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Maximizing Climate Solutions: Assessing Forest Plantation Productivity and Carbon Sequestration Potential of Tree Species

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Abstract

Climate change is projected to negatively impact forest ecosystems and related industries, emphasizing the urgency of effective mitigation strategies. Forests play a crucial role in climate change mitigation by sequestering carbon dioxide (CO_2). Planting trees can contribute significantly, absorbing tonnes of CO_2 annually and limiting climate change impacts. This process underscores the vital contribution of forests to mitigating climate change. The aim is to evaluate the role of forest plantation productivity in mitigating climate change and assess the carbon dioxide sequestration potential of some tree species. The carbon dioxide (CO_2) sequestration potential of the tree plantations was highest in the moist semi-deciduous north-west (MSDNW) zone followed in a decreasing order by the dry semi-deciduous (DSD) and forest-savannah transition (FST) zones with the values being 23.02 ± 21.84 (SD), 11.16 ± 6.00 and 9.25 ± 5.25 Mg CO_2eq ha^{-1} $year^{-1}$, respectively. For the various tree species plantations, the CO_2 sequestration potential exhibited by Cedrela odorata, mixed species and Tectona grandis stands was given as 36.93 ± 31.21 (SD), 19.06 ± 11.99 and 8.98 ± 4.67 Mg CO_2eq ha^{-1} $year^{-1}$, respectively. The comprehensive findings underscore the need for nuanced strategies in climate change policies and afforestation initiatives. Sustainable forest management, tailored afforestation practices are recommended to optimize forest plantation contributions to global climate goals.

Keywords: Diameter at Brest height, Height, Ecological Zones

Introduction

Climate change is one of the most pressing global challenges of our time, with far-reaching implications for ecosystems, societies and economies worldwide. As concerns about the increasing concentration of greenhouse gases in the atmosphere grow, there is a critical need to explore effective strategies for mitigating climate change. Among the various climate change mitigation efforts, the role of forest plantations and their productivity has emerged as a subject of significant interest and investigation. Forest ecosystems are recognized as crucial natural carbon sinks, capable of sequestering and storing vast amounts of carbon dioxide through the process of photosynthesis. Forest plantations, in particular, have gained attention as a potential tool for enhancing climate change mitigation due to their ability to sequester carbon at a relatively rapid rate. Plantation forestry involves the intentional establishment of tree stands with the primary purpose of timber production, but they also offer considerable potential for climate change mitigation through carbon sequestration.

Extensive research has shown that the productivity of forest plantations can significantly affect their carbon sequestration capacity. Several studies have highlighted the positive correlation between plantation productivity and carbon accumulation in above-ground biomass (AGB) and below-ground biomass (BGB). For instance, Smith et al. (2019) conducted a comparative analysis of different forest plantation productivity levels and found that higher productivity resulted in greater carbon sequestration rates. Furthermore, research by Jones and Brown (2018) demonstrated that well-managed and productive forest plantations have the potential to serve as more effective carbon sinks, contributing to climate change mitigation efforts on a local and global scale. Their findings emphasized the importance of considering forest plantation productivity in climate change policies and afforestation initiatives.

While some studies have focused on the positive impact of forest plantation productivity on carbon sequestration, others have also explored potential challenges and trade-offs. For instance, Johnson et al. (2020) examined the influence of plantation species composition and management practices on productivity and carbon storage. They found that certain management practices might enhance productivity but could also have unintended consequences for biodiversity and ecosystem resilience. In this study, we aim to consolidate and critically analyze existing literature to offer a comprehensive understanding of the relationship between forest plantation productivity and climate change mitigation. By examining the latest research findings and insights, it is sought to identify best practices and policy implications that can enhance the role of forest plantations in carbon sequestration efforts.

Climate change remains one of the most urgent challenges facing humanity, with its far-reaching impacts on ecosystems, economies and societies. As the concentration of greenhouse gases continues to rise in the atmosphere, there is an urgent need to explore effective strategies to mitigate its effects. Among the various approaches to combat climate change, forest plantations and their productivity have garnered significant attention as potential contributors to climate change mitigation efforts.

The objective of this study is to evaluate the role of forest plantation productivity in mitigating climate change and assess the carbon dioxide sequestration potential of some tree species. Exploring the relationship between plantation productivity and carbon sequestration will provide valuable insights into the role of forest plantations in mitigating the impacts of climate change. The importance of this analysis lies in its potential to inform policymakers, forest managers, and stakeholders about the significance of considering plantation productivity in climate change mitigation strategies. Additionally, the insights gained from this research can contribute to ongoing discussions surrounding afforestation, reforestation, and sustainable forest management initiatives aimed at mitigating climate change and achieving global climate goals.

Materials and Methods

Study Area

The Research concentrated on forest plantations in three ecological zones within Ghana, specifically covering the Ahafo, Bono, and Bono East administrative regions. This geographic area is situated between latitudes 7° 44' 59.99'' N and longitude -1° 29' 59.99'' W, encompassing approximately 39,557 km² (15,273 sq mi) of land. These three regions are located in the southern part of Ghana, bordered by the Black Volta

River to the north, the Lake Volta to the east, and the Ashanti, Eastern, and Western regions to the south. To the west, they share a border with the southeastern part of Ivory Coast.

The vegetation cover in these regions is diverse, spanning from forests in the south, transitional areas, to savannas in the north, representing the different parts of the region accordingly. The climate in these zones experiences bi-modal rainfall, with an average annual total ranging from 1,088 mm to 1,197 mm. For further information about the ecological zones and their corresponding sites, please refer to figure 1.0 in the study.

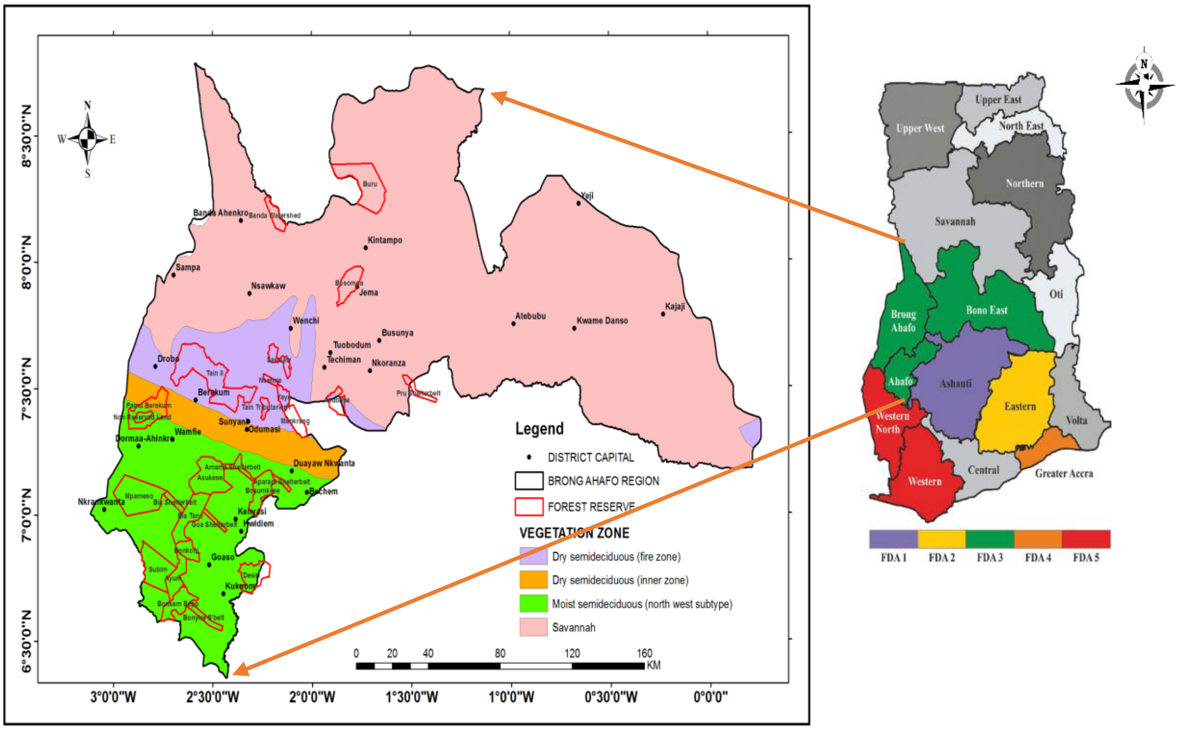

Figure 1.0 Map of Study Area

Table 1. Selection of plots based on their ecological zones

Ecological Zone	Site	Plot Type	No. of plots
Dry Semi Deciduous (DSD)	Boadwo	30 m x 30 m	2
	Berekum	30 m x 30 m	3
	Sunyani	30 m x 30 m	3
	Techire	30 m x 30 m	2
Semi-deciduous moist (North West Sub Type)	Goaso	30 m x 30 m	2
	Bediako No.1	30 m x 30 m	2
	BediakoNo.2	30 m x 30 m	2
	Gambia no.1	30 m x 30 m	3
	Dormaa	30 m x 30 m	1
Forest Savannah Transition (FST) zone	Jema	30 m x 30 m	15
			35

Study Site Sampling.

The study area was chosen using stratified random sampling. Three distinct ecological zones were identified, namely the Dry Semi-Deciduous (DSD) zone, the wet Semi-Deciduous zone North West (MSDNW), and the Forest Savanna Transition (FST) zone. The ecological zones were classified according to the established categorizations outlined by (Asante & Benefoh, 2013). Thirty-five (35) sampling plots were placed in the three ecological zones. The specific classifications are outlined in Figure 2.0

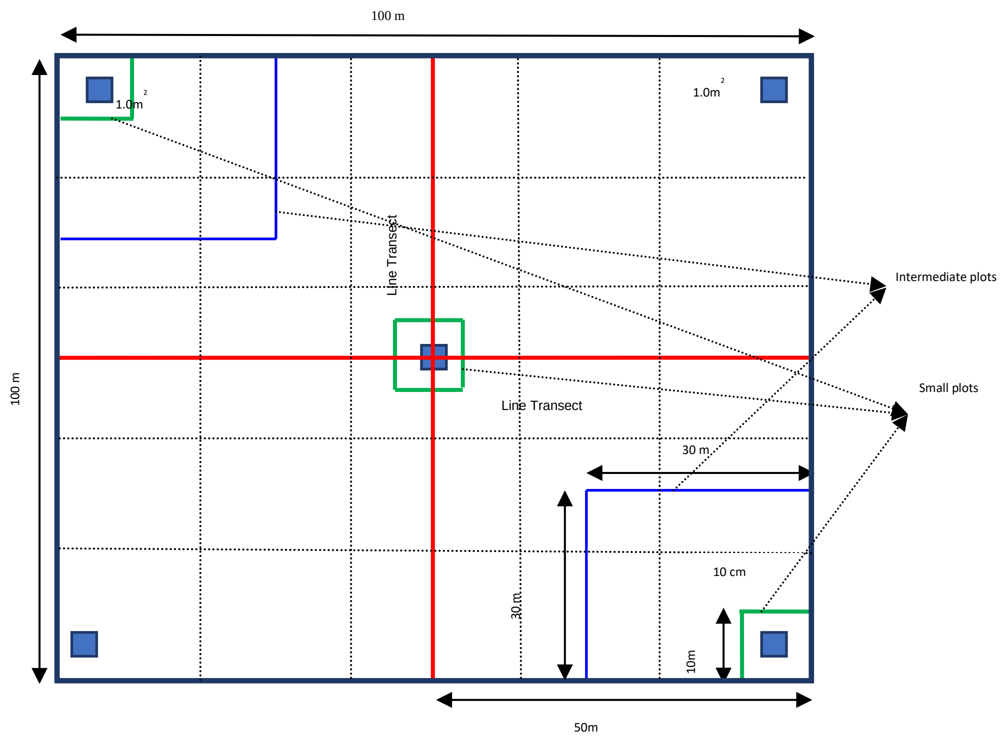

Figure 2.0 Layout of nested plot design for a 1.0 ha square plot for the Forest ecological zones. Adopted from Adu-Bredu et al., 2018

A field manual (Hawthorne & Gyakari, 2006) was used to identify and count all trees with a diameter at breast height (DBH) of 10 cm or greater. Tree height was measured using Nikon Forestry Pro-II Laser Rangefinder/Hypsometer (Nikon, USA).

Results and Discussion

The Impact of Age on Carbon Stock Parameters

Except the 8-year-old plantation, which had a higher mean aboveground biomass carbon stock (AGC) value of 36.06 ± 31.74 (SD) Mg C ha^{-1}, the others had AGC increased with increasing plantation age (Table 5.1). This might have been since all the 8-year-old plantations were found in the moist semi-deciduous north west (MSDNW) and consists of mixed and teak plantations. The mean AGC of the other ages were 16.73 ± 4.83 (SD), 19.43 ± 6.09, 41.41 ± 23.04, 38.70 ± 51.20 and 45.43 ± 15.07 Mg C ha^{-1} for the 10-, 11-, 12, 13 and 14-year-old plantations, respectively (Table 2.0).

Table 2.0: Influence of plantation age on biomass carbon stock

	Mg C ha^{-1}					
Age (years)	**Mean AGC**	**SD of AGC**	**Mean BGC**	**SD of BGC**	**Mean BCS**	**SD of BCS**
8	36.06	31.74	6.46	5.11	42.51	36.84
10	16.73	4.83	3.70	0.97	20.43	5.80
11	19.43	6.09	4.15	1.12	23.58	7.19
12	41.41	23.04	8.98	4.43	50.38	27.47
13	38.70	51.20	7.54	7.78	46.24	58.96
14	45.43	15.07	9.72	3.17	55.15	18.23

Note: AGC = Aboveground biomass carbon stock; BGC = Belowground biomass carbon stock; BCS (Total biomass carbon stock) = Sum of AGC and BGC; SD = Standard deviation.

The trends for the belowground (BGC) and total (BCS) biomass carbon stock was similar to that of the AGC. The values for the BGC were 6.46 ± 5.11, 3.70 ± 0.97, 4.15 ± 1.12, 8.98 ± 4.43, 7.54 ± 7.78 and 9.72 ± 3.17 Mg C ha^{-1}, while for the BCS the values were 42.51 ± 36.84, 20.43 ± 5.80, 23.58 ± 7.19, 50.38 ± 27.47, 46.24 ± 58.96 and 55.15 ± 18.23 Mg C ha^{-1} for the 8-, 10-, 11-, 12-, 13- and 14-year-old plantations, respectively.

The data highlight a clear trend of increasing above-ground biomass with the age of the plantation. The higher AGC in 8-year-old plantations can be attributed to their specific location in the moist semi-deciduous northwest (MSDNW) and the presence of mixed and teak plantations. This aligns with findings by Sharma et al. (2018), which emphasize the pivotal role of environmental factors, such as moisture levels and vegetation composition, in shaping carbon stock variations within forest ecosystems. This finding follows typical forest growth patterns, where older stands tend to have higher biomass due to longer periods of growth and accumulation as indicated by Alexandrov, (2007); Cao et al., (2019) and X. Wang et al., (2020) in their various studies. Kohl et al. (2017) in their research found out that mature trees in the upper crown canopy exhibit substantial carbon accumulation, maintaining high rates throughout their later years. This differs from managed forests, which often display sigmoidal growth patterns due to limited growth factors as trees age. This result follows the same trend as has been depicted in the Stephenson et al. (2014) study. They observed that biomass growth correlates positively with tree size across 403 tree species. However, Sheil et al. (2017) question the generalization of size-related growth trends, emphasizing the need for considering varying time intervals and the complexity of individual tree growth patterns. Longevity necessitates the reconstruction of lifetime growth patterns to understand overall tree growth dynamics fully.

It is interesting to note that the (14+) age class shows relatively lower above-ground biomass compared to the (13-14) age class. This observation may be attributed to the fact that few plantations were within such an age group in the selected study area. Conversely, plant species within such age groups are known for their high level of biomass production. The age class (13-14) stands out as the one with the highest above-ground biomass, indicating the importance of maintaining and preserving older forests to maximize carbon sequestration and ecosystem services. The highest above-ground biomass in the (13-14) age class is in line with the general understanding that older stands tend to accumulate more biomass due to extended growth periods. This is in agreement with assertion by Alexandrov, (2007) and Hoover & Smith, (2023). Relatively lower above-ground biomass in the (14+) age class could be attributed to the scarcity of plantations in that specific age group in the study area, emphasizing the importance of considering regional

variations which is consistent with the findings of Alexandrov, (2007) and Hoover & Smith, (2023). Older forests tend to have more complex ecological interactions, greater biodiversity, and higher carbon storage capacity. The relatively lower above-ground biomass in the younger age classes (10-11, 11-12, and 12-13) underscores the early stages of forest development and highlights the need for continued growth and management to achieve optimal biomass accumulation over time. An observation in a study done by Hoover & Smith, (2023) is consistent with the result of the younger age class in this study.
Similar to the trend observed in above-ground biomass, the below-ground biomass also shows variation with age. The (13-14) age class had the highest below-ground biomass, measuring 416.58 MgC/ha, indicating substantial root biomass and carbon storage. This finding is consistent with similar work done by Hoover & Smith, (2023), where they posited that, such a result is expected as older trees generally have more extensive root systems. The (8-10) age class follows closely with below-ground biomass of 123.43 MgC/ha, reflecting active root growth and carbon accumulation in these relatively young plantations. The (10-11) and (12-13) age classes both record below-ground biomass slightly above 8 MgC/ha. These values are relatively lower compared to older age classes, indicating that the root systems of younger trees are still developing. The (11-12) age class records the lowest below-ground biomass at 5 MgC/ha. This finding suggests that at this stage of growth, the root systems may not have been fully established or that other factors are influencing root development as corroborated by the findings from the studies by Alexandrov, (2007) and Hoover & Smith, (2023). The below-ground biomass contributes significantly to the overall carbon storage of the forest ecosystem. Understanding the patterns of below-ground biomass in different age classes is essential for estimating the total carbon sequestration potential and the forest's contribution to mitigating climate change as asserted by Hoover & Smith, (2023) and X. Wang et al., (2020).

The Impact of diameter at breast height on Carbon Stock Parameters

The contribution of tree size, specified by diameter at breast height (DBH), is illustrated in Table 3.0. It indicates the contribution of different tree size categories to carbon storage in the forest plantation. Crucial information for understanding carbon sequestration patterns, forest growth dynamics and ecosystem carbon balance is provided. The mean aboveground tree mass (AGTM) gradually increased from the lower DBH class to the higher classes. The AGTM for the 4.0-9.0, 10-19, 20-29, 30-39, 40-49, 50-59 and 60-69 cm DBH classes were 4.08 ± 2.21 (SD), 25.62 ± 10.73, 56.61 ± 21.21, 159.87 ± 71.00, 469.13 ± 170.04, 976.08 ± 208.01 and 1612.96 ± 304.70 kg C tree^{-1}, respectively (Table 5.3). The mean belowground tree mass (BGTM) followed a similar trend, with the values being 1.19 ± 0.57, 6.04 ± 2.25, 12.20 ± 3.97, 30.47 ± 11.69, 78.96 ± 25.83, 157.59 ± 29.09 and 236.53 ± 39.42 kg C tree^{-1}, respectively (Table 5.2). This demonstrates a continued growth and hence carbon accumulation with increasing stem diameter.

Table 3.0: Contribution of diameter at breast height (DBH) to biomass carbon stock

			kg C tree^{-1}			
DBH Class (cm)	**Mean AGTM**	**SD of AGTM**	**Mean BGTM**	**SD of BGTM**	**Mean TMC**	**SD of TMC**
4.0-9.0	4.08	2.21	1.19	0.57	5.27	2.78
10-19	25.62	10.73	6.04	2.25	31.65	12.98
20-29	56.61	21.21	12.20	3.97	68.81	25.18
30-39	159.87	71.00	30.47	11.69	190.34	82.69
40-49	469.13	170.04	78.96	25.83	548.09	195.86

50-59	976.08	208.01	151.59	29.09	1127.67	237.09
60-69	1612.96	304.70	236.53	39.42	1849.49	344.12

Note: AGTM = Aboveground tree carbon mass; BGTM = Belowground tree carbon mass; TMC = Tree carbon mass (AGTM + BGTM).

The mean tree mass (TMC; kg C $tree^{-1}$), sum of the aboveground and belowground tree mass, was related to the median DBH class, as presented in Figure 5.1. The relationship which was found to be well represented by the power function, was given as (Equation 5.1):

$$TMC = 0.0344\, DBH^{2.5402}\ (R^2 = 0.9873) \qquad (5.1)$$

The exponent value of 2.5402, which is greater than unity, is an indication that the rate of mass accumulation increases more than 2.5 times with increasing mean diameter at breast height. The mean TMC can thus be fairly estimated from the mean DBH. Silviculture and management practices, like thinning, site preparation and maintenance, that result in higher mean stem diameter should be encouraged.

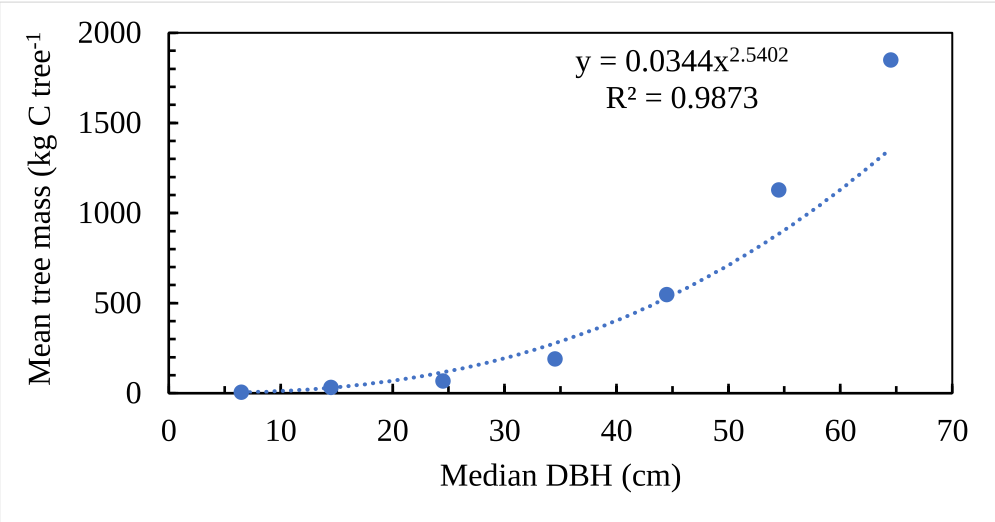

Figure 3.0: Mean tree mass as a function of diameter at breast height (DBH).

The results reveal a clear pattern of increasing Above-Ground Biomass (AGB) as trees progress from smaller to larger DBH classes, reflecting their growth and carbon accumulation over time. Young trees in the (Under 10) class store relatively lower carbon, but as they grow and move into larger size classes, their AGB increases substantially. The observed pattern of increasing Above-Ground Biomass (AGB) with the progression from smaller to larger Diameter at Breast Height (DBH) classes is consistent with existing knowledge in forestry and carbon dynamics. Several authors have held the view that diameter at breast height (DBH) serves as a fundamental metric for tree size and correlates positively with aboveground biomass, indicating greater carbon storage potential This assertion is in agreement with similar work done by Kutsch et al., (2009); Meinzer et al., (2011); Carey et al., (2001); Phillips et al., (2008); Piper and Fajardo and Weiner and Thomas (2001). They posited that trees with larger DBH tend to sequester more carbon over their lifespan due to enhanced biomass accumulation rates, crucial for understanding forest carbon dynamics and mitigating climate change. DBH plays a pivotal role in forest management practices like selective logging and carbon accounting, aiding in sustainable forest management and carbon sequestration strategies. Stephenson et al., (2014), in a similar study whose result was in line with this study, demonstrated that irrespective of competition, 85% of species exhibit mass growth rates that consistently rise with tree size, across various species, continents, and forest types. This finding contradicts the notion of declining individual tree growth with size and age, often attributed to reduced productivity at both organ (leaves) and population (even-aged stands) scales.

The Impact of Height on Carbon Stock Parameters

The influence of the height of the trees on biomass carbon accumulation was assessed by grouping the height into height classes. The mean aboveground mass of the trees increased with increasing height class. For the height class of 1-4.9, 5.0-9.9, 10-14.9, 15-19.9, 20-24.9 and 25-29.9 m, the mean aboveground tree mass (AGTM) was found to be 7.98 ± 9.13 (SD), 19.31 ± 15.78, 36.94 ± 25.80, 68.90 ± 57.78, 364.19 ± 136.86 and 755.69 ± 420.17 kg C tree^{-1}, respectively (Table 4.0). A similar trend was exhibited by the belowground tree mass (BGTM) with the values being 2.08 ± 2.11, 4.63 ± 3.23, 8.27 ± 4.88, 14.23 ± 10.15, 63.08 ± 21.76 and 119.31 ± 59.17 kg C tree^{-1}, respectively. The wide standard deviation for all the height classes is an indication of the height variation within the height classes (Table 4.0).

Table 4.0: Contribution of tree height (Ht) to biomass carbon stock

			kg C tree^{-1}			
Ht Class (cm)	**Mean AGTM**	**SD of AGTM**	**Mean BGTM**	**SD of BGTM**	**Mean TMC**	**SD of TMC**
1.0-4.9	7.98	9.13	2.08	2.11	10.06	11.24
5.0-9.9	19.31	15.78	4.63	3.23	23.93	19.01
10-14.9	36.94	25.80	8.27	4.88	45.21	30.67
15-19.9	68.90	57.78	14.23	10.15	83.13	67.91
20-24.9	364.19	136.86	63.08	21.76	427.27	158.61
25-29.9	755.69	420.17	119.31	59.17	874.99	479.29

Note: AGTM = Aboveground tree carbon mass; BGTM = Belowground tree carbon mass; TMC = Tree carbon mass (AGTM + BGTM).

The mean TMC was related to the median height of the height classes to ascertain the mode of the mean mass accumulation with increasing tree height. The relationship, which is exhibited in Figure 5.2, indicates exponential relation as the best function. The relationship was given as (Equation 5.2):

$$TMC = 5.2662 \exp^{(0.1832Htm)} \; (R^2 = 0.9853) \qquad (5.2)$$

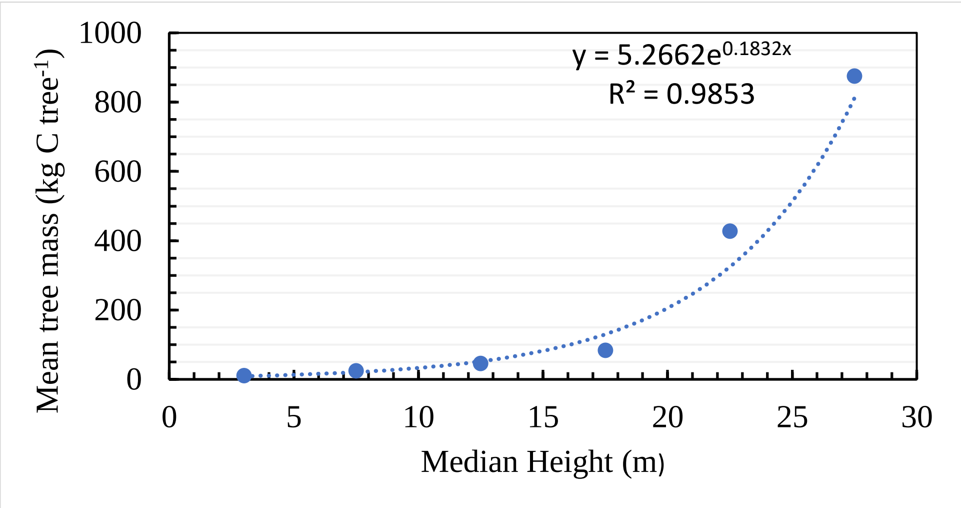

Figure 4.0: Mean tree mass as a function of median tree height (*Ht*m).

This height and carbon stock variable data provide valuable insights into the carbon distribution in the ecosystem at different tree height classes, offering essential information for understanding the carbon storage capacity and dynamics within the forest plantation system. The data show that the carbon content (both AGB and BGC) varies significantly across different height classes. As trees grow taller and older, they tend to accumulate more carbon in both above-ground and below-ground biomass. This is evident from the progressive increase in carbon content from the (5-10) height class to the (25+) height class. Above-ground biomass (AGB), which includes stems, branches, and leaves, makes up the majority of the carbon content in all height classes. This is expected since trees invest a considerable amount of energy in their above-ground structures to capture sunlight and grow taller. The provided data on tree height and carbon stock variables aligns with existing knowledge, supporting the understanding of the intricate relationship between tree height and carbon storage in forest ecosystems. Multiple studies reinforce the idea that taller and older trees tend to accumulate more carbon, both in above-ground and below-ground biomass as corroborated by Baishya et al., (2009); Proulx, (2021); Y. and Wang et al., (2021) in their research work.

The data also highlight the significance of below-ground carbon (BGC) in the ecosystem's carbon storage. Although Below-Ground Carbon (BGC) is generally lower than AGB, it still contributes a substantial portion to the total carbon content. Roots play a crucial role in carbon sequestration and nutrient uptake, making below-ground carbon an important component of the ecosystem's overall carbon balance. The (25+) height class stands out as the height class with the highest carbon content. This indicates that older and taller trees have a greater capacity to store carbon, making them essential contributors to the ecosystem's carbon sequestration potential. The progressive increase in carbon content observed from the (5-10) height class to the (25+) height class is consistent with the notion that as trees mature, they allocate more resources to carbon storage, emphasizing the importance of older and taller trees in carbon sequestration. This observation is consistent with studies done by Baishya et al., (2009); Proulx, (2021); Y. and Wang et al., (2021). The total carbon content across all height classes (11900.99 MgC/ha) provides an estimate of the ecosystem's carbon sequestration potential. This potential highlight the importance of conserving and restoring forests as effective nature-based solutions for mitigating climate change as indicated by Yin et al., (2012).

Carbon Dioxide Sequestration for the Various Sites, Species and Stand Age

The MSDNW ecozone stands out for its remarkable potential in sequestering carbon dioxide, boasting the highest average among the studied ecological zones. Following closely, the DSD ecozone also demonstrates a noteworthy capacity for carbon dioxide sequestration, albeit slightly lower in comparison. Meanwhile, the FST ecozone, while still contributing positively, showcases the lowest average carbon dioxide equivalent emissions within the surveyed areas. For the MSDNW zone, the CO_2 sequestration ranged from 5.73 to 71.73, with a mean value of 23.02 ± 21.84 (SD) Mg CO_2eq ha^{-1} $year^{-1}$, and for the DSD zone it ranged from 4.44 and 24.84 with a mean value of 11.16 ± 6.00 Mg CO_2eq ha^{-1} $year^{-1}$, while for the FST zone it varied from 4.35 to 24.84 with a mean value of 9.25 ± 5.25 Mg CO_2eq ha^{-1} $year^{-1}$ (Table 5.0).

Table 5.0: Carbon dioxide sequestrations of tree plantations in the various ecological zones

	Mg CO_2eq ha^{-1} $year^{-1}$			
Ecozone	**Average**	**Minimum**	**Maximum**	**SD**
MSDNW	23.02	5.73	71.73	21.84
DSD	11.16	4.44	21.33	6.00
FST	9.25	4.35	24.84	5.25

Concerning the various tree species, *Cedrela odorata* exhibited the highest CO_2 sequestration that ranged from 11.39 to 71.73 with a mean value of 36.93 ± 31.21 Mg CO_2eq ha^{-1} $year^{-1}$. This was followed by mixed species plantations with the sequestration ranging from 8.15 to 42.77 with the mean value of 19.06 ± 11.99 Mg CO_2eq ha^{-1} $year^{-1}$. Whereas the *Tectona grandis* stands had the least sequestration ranging between 4.35 and 21.33 with a mean value of 8.98 ± 4.67 Mg CO_2eq ha^{-1} $year^{-1}$ (Tables 6.0 and 7.0).

Table 6.0: Carbon dioxide sequestrations of the various tree species plantations

	Mg CO_{2eq} ha^{-1} $year^{-1}$			
Species	**Average**	**Minimum**	**Maximum**	**SD**
Cedrela	36.93	11.39	71.73	31.21
Mixed	19.06	8.15	42.77	11.99
Teak	8.98	4.35	21.33	4.67

Table 7.0: Carbon dioxide sequestration for the various sites, species and stand age

				Mg CO_2eq ha^{-1} $year^{-1}$			
Ecozone	**District**	**Species**	**Age**	**Average**	**Minimum**	**Maximum**	**SD**
DSD	Dormaa	Teak	10	7.01	4.44	9.41	2.12
			11	5.11	5.11	5.11	
			13	10.92	10.92	10.92	
	Sunyani	Teak	10	9.41	9.41	9.41	
			12	15.40	9.46	21.33	8.39
			14	19.26	18.69	19.82	0.80
FST	Kintampo	Mixed	13	13.98	8.15	24.84	7.41
			14	13.75	13.75	13.75	
		Teak	13	6.72	4.35	12.83	2.60
			14	8.57	8.57	8.57	
MSDNW	Goaso	Cedrela	13	49.70	27.68	71.73	31.15
			14	11.39	11.39	11.39	
		Mixed	8	31.88	20.98	42.77	15.41
		Teak	8	7.09	5.73	8.46	1.93
			11	9.24	8.95	9.52	0.41

Delving deeper into specific plantation types, Forest Plantations of Age 13 emerge as the frontrunner, exhibiting the highest average carbon dioxide sequestration potential. Similarly, *Teak* Plantations, *Cedrela* Plantations, and Mixed Plantations all demonstrate substantial capabilities in carbon sequestration, each recording the highest averages within their respective categories.

The study under scrutiny delves deep into the intricate dynamics of carbon sequestration potential across various ecological zones and tree species within forest ecosystems. By scrutinizing CO_2 sequestration rates, it sheds invaluable light on the underlying factors that contribute to carbon storage variability, thus illuminating crucial aspects of forest carbon dynamics. Firstly, the study reveals the standout performance of the Moist Semi-Deciduous Northwest (MSDNW) ecozone in terms of CO_2 sequestration. This ecozone emerges as a frontrunner, boasting the highest average among all surveyed ecological zones. Conversely, the Forest Savanna Transition (FST) ecozone, while showcasing the lowest average CO_2 equivalent emissions, still contributes positively to carbon sequestration. These findings resonate with previous research by Kumar et al. (2024), which underscores the significant influence of environmental conditions, such as moisture levels and vegetation composition, on carbon sequestration rates.

Furthermore, the study uncovers noteworthy insights into the CO_2 sequestration potential of different tree species. Cedrela odorata stands out as a top performer in carbon uptake and storage, highlighting its efficiency in sequestering CO_2. Mixed species plantations also exhibit substantial CO_2 sequestration capabilities, underscoring the importance of biodiversity in enhancing carbon sequestration rates within forest ecosystems. Conversely, *Tectona grandis* stands to demonstrate comparatively lower CO_2 sequestration rates, emphasizing the critical role of species selection in maximizing carbon sequestration potential. These findings not only deepen our understanding of carbon dynamics within forests but also have significant implications for sustainable forest management and climate change mitigation strategies. By identifying key contributors to carbon sequestration, the study provides a solid foundation for informed decision-making aimed at enhancing carbon storage in forest ecosystems.

In essence, the research offers a comprehensive overview of carbon sequestration dynamics, emphasizing the multifaceted interplay between ecological zones, tree species, and environmental factors in shaping carbon storage within forest ecosystems.

Conclusion

The study revealed a nuanced understanding of the influence of forest plantation productivity on climate change mitigation efforts. Older plantations and larger, taller trees demonstrate higher carbon sequestration potential, emphasizing the importance of maintaining and preserving mature forests. The observed patterns in above-ground and below-ground biomass across different age, DBH, and height classes contribute valuable insights for optimizing carbon storage and enhancing the effectiveness of afforestation and reforestation initiatives. As policymakers strive to address climate change challenges, integrating the findings into strategies and policies can maximize the positive impact of forest plantations on global climate goals.

Recommendations

In light of the derived conclusions, the following recommendations are put forth for policy consideration. The research advocates for the adoption of sustainable forest management practices that prioritize the cultivation and upkeep of mature forest plantations by the Forestry Commission and other plantation developers. This entails the conservation of older stands and the implementation of measures supporting the cultivation of larger and taller trees. Additionally, it recognizes the pivotal role of below-ground carbon in overall carbon storage. Hence, policies and management strategies should acknowledge the importance of roots in carbon sequestration and nutrient absorption, fostering a comprehensive approach to the health of forest ecosystems.

Natural resources managers are advised to formulate afforestation and reforestation initiatives that center on species and management practices enhancing productivity and carbon sequestration. Special attention should be given to specific age, DBH, and height classes that contribute most effectively to climate change mitigation. The Forestry Commission of Ghana is encouraged to integrate these research findings into climate change policies, emphasizing the role of forest plantation productivity in the pursuit of global climate goals. It is emphasized that collaboration between scientists, policymakers, and practitioners is indispensable for the successful implementation of these recommended strategies.

References

1. Alexandrov, G. A. (2007). Carbon stock growth in a forest stand: the power of age. Carbon Balance and Management, 2(1), 1–5.
2. Anderegg, W. R. L., Trugman, A. T., Badgley, G., Anderson, C. M., Bartuska, A., Ciais, P., Cullenward, D., Field, C. B., Freeman, J., & Goetz, S. J. (2020). Climate-driven risks to the climate mitigation potential of forests. *Science*, *368*(6497), eaaz7005.
3. Asante, W. A., & Benefoh, D. T. (2013). *Working Paper Potential REDD+ Project Types in Off-Reserve Areas, Agroforests and Secondary Forests in Various Ecological Zones of Ghana*.
4. Canadell, J. G., & Raupach, M. R. (2008). Managing forests for climate change mitigation. *Science*, *320*(5882), 1456–1457.
5. Cao, J., Gong, Y., Adamowski, J. F., Deo, R. C., Zhu, G., Dong, X., Zhang, X., Liu, H., & Xin, C. (2019). Effects of stand age on carbon storage in dragon spruce forest ecosystems in the upper reaches of the Bailongjiang River basin, China. Scientific Reports, 9(1), 3005.
6. FAO. (2020). *Global Forest Resources Assessment 2020. Main report. Food and Agriculture Organization of the United Nations, Rome.*
7. Freer-Smith, P. H., Muys, B., Bozzano, M., Drössler, L., Farrelly, N., Jactel, H., Korhonen, J., Minotta, G., Nijnik, M., & Orazio, C. (2019). *Plantation forests in Europe: challenges and opportunities* (Vol. 9). European Forest Institute Joensuu, Finland.
8. Hawthorne, W., & Gyakari, N. (2006). *Photoguide for the Forest Trees of Ghana: A treespotter's guide field guide. Publ*. Oxford Forestry Inst. UK. 432pp.
9. Hoover, C. M., & Smith, J. E. (2023). Aboveground live tree carbon stock and change in forests of conterminous United States: influence of stand age. Carbon Balance and Management, 18(1), 7.
10. IPCC. (2018). *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.*
11. Johnson, E., and Heinen, R., 2004. Carbon trading: Time for industry involvement. Environment International 30: 279-288.
12. Jones, M. R., & Brown, C. D. (2018). The Future of Work: Implications for Managerial Innovation and Resource Management. Business Horizons, 61, 1-12.
13. Köhl, M., Neupane, P. R., & Lotfiomran, N. (2017). The impact of tree age on biomass growth and carbon accumulation capacity: A retrospective analysis using tree ring data of three tropical tree species grown in natural forests of Suriname. *Plos one*, *12*(8), e0181187.
14. Liu, S., Innes, J., & Wei, X. (2013). Shaping forest management to climate change: An overview. In *Forest Ecology and Management* (Vol. 300, pp. 1–3). Elsevier.
15. Mardiatmoko, G. (2018). From forest biomass to carbon trading. In *Renewable Resources and Biorefineries*. IntechOpen.

16. Mayer, M., Prescott, C. E., Abaker, W. E. A., Augusto, L., Cécillon, L., Ferreira, G. W. D., James, J., Jandl, R., Katzensteiner, K., & Laclau, J.-P. (2020). Tamm Review: Influence of forest management activities on soil organic carbon stocks: A knowledge synthesis. *Forest Ecology and Management*, *466*, 118127.
17. Nabuurs, G. J., M. O., A. K., Benitez-Ponce, P., B. R., D. M., & Ravindranath, N. H. (2007). *Forestry. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*.
18. Noormets, A., Epron, D., Domec, J.-C., McNulty, S. G., Fox, T., Sun, G., & King, J. S. (2015). Effects of forest management on productivity and carbon sequestration: A review and hypothesis. *Forest Ecology and Management*, *355*, 124–140.
19. Orlando, B. (2002). *Carbon, forests and people: towards the integrated management of carbon sequestration, the environment and sustainable livelihoods* (Issue 1). IUCN.
20. Pan, Y., Birdsey, R. A., Fang, J., Houghton, R., Kauppi, P. E., Kurz, W. A., Phillips, O. L., Shvidenko, A., Lewis, S. L., & Canadell, J. G. (2011). A large and persistent carbon sink in the world's forests. *Science*, *333*(6045), 988–993.
21. Schweier, J. (2019). Introduction for IJFE special article collection "The Role of Forest Operations in Climate Change Affected Forests." *International Journal of Forest Engineering*, *30*(3), 218.
22. Smith, P., Davis, S. J., Creutzig, F., Fuss, S., Minx, J., Gabrielle, B., ... & Yongsung, C. (2016). Biophysical and economic limits to negative CO2 emissions. *Nature climate change*, *6*(1), 42-50.
23. van Minnen, J. G., Strengers, B. J., Eickhout, B., Swart, R. J., & Leemans, R. (2008). Quantifying the effectiveness of climate change mitigation through forest plantations and carbon sequestration with an integrated land-use model. *Carbon Balance and Management*, *3*, 1–20.
24. Wang, X., Guo, Z., Guo, X., & Wang, X. (2020). The relative importance of succession, stand age and stand factors on carbon allocation of Korean Pine Forests in the Northern Mt. Xiaoxing'anling, China. Forests, 11(5), 512.