An Evaluation of Carbon Sequestration in *Melaleuca cajuputi* Powell forest in U Minh Ha National Park, Ca Mau, Viet Nam

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Research Article

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Abstract

Melaleuca forests significantly contribute to economic development through silviculture and play an important role in carbon sequestration and supply of oxygen. Currently, *Melaleuca* seedlings are planted on bunds in inundated areas or on trenches in elevated areas. Little is known of what planting methods and growth stage of *Melaleuca* trees are best for developing new forest areas and sequestering highest levels of carbon. We selected U Minh Ha National Park in search for answers to the questions. We established 12 standard plots (10m x 10m) in the park where *Melaleuca* trees at two ages (10 years of age and 15 years of age) were planted on bunds and trenches. We employed Anova analysis, SPSS software and numerical analysis for analyzing and evaluating carbon sequestration by Melaleuca trees. We found that planting method significantly contributes to developing new forest areas in terms of tree volume, biomass, and carbon sequestration. Bund-based planting proves to be more cost-effective in developing new forest areas and carbon sequestration than trench-based planting. Trees at the age of 10 planted on bunds has been the most effective category for sequestering carbon. Our methodology in examining the relationship proves to be a feasible reference to new forest development and payment for forest service scheme in the Mekong Delta region or elsewhere in the broader region.

1. Introduction

Forests play an important role in mitigating and minimizing effects of climate change through absorption, sequestration and accumulation of Carbon Dioxide (CO_2) (Brack 2019). Forests and woodlands absorb approximately one twelfth of the global CO_2 atmospheric output, and store about 72% of the Earth's total carbon reservoirs (Malhi et al. 2002). Tropical forests and subtropical forests sequester half of a total amount of CO_2 sequestered by all types of forests (Canadell & Raupach 2008). A study undertaken in 2010 by Food & Agriculture Organization (FAO) estimated a smaller total forest carbon stock of 652 Gt of carbon, with 44% in living biomass, 5% in dead wood, 6% in litter and 45% in soils (FAO 2010).

Over-exploitation and forest encroachment significantly degrade forest resources. The forest degradation results in reducing absorption of CO_2 (Müller et al. 2014). Approximately 5,8 Gt/year of CO_2, accounting for about 20% of the world's annual CO_2 emissions, emitted due to forest loss in the 1990s (IPCC 2007). The current greenhouse gas concentration has doubled, ranging from 722 ppb in 1750 to 1803 ppb in 2011 (IPCC 2014).

Forest protection and new forest development are an effective mechanism that helps decrease carbon emission and increase capacities of carbon sequestration. Previous studies show that tree age and volume are important for carbon accumulation (Johnson &Abrams 2009). Trees grow with an increase in diameter and carbon accumulation over time (Canadell & Raupach 2008). Four concerns with respect to tree growth include (1) metabolism of trees which tends to increase mass productivity for the tree size (Purves et al. 2007; West 1999); (2) space competition among trees (Pretzsch 2009); (3) increased total leaf area and positive feedback of light for tree growth (Bloor & Grubb 2003) and (4) respiration of photosynthesis decreasing the adaptation process (Ishii et al. 2007).

1.1. Melaleuca forests and carbon sequestration

Previous studies show that *Melaleuca* forests, a genus of Myrtaceae family, store a substantial amount of carbon (Tran et al. 2013; Tran & Dargusch 2016). *Melaleuca cajuputi* Powell provides a large amount of woody biomass for human use such as charcoals, and construction materials, and plays an important role in carbon sequestration and supply of oxygen (Hong et al. 2015). Trees of *Melaleuca cajuputi* Powell with less than 10-year-old and more than ten-year-old trees store about 15.18 tons CO_2/ha and 31.76 tons of CO_2/ha respectively (Dan et al. 2014). Fragmented *Melaleuca* forests also play a crucial role in storing carbon (Tran et al. 2015).

1.2. Research gaps and the aims of this study

With the background discussed above, two questions remain, (1) how *Melaleuca* trees are planted in order to sequester highest levels of carbon, (2) what is the best growth stage of *Melaleuca* trees in storing carbon. The questions are urgent, particularly in the context in the Mekong Delta of Vietnam where *Melaleuca* forests are annually grown for developing new forest areas and improving local livelihoods under the *Five Million Forest Ha Program* issued by the Government of Vietnam (Vietnamese Prime Minister 1998), and revised in 2021 (Vietnamese Prime Minister 2021). *Melaleuca* seedlings are planted on bunds in inundated areas or in elevated areas. The planting is undertaken in protected areas and privately owned lands. Meanwhile, The Vietnamese Mekong Delta contains 176,296 hectares of *Melaleuca cajuputi* Powell (Quy 2010).

We select U Minh Ha National Park, Ca Mau, the Vietnamese Mekong Delta in search for answers to the questions identified in the literature because *Melaleuca cajuputi* Powell trees are well-protected in addition to new forest areas established with seedlings of *Melaleuca cajuputi* Powell planted annually. This study aims to explore the relationship between planting of *Melaleuca* forests and carbon sequestration. Our goals are to (1) identify how *Melaleuca* seedlings are planted in order to best sequester carbon and (2) determine at what tree growth process *Melaleuca* forests are best for sequestering carbon. To achieve these goals, we establish 12 standard plots where *Melaleuca* trees with 10 years of age and 15 years of age were planted on bunds and trenches. Then, we undertake field experiments in an attempt to analyze the correlation between carbon accumulation and the tree growth process. Finally, in response to the analysis, we provide recommendations in order to address the issues in relation to sustainable forest management and reduction of greenhouse gas emissions.

2. Materials And Methods

2.1. Site description

U Minh Ha National Park, about 30 km from Ca Mau city of Ca Mau province in the south, covers an area of 8,286 ha. The park with the coordinates 9°12'30" to 9°17'41" North Latitude to 104°54'11" to 104°59'16" East Longitude stretches from U Minh district to Tran Van Thoi district (Fig. 1). It has tree density of approximately 6,500 trees/hectares, that can provide around 75.74 tons/ha of fresh biomass, equivalently about 35.99 tons/ha of dry biomass (Hong et al. 2015).

Of 7,639 ha of *Melaleuca* forests of the park, 1,100.6 ha are natural forests; 6,538.4 ha plantation forests and bareland areas 888.8 ha. The park is divided into three different ecological zones including strict ecological restoration (2,592.6 ha), sustainable use of wetlands (5,134.2 ha), and administration service (801 ha).

Soils within the park are classified as Proto Thionic Fluvisols with a 15 cm layer of thionic sulfidic material at a depth of 100 cm (WRB 2006). The field experiment was undertaken in two areas with Epi Proto Thionic Fluvisols at a depth of less than 50 cm and Endo Proto Thionic Fluvisols at a depth of more than 50 cm.

2.2. The research design

Two different age groups of *Melaleuca cajuputi* Powell trees (10 years of age and 15 years of age) and two planting methods (bund-based and trench-based) were selected for this study. Of the 12 standard plots (10m x 10m) were established in the sites, half of the plots were selected for trees planted on bunds and the remaining plots for trench-based trees in order to collect data in relation to tree density, diameter, potential biomasss and carbon storage.

2.3. Data collection and data analysis

The Anova analysis and SPSS software were applied to analyze and evaluate carbon sequestration by Melaleuca trees. Fresh biomass and the dry biomass of the trees were calculated using the formulas recommended by Nam & Dieu (2013).

The formulas used for calculating fresh carbon as below:

$W_{TF} = 0.379 * (D_{1.3}{}^{2,0682})$

$W_{DB} = 0,144 * (D_{1.3}{}^{2,16})$

Where:

- W_{TF} is the total of fresh biomass
- W_{TD} is dry total of dry biomass
- $D_{1.3}$ is the tree diameter at 1.3m height

The formula for calculating total carbon sequestration as below:

$C_{Tc} = 0,066 * D_{1.3}^{2,1287}$

Where:

- C_{Tc} is the total C accumulation
- $D_{1.3}$ is the tree diameter at 1.3 m height

3. Results

3.1. Tree density and trunk diameter

The results show that the bund-based trees had a higher level of tree density and a higher value of trunk diameter that the trench-based trees for both age groups. Bund-based trees at the age of 10 contained a higher value in tree density and trunk diameter than those at the age of 15. Trench-based trees at the age of 15 received a lower level of tree density, but higher value of trunk diameter than those at the age of 10 (Table 1).

Table 1
Tree density and trunk diameter measured in the plots

Age and planting type	Tree density (trees/ha)	Trunk diameter (cm)
10 years – bund	3700 ± 173.21 [a]	11.31 ± 1.2 [a]
10 years – trench	3600 ± 346.41 [a]	7.46 ± 0.48 [b]
15 years – bund	3567 ± 305.51 [a]	9.05 ± 1.29 [ab]
15 years – trench	3300 ± 300.00 [a]	8.60 ± 0.68 [b]
Note: a and b are the same value in the same column.		

There was four levels of tree trunk diameter, which included > 15 cm, 10–15 cm, 5–10 cm, and < 5 cm. The bund-based trees at two age groups with the trunk diameter of more than 10 cm received larger percentages than the trench-based trees of the same categories. By contrast, the trench-based trees at two age groups with the trunk diameter of less than 10 cm had larger percentages than the bund-based trees of the same categories. Meanwhile, the trench-based trees at the age of 10 with trunk diameter less than 5 cm had the largest percentage of all categories (Fig. 2).

3.2. Carbon sequestration

The results show that bund-based trees had higher values in terms of fresh biomass, dry biomass and carbon sequestration than trench-based trees for two age groups. Bund based 10 year trees had higher values in terms of fresh biomass, dry biomass and carbon sequestration than those at the age of 15.

Trench-based, 15 year trees had higher values in fresh and dry biomass and carbon sequestration than those at the age of 10 (Table 2).

Table 2
The biomass and carbon accumulation in the trees

Year of age and planting type	Fresh biomass (ton/ha)	Dry biomass (ton/ha)	Carbon sequestration
10 years - bund	225.81 ± 58.48a	108.35 ± 29.2 a	45.86 ± 12.2 a
15 years - bund	171.63 ± 26.01a	81.46 ± 12.81 a	29.86 ± 11.62 ab
10 years - trench	98.25 ± 7.84b	46.51 ± 2.45 b	19.89 ± 1.01 b
15 years - trench	106.05 ± 10.33b	49.28 ± 4.91 b	21.09 ± 2.08 b
Note: a and b are the same value in the same column.			

There was a correlation between carbon sequestration trunk diameter. Levels of carbon sequestration for two age groups varied from 20.52 ton carbon/ha to 54.39 ton carbon/ha (Fig. 3).

4. Discussion

4.1. Planting methods, tree density and carbon sequestration

Planting method is a crucial factor in determining change in tree growth, trunk diameter, biomass productivity and carbon sequestration. Theoretically, when growing older, trees compete with others for the sunlight available on sites. When being shaded or overtopped, trees have limited access to sunlight, causing the trees to be slow in growth or eventually die as a consequence of being overtopped (Pretzsch 2009; Bloor & Grubb 2003; Ishii 2007). The study shows that bund-based planting method is more effective in sequestering carbon than trench-based planting one, as shown in Fig. 2, Tables 1 and 2 of this study. Although the same density (10,000 seedlings/ha) was applied by two planting methods, bund-based planting method provides a better condition that helps trees adapt themselves to the sunlight competition. As a result, surviving trees grew in a higher density, but with an increase in trunk diameter and sequestration of a substantial amount of carbon.

4.2. Tree growth and carbon sequestration

Previous studies show that trees grow with increase in trunk diameter and carbon accumulation over time (Canadell & Raupach 2008). Tree age and tree trunk are significant contributors to carbon sequestration (Johnson & Abrams 2009). Trees with big trunk diameter sequester a substantial amount of carbon (Canadell &Raupach 2008; Johnson & Abrams 2009; Sheil et al. 2017). In this study, trees at the age of 10 planted on bunds appear to be the most effective category for sequestering carbon because they achieved the biggest trunk diameter size, and consequently sequestered a higher value in carbon sequestration than other categories.

4.3. Potential replication of the findings in the future

Global climate change is a serious concern for both human well-being and the socio-economic development (IPCC 2014). All signatory countries of the landmark Paris Agreement pledged to reduce their national greenhouse gas (GHG) emissions and enhance resilience to climate change through the Nationally Determined Contributions (NDCs) with domestic or international support (United Nations FCCC 2016). In Vietnam, *the Payment for Forest and Environmental Services*, issued in 2010 (Vietnamese Prime Minister 2010) and revised in 2016 (Vietnamese Prime Minister 2016) is economic incentives offered to local communities in return for protecting and developing forests and environmental services. Currently, *Melaleuca* trees are grown on bunds and trenches for developing new forest are in the Vietnamese Mekong Delta under the *Five Million Forest Ha Program* issued by the Government of Vietnam (Vietnamese Prime Minister 2021). In this study, planting of *Melaleuca* trees on bunds is more cost-effective in developing new forest areas than planting on trenches in term of tree density and volume. In term of silviculture, bund-based planting is more effective in storing fresh and dry biomass and carbon, as shown in Table 2 and Fig. 3. It means that bund-based planting would guarantee success in developing new forest areas, storing fresh and dry biomass, and sequestering carbon; therefore, providing local tree growers an access to the *Payment for Forest and Environmental Services.* Therefore, the findings of this study provide a technical reference for forest protection and development and silviculture in response to carbon emissions and building of forest resilience in the Vietnamese Mekong Delta and elsewhere in the broader region.

5. Conclusions

In exploring the relationship between planting of *Melaleuca* forests and carbon sequestration in U Minh Ha National Park, Ca Mau, Vietnam, we found that planting method significantly contributes to developing new forest areas in terms of tree volume, biomass, and carbon sequestration. Bund-based planting proves to be more cost-effective in developing new forest areas and carbon sequestration than trench-based planting. Trees at the age of 10 planted on bunds has been the most effective category for sequestering carbon. Our methodology in examining the relationship proves to be a feasible reference to new forest development and payment for forest service scheme in the Mekong Delta region or elsewhere in the broader region.

Declarations

Ethics approval and consent to participate: Not applicable

Consent for publication: Not applicable

Availability of data and materials: The manuscript contains all data and materials that support the results and are presented in the paper.

Competing interests: The authors declare that they have no conflict of interest.

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Authors' contributions: Loi, L.T. was responsible for conceptualizing the format, analyzing the data, and drafting the manuscript. Hoang, N.X. was responsible for searching for the data, analyzing the data. Nguyen, T.P. was in charge of finalizing, proofreading, and submitting the manuscript.

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Figures

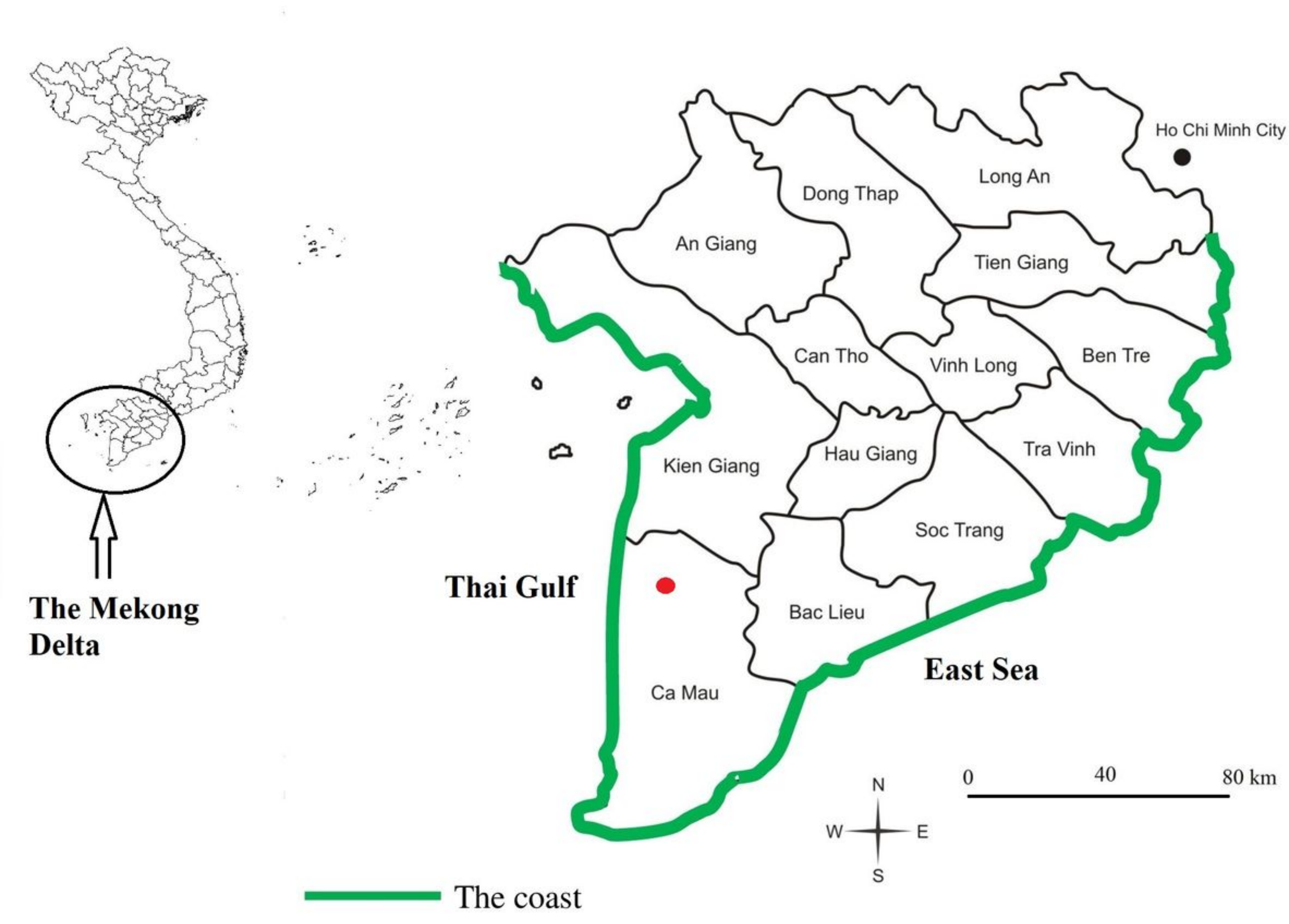

Figure 1

U Minh Ha National Park (red dot) of Ca Mau, Vietnam in the regional context. The background is Google image

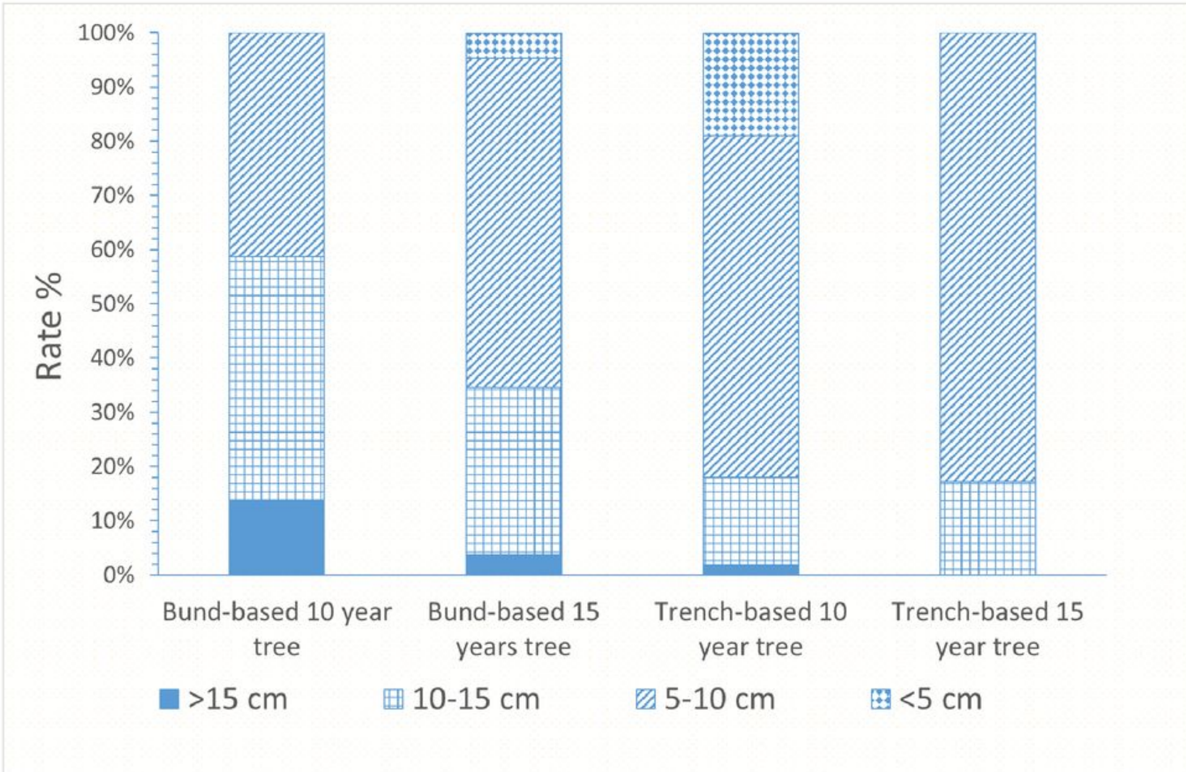

Figure 2

Trunk diameter of Melaleuca trees across the plots

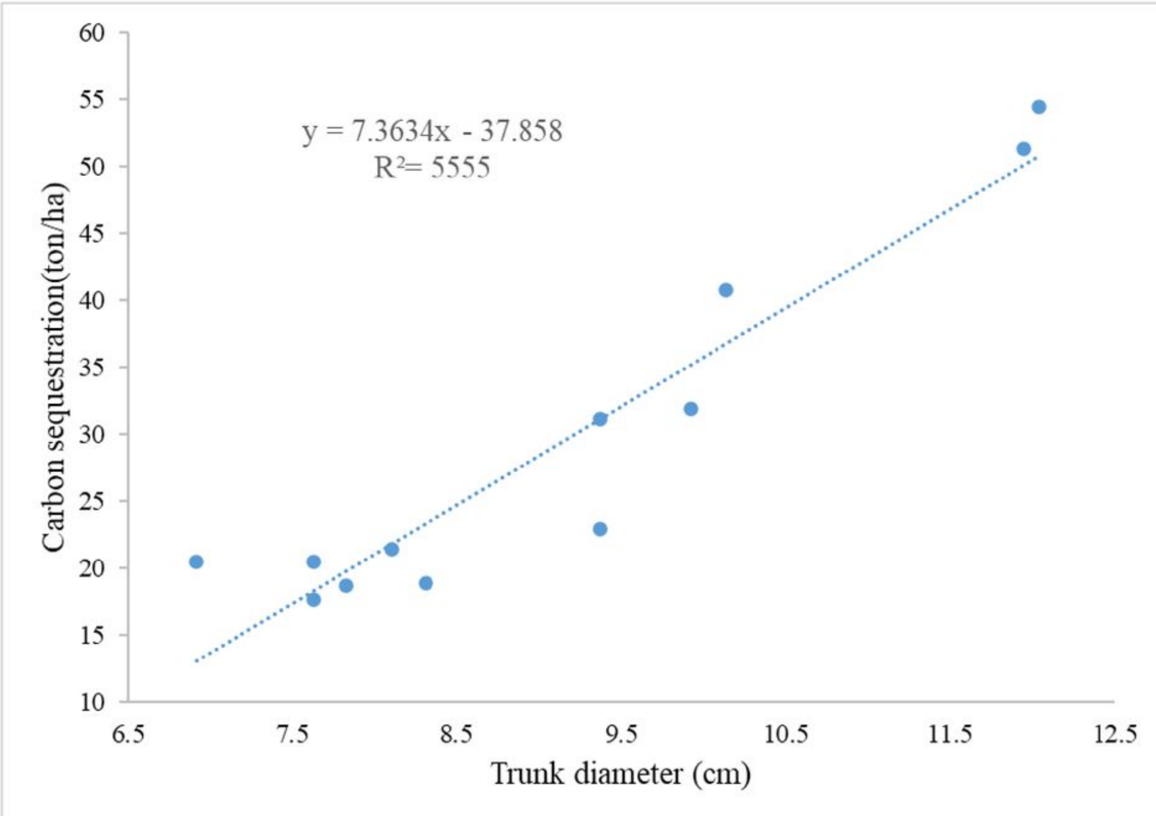

Figure 3

The correlation between carbon accumulation and trunk diameter