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Cedrella odorata Stand Structure, Carbon Stocks, and Understorey Species Diversity along Topographic Gradients in the Deciduous Forest Zone of Ghana

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Introduction

Cedrela odorata L. (Red Cedar), a native of the West Indies, was introduced in tropical West Africa (in Ghana) in the early 20th century. It thrives in a wide range of precipitation regimes; from dry to wet rainfall zones (Citron, 1990), albeit growth may be repressed and slow in water stressed environments (Alderete-Chavez et al., 2010). It is valued internationally for its attractive, ductile, and durable wood (Salazar et al. 2000; Orwa et al. 2009) with the wood mostly likened to that of mahogany. It is also widely known for its use in erosion control and soil fertility conservation, traditional medicines, apiculture, and production of handicrafts and ornaments. The demand for C. *odorata* wood and other products is high and large scale plantations of this species to augment natural populations and reduce its wood demand and supply deficit are urgently required.

There have been significant progress in establishing large scale plantations of C. *odorata* in many parts of the tropics, including parts of sub Saharan Africa (Brown et al., 2020; Novor & Abugre, 2020). It is one of the most promising fast growing exotic species widely cultivated in pure and mixed plantations in Ghana for its multipurpose attributes (Novor and Abugre 2020). Cedrela stands currently occur in several ecological zones in the country mainly as pure and mixed plantations (Brown et al., 2020; Novor & Abugre, 2020) and is one of the species earmarked for future plantation expansion programs. Ages of these plantations vary with some being over 30 years old but are not intensively managed. These cedrela plantations occur on all terrain types of different slopes and elevation attributes. Nevertheless, the total area extent of C. *odorata* plantations is largely unknown and its productivity, biodiversity conservation and climate mitigation potential at its myriad geomorphic locations remain nebulous. With global planted forest area expected to expand by 11 – 14% in the next 3 to 4 decades (Korhonen et al. 2021), and diversification in the species used for plantations advocated, C. *odorata* planted area is likely to expand tremendously, considering its favourable habits of high germination index, relatively rapid growth rates (Ward et al. 2008; Alderete-Chavez et al. 2010), and the colossal demand for its products. Furthermore, the effect of topography on stand productivity and natural regeneration of other woody species in cedrela plantations remains a significant knowledge gap. This study examined the stand structural attributes of matured *Cedrela odorata* plantations and understorey woody species diversity and composition on three topographic positions in the Tinte Bepo Forest Reserve in Ghana.

Material and Methods

The study was conducted in experimental plots within compartments 30, 42 and 56 of the Tinte Bepo Forest Reserve in the Mankranso Forest District, Ashanti Region, Ghana which is within the Moist Semi-Deciduous North West (MSNW) ecological zone. The mean annual rainfall is 1350 mm and the annual mean minimum and maximum temperatures are 21°C and 32.5°C, respectively (Forestry Commission, 2016). The *C. odorata* plantations in compartment 42, located on the hilly terrain, was established in 1999 and covers an area of 112 ha. Compartments 30 and 56 which are respectively located on the flat terrain and the valley bottom were established in 2003 and 2004 with the plantation areas of 164.24 and 110 ha, respectively.

Each compartment was divided into several 40 x 40 m plots arranged in series. Five plots were then systematically selected from each compartment for the vegetation survey. Following the selection of the first sample plot, subsequent sample plots were about 600 m (0.6 km) apart for each compartment. The plots on the hilly terrain and the valley bottom were located on the same aspect of the landscape. Within each plot, the diameters at breast height (DBH), total tree height, and stand tree density were measure/determined. In addition, the slope and elevation of each plot in each topographic position was determined.

Within each 40 x 40 m plot, two 1 x 1 m subplots were randomly established and used to assess species regeneration or recruitments. All woody species < 10 cm in DBH in each 1 x 1 m subplot were surveyed and their scientific names, families and frequencies recorded. Species identification was done with the assistance of a tree spotter (taxonomist) and tree identification guides.

Stand density, diameter at breast height, total tree height, basal area, and size class distribution (SCD) were estimated and constituted the basis for describing the Cedrela plantation structure of the Tinte Bepo forest reserve. In addition, DBH data of the three topographic positions were fitted to two diameter distribution models: Weibull and Johnsons SB distributions. Tree stem density, basal area and aboveground biomass carbon were also estimated.

Results and Discussion

Stand structure of C. *odorata* plantations

The goodness-of-fit statistics for the Bayesian modelling of Johnson's SB and Weibull distribution revealed that the Weibull distribution was a better fit for the data at the ridge crest or summit while the JSB distribution was the best fit model for the DBH data at the flat terrain and Valley bottom (Table 1). Overall the Anderson-Darling, Cramer-von Misses, and Kolmogorov Smirnov test statistics for the Weibull distribution on the hilly terrain were the lowest compared to both Weibull and JSB distributions for the other topographic positions. These disparities may arise from management factors such as thinning and natural factors affecting diameter distribution such as heterogeneity in site conditions and irregular stand densities caused by windthrow or fires (Pogoda et al., 2019).

Table 1. Goodness of fit statistics for Weibull and Johnsons SB diameter distribution models for *Cedrela odorata* plantations in three topographic positions; hill tops, valleys and flat terrain.

Site / topo-position	Parameter	AD	CVM	KS	LogLikelihood
Hill top	Weibull	1.22	0.204	0.06	-1221.4
	JSB	2.17	0.39	0.075	-1224.7
Flat terrain	Weibull	2.98	0.39	0.077	-1455.0
	JSB	1.55	0.18	0.057	-1445.7
Valley bottom	Weibull	3.28	0.51	0.080	-1218.7
	JSB	2.81	0.43	0.073	-1226.5

AD – Anderson-Darling, CVM – Cramer-von Misses, KS – Kolmogorov-Smirnov

Ancova results of the plantation stand structure showed significant differences among stand variables such as diameter at breast height ($p<0.0005$), total tree height ($p = 0.0314$), and stand density ($p = 0.0014$, Table 2). The flat terrain had the highest number of trees per unit area, 588.8±29.5 trees ha^{-1} with the hilly tops having the least, 392.5±34.5 trees ha^{-1} (Table 2). The total height and DBH of trees in the valley bottom were significantly higher than that of the flat terrain. The flat terrain which had the least DBH, had the highest basal area of 65 m^2 ha^{-1} (Table 2). However, basal area, just like total tree carbon was not significantly different among the three relief positions. This is similar to plantation responses of teak in Lao, where higher tree yield occurred on the flat terrain than on the steep slopes, but with no significant differences in the soil nutrient status (Vongkhamho et al., 2022). The carbon stocks of the C. *odorata* plantation at the Tinte Bepo Forest Reserve was similar to the carbon stocks of unmanaged 42-year old plantations (159.7 ± 14.3 Mg ha^{-1}) and primary forest (173.0 ± 25.1 Mg ha^{-1}) in south western Ghana (Brown et al., 2020) but far below carbon stocks of C. *odorata* species in mixed species plantations (313.73 - 465.21 Mg C ha^{-1}) within the semi-deciduous forest zone of Ghana (Novor & Abugre, 2020).

Table 2.0 Stand characteristics of *Cedrella odorata* plantations at three topographic positions in the Tinte Bepo Forest Reserve. Means followed by the same letter are not significant different.

Parameter	Hilly top	Flat terrain	Valley bottom	p-value
Diameter at breast height (cm)	41.6±0.38a	37.3±0.39b	42.4±0.91a	0.00055 ***
Total height (m)	18.5±0.25 b	18.7±0.33ab	19.7±0.13a	0.0314*
Basal area ($m^2 ha^{-1}$)	57.8±5.3	65.8±3.9	61.3±4.7	0.591
Stem density (#stems ha^{-1})	392.5±34.5b	588.8±29.5a	408.8±12.82b	0.0014**
Total tree carbon (Mg ha^{-1})	105.7±10.2	110.1±7.5	116.4±10.6	0.791

Understorey woody species regeneration

Overall 120 woody plants in 11 species and 8 families were recorded in the understorey of the *Cedrela odorata* plantation at the Tinte Bepo Forest Reserve, Ghana. Alpha diversity parameters were not significantly different among the three topographic positions. Qualitatively, the valley-bottom recorded the highest species richness, abundance and other diversity indices compared to the flat terrain and the ridge crest. However, species composition of the valley-bottom was more dissimilar from those of the flat terrain and the hill top (Figure 1).

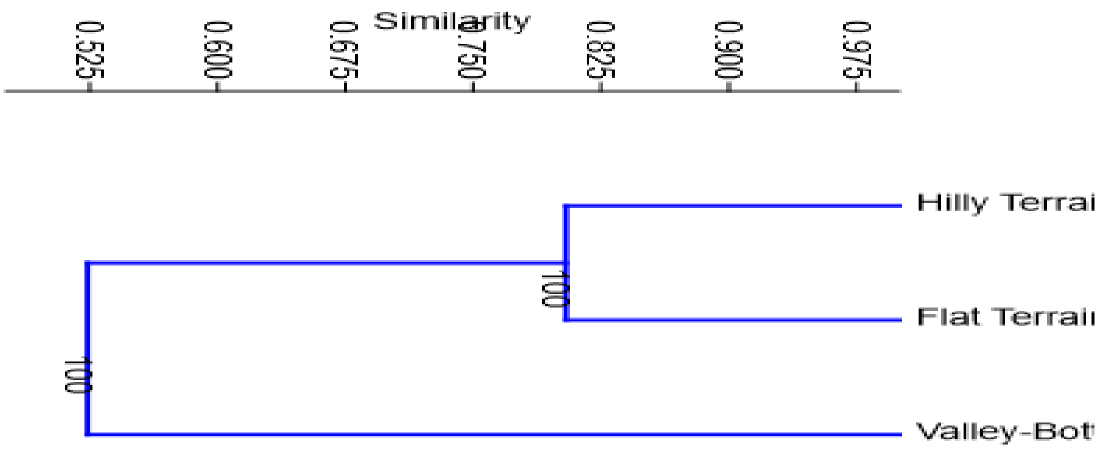

Figure 1 Cluster diagram showing the distance in similarity of species among the three topographic positions.

ANCOVA results showed that understorey species diversity (richness and Shannon H) is strongly influenced by the elevation of the landscape ($p<0.026$). The model explained 42.4% of the total variability in species richness and 48.5% of the Shannon H. *Alstonia boonei*, *Quassia undulata*, and *Margaritaria discoidea* occurred exclusively in the valleys while *Cola gigantea* and *Blighia sapida* occurred only in the flat terrain and the ridge crest. Both *Cola gigantea* and *Blighia sapida* are non-pioneer light demanders (NPLD). NPLD constituted about 40% and 33% of the species composition of the ridge crest and flat terrain, respectively. By contrast, *Mansonia altissima* was the only NPLD species occurring in the understorey of the valley and much lower in abundance compared to NPLD on the other geomorphic positions. Thus, shading may have been a bit more pronounced on the ridge crest and flat terrain than on the valleys.

Conclusions and Outlook

This study concludes that the stand structural attributes of unmanaged matured C. *odorata* plantations within the moist semi-deciduous zone of Ghana depend to some extent on relief. The valleys favoured better diameter and height growth while the flat terrain supported greater stocking. As a result, the stand level climate mitigation potential appears independent of relief, and tree carbon stock values at various terrestrial inclines in this plantation compare favourably with some plantations of similar ages and even primary forest within Ghana and the West African subregion. Furthermore, the DBH distribution of the cedrela plantation depends on the relief: Weibull distribution was a better fit for the data at the ridge crest or summit while the Johnson SB distribution was the best fit at the flat terrain and Valley bottom. The C. *odorata* plantations also have the potential to facilitate recruitment of woody vegetation and restore indigenous species diversity.

References

Alderete-Chavez, A., Zapata-Cocon, G. D. J., Ojeda-Trejo, E., Guevara, E., Cruz-Landero, N. D. la, Guerra-Santos, J. J., Brito, R., & del Angel, E. A. (2010). Alderete-Chavez et al 2010 Evaluation of C. odorata growth in a secondary forest area.pdf. *Research Journal of Forestry*, *4*(3), 145–150.

Brown, H. C. A., Berninger, F. A., Larjavaara, M., & Appiah, M. (2020). Above-ground carbon stocks and timber value of old timber plantations , secondary and primary forests in southern Ghana Forest Ecology and Management Above-ground carbon stocks and timber value of old timber plantations , secondary and primary forests in. *Forest Ecolology and Management*, *472*, 1–11. https://doi.org/10.1016/j.foreco.2020.118236

Citron, B. B. (1990). Cedrela odorata L. Cedro Hembra, Spanish-Cedar. In R. M. Burns & B. H. Honkala (Eds.), *Hardwoods, Silvics of North America. USDA Forest Service Agriculture Handbook* (Vol. 2, pp. 501–513). USDA Forest Service.

Estrada-contreras, I., Equihua, M., Laborde, J., Martı, E., & Sa, R. (2016). Current and Future Distribution of the Tropical Tree Cedrela odorata L . in Mexico under Climate Change Scenarios Using MaxLike. *PLOSone*, *11*(10), 1–14. https://doi.org/10.1371/journal.pone.0164178

Forestry Commission. (2016). *Tinte Bepo Forest Reserve management plan (Mankranso Forest District)*.

Korhonen, J., Prestemon, J. P., & Cubbage, F. W. (2021). Projecting global and regional outlooks for planted forests under the shared socio - economic pathways. *New Forests*, *52*(2), 197–216. https://doi.org/10.1007/s11056-020-09789-z

Novor, S., & Abugre, S. (2020). Growth Performance, Undergrowth Diversity and Carbon Sequestration Potentials of Tree Species Stand Combinations, Ghana. *Open Journal of Forestry*, *10*(01), 135–154. https://doi.org/10.4236/ojf.2020.101010

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R. & Anthony, S. (2009). *Agroforestree Database: a tree reference and selection guide. Version 4.0* (Vol. 0). World Agroforestry Center.

Pogoda, P., Ochał, W., & Orzel, S. (2019). Modeling Diameter Distribution of Black Alder (Alnus glutinosa (L .) Gaertn .) Stands in Poland. *Forests*, *10*(412), 1–16.

Salazar, R., Jøker, D., & Schmidt, L. (2000). *Cedrela odorata L.* (Issue Seed Leaflet no. 20, pp. 20–21). Danida Forest Seed Centre, CATIE.

Vongkhamho, S., Imaya, A., Yamamoto, K., Takenaka, C., & Yamamoto, H. (2022). Influence of Topographic Conditions on Teak Growth Performance in Mountainous Landscapes of Lao PDR. *Forests*, *13*(118).

Ward, S. E., Wightman, K. E., & Santiago, B. R. (2008). Early results from genetic trials on the growth of Spanish cedar and its susceptibility to the shoot borer moth in the Yucatan Peninsula , Mexico. *Forest Ecology and Management*, *255*, 356–364. https://doi.org/10.1016/j.foreco.2007.09.057