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Estimating Carbon Stock in Biomass and Soil of Young Eco-Forest in Urban City, Thailand

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One method of mitigating the effect of climate change is to increase carbon sequestration areas in eco-forest plantations that are important for carbon cycling. The Miyawaki technique of afforestation has been recommended for eco-forest plantations in urban city settings because of its suitability for rapid growth of thick trees, carbon sequestration, and improved air quality. The objectives of this study were to estimate the potential of carbon sequestration in above-ground and below-ground biomass using an allometric equation and soil collected from the young eco-forest at the Environmental Research and Training Center (ERTC) in Technopolis, Pathum Thani Province during June 2019–February 2020. Carbon fraction was analyzed with a CHN analyzer. The results showed that carbon content of plants in the young eco-forest was highest in roots (45.34), leaves (44.92), and stems and branches (44.20). The percent carbon content in the soil at depths of 0–100 cm ranged from 1.0–2.8. Total potential for total carbon storage was 156.53 t C ha^{-1}, derived from the average of carbon stocks recorded in above-ground biomass, below-ground biomass, and soil, which were 15.02, 3.72, 137.79 t C ha^{-1}. Thus, eco-forest can indicate potential for reducing carbon dioxide concentration in the atmosphere, fixing carbon in living biomass and soil, and maintaining environmental balance in an ecosystem.

1. Introduction

Global warming is the increase in average global surface temperature and is an important indicator of global climate change. Scientific evidence has shown that global warming is mainly caused by increased atmospheric concentrations of greenhouse gases (GHG), such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The global average atmospheric CO_2 concentration increased from about 285 ppmv (parts per million on a volume basis) in 1850 to 379 ppmv by 2005, with the average global temperature increasing at a rate of 0.74 ± 0.18°C yr^{-1} (IPCC, 2007). These changes have certain adverse effects on global environments, including changes in precipitation patterns, sea level rise, and increased frequency and intensity of extreme weather events. Tree plantation is one way to reduce greenhouse gases concentration in the atmosphere. This is initiated when carbon is fixed by plants via photosynthesis processes. Some of the fixed organic carbon compounds are used to grow tissues, such as stems, branches, leaves, and roots, while others are broken down to supply the plants with energy. During this process, carbon is released into the atmosphere by ecosystem respiration, disturbance, and herbivory. Trees also reduce air pollution. Road traffic emissions, for example, are the primary source of urban particulate pollution (Pant and Harrison, 2013) and can threaten the health of residents who experience long-term exposure to busy traffic areas (HEI, 2010). Tree planting increases afforestation, especially in urban and community areas, and it is one of the Sustainable Development Goals (SDGs) to promote forest management of all types by halting deforestation, restoring degraded forests, and increasing the planting of forests. Thailand's Climate Change Master Plan 2015–2050 corresponds with these national strategies and policies.

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In alignment with its greenhouse gas (GHG) emission reduction policy, Thailand has employed a global approach by submitting Nationally Appropriate Mitigation Actions (NAMAs) to lower greenhouse gas emissions below business-as-usual (BAU) levels by 2020. Moreover, Thailand will work to reduce emissions a further 20–25 % by 2030 compared to the BAU level. With the revision of the 20-Year National Strategy in 2018, the government stated it would be increasing forest areas in degraded forest, conservation forest, abundant areas, etc. Tree plantation in urban areas using the Miyawaki method is a good alternative solution for reducing greenhouse gases and air pollution in urban environments, as it is one of the most effective tree planting methods, particularly regarding creation of forest cover on degraded land that has been used for other purposes, such as agriculture or construction. This technique was devised by Japanese botanist Akira Miyawaki, and can be used worldwide, irrespective of soil and climate conditions. In environmental and ecologically damaged territories, as well as urban environments, the Miyawaki approach has been used in many countries, such as India, South American nations, Japan, the Far East, Malaysia and Thailand (Poddar, 2021). Over 2000 forests have been successfully created using this method. It has some significant benefits over more traditional forestry methods when used in smaller afforestation projects and is particularly effective in the urban environment. Trees planted by this method grow much faster, accelerating the forest creation process and capturing more carbon (Schirone, et al., 2011). However, there is little data on carbon pools in above-ground and below-ground biomass and soil of young eco-forest planted using the Miyawaki method in Thailand. Previous research has shown rapid growth of plants and reduction the air pollution. Urban forests offer numerous benefits, including reduced temperature, improved air quality and ecology, reduced small particle matter, CO_2 sequestration, and improved wellbeing indices. Thus, a better understanding of carbon stock in biomass and soil could better explain carbon sequestration and improve the prediction of climate impacts on carbon cycling by eco-forests.

2. Methodology

2.1 Study sites and plot establishment in Thailand

The site study was performed in the eco-forest plot at Khlong Luang District, Pathum Thani, Central Thailand from May 2019–February 2020. The experimental site was located at 14° 02' 46.6" N, and 100° 42' 50.6" E, in the Environmental Research and Training Center (ERTC), Technopolis campus (Figure 1). The age of the young eco-forest was 3 years and was planted according to the Miyawaki method (Miyawaki et al., 1998). Miyawaki is a method developed by Japanese botanist Akira Miyawaki, which provides the advantage of rapid growth of thick plants rather than natural forest. According to the plant saplings were up to 80 cm high, with 3 to 5 saplings per square meter, once the soil has been modified to a depth of 1 m. Normally, a forest experiences competitive growth so dense that sunlight cannot reach the ground after eight months. Every drop of precipitation that falls is saved at this stage, and every leaf that falls is transformed into humus through decomposition. The more the forest expands, the more nutrients it produces for itself, allowing it to expand even faster allowing even faster tree growth. Individual trees begin to compete for sunlight as a result of this density, which is why these forests grow so quickly and can develop more carbon pools in plant biomass and life in the soil (Poddar, 2021).

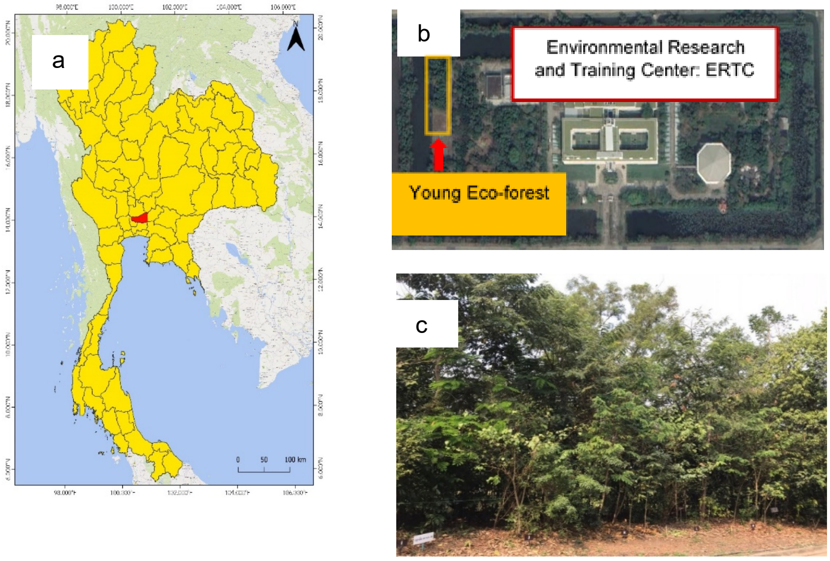

Figure 1: (a) Location of the study site in Khlong Luang District, Pathum Thani, Central Thailand, Field (b,c) layout of eco-forest plantation in Environmental Research and Training Center (ERTC), Technopolis campus

2.2 Principal of the Miyawaki Method

The Miyawaki method is developed from natural reforestation principles, which use native forests with native trees based on vegetation-ecological theories, thereby replicating natural forest regeneration processes. This method can restore native green environments, multi-layer forests, and natural biocoenosis, and quickly establish well-developed ecosystems due to the simultaneous use of intermediate and late successional species in plantations. The Miyawaki method requires surveying the potential natural vegetation of the area to be reforested and recovering topsoil to a depth of 20–30 cm by mixing soil and compost from organic materials. With this approach, the time of the natural process of soil evolution generated by the vegetational succession is reduced. Tree species must be selected from the forest communities of the area in order to restore multi-layer natural or quasi-natural forests. After these field surveys and preparation, all intermediate and late successional species are mixed and densely planted, with as many companion species as possible. Soil between them is mulched to prevent soil dryness and erosion on steep slopes (even with heavy rainfall), weed growth, to protect seedlings against cold, and to serve as manure as materials decompose. This method serves as a model for reconstructing degraded natural habitats and native plant environments, and is grounded on solid scientific documentation and reporting, with numerous experiments having been carried out in many contexts. It has been shown that the Miyawaki urban forests in Japan and Southeast Asia grow 10x faster, 30x denser, and with 20x more biodiversity (Schirone, et al., 2011).

2.3 Estimation carbon stock in the young eco-forest

This study estimated carbon stock in the young eco-forest using above-ground and below-ground plant biomass. The above-ground and below-ground biomass of the 717 trees was estimated using an allometric equation of the relationship between the diameter at 130 cm from ground level (D) and height (H). Generally, total above-ground biomass was estimated from the allometric equations of stems (WS), branches (WB), leaves (WL), and coarse roots (WR). Then, the above-ground and below-ground biomasses were calculated (kg of dry mass per ha-1) with allometric equations separated by plant species in Table 1.

Table 1: Allometric equations used for biomass calculation of eco-forest trees in the study site

Allometric equation	Species	References
$W_S = 0.0396(D^2H)^{0.9326}$ $W_B = 0.006003(D^2H)^{1.0270}$ $W_L = (28/(W_S+W_B+0.025))^{-1}$ $W_R = 0.0264(D^2H)^{0.7750}$	*Barringtonia acutangula* (L.) Gaertn., *Lagerstroemia speciosa* (L.) Pers., *Glochidion wallichianum* Muell. Arg., *Mimusops elengi* L., *Cordia sebestina* L., *Diospyros buxifolia* (Blume) Hiern., *D. decandra* Lour., *D. dasyphylla* Kurz ST.,*Aegle marmelos* (L.) Correa., *Calophyllum inophyllum* L., *Syzygium jambos* (L.) Alston., *Garcinia cowa* Roxb., *Spathodea campanulata* P.Beauv., *Cinnamomum camphora* (L.) J.Presl., *Syzygium cumini* (L.) Skeels., *Schinus terebinthifolius* Raddi., *Dillenia indica* L., *Lepisanthes fruticosa* (Roxb.) Leenh., *Shorea roxburghii* G.Don., *Lagerstroemia loudonii*, Teijsm. & Binn.,*L. floribunda* Jack., *Dolichandrone serrulata*, (Wall. ex DC.) Seem., *Millettia brandisiana* Kurz., *Cassia bakeriana* Craib., *Mansonia gagei* Drumm., *Butea monosperma* (Lam.) Taub., *Phyllocarpus septentrionalis*, Donn.Sm., *Cassia fistula* L., *Terminalia bellirica* (Gaertn.) Roxb., *Crateva magna* (Lour.) DC., *Cotylelobium lanceolatum* Craib., *Cotylelobium melaoxylon* Pierre., *Irvingia malayana* Oliv. ex A.W.Benn., *Dalbergia oliveri* Gamble., *Pterocarpus macrocarpus* Kurz., *Vitex glabrata* R.Br., *Careya sphaerica* Roxb., *Senna siamea* (Lam.) Irwin & Barneby., *Fagraea fragrans* Roxb., *Xylia xylocarpa* (Roxb.) Taub., *Phyllanthus emblica* L., *Terminalia chebula* Retz., *Caesalpinia sappan* L., *Hydnocarpus antelminthica* Pierre ex Laness., *Dipterocapus alatus* Roxb., *Cratoxylum formosum* (Jack) Dyer., *Hopea odorata* Roxb., *Dipterocapus obtusifolius* Teijsm. ex Miq., *Melaleuca quinquenervia* (Cav.) S.T. Blake.	Ogawa et al., (1965)
$W_S = 0.0509(D^2H)^{0.919}$ $W_B = 0.00893(D^2H)^{0.977}$ $W_L = 0.0140(D^2H)^{0.669}$ $W_R = 0.0313(D^2H)^{0.805}$	*Syzygium gratum* (Wight) S.N.Mitra var. *gratum*., *Melodorum fruticosum* Lour., *Afzelia xylocarpa* (Kurz) Craib., *Manikara hexandra* (Roxb.) Dubard., *Aquilaria crassna* Pierre ex Lecomte., *Xanthophyllum lanceatum* (Miq.) J.J.Sm., *Microcos tomentosa* Sm., *Spondias pinnata* (L.f.) Kurz., *Artocarpus lakoocha* Roxb., *Ardisia polycephala* Wall., *Mitrephora tomentosa* Hook.f. & Thomson., *Knema angustifolia* (Roxb.) Warb., *Borassus flabellifer* L., *Glochidion wallichianum* Muell. Arg.	Tsutsumi et al., (1983)

Estimated carbon stock in living biomass were calculated following plant carbon stock (PCS) as shown in Eq(1):

$$PCS = B \times \%C \times PD \tag{1}$$

PCS: plant carbon storage, B: biomass of plant (kg d.m.tree/m^2), %C: carbon ratio, PD: plant density (tree/m^2).

2.4 Soil properties analysis

2.4.1 % carbon and % nitrogen ratios

Carbon and nitrogen ratio in biomass and soil were analyzed by CHN Analyzer (PerkinElmer 2400 series II CHNS/O Elemental Analyzer: 628 series, LECO Corporation, St Joseph, Michigan, USA). It was measured by oven samples dry method and crushes each plant and different soil depth layers. Soil Organic Carbon (SOC) was analyzed from the ten soil depth layers of 0-100 cm by using CHN Analyzer.

2.4.2 Soil pH

Soil pH was measured in a 1:1 soil : water suspension using a glass electrode pH meter (Hi-3220, Hanna Instruments, Inc., USA). Air-dried soil samples were sifted through a 2 mm sieve prior to suspension by separated 10 soil depth layers.

2.4.3 Carbon stock in soil

Soil carbon stocks were determined at the representative soil profile in the vertical soil depth layers of 0-100 cm by using soil core. The soil carbon stock was calculated by multiplying the carbon concentration by the soil bulk density of the soil layer and cumulating to a certain depth Eq(2).

$$SOC = BD \times \%C \times D \tag{2}$$

Where, SOC = soil organic carbon (t C/ha), BD = bulk density of soil (g/cm^3), %C = % carbon ratio (%) and D = soil depth (cm). The BD was calculated density of soil in laboratory using the oven dry method and %C was estimated using CHN Analyzer (PerkinElmer 2400 series II CHNS/O Elemental Analyzer).

3. Result and discussion

3.1 Soil property and carbon stock

Soil was sampled in April, 2019 and analyzed for pH, bulk density, % carbon, % nitrogen, C/N ratio, and total organic carbon (Table 2). Soil pH at the site was acidic, most so in the highest soil layer. However, pH difference across the 100 cm depth was quite small. This may indicate the limited influence of an immature forest canopy on soil when compared to a mature forest. In old-growth forests in Thailand, for example, pH at the top layer is usually significantly higher than at the layers beneath because of the active supply of litter fall and the existence of a litter layer at the surface (Ogawa, et al., 1961). pH value in the surface soil layer was higher than in the subsoil at 5.76 (0–20 cm); the second layer had a pH of 5.34 (20–45 cm), the third layer 5.26 (45–60 cm), and the last layer 5.33 (> 60 cm). Moreover, bulk density tended to increase as the soil depth increased, ranging from 0.70–0.88 g cm-3. The total density of the soil increased with the depth of the soil because the subsoil had less organic matter, with more compaction leading to reduce soil holding. Soil organic carbon promotes good soil structure by binding soil particles together in stable aggregates, which aids aeration and soil water holding capacity. The % of carbon (%C) and nitrogen (%N) trends decreased as soil depth increased, ranging from 1.0–2.8% C and 0.03–0.11 % N. Additionally, the amount of total soil organic carbon (SOC) in 100 cm soil depth was 137.79 t C ha-1. The highest SOC content in the natural forest, reforested area, and agricultural (maize) soils were 118, 66, and 60 t C ha-1 (Chidthaisong and Lichaikul, 2005). Assessment of SOC at two different soil depth layers of 0–15 and 15–30 cm in the Ban Phrao community forest, Sa Kaeo province, Eastern Thailand found that SOC of surface soil was higher than subsoil, measuring at 21.02 and 18.05 t C ha-1 (Mokopen, et al., 2021). In this study, the conversion of eco-forest plantation should lead to increased carbon sequestration in soil because of carbon input to the soil by above-ground biomass, including litterfall decomposition, microbial biomass, and soil activity. However, the pH, bulk density, %carbon, %nitrogen and total soil organic carbon in 71–100 cm soil depth were higher than in the surface soil because the background of the area was paddy field before the land was reclaimed to build the research station. Hence, the depth soil properties were stable and similar to the traditional surface soil properties, but the soil surface properties depended on land use, land management, and plant productivity.

3.2 Plant growth and carbon stock in eco-forest

Allometric equations in Table 1 were applied to evaluate the biomass separated by plant species in the eco-forest. The diameter (D) and height (H) of the trees were carried out at the end of year 3 post-tree-planting. The eco-forest consisted of 62 tree species across 717 trees. Average plant height and diameter in the eco-forest were 3.43 ± 1.74 m and 7.60 ± 1.74 cm. The average carbon contents in stems, branches, leaves, and roots in the forest were 44.20, 44.20, 44.92, and 45.34 %. The average nitrogen content in stems, branches, leaves, and roots for these species were 1.26, 1.26, 1.48 and 0.96 %. The average carbon and nitrogen contents in the biomass were 44.67 % C and 1.24 % N.

Analyses of tissue-specific carbon values indicated that root and stem C provided a surprisingly good direct approximation for C content in other tissues. This result suggests that root and stem carbon can be used to represent all components. The carbon content in leaves was highest in this study, allowing the potential addition of carbon stock to the surface soil after litter decomposition. In the vast majority of local, regional, and global assessments, C content has been assumed to be 50 %. Moreover, the average carbon stock in the biomass based on IPCC 2006 guidelines for national greenhouse gas inventory was 47 % carbon fraction (Thomas and Martin, 2012). Total carbon stock of the trees was evaluated using the carbon contents of stems, branches, leaves, and roots of the trees. The average percent carbon contained in the eco-forest biomass was 44.67 %. However, recent studies suggest that neither of these assumptions were accurate, but were rather under- or over-estimated. Hence, the site specificity of biomass carbon content should be found in order to increase the accuracy of carbon storage in each forest. In this study, the estimate of the total above-ground and below-ground biomass was 42.15 t dry matter ha-1. C stock is shown using %C in Table3.

Table 2: Soil properties in the young eco-forest

Soil depth (cm)	pH	Bulk density (g cm^{-3})	% Carbon	% Nitrogen	C/N ratio	Soil organic carbon (t C ha^{-1})
0-10	4.80	0.73 (±0.20)	1.00	0.05	19.42	7.30
11-20	4.67	0.70 (±0.14)	1.55	0.04	38.16	10.85
21-30	4.94	0.79 (±0.16)	1.33	0.03	40.68	10.51
31-40	4.64	0.75 (±0.22)	1.35	0.04	35.17	10.13
41-50	4.52	0.70 (±0.21)	1.70	0.03	48.96	11.90
51-60	5.00	0.84 (±0.18)	1.71	0.04	38.75	14.36
61-70	4.20	0.77 (±0.11)	1.81	0.05	33.89	13.94
71-80	5.17	0.73 (±0.21)	2.35	0.09	27.04	17.16
81-90	5.33	0.88 (±0.50)	2.77	0.11	25.45	24.38
91-100	5.11	0.80 (±0.62)	2.16	0.08	25.68	17.28

Table 3: Plant biomass and carbon stock in different components of young eco-forest in Thailand

Plant Components	% Carbon	% Nitrogen	C/N ratio	Plant Biomass (t dry matter ha^{-1})	Plant carbon stock (t C ha^{-1})
Stem	44.20	1.26	35.25	27.68±0.12	12.24
Branch	44.20	1.26	35.25	4.79±0.02	2.12
Leaves	44.92	1.48	30.26	1.47±0.01	0.66
Root	45.34	0.96	47.46	8.21±0.03	3.72
Total				42.15	18.74

Forest plantation can reduce CO_2 from the atmosphere, according to CO_2 sink of 200 trees plantation in Pang Sida National Park, Thialand was 1,786 kg CO_2 ha^{-1} yr^{-1} (Promjittiphong et al., 2016). Total carbon stock of the 3 years eco-forest was 18.74 t C ha^{-1}, or 6.25 t C ha^{-1} yr^{-1}. Carbon stock in the eco-forest under the Miyawaki method can be attributed to rapid plant growth. Carbon stock and removal of CO_2 in young stands of forest restoration stands (75 months) in Brazil was 15.7 t D.M. ha^{-1}, which corresponds to an average annual carbon fixation of 2.5 t C ha^{-1} yr^{-1} (Sanquetta et al., 2020). Bhat and Ravindranath (2011) reported that accumulation rates of carbon ranged from 0.31–3.19 t C ha^{-1} yr^{-1} in tropical rainforests of India. In the community forests of Dolakha, Nepal, the annual rate of carbon sequestration was 2.19 t C ha^{-1} (Shrestha, et al., 2014). The average carbon sequestration of urban trees in parks and street in Bangkok Metropolitan, Thailand ranged between 0.009–0.012 t C tree^{-1} yr^{-1} (Fujimoto et al., 2016). According to the range of carbon sequestration followed by the range of default values set by the IPCC Good Practice Guidance for LULUCF in urban trees in parks and streets were sink carbon stock in the plant as about 0.0033-0.0142 t C tree^{-1} yr^{-1} (IPCC, 2003). The carbon stock in biomass and soil increases as age increases. The eco-forest in this study has rapidly grown so densely that sunlight cannot reach the ground, with all rainfall and all leaf fall in the area transformed into humus and nutrients in soil. The more a tree expands, the more nutrients it produces for itself, allowing even faster expansion (Poddar, 2021). Individual trees begin to compete for sunlight as a result of high density, which is another reason contributing to why these forests develop growth so quickly.

4. Conclusion

Eco-forests can play a significant role in reducing atmospheric CO_2 in urban areas. The potential of total carbon storage in young eco-forest grown with the Miyawaki method was 156.53 t C ha^{-1}. This consisted of the average carbon stock in the above-ground and below-ground biomass and soil, measuring 15.02, 3.72, 137.79 t C ha^{-1}. The results showed rapid growth rate and carbon sequestration in the plants. More field data are needed to continuously measure the carbon stock on an annual basis in order to explain the speed of growth and carbon sequestration in the forest. Additionally, carbon balance is an important indicator of global carbon dynamics, so accumulation of carbon can explain by Net Ecosystem Production (NEP). These terms refer to the difference between the amount of organic carbon fixed by photosynthesis and respiration. It represents the organic carbon available for storage in the system or loss of it by export or non-biological oxidation. It is expected that the results from the NEP will be useful for improving our understanding of carbon cycle processes in eco-forests.

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