromolaena odorata* and *Panicum maximum* community (10 ± 3). The Shannon Wiener diversity index showed a lower species diversity within the *Chromolaena odorata* and *Panicum maximum* community (1.08 ± 0.23) while the highest value was found in the *Mallotus oppositifolius* and *Cnestis ferruginea* community (3.14 ± 0.21). With the Pielou evenness index of 0.57 ± 0.04, the latter presented a better balance in the distribution of the abundance-dominance. Globally, the plant communities had an average species diversity index but a weak balance in species abundance-dominance distribution.

The pH_{water} and pH_{KCl} of the plant communities indicate that the plantations' substrates were slightly acidic. There was an average of organic matter ranging from 1.38 to 2.45% for, respectively, the *Mallotus oppositifolius* and *Reissantia indica* community and the *Mallotus oppositifolius* and *Paullinia pinnata* community. The CEC is above 10 $cmol^+/kg$ for all the plant communities except the *Mallotus oppositifolius* and *Reissantia indica* community which recorded the lowest value (7.7 $cmol^+/kg$). The granulometric analysis showed a globally high sand content (around 77%) in soils under the *Mallotus oppositifolius* communities while the highest clay content was recorded in the *Chromolaena odorata* and *Panicum maximum* community (29.0%) and in the community of *Dichapetalum madagascariense* and *Cnestis ferruginea* (26.9%). Hence the undergrowth plant communities of the studied plantations develop on slightly acidic soils with a low content in organic matter; and these soils are generally sandy over the first 30 cm of the soil profile.

The ages of the sample plantations ranged from 2 to 5 ± 3.6-years. The mean quadratic diameter, the mean height, and the mean height of the biggest trees were respectively under 6.5 cm, 7.5 m, and 9 m for all plant communities (Table 2). Only the *Mallotus oppositifolius* and *Dichapetalum madagascariense* community had the lowest mean basal area but it did not possess the lowest growth performance. Based on the annual average increment, the *Dichapetalum madagascariense* and *Cnestis ferruginea* community had the lowest increment in diameter and the *Mallotus oppositifolius* and *Rourea coccinea* community had the lowest increment in height and basal area while the *Mallotus oppositifolius* and *Cnestis ferruginea* community held the highest growth performance.

Relationship Between Biotic and Abiotic Factors of the Plant Communities

The results of the PCA performed on the biotic variables showed that the first 3 principal components explained 90% of the overall information on the plant communities (Table 3). Variables corresponding to dendrometric characteristics were positively correlated with the first principal component (Pc1), whereas growth parameters were all positively correlated with the second principal component (Pc2), and the biological indices were positively correlated with the third principal component (Pc3) (Table 3). Therefore, it has been deduced that the first principal component expresses a dendrometric gradient, whereas the second expresses a growth gradient, and the third a gradient of biological indexes.

At 5% of probability level, there exists a positive correlation between the silt rate within the first 30 cm of the soils and the first principal component (dendrometric gradient). At the same probability level, the soil's texture within 10 to 20 cm and 30 to 40 cm in depth was negatively correlated with the second principal component (growth gradient). The soil texture from 20 to 30 cm and from 40 to 50 cm is also negatively correlated with the second principal component but at 10% of the probability level (Table 4).

The positive correlation of the dendrometric gradient with the soil content in silt could imply that the increase in silt within the first 30 cm of the soils causes an increase in the mean quadratic diameter, mean height, and mean basal area. Besides, the negative correlation between the soil texture and the growth gradient leads to the suspicion that the more clayish the texture of the soil gets (heavy soil), the less the trees grow in diameter, height, and basal area. This finding suggested that teak stands could not grow well on clayish soil. Similar findings were made by Dhar *et al*. (1992) when they were studying how soil was a causative factor for the poor growth

Table 1. Plant communities' diversity indexes and soil characteristics in first 30 cm depth

		Plant communities								
Characteristics	**Values**	**DM CF**	**MO CF**	**MO DM**	**MO ML**	**MO PP**	**MO RC**	**MO RI**	**PM CO**	**UC CF**
Slope	Mean	0.05	0.04	0.02	0.01	0.02	0.01	0.06	0.06	0.08
	SD	0.03	0.04	0.01	0.01	0.02	0.00	0.02	0.07	0.02
Species richness	Mean	41	45	34	41	34	32	42	10	37
	SD	9	2	2	3	4	0	3	3	0
Shannon Wiener index	Mean	2.77	3.14	2.76	2.95	2.55	2.18	2.31	1.08	2.23
	SD	0.38	0.21	0.63	0.65	0.51	0.62	0.72	0.23	0.00
Pielou evenness index	Mean	0.51	0.57	0.44	0.55	0.39	0.44	0.37	0.31	0.40
	SD	0.05	0.04	0.10	0.12	0.08	0.12	0.12	0.05	0.00
pH_{water}	Mean	5.6	5.9	6.0	6.4	6.3	6.1	6.0	6.0	5.7
	SD	0.5	0.2	0.3	0.1	0.3	0.0	0.2	0.9	0.2
pH_{KCl}	Mean	4.7	5.2	5.2	5.6	5.5	5.2	5.2	5.1	4.9
	SD	0.6	0.4	0.4	0.1	0.5	0.1	0.4	1.0	0.3
Sand rate (%)	Mean	70.1	77.4	76.9	80.8	77.0	68.1	80.6	67.3	74.8
	SD	8.9	8.8	6.3	1.3	5.9	4.4	2.7	21.2	11.3
Silt rate (%)	Mean	3.0	2.1	3.4	3.9	2.6	7.4	1.8	3.8	3.3
	SD	1.9	1.6	1.7	1.1	0.8	0.5	0.7	1.1	0.4
Clay rate (%)	Mean	26.9	20.5	19.7	15.3	20.5	24.5	17.7	29.0	22.0
	SD	8.8	8.4	5.5	2.1	5.2	4.9	3.3	20.2	11.7
Organic matter (%)	Mean	1.87	1.64	1.66	1.66	2.45	2.20	1.38	2.16	2.02
	SD	0.39	0.24	0.44	0.26	1.24	0.55	0.04	0.24	0.15
CEC ($cmol^+/kg$)	Mean	14.3	9.5	10.0	6.5	10.4	13.5	7.7	13.5	11.5
	SD	4.8	4.7	3.5	1.7	4.0	3.5	3.2	10.6	9.2

Caption: SD = Standard deviation; DMCF = *Dichapetalum madagascariense* and *Cnestis ferruginea* community ; MOCF = *Mallotus oppositifolius* and *Cnestis ferruginea* community; MODM = *Mallotus oppositifolius* and *Dichapetalum madagascariense* community; MOML = *Mallotus oppositifolius* and *Macrosphyra longistyla* community ; MOPP = *Mallotus oppositifolius* and *Paullinia pinnata* community; MORI = *Mallotus oppositifolius* and *Reissantia indica* community ; UCCF = *Uvaria chamae* and *Cnestis ferruginea* community; PMCO = *Chromolaena odorata* and P*anicum maximu*m community; MORC = *Mallotus oppositifolius* and *Rourea coccinea community*.

of teak in the South Balaghat Forest in India. They found that soil with a high clay content along with its shrink-swell property was responsible for the poor growth of the species. However, in Lama Forest in the south of Benin, the state teak stands were established on vertisols characterized by the highest content of clay with a shrink-swell property. The soils under these plantations were plowed in depth to assure good soil porosity. Furthermore, furrows were made before plantations were established to control water circulation and floods after precipitations assuring the aeration of the trees' roots. Accordingly, not only could the soil clay content itself be seen as a factor of low growth, but also the reduction of porosity it leads to. This fact is in accordance with previous works. Indeed, Dhar *et al*. (1992) have included in their findings that impeded drainage was part of the factors responsible for the poor growth of teak. Maldonado and Louppe (1999) have reported that the best development of teak depends on soil properties, naming deepness and good drainage. Krishnapillay (2000) reported that teak can grow on diverse soils, but the growth depends on the depth, structure, porosity, and

Table 2. Dendrometric characteristics and growth performances of teak plantations according to the plant communities

		Plant communities								
Characteristics	**Values**	**DM CF**	**MO CF**	**MO DM**	**MO ML**	**MO PP**	**MO RC**	**MO RI**	**PM CO**	**UC CF**
Number of Observation		4	4	3	4	5	2	3	2	2
Shoots Age (yr)	Mean	5	3	3	5	3	5	4	3	2
	SD	2.6	0.9	1.4	3.6	0.7	0.5	1.7	1.0	0.0
Mean diameter (cm)	Mean	5.21	5.53	2.94	5.44	3.80	6.33	4.56	5.73	3.83
	SD	3.14	1.40	1.28	1.81	0.79	1.07	0.95	2.80	0.93
Mean height (m)	Mean	6.34	7.27	4.58	6.63	5.13	6.20	6.49	6.80	5.96
	SD	2.61	1.74	2.91	2.05	1.17	1.19	0.92	2.59	1.14
Biggest tree height (cm)	Mean	8.55	8.84	5.02	7.68	6.32	8.31	8.47	7.24	6.85
	SD	5.04	2.26	3.20	2.03	1.23	1.87	2.01	2.03	1.46
mean basal area (m^2/ha)	Mean	14.25	14.58	6.01	12.24	7.04	11.24	11.20	12.44	9.02
	SD	10.02	5.69	4.68	4.73	1.00	3.29	1.03	6.80	3.86
AAID (cm/yr)	Mean	1.21	2.29	1.41	1.59	1.4	1.41	1.27	1.90	1.91
	SD	0.51	0.25	0.79	0.88	0.24	0.01	0.59	0.03	0.33
AAIH (m/yr)	Mean	1.57	3.10	2.04	2.11	1.87	1.37	1.86	2.32	2.98
	SD	0.66	0.86	1.02	1.32	0.19	0.03	0.96	0.16	0.40
AAIG (m^2/ha/yr)	Mean	3.39	6.06	2.82	3.52	2.64	2.47	3.20	4.06	4.51
	SD	1.95	2.06	1.82	1.76	0.52	0.24	1.62	0.25	1.36

Caption: AAID: annual average increment in diameter; AAIH: annual average increment in height; AAIG: annual average increment in basal area; SD = Standard deviation; DMCF = *Dichapetalum madagascariense* and *Cnestis ferruginea* community; MOCF = *Mallotus oppositifolius* and *Cnestis ferruginea* community; MODM = *Mallotus oppositifolius* and *Dichapetalum madagascariense* community; MOML = *Mallotus oppositifolius* and *Macrosphyra longistyla* community; MOPP = *Mallotus oppositifolius* and *Paullinia pinnata* community; MORI = *Mallotus oppositifolius* and *Reissantia indica* community; UCCF = *Uvaria chamae* and *Cnestis ferruginea* community; PMCO = *Chromolaena odorata* and *Panicum maximum* community; MORC = *Mallotus oppositifolius* and *Rourea coccinea* community.

Table 3. Eigenvalues and proportions of information explained after principal component analysis run and correlation between principal components and biotic variables

	Biotic variables	Principal components		
		Pc1	**Pc2**	**Pc3**
Eigenvalue		3.82	2.80	2.37
Proportion		38.24	28.00	23.71
Cumulative		38.24	66.24	89.95
	Species richness	0.26	0.34	0.71
Plant communities	Shannon Wiener diversity index	-0.04	0.36	0.91
	Pielou evenness index	0.09	0.30	0.85
	Quadratic diameter average	0.85	-0.41	0.05
	Total height average	0.93	-0.24	-0.05
	Height average of the biggest tree	0.93	-0.23	0.04
Teak plantation	Basal area	0.95	-0.19	0.03
	annual average increment in diameter	0.28	0.84	-0.36
	annual average increment in height	0.23	0.90	-0.35
	annual average increment in basal area	0.51	0.80	-0.24

the draining and water retention capacity of the soils. It was clearly pointed out that teak prefers well-drained, fertile, and deep soils, particularly the volcanic substrates or alluvial soils of different origins with the pH comprised between 6.5 and 7.5. Pandey and Brown (2000) underlined that the most successful teak forests (natural or planted) are observed on well-drained and deep alluvium soil and that teak plantations do not survive when established on clayish and poorly-drained lowlands. It appears obvious that the soil porosity is important for good growth of teak. However, other factors such as calcium (Ca), phosphorus (P), nitrogen (N), potassium (K), and magnesium (Mg), the C/N ratio, and the CEC appeared to have significant and positive correlations with teak growth in many studies (CTFT, 1969; Zech and Drechsel, 1991; Watanabe *et al*., 2010; De Favare *et al*., 2012). The influence of pH in teak growth is controversial because, while it has been reported that a high pH contributed to poor growth (Dhar *et al*., 1991), soil pH was not correlated to growth in Ghana (Watanabe *et al*., 2010) or in our study.

To encourage their involvement in the establishment of teak stands and to improve their stands' growth, farmers should be sensitized and trained to use well drained lands for coppice teak production and also to maintain the optimal number of shoots per stump, as suggested in a former study (Yêvidé *et al*., 2011b).

Conclusions

Coppice teak stands are widely established by farmers in the Republic of Benin and their wood is used for many purposes by consumers in cities. Coppice teak stands have been at the center of interest through many studies during recent decades. This work, the objectives of which were to assess the relationships between the soils'

Table 4. Canonical correlation of abiotic variables with the major principal components of biotic variables

Abiotic variables	Principal components					
	Pc1		Pc2		Pc3	
	r	p	r	p		p
pH_{water}	0.26	0.172	0.16	0.515	0.22	0.252
pH_{KCl}	0.15	0.439	0.17	0.374	0.02	0.918
Sand	-0.06	0.774	0.23	0.232	0.07	0.709
Silt	0.39	0.034	0.03	0.866	-0.13	0.505
Clay	-0.03	0.881	-0.25	0.190	-0.05	0.805
Organic matter	0.19	0.325	-0.16	0.418	0.29	0.124
CEC	-0.04	0.856	-0.27	0.153	0.03	0.865
Slope	0.01	0.973	-0.16	0.404	-0.19	0.325
Texture at 10 cm in depth	-0.02	0.913	-0.13	0.486	-0.13	0.503
Texture at 20 cm in depth	0.07	0.732	-0.34	0.048	0.15	0.429
Texture at 30 cm in depth	0.02	0.921	-0.32	0.095	0.16	0.419
Texture at 40 cm in depth	-0.11	0.585	-0.37	0.047	0.11	0.587
Texture at 50 cm in depth	0.07	0.726	-0.36	0.055	0.21	0.282

Caption: r = Correlation coefficient; p = probability

properties and the dendrometric characteristics of coppice teak stands and to identify the main ecological parameters that control teak growth, highlighted the soil clay content as the principal abiotic factor among the studied factors which influence teak growth. The soil clay content over 50 cm deep impacts negatively on teak growth in coppice stands. However, it has been emphasized that it is the reduction of porosity due to the increase of clay contained in the soil texture that engenders low growth of stands instead of the soil clay content itself. In addition to the findings from former studies in Beninese coppice teak stands, the current results are guidelines to help farmers improving their management practices. Thus, farmers should be sensitized to choose adequate lands for establishment of their plantations and maintain the optimal number of shoots per stump for better productivity.

Acknowledgements

We wish to express our gratitude to the Ministry of Foreign Affairs and the Commission Universitaire pour le Développement of Belgium who funded this study. The authors also wish to thank the farmers of the Atlantic department who agreed to let us carry out the study.

References

Aoudji, A.K.N., Adégbidi, A., Ganglo, J.C., Agbo, V., Yêvidé, A.S.I., De Cannière, C., and Lebailly, P. (2011). Satisfaction across urban consumers of smallholder-produced teak (*Tectona grandis* L.f.) poles in South Benin. Forest Policy Econ., 13:642-651.

Aoudji, A.K.N., Adégbidi, A., Agbo, V., Atindogbé, G., Toyi, M.S.S., Yêvidé, A.S.I., Ganglo, J.C., and Lebailly, P. (2012). Functioning of farm-grown timber value chains: Lessons from the smallholder-produced teak (*Tectona grandis* L.f.) poles value chain in Southern Benin. Forest Policy Econ., 15:98-107.

Atindogbe, G., Fonton, N.H., Fandohan, B., and Lejeune, P. (2012). Caractérisation des plantations privées de teck (*Tectona grandis* L.f.) du département de l' Atlantique au Sud-Bénin. Biotechnol. Agron. Soc., , 16(4):441-451.

Behaghel, I. (1999). Etat des plantations de teck (*Tectona grandis* L. F.) dans le monde. Bois et Forêts des Tropiques, 262(4):6-19.

Catinot, R. (1970). Les déformations des fûts du teck au Dahomey – Hypothèse générale d'explication des bosses et déformations des fûts du Teck. Bois et Forêts des Tropiques, 132:3-22.

Centre Technique Forestier Tropical (CTFT). (1969). Compte rendu d'un déplacement effectué au Dahomey du 19 au 27 décembre 1968. CTFT, Nogent sur Marne, France, 15p.

De Favare, L.G., Guerrini, I.A., and Backes, C. (2012). Increasing levels of base saturation and initial development of teak in an oxisol of medium texture. Ciencia Florestal, 22(4):693-702.

Dhar, B.L., Jha, M.N., Suri, S., and Singh, K. (1992). Mineralogy and nutrient status of teak-growing soils. Journal of the Indian Society of Soil Science, 40(1):156-161.

Duplat, P. and Perrote, G. (1981). Inventaire et Estimation de l'Accroissement des Peuplements Forestiers. Office Nationale des Forêts, Paris, France, 432p.

Food and Agriculture Organisation of the United Nations (FAO). (2009). Situation des forêts du monde 2009. Organisation des Nations Unies pour l'Alimentation et l'Agriculture (FAO), Rome, Italy, 152p.

Food and Agriculture Organisation of the United Nations (FAO). (2011). Situation des forêts du monde 2011. Organisation des Nations Unies pour l'Alimentation et l'Agriculture (FAO), Rome, Italy, 193p.

Ganglo, J.C., De Foucault, B., and Lejoly, J. (2006). The Psychotria vogeliana-community in the spontaneous under growth of teak (*Tectona grandis* L.f) plantation in south-Bénin: ecological and silvicultural indicatory values. Acta Bot. Gallica, 153(1):125-135.

Ganglo, J.C., Lejoly, J., and Pipar, T. (1999). Le teck (*Tectona grandis* L. f.) au Bénin, gestion et perspectives. Bois et Forêts des Tropiques, 261(3):17-27.

Ganglo, J.C. (2005). Groupements de sous-bois, identification et caractérisation des stations forestières : cas d'un bois au Bénin. Bois et Forêts des Tropiques, 285(3):35-46.

Krishnapillay, B. (2000). La sylviculture et la gestion des plantations de teck. Unasylva, 201(51):14-21.

Maldonado, G. and Louppe, D. (1999). Plantations villageoises de teck en Côte d'Ivoire. Bois et Forêts des Tropiques, 262(4):19-30.

Noumon, C.J., Ganglo, C.J., Azontondé, H.A., De Foucault, B., and Adjakidjè, V. (2009). Ecological and silvicultural indicatory value of plant-communities of Koto forest reserve (Centre-Benin). Int. J. Biol. Chem. Sci., 3(2):367-377.

Pandey, D. and Brown, C. (2000). Le teck dans le monde. Unasylva, 201(51):3-13.

Quenum, I.A. (2002). Etude dendrométrique et contribution à la gestion des plantations privées de Tectona grandis L. f au Sud-Bénin : cas de la Commune de Tori-Bossito. Thèse d'ingénieur agronome, Faculty of Agronomic Sciences, University of Abomey-Calavi, Cotonou, Bénin, 80p.

Volkoff, B. and Willaime, P. (1976). Notice explicative 66. Carte pédologique de reconnaissance de la République du Bénin à 1/200 000 : Feuille de Porto-Novo (1). Office de la Recherche Scientifique et Technique Outre-mer (ORSTOM), Paris, France, 39p.

Watanabe, Y., Owusu-Sekyere, E., Masunaga, T., Buri, M.M., Oladele, O.I., and Wakatsuki, T. (2010). Teak (Tectona grandis) growth as influenced by soil physicochemical properties and other site conditions in Ashanti region, Ghana. J. Food Agric. Environ., 8(2):1040-1045.

Yêvidé, A.S.I., Ganglo, J.C., Aoudji, A.K., Toyi, M.S., De Cannière, C., De Foucault, B., Devineau, J.L., and Sinsin, B. (2011a). Caractéristiques structurelles et écologiques des phytocénoses de sous-bois des plantations privées de teck du département de l'Atlantique (Sud-Bénin, Afrique de l'Ouest). Acta Bot. Gallica, 158(2):263-283.

Yêvidé, A.S.I., Ganglo, J.C., Glèlè-Kakaï, R.L., and De Cannière, C. (2011b). Effet de la densité, de l'âge et des groupements végétaux de sous-bois sur la vigueur des plantations privées de teck (*Tectona grandis* L.f.) gérées en régime de taillis au sud-Bénin (Afrique de l'Ouest). Int. J. Biol. Chem. Sci., 5(3):1215-1231.

Yêvidé, A.S.I., Ganglo, J.C., Glèlè Kakaï, R.L., De Cannière, C., and Fonton, N.H. (2014). Growth modeling of short rotation coppice teak (*Tectona grandis* L.f) stands in Republic of Benin. Int. J. Adv. Agric. Res., 2(4):58-66.

Zech, W. and Drechsel, P. (1991). Relationships between growth, mineral-nutrition and site factors of teak (*Tectona grandis*) plantations in the rain-forest zone of Liberia. Forest Ecol. Manag., 41(3-4): 221-235.