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Palmyrah (*Borassus flabellifer*) palm land-use system: A potential key tool for enhancing carbon stock and floristic diversity in a dry zone tropical landscape

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ABSTRACT

The threat of global warming, biodiversity loss, and land degradation highlight the urgency of identifying sustainable land use systems that serve as climate-adaptive solutions. This study assessed the carbon stock and floristic diversity of the *Borassus flabellifer* (Palmyrah palm) land uses under 14 different soil series in the Jaffna district of Sri Lanka. A total of 75 sampling quadrats (10 m × 10 m) were surveyed, collecting data on the number of Palmyrah palms and other flora species and, the height. Soil samples were collected at three depths (0–10 cm, 10–20 cm, and 20–30 cm) for organic carbon analysis. Carbon stock in biomass was estimated using standard allometric equations, and total carbon stock was calculated by summing biomass (above-ground and below-ground) and soil carbon. The study found that soil organic carbon percentage of surface layer (0 – 30 cm) in different soil series ranged from 0.31 to 1.61 %. The topmost layer (0 – 10 cm) had higher average soil organic carbon stock (12.25 Mg C ha^{-1}) than sub surface layers (10 – 20 cm – 11.57 Mg C ha^{-1}), 20 – 30 cm – 10.11 Mg C ha^{-1}). A total of 22 floral species belonging to 13 families were identified in the surveyed quadrats. Shannan Weaver index (SWI) and the evenness were 1.2 and 0.74, respectively indicating moderate biodiversity levels. The average values of Palmyrah palm density, biomass carbon stock, soil carbon stock, and total carbon stock were 914 ± 179 stems ha^{-1}, 72.48 ± 15.11 Mg C ha^{-1}, 36.05 ± 15.81 Mg C ha^{-1}, and 108.53 ± 21.47 Mg C ha^{-1}, respectively. These findings highlight Palmyrah palm land use as a significant carbon sink with substantial potential for biodiversity conservation. Promoting this land use system could contribute to sustainable climate mitigation and adaptation strategies in regions facing similar ecological challenges.

1. Introduction

Climate change in recent decades has decreased the land productivity and biodiversity (Gisladottir and Stocking, 2005). Crop failures due to climate change has been reported by the end of the 21st century (Pathak et al., 2003). Crop production is highly climate-sensitive (Godde et al., 2021), while studies suggest that the countries in the tropical and subtropical regions are more vulnerable to impact by climate change in terms of food supply (Tchonkouang et al., 2024). Impact of climate change on agriculture is mainly attributed to drought or flood conditions consequent to climate change, increased pest and disease incidences, loss of biodiversity, decline in soil fertility and temperature and salt stress, all these in turn affect the global food security (Pathak et al., 2012). The significance of land use-based mitigation options for climate change has been discussed from long past, subsequent to Kyoto protocol in 1997 (Carton et al., 2020; Yin et al., 2007), till now (Karki et al., 2023; Yin et al., 2023). The Intergovernmental Panel on Climate Change (IPCC) forecasted alterations in areas suitable for carbon storage, and biodiversity (IPCC, 2019). The ecosystem carbon sequestration potential either as soil carbon or in vegetation is influenced by climatic conditions, soil type, land management (Fujisaki et al., 2018; Menezes et al., 2021; Paramesh et al., 2022), and vegetative cover and plant species (Dung et al., 2016; Ngo et al., 2013). Taking action on soil carbon sequestration will increase organic matter content which in turn have

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substantial positive influences on soil properties and creates a favorable impact on environmental or agricultural potential and biodiversity of land resources (FAO, 2001; Vågen et al., 2005). The outcomes will involve enhanced soil fertility, improved land productivity for food production, and better food security. To address the challenges posed by climate change on land productivity, biodiversity, and food security, it is essential to implement site-specific mitigation and adaptation mechanisms that enhance soil carbon sequestration, and conserve the biodiversity, and support sustainable agricultural productivity.

Despite the global response on climate change through initiatives of many mitigation and adaptation mechanisms, the knowledge regarding the carbon stocks associated with different land uses is still inadequate (Marquardt et al., 2023; Menezes et al., 2021), especially in developing countries (Vågen et al., 2005). Above-ground biomass is an important information for understanding ecological processes and identifying management strategies in tropical forests. The palms are considered significant global carbon stores (Draper et al., 2014; Goodman et al., 2013; Molina et al., 2015; Murdiyarso et al., 2010; Posa et al., 2011). The deforestation and degradation of palm land-use can significantly elevate greenhouse gas emissions and contribute climate change (Hergoualc'h et al., 2017; Molina et al., 2015). There is untapped potential exist in the tropical, semiarid and arid regions in the land uses covering native or exotic palm species. However, studies on the carbon stock aspects of palm land uses are limited except a few on soil carbon studies of oil palms (Behera et al., 2021; Gomes et al., 2021; Rüegg et al., 2019) and study on above-ground biomass of *Areca catechu, Cocos nucifera* and *Borassus flabellifer* (Dey et al., 2014) in homegardens.

B. flabellifer, is classified under the family Arecaceae, which have a common name as Palmyrah palm (Prance and Nesbitt, 2012). It is a dioecious evergreen palm tree with a single stem that can grow up to 30 m tall and trunk diameter of as much as 1 m (Davis and Johnson, 1987). The trunk of this palm is straight, and outer colour appeared in black. The first flowering takes place when the palm is 12–20 years of age. The female inflorescences are branched, giving rise to 4–10 flower-bearing spikes. The Palmyrah palm has a lifespan over 100 years (Jana and Jana, 2017). A mature tree may bear 200–300 fruits annually and a fruit has 3 or 2 seeds. Average weight of the fruit is 1.5 kg at diameter of 15–20 cm. Shape of the fruits is round (Davis and Johnson, 1987). Germination is observed within 45–60 days after planting (Morton, 1988), and the first leaf emerge out after a period of 100 days (George and Karun, 2011). Germination percentage of seeds varied from 15 % to 20 % (Ravindran and Ramanan, 2020; Tomlinson, 1990) and this percentage was reported to increase to 73 % - 89 % by seed treatments (Masilamani et al., 2023; Ravindran and Ramanan, 2020). Very strong and durable wood are produced from the mature stem of the Palmyrah palm. A palm about 85-year-old may yield a 20 m tall stem (Davis and Johnson, 1987). This palm has been utilized for various purposes, including food products such as fruit, tuberous seedlings, endosperm, fermented and fresh beverages, and sugar derived from the sap. It also provides non-wood products like fiber from the leaves and leaf bases for brushes, materials for cottage roofing and weaving, as well as wood from the trunk for fuel and construction (Davis and Johnson, 1987; Srivastava et al., 2017), along with numerous other handicraft products. A famous Tamil language poem in India that praises this palm as a "tree of life" and catalogues 801 uses in diverse aspects, indicating its multipurpose uses (Arulraj and Augustine, 2008; Davis and Johnson, 1987).

Palmyrah palm is one that is capable of addressing climate change issues through mitigation and adaptation strategy. This palm provides many ecosystem services including less water demanding and regulate water tables as well as they could effectively reduce erosion in the landscape they are found. Additionally, it serves as a habitat for many birds, bats as well as wild animals (Jana and Jana, 2017). The Palmyrah palm is adaptable to various soil textures, including sandy, clay, and loamy soils, and can thrive even in less fertile conditions. It is also suitable for soils with a wide pH range, from acidic and neutral to alkaline and highly alkaline (Veilmuthu, 2014). Furthermore, the Palmyrah palm can also thrive in extreme weather conditions, making it an ideal floral species for cultivating on marginal lands. Afforesting such lands with Palmyrah palm could serve as an effective strategy for mitigating climate change. Palmyrah seed/nut shell char was reported to have many beneficial effects in sandy regosol soils, when mixed with inorganic fertilizers. Effects include increased available N, P and K, cation exchange capacity, organic carbon and moisture content (Senthuran and Gnanavelrajah, 2015). The wood of this palm can also be converted into charcoal. The caloric value of Palmyrah wood is ten times higher than that of dicot fuel wood (Davis and Johnson, 1987), providing a sustainable and accessible energy source. As a hardy plant, the Palmyrah palm is resistant to pest or disease attacks. With its variety of potential food options, reinventing the traditional foods made from this palm, developing innovative food products, and utilizing the various parts could be an adaptation mechanism to climate change. Further, there has been many research conducted in different countries regarding its medicinal values (Ariyasena et al., 2001; Behera et al., 2021; Dey et al., 2014; Gummad et al., 2016; Muniyandi et al., 2021; Naguleswaran et al., 2010; Prasad et al., 2022; Srinivasababu et al., 2014; Thevamirtha et al., 2021). However, its values as carbon stock and biodiversity aspects have not been studied in detail except for few studies on above-ground biomass of this palm in homegardens and soil conditions. Given its multiple uses, benefits, and remarkable environmental adaptability, Palmyrah palm land uses have a higher potential for contributing to climate change adaptation and mitigation compared to coconut and other palm species.

Palmyrah palm is found widely in Southeast Asia and South Asia particularly in northern Sri Lanka, coastal belts of India, and eastern Indonesia (Behera et al., 2021; Davis and Johnson, 1987). Natural distribution of this palm is found in Pakistan, Indonesia, Thailand, Bangladesh, Malaysia, and some African countries (Sankaralingam et al., 1999; Siju and Sabu, 2020). According to estimates from the 1990s, the population of the Palmyrah palm was approximately 80 million in India, 10 million in Indonesia, 2 million in Thailand, and 11 million in Sri Lanka. The estimated population of this palm was 3.5 million in the Jaffna district of Sri Lanka (Palmyrah Development Board, 2019), the focus area of this study. However, substantial reduction was expected in this district, due to the destruction of these palms for various purposes and current distribution is unknown (Nareshkumar et al., 2019). Palmyrah land use is observed in two forms: first, as land close to community land, managed by owners for various purposes; and second, as abandoned land with no management practices (Appendix A). In both cases, soils under Palmyrah are rarely disturbed and mostly covered by shrubs and herbs hence must have more carbon than those under coconut palm or any annual crops. Soil is the major carbon (C) pool in terrestrial ecosystems (Schlesinger and Andrews, 2000). Therefore, carbon stock assessment of Palmyrah land-uses is important for understanding their role in carbon sequestration, climate change mitigation, and sustainable land use management practices. Accordingly, this study was conducted to assess carbon sequestration potential and floristic diversity of Palmyrah land use in a dry tropical region of Sri Lanka. The specific objectives of this study were to estimate soil organic carbon of Palmyrah land use in Jaffna district in different soil series, to estimate biomass carbon stock of Palmyrah palm in different soil series, and to assess floristic diversity of the same land use. As the Palmyrah palm is widely distributed in the other countries (Behera et al., 2021; Sankaralingam et al., 1999; Siju and Sabu, 2020), the results of this study and similar research of this kind would help the researchers and policy makers to include this land use in potential carbon trading initiatives.

2. Materials and methods

2.1. Study area

The study was carried out in the Jaffna district located in the Northern Province of dry zone in Sri Lanka (Fig. 1a). Ranges of average

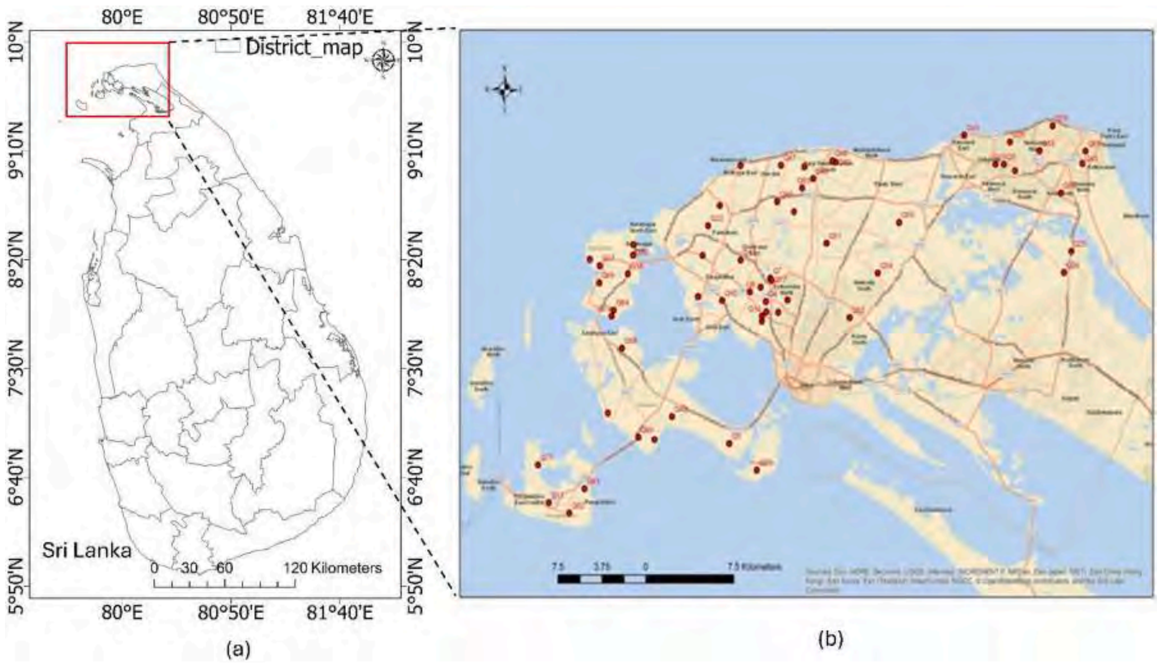

Fig. 1. Locations of study site and sampling quadrats; (a) Location of Study area, Jaffna district, Northern Province in Sri Lanka; (b) Locations of the sampling quadrats in Jaffna district. Red points indicate the locations of the sampling quadrats and red line represents the major roads.

temperature and annual rainfall were 26 – 33 °C and 696 – 1125 mm, respectively. Soils in the study area belong to order Entisols and great groups Typic Ustorthents, Oxyaquic Udorthents, Aeric Epiaquents, Sodic Psammaquents, and Aquic Quartzipsamments according to USDA soil taxonomy (Dassanayake and Mapa, 2022). However, according to local classification, based on drainage, and physiography soils of this district were classified into fourteen soil series (Joshua, 2003).

2.2. Sample collection

Fig. 1b illustrates the distribution sampling quadrats in the study area. A total of 75 quadrats were sampled, each with dimensions of 10 m × 10 m. In this study, we estimated the soil and biomass carbon, and floristic diversity. Therefore, we followed 10 m × 10 m plot as a sampling quadrat and this was consistent with previous studies (Gnanavelrajah et al., 2008; Shrestha et al., 2010). The number of quadrats per soil series was decided as the percentage of Palmyrah palm which is calculated as the number of Palmyrah palm in each soil series divided by the total number of Palmyrah palm in the study area, multiplied by 100. The names of soil series and numbers of sampling quadrats from each series is given in Table 1. The number of Palmyrah palm were estimated using multi spectral and panchromatic bands derived from high-resolution Quick bird Satellite images of 2016 in a previous study (Nareshkumar et al., 2019). The multispectral bands and the panchromatic band were having spatial resolution 2.4 m and 0.6 m, respectively. The images of the Palmyrah palm were extracted through visual image interpretation technique in ArcMap software (version 10.4). The images were carefully inspected manually, and the Palmyrah palm was traced using digitizing tools embedded in ArcMap software. The digitization process was done from February to July 2017 to cover the total number of 159,339 Palmyrah palm. The digitalized Palmyrah palm layer and soil series layer were added to the ArcMap software. Then, the number of Palmyrah palm in each soil series was calculated by overlaying soil series maps on the Palmyrah palm layer. The quadrats for soil sampling and other data collection were selected away from the roadsides, buildings and fences. Satellite assessment was used solely to determine the number of sampling quadrats in each soil series. Subsequently, field data for both Palmyrah palm and other vegetation were collected from the sampling quadrats (10 m x 10 m) established in the field. From each quadrat following data were collected: Number of Palmyrah palm and other floral species, and height of Palmyrah palm using clinometer. Well-known floral species were identified by survey members, while unidentified species were further validated by a local expert. The vernacular names of all species were listed, and their scientific names were confirmed using both the herbarium and the checklist of flowering plants in Sri Lanka (Senaratna, 2001). To determine soil organic carbon, disturbed composite soil samples were collected within each quadrat at three 10 cm depths, up to a depth of 30 cm. Soil depth of D1 (surface layer), D2 (First sub surface layer) and D3 (second sub surface layer) were 0–10 cm, 10–20 cm, and 20–30 cm, respectively (Appendix B). Location of each quadrat was identified using Global Positioning System (GPS).

Table 1
Soil series-wise sampling quadrats.

Name of soil series	Extent of the soil series (ha)	Estimated number of Palmyrah palm	Percentage of Palmyrah palm	No of sampling points
Anaicottai	511	2000	1.3	2
Ariyalai	427	27,060	17.0	13
Chankanai	11,369	48,000	30.1	22
Chemmanai	2442	13,750	8.6	6
Columbuthurai	208	2850	1.8	2
Innuvil	10,232	25,000	15.7	12
Karainagar	76	3000	1.9	2
Navatkuli	934	7500	4.7	3
Palali	2996	7000	4.4	3
Puliyantheevu	1517	4945	3.1	2
Saravanai	2714	5650	3.5	2
Thachchanthoppu	533	3700	2.3	2
Thondamanaru	9542	4309	2.7	2
Velanai	1027	4575	2.9	2
Total	44,528	159,339	100.0	75

2.3. Soil analysis

Soil samples were air-dried at room temperature. The quartering method was used to separate soil, ensuring uniformity and representativeness for subsequent analysis. Large soil aggregates were then crushed by using wooden hammer, after which the crushed samples were ground by using pestle and motor and sieved through a 2 mm mesh sieve. Soil organic carbon was estimated by loss on ignition method as described by Ben-Dor and Banin (1989), in brief, the soil sample was dried at 105 °C for 24 h followed by ignition for 8 h at 400 °C. The loss of weight during ignition is the loss of organic matter. By dividing the organic matter by the conversion factor of 1.724, organic C was determined. Bulk density was determined by collecting an undisturbed soil sample using a core sampler and determining the weight of soil after oven drying at 105 °C for 48 h. Bulk density was determined by dividing the dry weight by the volume of the core. Soil organic carbon stock was calculated using the equation for mineral soil as described by FAO (2017) as follows:

$$SOC_{stock} = d \times BD \times (C_{tot} - C_{min}) \times CF_{st}$$

Where: SOC_{stock} = soil organic carbon stock (kg m^{-2})

d = depth of horizon/depth class (m)
BD = bulk density (kg m^{-3})
C_{tot} and C_{min} = total and mineral (or inorganic) carbon content (g^{-1}), to be considered for calcareous soils, and if dry combustion is used with typically high temperatures (otherwise: C_{tot} equals C_{min})
CF_{st} = correction factor for stoniness ((100 - % stones)/100), including subtraction of gravel and stones

2.4. Biomass estimation

Widely used biomass estimation models for palm species were chosen due to the absence of location specific and species-specific models. We used the flowing equations to estimate the above-ground and below-ground biomass of Palmyrah palm;

Above-ground biomass (AGB, kg) (Abeysekara et al., 2018; Frangi and Lugo, 1985)

$$AGB = 4.5 + 7.7\,H$$

H = height (m)

Below-ground biomass (BGB, kg) (Abeysekara et al., 2018; Cairns et al., 1997; Pearson et al., 2007)

$$BGB = \exp(-1.0587 + 0.8836 \ln(AGB))$$

Total biomass (kg)
= AGB (kg) + BGB (kg)
Total biomass carbon
= Total biomass × conversion factor

According to IPCC report in 2006, conversion factor is 0.47 (Smith et al., 2014).

2.5. Floristic diversity

The floristic diversity, species richness, maximum diversity, and evenness were estimated in terms of Shannon–Weaver index (SWI) (Shannon and Weaver, 1949). All the comparisons were completed by using SAS version 9.1.3. Duncan's multiple range tests was used to compare the means.

3. Results

3.1. Soil organic carbon of Palmyrah land use in different soil series

Soil organic carbon (SOC) of Palmyrah land use in different sampling quadrats ranged between 0.31 – 1.61 %. The mean values of SOC in different soil series varied between 0.36 to 1.22 (Table 2). There was no significant difference among SOC percentage in different soil series. However, the mean values of SOC in surface layer (0 – 10 cm) was higher than other first subsurface layer (10 – 20 cm) which in turn was more than second subsurface layer (20 – 30 cm) in all the soil series. The SOC stock (0 – 30 cm) varied from 13.81 to 59.72 Mg C ha^{-1} in different soil series under Palmyrah land use (Fig. 2) in the study area. Anaikotai series had the lowest SOC stock, while the highest was in Velanai soil series. Significant differences in SOC stock among different soil series were observed.

Table 2
Soil organic carbon (%) in sampling quadrats of different soil series and average SOC (Mg C ha^{-1}) at different soil depth (D1, D2 and D3).

Soil series	Value	OM D1 (%)	OM D2 (%)	OM D3 (%)
Innuvil	Mean ± Sd	0.91 ± 0.5	0.83 ± 0.5	0.80 ± 0.16
	Range	0.35 – 1.85	0.32 – 1.75	0.30 – 1.54
Chemmani	Mean ± Sd	0.54 ± 0.35	0.49 ± 0.35	0.43 ± 0.35
	Range	0.31 – 0.97	0.31 – 0.97	0.1 – 0.93
Chankanai	Mean ± Sd	0.62 ± 0.33	0.57 ± 0.31	0.51 ± 0.28
	Range	0.31 – 1.61	0.25 – 1.45	0.1 – 1.12
Ariyalai	Mean ± Sd	0.48 ± 0.21	0.44 ± 0.19	0.39 ± 0.19
	Range	0.31 – 1.31	0.31 – 1.30	0.30 – 0.92
Navatkuli	Mean ± Sd	0.46 ± 0.10	0.44 ± 0.08	0.41 ± 0.06
	Range	0.32 - 1.49	0.32 - 1.25	0.31 - 1.16
Palai	Mean ± Sd	0.58 ± 0.33	0.49 ± 0.31	0.41 ± 0.28
	Range	0.31 – 1.41	0.25 – 1.25	0.2 – 1.12
Anaikottai	Mean ± Sd	0.36 ± 0.07	0.34 ± 0.05	0.32 ± 0.01
	Range	0.32 – 0.41	0.31– 0.38	0.30 – 0.33
Velanai	Mean ± Sd	1.22 ± 0.38	1.21 ± 0.48	0.86 ± 0.10
	Range	0.95 – 1.46	0.88 – 1.55	0.79 – 0.94
Saravanai	Mean ± Sd	1.04 ± 0.2	0.98 ± 0.18	0.83 ± 0.26
	Range	0.90 – 1.18	0.86 – 1.11	0.65 – 1.01
Upparu	Mean ± Sd	1.18 ± 0.89	0.96 ± 0.93	0.92 ± 0.87
	Range	0.55 – 1.81	0.3 – 0.96	0.30 – 1.54
Puliyantheevu	Mean ± Sd	0.85 ± 0.07	0.83 ± 0.04	0.70 ± 0.08
	Range	0.80 – 0.90	0.80 – 0.86	0.65 – 0.76
Thatchanthopu	Mean ± Sd	0.83 ± 0.03	0.75 ± 0.02	0.70 ± 0.01
	Range	0.81 – 0.86	0.73 – 0.76	0.68 – 0.71
Columbuthurai	Mean ± Sd	0.46 ± 0.21	0.40 ± 0.14	0.35 ± 0.07
	Range	0.31 – 0.60	0.31 – 0.50	0.30 – 0.40
Average SOC	Mean ± Sd	12.25 ± 5.53	11.57 ± 5.75	10.11 ± 5.45
Mg C ha^{-1}	Range	3.78–28.27	3.53–26.69	1.42–26.59

OM- Organic matter; Sd-standard deviation; D1- soil depth 0–10 cm; D2- soil depth 10–20 cm; D3- soil depth 20–30 cm; SOC- Soil organic carbon.

3.2. Biomass carbon stock of Palmyrah land use in different soil series

Biomass carbon was significantly differed among the different soil series (Fig. 3). Biomass carbon stock ranged between 36.97 – 107.36 Mg C ha^{-1} with a mean value of 72.48 Mg C ha^{-1}. Karainagar soil series had the highest biomass carbon while the lowest was recorded in Palali soil series, where the difference was statistically significant. However, the biomass carbon stock in Palali soil series was not significantly different compared with Saravanai and Thondamanaru soil series. The biomass carbon stock of other soil series was comparable among them.

In order to determine the influence of Palmyrah palm density with biomass carbon stock, the correlations between palm density and biomass carbon stock were assessed. Fig. 4 shows the correlations between biomass carbon and palm density. Palm density had positive correlations (R^2 = 0.71) with biomass carbon stock. Fig. 5 shows the palm density with different soil series. Highest palm density was recorded in Karaingar whereas it was low in Palali.

3.3. Total carbon stock of Palmyrah land uses in different soil series

Total carbon stock ranged between 64.13 – 147.56 Mg C ha^{-1} with a mean value of 108.53 Mg C ha^{-1} (Fig. 6). Total carbon stock was the highest in Karainagar soil series (148 Mg C ha^{-1}), which was significantly different from all the soil series except Velanai. Palali soil series had the lowest total carbon stock (64 Mg C ha^{-1}), which was significantly lower than others except Saravanai, Thondamanaru and Anaikodai. There was no significant difference in total carbon stock in other soil series.

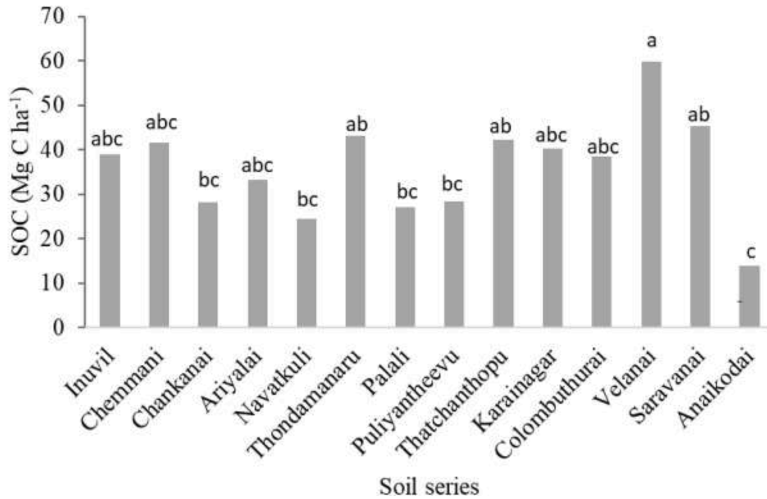

Fig. 2. Soil organic carbon (0 – 30 cm) of Palmyrah land use in different soil series. Letters a, b, c in the Figure shows the statistical significance among the soil series. Same letters among the soil series were not statically significance at $\alpha = 0.05$.

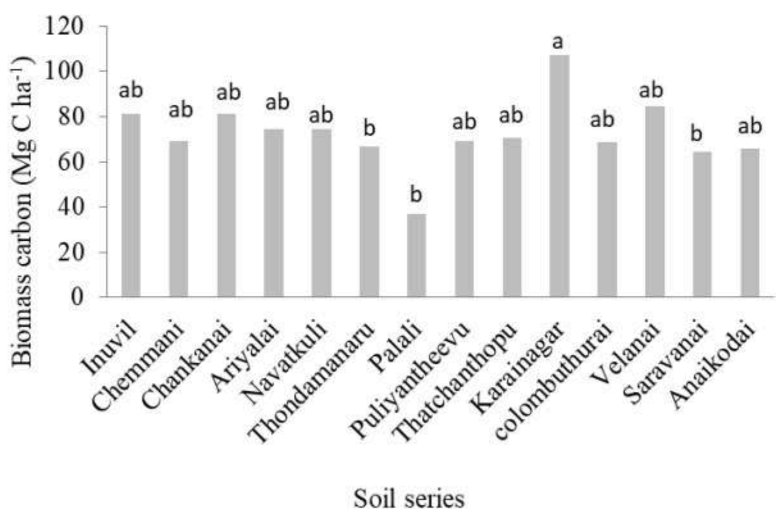

Fig. 3. Average biomass carbon in different soil series. Letters a, b, c in the Figure shows the statistical significance among the soil series. Same letters among the soil series were not statically significance at $\alpha = 0.05$.

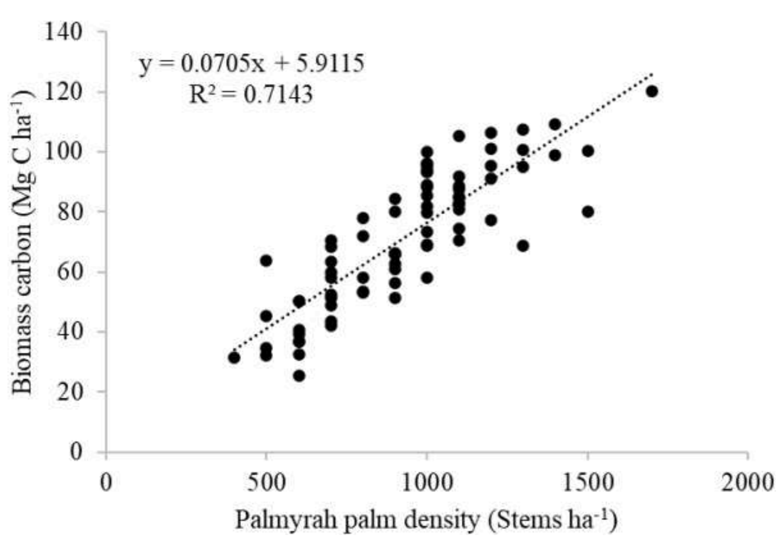

Fig. 4. Correlations between biomass carbon and number of Palmyrah palm.

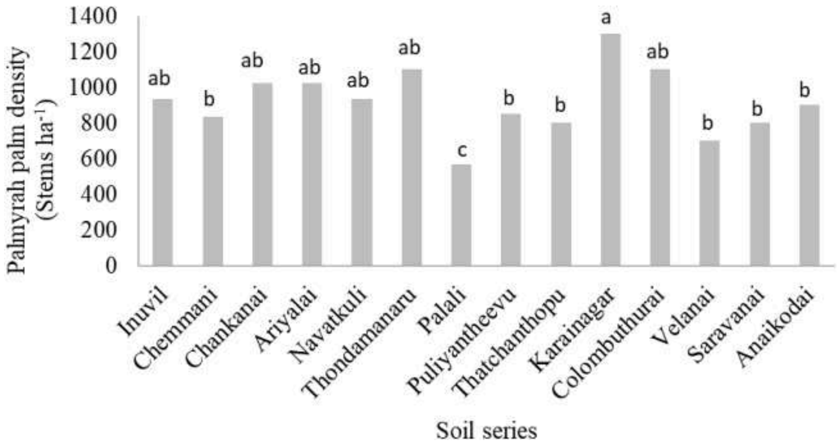

Fig. 5. Palmyrah palm density in different soil series. Letters a, b, c in the Figure shows the statistical significance among the soil series. Same letters among the soil series were not statically significance at α = 0.05.

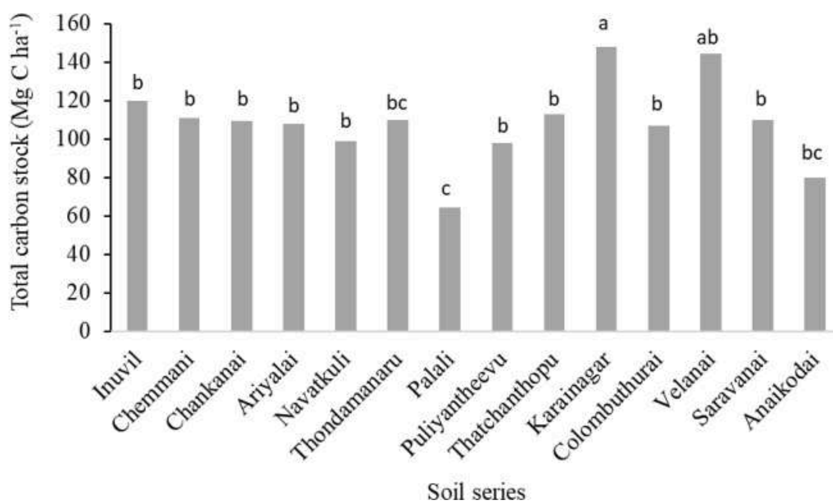

Fig. 6. Total carbon stock in different soil series. Letters a, b, c in the Figure shows the statistical significance among the soil series. Same letters among the soil series were not statically significance at α = 0.05.

3.4. Floristic diversity in Palmyrah land-uses

A total of 825 individuals identified from 22 species and 13 families in the study areas. The Arecaceae family was widely distributed in Palmyrah land use followed by Rutaceae, Rubiaceae, Myrtaceae and Meliaceae. Among other floral species except Palmyrah palm, *Morinda coreia* Buch-Ham. was highly distributed followed by *Glycosmis pentaphylla* (Retz.) A. DC. and *Azadirachta indica* A. Juss. (Table 3; Appendix C). Mean value of Shannan Weaver index (SWI) was 1.2 and this result revealed that diversity of floristic species was low. However, series Navatkuli had high floristic diversity followed by Chankanai. Mean value of evenness was 0.74 and it revealed that floristic species was equally distributed with average species richness of 7 (Table 4). The highest species diversity in terms of number of species (17), number of families (11) and individuals (257) was reported in Chankanai series. On the other hand, lowest diversity was observed in Thatchanthopu and Saravanai series, having only 2 species. The variation in species diversity in different soil series is mainly due to the number of sampling quadrats in each series, which was based on extent of area with Palmyrah palms in the study area. Chankanai series had 22 sampling quardrats while Thatchanthopu and Saravanai series had 2 quardrats each.

3.5. Palmyrah palm density and height

The average palm density of Palmyrah land uses in different soil series ranged between 500 – 1300 stems ha^{-1} (Table 5). Karainagar soil series had the highest average palm density (1300 stems ha^{-1}). Palali soil series had lower average palm density (500 stems ha^{-1}). The highest average palm height was recorded in Navatkuli series while the lowest was recorded in Palali series.

4. Discussion

4.1. Soil organic carbon

The soil organic carbon (SOC) of Palmyrah land use in different sampling quadrats ranged between 0.31 – 1.61 %. In a previous study to assess SOC of different land uses in the similar soils of Jaffna district, abandoned homegardens had the highest SOC percentage of 0.6 % compared to other land uses such as annual mono-cropped soils with either organic or inorganic nutrient management, maintained homegardens or perennial crops such as continuous banana cultivated lands (Ratnayake et al., 2019). In a dry and wet zone of Sri Lanka, SOC percentage was 1.48 % and 1.58 %, respectively (Kuruppuarachchi et al., 2016). In this study, the high SOC in soils of Palmyrah land-use is probably attributed to the undisturbed nature of soils and continuous

Table 3
Identified floral species in Palmayrah land use.

Species	Family	Common name	Number of individuals	Occurrence (%)
Annona squamosa L.	Annonaceae	Annamunna	11	15
Azadirachta indica A. Juss.	Meliaceae	Neem	36	62
Bambusa vulgaris Schrad. ex J.C.Wendl.	Poaceae	Bamboo	1	8
Borassus flabellifer L.	Arecaceae	Palmyrah	335	100
Citrus aurantium L	Rutaceae	Wild oranage	2	8
Cocos nucifera L.	Arecaceae	Coconut	27	46
Commiphora caudata (Wight & Arn.) Engl.	Burseraceae	Kiluvai	6	23
Glycosmis pentaphylla (Retz.) A. DC.	Rutaceae	Pannai	44	38
Hibiscus rosa-sinensis L.	Malvaceae	Hibiscus	1	8
Leucaena leucocephala (Lam.) De Wit	Fabaceae	Ipil ipil	5	31
Limonia acidissima L.	Rutaceae	Wood apple	5	15
Mangifera indica L.	Anacardiaceae	Mango	29	15
Morinda coreia Buch-Ham.	Rubiaceae	Manjavunna	45	62
Moringa oleifera Lam.	Moringaceae	Moringa	22	23
Murraya koenigii (L.) Spreng	Rutaceae	Curry leaf	194	46
Polyalthia longifolia (Sonn.) Thw.	Annonaceae	Asoka	2	15
Psidium guajava L.	Myrtaceae	Guava	20	46
Syzygium cumini Skeels	Myrtaceae	Naval	7	31
Tamarindus indica L.	Fabaceae	Tamarind	5	15
Tephrosia purpurea (L.) Pers.	Fabaceae	Kavilai	3	8
Thespesia populnea (L.) Sol. ex Correa	Malvaceae	Poovarasu	11	31
Thevetia peruviana (Pers.) Merr	Apocynaceae	Alari	14	23
22	**13**		**825**	**100**

additions of organic matter from tree leaves and dry grasses and shrubs during dry seasons. This is because most of the Palmyrah land-uses in the study site are never maintained or tilled. They are maintained as grazing lands or abandoned lands except for getting fruits or other products seasonally.

The range of SOC of the Palmyrah stands in different agroecological zones in Oddisa, India was 0.05 – 1.38 % (Behera et al., 2021), where the lowest and highest values are lower than the values in this study. The difference in climatic conditions especially the comparatively higher temperature (36 – 40 °C maximum mean) in Oddisa may have contributed to a lower range of SOC. Agroforestry systems have the potential to enhance carbon sequestration in soil when compared with agricultural ones (Montagnini and Nair, 2004). Fine roots of oil palm contributed more to the stabilization of SOC compared to management practice (Rüegg et al., 2019). The SOC content in coconut land uses was recorded as 19.53 Mg C ha^{-1} in 0 – 20 cm depth in Sri Lanka (Ranasinghe and Thimothias, 2012), whereas the equivalent SOC under Palmyrah in the present study varies between 14 – 60 Mg C ha^{-1}, indicating a higher potential of SOC accumulation under Palmyrah land use. On the other hand, the total SOC in dry zone tropical forest in Sri Lanka was recorded as 93.62 Mg ha^{-1} (Kuruppuarachchi et al., 2015). The SOC was higher in Palmyrah land uses than other land uses in the study area with similar soil and climatic conditions, having monoculture of previous studies reported by Ratnayake et al. (2019). This could be attributed to high floristic diversity in the Palmyrah land-use system, which could have contributed to SOC as leaf fall and root biomass.

A similar decreasing trend of SOC with depth as that in present study was reported by Behera et al. (2021) as well. The influence of depth in soil organic carbon varied with vegetation type. The characteristics and amount of SOC mainly influenced by accumulation of root biomass, organic matter addition, transportation of organic carbon from surface soil to lower horizons and physical protection and oxidation of organic matter (Harper and Tibbett, 2013). The understory of the Palmyrah land use of the study area is filled with different floral species that could contributed to SOC accumulation in the Palmyrah land use.

4.2. Biomass carbon

The biomass carbon of the different sampling quadrats of Palmyrah land uses in this study ranged 36.97 – 107.36 Mg C ha^{-1} with an average value of 72.48 Mg C ha^{-1}. The biomass carbon of tropical forest in dry zone of Sri Lanka was 77.21 Mg C ha^{-1} (Kuruppuarachchi et al., 2015). In other areas of dry zone of Sri Lanka, AGB carbon ranged from a minimum of 75.7 Mg C ha^{-1} in the Kumbukkan forest to a maximum of 129.6 Mg ha^{-1} in the Kantalai forest (Kumarathunge and Iqbal, 2009), and average of 206.34 Mg C ha^{-1} in Mullaitivu district (Thirukkumaran et al., 2017). Biomass carbon of natural forest and plantations of Udawattakele forest reserve in wet zone of Sri Lanka was 36.55 and 45.06 Mg C ha^{-1}, respectively (Abeysekara et al., 2018), both values were lower than Sinharajah rain forest in wet zone of Sri Lanka (336.8 Mg ha^{-1}) (Kumarathunge and Iqbal, 2009). Average AGB carbon in the homegardens of same study area, Jaffna district was 23.80 Mg C ha^{-1} (Lowe et al., 2024) and 40.51 Mg C ha^{-1} (Jeyavanan et al., 2017), these values were lower than the Palmyrah land use system in this study. Biomass carbon in agricultural land uses such as eucalyptus, rubber plantations and mixed orchard was reported as 33.09 Mg C ha^{-1}, 103.14 Mg C ha^{-1} and 77.97 Mg C ha^{-1} (Gnanavelrajah et al., 2008) in similar tropical climatic conditions in Thailand. Climatic condition of the study area of Thailand is tropical monsoon with the rainy season extending from May to October. The average annual rainfall is 1383 mm. The average annual temperature is 28.3 °C. This climate is more or less similar to our study area. Rubber plantations in Sri Lanka stored 78 Mg C ha^{-1} and 66 Mg C ha^{-1} in wet zone and intermediate zone, respectively (Munasinghe et al., 2014). Total AGB carbon of *Pinus caribea* plantation was 103.6 Mg C ha^{-1} in a wet zone of Sri Lanka (Subasinghe and Munasinghe, 2011). According to Dey et al. (2014), biomass of Palmyrah palm (3.02 Mg C ha^{-1}) in homegardens was estimated to be lower than that of coconut palm (12.48 Mg C ha^{-1}) in Ceyhet city in Bangladesh. This could be attributed to the lower density of Plamyrah palm in the homegardens that have contributed to the differences in biomass carbon. In our study, high biomass carbon was closely related to high density of the palm. Biomass carbon of the Palmyrah land use in the study area has equivalently contributed to the biomass carbon of other land uses of the dry zones of tropics.

We used the generalized allometric equations used for palm for biomass estimation. Though Palmyarh is a palm species, wood of this palm is very strong used construction of roof for building. This could be attributed to high wood density of this palm. The average wood density of Palmyrah palm was 715.5 kgm^{-3} (Mishra et al., 2023), and it was higher than coconut wood density, 600 kg m^{-3} (Wang et al., 2023), 359 kgm^{-3} to 532 kgm^{-3} (Fathi, 2014), and 460 kgm^{-3} (Rana et al., 2015). Further, best of knowledge no biomass palm model has been developed using wood density as one of the variables. Including wood density could be advantage for accurate biomass carbon estimation (Fernando et al.,

Table 4
Floristic diversity in Palmyrah land use.

Soil series	Number of species	Number of family	Number of Individuals	SWI	Species richness	Evenness
Inuvil	12	9	81	1.62	12	0.65
Chankanai	17	11	257	1.83	17	0.65
Ariyalai	12	9	121	1.75	12	0.71
Chemmani	7	5	111	1.26	7	0.65
Navatkuli	10	9	26	1.95	10	0.85
Palai	6	5	25	1.13	6	0.63
Thondamanaru complex	5	5	10	1.47	5	0.91
Puliyantheevu	3	3	30	0.39	3	0.35
Thatchanthopu	2	1	13	0.67	2	0.96
Saravanai	2	2	7	0.60	2	0.86
Velanai	3	3	34	0.97	3	0.88
Karainagar	5	5	96	0.94	5	0.59
Anaikodai	3	3	14	1.08	3	0.98
Columbuthurai	3	3	31	0.39	3	0.35
Average	**6.69**	**5.38**	**63.46**	**1.20**	**6.69**	**0.74**

Table 5
Palmyrah palm density and height in different soil series.

Soil type	Average palm density (Stems ha^{-1})	Palm density Lowest (Stems ha^{-1})	Palm density highest (Stems ha^{-1})	Average height (m)	Minimum height (m)	Maximum height (m)
Inuvil	900	700	1400	17.10	9.32	22.01
Chemmani	800	600	1000	16.88	15.00	21.63
Chankanai	1000	500	1900	18.37	14.26	22.61
Ariyalai	1000	500	1500	16.06	14.14	19.89
Navatkuli	900	400	1200	22.20	19.25	24.71
Thondamanaru	1100	900	1300	17.56	17.23	17.89
Palali	600	500	600	15.62	9.08	23.00
Puliyantheevu	900	800	900	15.67	12.52	18.82
Thatchanthopu	800	600	1000	17.25	11.68	22.81
Karainagar	1300	1300	1300	17.78	17.56	18.00
Colombuthurai	1100	1100	1100	20.05	19.05	21.04
Velanai	700	600	800	19.35	18.70	20.01
Saravanai	800	600	1000	16.88	13.78	19.98
Anaikodai	900	900	900	21.07	20.00	22.14

2024; Subasinghe and Munasinghe, 2011). Therefore, developing species specific allometric equation by considering wood density, diameter, height and other variables is required in future for accurate biomass estimation.

4.3. Total carbon stock

The total carbon stock of sampling quadrats under Palmyrah land use ranged between 0.25 – 1.65 Mg C100 m^{-2} which is equivalent to 25.40 – 165.78 Mg C ha^{-1}. Total carbon stock among soil series varied from 64.13 – 147.56 Mg C ha^{-1} with the average value of 108.53 Mg C ha^{-1}. The carbon stock of total ecosystem under coconut land uses was recorded as 63, 54 and 37 Mg C ha^{-1} in wet zone, intermediate zone and dry zone, respectively in Sri Lanka (Ranasinghe and Thimothias, 2012). Total carbon stock in dry zone tropical forest in Sri Lanka was recorded as 180.42 Mg C ha^{-1} (Kuruppuarachchi et al., 2015). From these total carbon stock of previous studies in forest and other land uses clearly showed that the Palmyrah land use also stored a fair amount of total carbon stock, with an average value of 108.53 Mg C ha^{-1}. This could be attributed to higher wood density, tree density, and height of Palmyrah palm.

4.4. Floral species and diversity

A total of 22 floral species were identified in the sampling quadrats during this study. In a study in eleven agricultural land-uses of a sub-watershed in Thailand, mixed orchard recorded highest floral species diversity recording 17 numbers, while coconut land-use had only 3. Other tree crop land use eucalyptus had only one species while other annual crop land uses did not have a single tree species (Shrestha et al., 2010) . In the homegardens of the Jaffna district, the high number of floral species was recorded with a value of 69 in 0.083 ha (Lowe et al., 2021) and 135 in 0.2 – 0.8 ha (Jeyavanan et al., 2017). In a study to find the diversity of homegardens in India having extent ranging 0.02 to 1.20 ha, with an average of 0.30 ha, floral species were recorded as 87 (Das and Das, 2005). The diversity of flora in this study is similar to other work reported by in tropical homegardens (Fernandes and Nair, 1986). Perera and Rajapakse (1991) reported that number of species in the Kandyan homegardens in Sri Lanka, varied 37 – 65 where the size of garden ranged from 0.05 to 2.50 ha. Floristic diversity of Palmyrah palm was 1.2 (SWI) in this study. This was consistent with the homegardens of the same study area with a value of 1.1 (Lowe et al., 2024). In other study in the same study area reported the value ranged from 1.72 (Jeyavanan et al., 2017) and this was due to the high number of species in selected homegardens. In the present study, floristic diversity was estimated using only 100 m^{-2} quadrats, which may have limited the number of floral species identified, as the species diversity of homegardens is positively correlated with the size of the land holding (Das and Das, 2005).

4.5. Palmyrah palm density

The number of Palmyrah palm in the studied quadrats varied 400 to 1900 stems ha^{-1} with an average of 967 stems ha^{-1}. For the Palmyrah plantations, recommended spacing was 3 m × 3 m according to Palmyrah Research Institute, Sri Lanka. At this spacing, tree density would be 1111 stems ha^{-1}. This indicates, refilling of the palms are possible in the existing Palmyrah land uses, which could improve the annual carbon sequestration of these land uses. Further studies are required to estimate the potential annual carbon sequestration by this land use and carbon stock studies in other countries where these palm trees are abundant (Fernando et al., 2024; Subasinghe and Munasinghe, 2011).

5. Conclusions

The SOC of Palmyrah land uses in different soil series ranged from 64.13 to 147.56 Mg C ha^{-1}. The uppermost layer (0–10 cm) contained a higher amount of SOC compared to the subsurface layers (10–20 cm and 20–30 cm). The average palm density of Plamyrah land uses in different soil series ranged 500 – 1300 stems ha^{-1}. Biomass carbon stock ranged between 36.97 – 107.36 Mg C ha^{-1}. Total carbon stock ranged 64.13 – 147.56 Mg C ha^{-1}. The study suggests that Palmyrah land use has significant potential for long-term carbon sequestration. A total of 22 floral species from 13 families were identified in the Palmyrah land use in the study site. The Arecaceae family was widely distributed across the Palmyrah land use followed by Rutaceae, Rubiacea, Myrtaceae and Meliaceae. Mean value of Shannan Weaver index (SWI) was 1.2 and this result revealed that diversity of floristic species was low. Mean value of evenness was 0.74 and it revealed that floristic species was equally distributed with average species richness of 7 in 100 m^2 of Palmyrah lands. Study therefore indicates the high carbon sequestration potential of Palmyrah land uses in the study area as well as a reasonable floristic diversity. The authors wish to suggest more research in landscapes having this palm to assess its potential ecosystem services and recognize the same to conserve and expand this land use for the betterment of this planet.

CRediT authorship contribution statement

Nalina Gnanavelrajah: Writing – review & editing, Writing – original draft, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Sathasivam Theepika:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jeyavanan Karthigesu:** Writing – review & editing, Supervision. **Selvarajah Raveendran:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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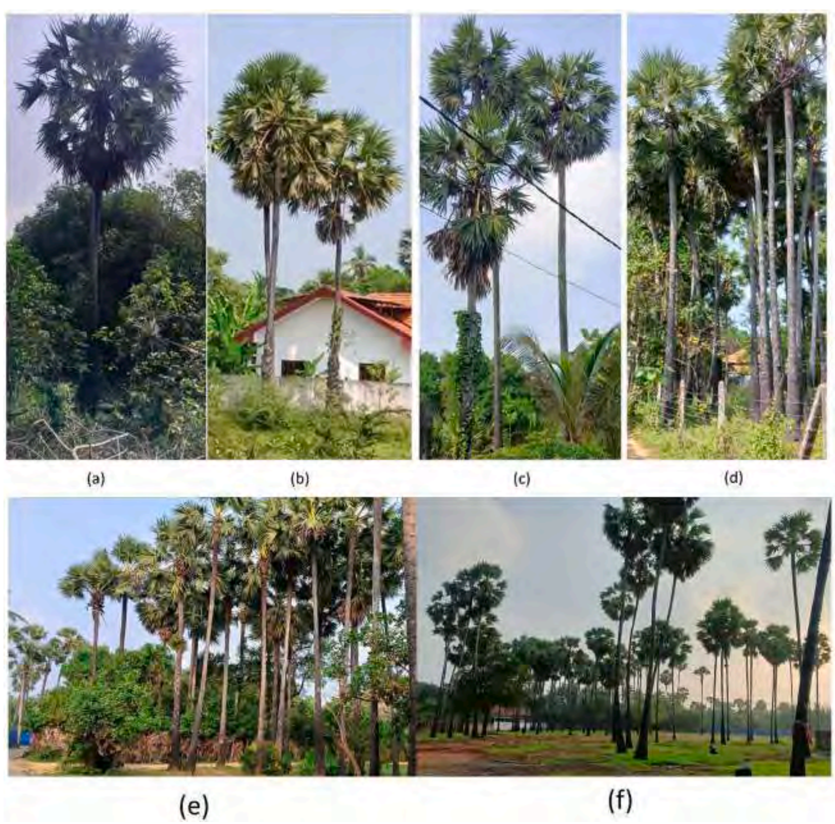
Appendix



Appendix A. Appearance of Palmyrah palm in different sites; (a) Palmyrah palm in abandoned land use; (b) Plamyrah palm nearby household; (c) Palmyrah palm within the household; (d) Palmyrah palm nearby road; (e, f) Palmyrah palm in large areas.

Appendix B. Soil sampling collection at different sites; The permission was obtained from each person to publish the photographs.

Appendix C
Soil series-wise floral species composition in the studied quadrats.

Soil series	Botanical name	Family name	Common name	Numbers
Inuvil	*Borassus flabellifer* L.	Arecaceae	Plamyrah seedlings	47
	Commiphora caudata (Wight & Arn.) Engl.	Burseraceae	Kiluvai	3
	Glycosmis pentaphylla (Retz.) A. DC.	Rutaceae	Pannai	4
	Hibiscus rosa-sinensis L.	Malvaceae	Hibiscus	1
	Leucaena leucocephala (Lam.) De Wit	Fabaceae	Ipil -Ipil	1
	Morinda coreia Buch-Ham.	Rubiaceae	Manjavunna	1
	Moringa oleifera Lam.	Moringaceae	Moringa	3
	Murraya koenigii (L.) Spreng	Rutaceae	Curry leaves	7
	Syzygium cumini Skeels	Myrtaceae	Naval	2
	Tamarindus indica L.	Fabaceae	Tamarind	4
	Thespesia populnea (L.) Sol. ex Correa	Malvaceae	Thespesia	5
	Thevetia peruviana (Pers.) Merr	Apocynaceae	Alari	3
Chankanai	*Azadirachta indica* A. Juss.	Meliaceae	Neem	1
	Bambusa vulgaris Schrad. ex J.C.Wendl.	Poaceae	Bamboo	1
	Borassus flabellifer L.	Arecaceae	Plamyrah seedlings	49
	Citrus aurantium L	Rutaceae	Wild orange	2
	Cocos nucifera L.	Arecaceae	Coconut	12
	Glycosmis pentaphylla (Retz.) A. DC.	Rutaceae	Pannai	9
	Leucaena leucocephala (Lam.) De Wit	Fabaceae	Ipil ipil	2
	Limonia acidissima L.	Rutaceae	Wood apple	3
	Mangifera indica L.	Anacardiaceae	Mango	25
	Morinda coreia Buch-Ham.	Rubiaceae	Manjavunna	7
	Murraya koenigii (L.) Spreng	Rutaceae	Curry leaves	117
	Polyalthia longifolia (Sonn.) Thw.	Annonaceae	Asoka	1
	Psidium guajava L.	Myrtaceae	Guava	13
	Syzygium cumini Skeels	Myrtaceae	Naval	2
	Tephrosia purpurea (L.) Pers.	Fabaceae	Kaavilai	3
	Thespesia populnea (L.) Sol. ex Correa	Malvaceae	Thespesia	1
	Thevetia peruviana (Pers.) Merr	Apocynaceae	Alari	9
	Azadirachta indica A. Juss.	Meliaceae	Neem	4
	Borassus flabellifer L.	Arecaceae	Plamyrah seedlings	56
	Cocos nucifera L.	Arecaceae	Coconut	4
	Glycosmis pentaphylla (Retz.) A. DC.	Rutaceae	Pannai	9
	Leucaena leucocephala (Lam.) De Wit	Fabaceae	Ipil-Ipil	1
	Mangifera indica L.	Anacardiaceae	Mango	4
	Morinda coreia Buch-Ham.	Rubiaceae	Manjavunna	15
	Moringa oleifera Lam.	Moringaceae	Moringa	18
	Polyalthia longifolia (Sonn.) Thw.	Annonaceae	Asoka	1
	Psidium guajava L.	Myrtaceae	Guava	1
	Syzygium cumini Skeels	Myrtaceae	Naval	1
Chemmani	*Morinda coreia* Buch-Ham.	Rubiaceae	Manjavuna	10
	Borassus flabellifer L.	Arecaceae	Palmyrah seedlings	26
	Murraya koenigii (L.) Spreng	Rutaceae	Curry leaves	62
	Azadirachta indica A. Juss.	Meliaceae	Neem	2
	Glycosmis pentaphylla (Retz.) A. DC.	Rutaceae	Pannai	8

(continued on next page)

Appendix C (*continued*)

Soil series	Botanical name	Family name	Common name	Numbers
	Psidium guajava L.	Myrtaceae	Guava	1
	Cocos nucifera L.	Arecaceae	Coconut	2
Navatkuli	*Annona squamosa* L.	Annonaceae	Annamunna	4
	Azadirachta indica A. Juss.	Meliaceae	Neem	2
	Borassus flabellifer L.	Arecaceae	Palmyrah seedlings	10
	Cocos nucifera L.	Arecaceae	Coconut	2
	Commiphora caudata (Wight & Arn.) Engl.	Burseraceae	Kiluvai	1
	Limonia acidissima L.	Rutaceae	Wood apple	2
	Morinda coreia Buch-Ham.	Rubiaceae	Manjavuna	2
	Moringa oleifera Lam.	Moringaceae	Moringa	1
	Psidium guajava L.	Myrtaceae	Guava	1
	Thespesia populnea (L.) Sol. ex Correa	Malvaceae	Thespesia	1
Palali	*Azadirachta indica* A. Juss.	Meliaceae	Neem	2
	Borassus flabellifer L.	Arecaceae	Palmyrah seedlings	17
	Cocos nucifera L.	Arecaceae	Coconut	2
	Commiphora caudata (Wight & Arn.) Engl.	Burseraceae	Kiluvai	2
	Leucaena leucocephala (Lam.) De Wit	Fabaceae	Ipil-Ipil	1
	Murraya koenigii (L.) Spreng	Rutaceae	Curry leaves	1
Upparu Thonda complex	*Annona squamosa* L.	Annonaceae	Annamunna	2
	Borassus flabellifer L.	Arecaceae	Palmyrah seedlings	4
	Murraya koenigii (L.) Spreng	Rutaceae	Curry leaves	1
	Tamarindus indica L.	Fabaceae	Tamarind	1
	Thevetia peruviana (Pers.) Merr	Apocynaceae	Alari	2
Puliyantheevu	*Azadirachta indica* A. Juss.	Meliaceae	Neem	1
	Borassus flabellifer L.	Arecaceae	Palmyrah seedlings	27
	Psidium guajava L.	Myrtaceae	Guava	2
Thatchanthopu	*Borassus flabellifer* L.	Arecaceae	Palmyrah seedlings	8
	Cocos nucifera L.	Arecaceae	Coconut	5
Saravanai	*Borassus flabellifer* L.	Arecaceae	Palmyrah seedlings	5
	Psidium guajava L.	Myrtaceae	Guava	2
Velanai	*Borassus flabellifer* L.	Arecaceae	Palmyrah seedlings	16
	Glycosmis pentaphylla (Retz.) A. DC.	Rutaceae	Pannai	14
	Morinda coreia Buch-Ham.	Rubiaceae	Manjavuna	4
Karainagar	*Azadirachta indica* A. Juss.	Meliaceae	Neem	22
	Borassus flabellifer L.	Arecaceae	Palmyrah seedlings	64
	Morinda coreia Buch-Ham.	Rubiaceae	Manjavuna	2
	Murraya koenigii (L.) Spreng	Rutaceae	Curry leaves	6
	Syzygium cumini Skeels	Myrtaceae	Naval	2
Anaikodai	*Borassus flabellifer* L.	Arecaceae	Palmyrah seedlings	6
	Morinda coreia Buch-Ham.	Rubiaceae	Manjavuna	4
	Thespesia populnea (L.) Sol. ex Correa	Malvaceae	Thespesia	4
Columbuthurai	*Borassus flabellifer* L.	Arecaceae	Palmyrah seedlings	16
	Azadirachta indica A. Juss.	Meliaceae	Neem	06
	Glycosmis pentaphylla (Retz.) A. DC.	Rutaceae	Pannai	08

Data availability

Data will be made available on request.

References

Abeysekara, A., Yatigammana, S., Premakantha, K., 2018. Biomass and carbon stock estimation of Udawattakele Forest Reserve in Kandy District of Sri Lanka. J. Trop. Forestry Environ. 8, 13–28.

Ariyasena, D.D., Jansz, E.R., Abeysekera, A.M., 2001. Some studies directed at increasing the potential use of palmyrah (*Borassus flabellifer* L) fruit pulp. J. Sci. Food Agric. 81, 1347–1352. https://doi.org/10.1002/jsfa.943.

Arulraj, S., Augustine, B.J., 2008. Underutilized palms. In: Peter KV (ed) Underutilized and Underexploited Horticultural Crops. New India Publishing Agency, New Delhi.

Behera, T.K., Bhol, N., Tongchangya, A.J.K., 2021. Studies on soil conditions under the stand of palmyra palm (Borassus flabellifer)–a climate resilient multipurpose tree species in Odisha. Environ. Ecol. 39, 162–171.

Ben-Dor, E., Banin, A., 1989. Determination of organic matter content in arid-zone soils using a simple "loss-on-ignition" method. Commun. Soil. Sci. Plant Anal. 20, 1675–1695. https://doi.org/10.1080/00103628909368175.

Cairns, M.A., Brown, S., Helmer, E.H., Baumgardner, G.A., 1997. Root biomass allocation in the world's upland forests. Oecologia 111, 1–11. https://doi.org/10.1007/s004420050201.

Carton, W., Asiyanbi, A., Beck, S., Buck, H.J., Lund, J.F., 2020. Negative emissions and the long history of carbon removal. WIREs Clim. Change 11. https://doi.org/10.1002/wcc.671.

Das, T., Das, A.K., 2005. Inventorying plant biodiversity in homegardens: a case study in Barak Valley, Assam, North East India. Curr. Sci. Assoc. 89, 155–163.

Dassanayake, A.R., Mapa, R.B., 2022. Morphology, characterization and classification of soils of the Northern region of Sri Lanka. In: Mapa, R.B. (Ed.), Soils of the Northern Region of Sri Lanka. Soil Science Society of Sri Lanka, Sri Lanka.

Davis, T.A., Johnson, D.V., 1987. Current utilization and further development of the palmyra palm (*Borassus flabellifer* L., Arecaceae) in Tamil Nadu state, India. Econ. Bot. 41, 247–266. https://doi.org/10.1007/BF02858972.

Dey, A., Islam, M., Masum, K.M., 2014. Above ground carbon stock through palm tree in the homegarden of Sylhet City in Bangladesh. J. Forest. Environ. Sci. 30, 293–300. https://doi.org/10.7747/JFS.2014.30.3.293.

Draper, F.C., Roucoux, K.H., Lawson, I.T., Mitchard, E.T.A., Honorio Coronado, E.N., Lähteenoja, O., Torres Montenegro, L., Valderrama Sandoval, E., Zaráte, R., Baker, T. R., 2014. The distribution and amount of carbon in the largest peatland complex in Amazonia. Environ. Res. Lett. 9, 124017. https://doi.org/10.1088/1748-9326/9/12/124017.

Dung, L.V., Tue, N.T., Nhuan, M.T., Omori, K., 2016. Carbon storage in a restored mangrove forest in can Gio Mangrove Forest Park, Mekong Delta, Vietnam. For. Ecol. Manage 380, 31–40. https://doi.org/10.1016/j.foreco.2016.08.032.

FAO, 2001. Soil Carbon Sequestration For Improved Land Management. Paris, France.

FAO, 2017. Measuring, Accounting Reporting and Verifying Soil Organic carbon, *In* Soil Organic Carbon: the Hidden Potential. Food and Agriculture Organization of the United Nations, Rome, Italy, p. 39.

Fathi, L., 2014. Structural and Mechanical Properties of the Wood From Coconut Palms, Oil Palms and Date Palms (Doctoral dissertation). Staats-und Universitätsbibliothek Hamburg Carl von Ossietzky.

Fernandes, E.C.M., Nair, P.K.R., 1986. An evaluation of the structure and function of tropical homegardens. Agric. Syst. 21, 279–310. https://doi.org/10.1016/0308-521X(86)90104-6.

Fernando, P.D.H., Subasinghe, S.M.C.U.P., Lokupitiya, R.S., 2024. Allometric models for biomass prediction of *Hevea brasilliensis*. Environ. Qual. Manag. 33, 401–410. https://doi.org/10.1002/tqem.22099.

Frangi, J.L., Lugo, A.E., 1985. Ecosystem dynamics of a subtropical floodplain forest. Ecol. Monogr. 55, 351–369.

Fujisaki, K., Chevallier, T., Chapuis-Lardy, L., Albrecht, A., Razafimbelo, T., Masse, D., Ndour, Y.B., Chotte, J.-L., 2018. Soil carbon stock changes in tropical croplands are mainly driven by carbon inputs: a synthesis. Agric. Ecosyst. Environ. 259, 147–158. https://doi.org/10.1016/j.agee.2017.12.008.

George, J., Karun, A., 2011. Marker assisted detection of seed sex ratio in palmyrah palm (*Borassus flabellifer* L.). Curr. Sci. 100, 922–925.

Gisladottir, G., Stocking, M., 2005. Land degradation control and its global environmental benefits. Land. Degrad. Dev. 16, 99–112. https://doi.org/10.1002/ldr.687.

Gnanavelrajah, N., Shrestha, R.P., Schmidt-Vogt, D., Samarakoon, L., 2008. Carbon stock assessment and soil carbon management in agricultural land-uses in Thailand. Land. Degrad. Dev. 19, 242–256. https://doi.org/10.1002/ldr.838.

Godde, C.M., Mason-D'Croz, D., Mayberry, D.E., Thornton, P.K., Herrero, M., 2021. Impacts of climate change on the livestock food supply chain; a review of the evidence. Glob. Food Sec. 28, 100488. https://doi.org/10.1016/j.gfs.2020.100488.

Gomes, M.F., Vasconcelos, S.S., Viana-Junior, A.B., Costa, A.N.M., Barros, P.C., Ryohei Kato, O., Castellani, D.C., 2021. Oil palm agroforestry shows higher soil permanganate oxidizable carbon than monoculture plantations in Eastern Amazonia. Land. Degrad. Dev. 32, 4313–4326. https://doi.org/10.1002/ldr.4038.

Goodman, R.C., Phillips, O.L., del Castillo Torres, D., Freitas, L., Cortese, S.T., Monteagudo, A., Baker, T.R., 2013. Amazon palm biomass and allometry. For. Ecol. Manage 310, 994–1004. https://doi.org/10.1016/j.foreco.2013.09.045.

Gummad, V.P., Battu, G.R., M, S., K, D., Manda, K., 2016. A review on palmyra palm (borassus flabellifer). Int. J. Curr. Pharm. Res. 8, 16–20.

Harper, R.J., Tibbett, M., 2013. The hidden organic carbon in deep mineral soils. Plant Soil. 368, 641–648. https://doi.org/10.1007/s11104-013-1600-9.

Hergoualc'h, K., Gutiérrez-Vélez, V.H., Menton, M., Verchot, L.V., 2017. Characterizing degradation of palm swamp peatlands from space and on the ground: an exploratory study in the Peruvian Amazon. For. Ecol. Manage. 393, 63–73. https://doi.org/10.1016/j.foreco.2017.03.016.

IPCC, 2019. Climate change and land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. https://doi.org/10.1017/9781009157988.

Jana, H., Jana, S., 2017. Palmyra palm: Importance in Indian agriculture. India.

Jeyavanan, K., Sivachandiran, S., Pushpakumara, D., 2017. Ecosystem services of homegarden agroforestry in Jaffna Peninsula. J. Dry Zone Agric. 3, 56–68.

Joshua, W.D., 2003. Soil resources in Jaffna Peninsula. In: Proceedings of the Seminar Held at the District Agricultural Training Center. District Agricultural Training center. Jaffna.

Karki, L., Lieu, J., Xylia, M., Laub, M., Ismangil, D., Virla, L., Rahn, E., Bilbao, B.A., Indriani, S.N., Martin Gallego, P., Suleiman, A.K.A., Schaldch, R., Takama, T., Marques da Silva, J.R., Johnson, F.X., 2023. Potentials and barriers to land-based mitigation technologies and practices (LMTs)—A review. Environ. Res. Lett. 18, 093003. https://doi.org/10.1088/1748-9326/ace91f.

Kumarathunge, M., Iqbal, M., 2009. Biomass estimation in some dry zone forests in Sri Lanka from Forest inventory data. In: International Forestry and Environmental Symposium. Sri Lanka. University of Sri Jeyawardenapura.

Kuruppuarachchi, K.A.J.M., Seneviratne, G., Madurapperuma, B.D., 2016. Carbon sequestration in tropical forest stands: its control by plant, soil and climatic factors. Open J. For. 06, 59–71. https://doi.org/10.4236/ojf.2016.62006.

Kuruppuarachchi, K.A.J.M., Seneviratne, G., Madurapperuma, B.D., 2015. Forest carbon sequestration and its control: a comparison between a dry zone tropical forest and an arboretum. Int. J. Agric. Forest. Plantat. 1, 35–44.

Lowe, A., Kuruppuarachchi, N., Silva, P., Pushpakumara, G., Suriyagoda, L., Weerahewa, J., 2024. Does human intervention modulate the above-ground carbon biomass of agroforestry systems? A study of homegardens in Jaffna Peninsula, Sri Lanka. Agric. Syst. 215, 103842. https://doi.org/10.1016/j.agsy.2023.103842.

Lowe, W.A.M., Sinniah, J., Jeyavanan, K., Silva, G.L.L.P., Pushpakumara, D.K.N.G., 2021. Can homegardens assist in enhancing the domestic food security?' A study in Jaffna Peninsula, Sri Lanka. Agrofor. Syst. 95, 1205–1216. https://doi.org/10.1007/s10457-021-00647-1.

Marquardt, J., Fünfgeld, A., Elsässer, J.P., 2023. Institutionalizing climate change mitigation in the global South: current trends and future research. Earth Syst. Governance 15, 100163. https://doi.org/10.1016/j.esg.2022.100163.

Masilamani, P., Rathika, S., Indurani, C., Venkatesan, S., 2023. Seed dormancy and germination behaviour of Palmyrah: a review. Agric. Rev. https://doi.org/10.18805/ag.R-2607.

Menezes, R.S.C., Sales, A.T., Primo, D.C., Albuquerque, E.R.G.M.de, Jesus, K.N.de, Pareyn, F.G.C., Santana, M.da S., Santos, U.J.dos, Martins, J.C.R., Althoff, T.D., Nascimento, D.M.do, Gouveia, R.F., Fernandes, M.M., Loureiro, D.C., Filho, Araújo, de, J.C., Giongo, V., Duda, G.P., Alves, B.J.R., Ivo, W.M.P.de M., Andrade, E.M.de, Pinto, A.de S., Sampaio, E.V.de S.B., 2021. Soil and vegetation carbon stocks after land-use changes in a seasonally dry tropical forest. Geoderma 390, 114943. https://doi.org/10.1016/j.geoderma.2021.114943.

Mishra, K., Bisht, S.S., Joshi, G., Shashikala, S., 2023. Axial and radial variation in physical and chemical properties of *Borassus flabellifer* L. (Palmyra palm). Int. Wood Prod. J. 14, 111–119. https://doi.org/10.1080/20426445.2023.2244762.

Molina, P., Asner, G., Farjas Abadía, M., Ojeda Manrique, J., Sánchez Diez, L., Valencia, R., 2015. Spatially-explicit testing of a general aboveground carbon density estimation model in a western amazonian forest using airborne LiDAR. Remote Sens. (Basel) 8, 9. https://doi.org/10.3390/rs8010009.

Montagnini, F., Nair, P.K.R., 2004. Carbon sequestration: an underexploited environmental benefit of agroforestry systems. Agrofor. Syst. 61-62, 281–295. https://doi.org/10.1023/B:AGFO.0000029005.92691.79.

Morton, J., 1988. Notes on distribution, propagation, and products of Borassus Palms (Arecaceae)l. Econ. Bot. 42, 420–441.

Munasinghe, E.S., Rodrigo, V.H.L., Gunawardena, U.A.D.P., 2014. Modus operandi in assessing biomass and carbon in rubber plantations under varying climatic conditions. Exp. Agric. 50, 40–58. https://doi.org/10.1017/S0014479713000410.

Muniyandi, M., Govindaraj, P., Bharath balji, G., 2021. Potential removal of Methylene Blue dye from synthetic textile effluent using activated carbon derived from Palmyra (Palm) shell. Mater. Today Proc. 47, 299–311. https://doi.org/10.1016/j.matpr.2021.04.468.

Murdiyarso, D., Hergoualc'h, K., Verchot, L.V., 2010. Opportunities for reducing greenhouse gas emissions in tropical peatlands. In: Proceedings of the National Academy of Sciences, 107, pp. 19655–19660. https://doi.org/10.1073/pnas.0911966107.

Naguleswaran, S., Vasanthan, T., Hoover, R., Liu, Q., 2010. Structure and physicochemical properties of palmyrah (Borassus flabellifer L.) seed-shoot starch grown in Sri Lanka. Food Chem. 118, 634–640. https://doi.org/10.1016/j.foodchem.2009.05.046.

Nareshkumar, S., Gnanavelrajah, N., Raveendran, S., 2019. Assessment of palmyrah palm distribution and density in east and south east of valikamam region in Jaffna peninsula using very high resolution satellite imagesImages. In: Proceedings of the Second International Symposium on Agriculture (ISA-2019) Faculty of Agriculture. Eastern University, Sri Lanka. Faculty of Agriculture, Eastern University, Sri Lanka, Sri Lanka, pp. 55–64.

Ngo, K.M., Turner, B.L., Muller-Landau, H.C., Davies, S.J., Larjavaara, M., Nik Hassan, NF bin, Lum, S., 2013. Carbon stocks in primary and secondary tropical forests in Singapore. For. Ecol. Manage 296, 81–89. https://doi.org/10.1016/j.foreco.2013.02.004.

Palmyrah Development Board, 2019. Annual Report. Colombo.

Paramesh, V., Singh, S.K., Mohekar, D.S., Arunachalam, V., Misra, S.D., Jat, S.L., Kumar, P., Nath, A.J., Kumar, N., Mahajan, G.R., Bhagat, T., 2022. Impact of sustainable land-use management practices on soil carbon storage and soil quality in Goa State, India. Land. Degrad. Dev. 33, 28–40. https://doi.org/10.1002/ldr.4124.

Pathak, H., Aggarwal, P.K., Singh, S.D., 2012. Climate Change impact, Adaptation and Mitigation in agriculture: Methodology For Assessment and Applications. Indian Agricultural Research Institute, New Delhi, India.

Pathak, H., Ladha, J.K., Aggarwal, P.K., Peng, S., Das, S., Singh, Y., Singh, B., Kamra, S. K., Mishra, B., Sastri, A.S.R.A.S., Aggarwal, H.P., Das, D.K., Gupta, R.K., 2003. Trends of climatic potential and on-farm yields of rice and wheat in the Indo-Gangetic Plains. Field. Crops. Res. 80, 223–234. https://doi.org/10.1016/S0378-4290(02)00194-6.

Pearson, R.H., Brown, S., Richard, A.B., 2007. Measurement Guidelines for the Sequestration of Forest Carbon. USDA Forest Service, Newtown Square, USA.

Perera, A.H., Rajapakse, R.M.N., 1991. A baseline study of Kandyan Forest Gardens of Sri Lanka: structure, composition and utilization. For. Ecol. Manage. 45, 269–280. https://doi.org/10.1016/0378-1127(91)90222-H.

Posa, M.R.C., Wijedasa, L.S., Corlett, R.T., 2011. Biodiversity and conservation of tropical peat swamp forests. Bioscience 61, 49–57. https://doi.org/10.1525/bio.2011.61.1.10.

Prance, S.G., Nesbitt, M., 2012. The Cultural History of Plants, 1st ed. Routledge, New York. https://doi.org/10.4324/9780203020906.

Prasad, B.A.R., Arunkumar, A., Vignesh, S., Chidanand, D.V., Baskaran, N., 2022. Exploring the nutritional profiling and health benefits of Palmyra palm haustorium. S. Afr. J. Bot. 151, 228–237. https://doi.org/10.1016/j.sajb.2022.01.027.

Rana, M.N., Das, A.K., Ashaduzzaman, M., 2015. Physical and mechanical properties of coconut palm (*Cocos nucifera*) stem. Bangladesh J. Sci. Ind. Res. 45, 39–46.

Ranasinghe, C.S., Thimothias, K.S.H., 2012. Estimation of carbon sequestration potential in coconut plantations under different agro-ecological regions and land suitability classes. J. Natl. Sci. Found. 40, 77. https://doi.org/10.4038/jnsfsr.v40i1.4171.

Ratnayake, R.R., Roshanthan, T., Gnanavelrajah, N., Karunaratne, S.B., 2019. Organic carbon fractions, aggregate stability, and available nutrients in soil and their interrelationships in tropical cropping systems: a case study. Eurasian. Soil Sci. 52, 1542–1554. https://doi.org/10.1134/S1064229319120123.

Ravindran, K.M., Ramanan, S.S., 2020. Shortening seed germination time for *borassus flabellifer* using compost pit seed pretreatment. Curr. Sci. 119, 1249–1251.

Rüegg, J., Quezada, J.C., Santonja, M., Ghazoul, J., Kuzyakov, Y., Buttler, A., Guillaume, T., 2019. Drivers of soil carbon stabilization in oil palm plantations. Land. Degrad. Dev. 30, 1904–1915. https://doi.org/10.1002/ldr.3380.

Sankaralingam, A., Hemalatha, G., Ali, A., 1999. A Treatise On Palmyrah, ICAR, All India Co-ordinated Research Project (Palms). Killikulam, Kasaragod, Kerala, India.

Schlesinger, W.H., Andrews, J.A., 2000. Soil respiration and the global carbon cycle. Biogeochemistry 48, 7–20. https://doi.org/10.1023/A:1006247623877.

Senaratna, L.K., 2001. A Check List of the Flowering Plants of Sri Lanka. National Science Foundation, Colombo.

Senthuran, S., Gnanavelrajah, N., 2015. Effects of biochar produced from different feed stock materials on soil properties in sandy regosol of Jaffna. In: Proceedings of the Young Scientist Forum Symposium. Sri Lanka, pp. 179–182.

Shannon, C.E., Weaver, W., 1949. The Mathematical Theory of Communication. University of Illinois Press.

Shrestha, R.P., Schmidt-Vogt, D., Gnanavelrajah, N., 2010. Relating plant diversity to biomass and soil erosion in a cultivated landscape of the eastern seaboard region of Thailand. Appl. Geogr. 30, 606–617. https://doi.org/10.1016/j.apgeog.2010.01.005.

Siju, S., Sabu, K.K., 2020. Genetic resources of Asian palmyrah palm (*Borassus flabellifer* L.): a comprehensive review on diversity, characterization and utilization. Plant Genet. Resour. 18, 445–453. https://doi.org/10.1017/S1479262120000477.

Smith, P., Bustamante, M., Ahammad, H., Clark, H., Dong, H., Elsiddig, E.A., Haberl, H., Harper, R., House, J., Jafari, M., 2014. Agriculture, Forestry and Other Land Use (AFOLU), in: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel On Climate Change. Cambridge University Press, pp. 811–922.

Srinivasababu, N., Kumar, J.S., Reddy, K.V.K., 2014. Manufacturing and characterization of long Palmyra palm/Borassus flabellifer petiole fibre reinforced polyester composites. Proc. Technol. 14, 252–259. https://doi.org/10.1016/j.protcy.2014.08.033.

Srivastava, A., Bishnoi, S.K., Sarkar, P.K., 2017. Value Addition in Palmyra Palm (Borassus Flabellifer L.): A potential Strategy For Livelihood Security and Poverty Alleviation. India.

Subasinghe, S., Munasinghe, G., 2011. Estimation of above ground tree biomass and carbon of Pinus caribaea (Morelet). J. Trop. Forest. Environ. 11, 56–70.

Tchonkouang, R.D., Onyeaka, H., Nkoutchou, H., 2024. Assessing the vulnerability of food supply chains to climate change-induced disruptions. Sci. Total Environ. 920, 171047. https://doi.org/10.1016/j.scitotenv.2024.171047.

Thevamirtha, C., Monichan, S., Selvakumar, P.M., 2021. Carbon-based materials from Borassus flabellifer and their applications. J. Environ. Nanotechnol. 10, 08–12. https://doi.org/10.13074/jent.2021.12.214445.

Thirukkumaran, S., Jeyavanan, K., Sivachandiran, S., 2017. Diversity, distribution and biomass of tree community in a tropical dry forest of Northern Sri Lanka. J. Dry Zone Agric. 3, 1–20.

Tomlinson, P.B., 1990. The Structural Biology of Palms. Oxford University Press. https://doi.org/10.1093/oso/9780198545729.001.0001.

Vågen, T.-G., Lal, R., Singh, B.R., 2005. Soil carbon sequestration in sub-Saharan Africa: a review. Land. Degrad. Dev. 16, 53–71. https://doi.org/10.1002/ldr.644.

Veilmuthu, P., 2014. Palmyrah – Nature's perennial gift in the phase of climate crisis.

Wang, K., Lim, H., Li, M., Srivaro, S., Oh, J.-K., 2023. Effects of density and load orientation on embedment behaviour of coconut wood. Constr. Build. Mater. 371, 130736. https://doi.org/10.1016/j.conbuildmat.2023.130736.

Yin, C., Zhao, W., Ye, J., Muroki, M., Pereira, P., 2023. Ecosystem carbon sequestration service supports the sustainable development goals progress. J. Environ. Manage. 330, 117155. https://doi.org/10.1016/j.jenvman.2022.117155.

Yin, Y., Xu, W., Zhou, S., 2007. Linking carbon sequestration science with local sustainability: an integrated assessment approach. J. Environ. Manage. 85, 711–721. https://doi.org/10.1016/j.jenvman.2006.09.005.