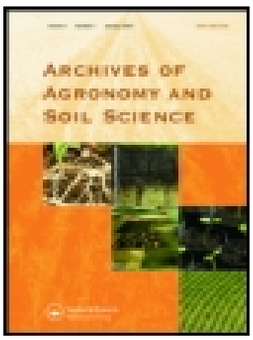

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Impact of the establishment of a botanical garden on soil carbon sequestration and nutrient availability in tropical soils

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ABSTRACT

The objective of the study was to identify the potential for soil C sequestration associated with the establishment of a botanical garden in the tropics. Since forest resources are dwindling and home gardens are limited botanical gardens could play a major role in mitigating CO_2 in the urban environment. This study determined C sequestration and nutrient availability of different thematic areas of a botanical garden 10 years after establishment in comparison with the primary land use, a dry zone forest at the establishment. The establishment of the botanical garden has created a significant improvement of the soil properties with compared to the primary land use. The soil C stocks were significantly high in the botanical garden with compared to the primary land use (7.3 t ha^{-1}). Thematic areas such as Arboretum Part B (13.04 t ha^{-1}), Herbal Garden (12.5 t ha^{-1}) and Valley path (13.23 t ha^{-1}) contained the highest amount of C in soil. Management practices used in maintaining this botanical garden may have affected the soil organic carbon and nutrient status of soil. This study showed that botanical gardens established in urban areas have a great capacity to store C and thereby to mitigate global warming.

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KEYWORDS
Carbon sequestration; microbial biomass C; total organic C; soil carbon stocks; soil nutrients

Introduction

Sequestering C in the soil could be one of the efficient mechanisms for reducing CO_2 emissions to the atmosphere and thereby reducing global warming. As the largest terrestrial reservoir of C, soils may exert a strong influence on atmospheric CO_2 concentrations as C sources or sinks (Lal 2009). Soil organic matter (SOM) is produced by the cycling of the organic compounds in plants, animals, and microorganisms into the soil (Schimel and Schaeffer 2012). Thus, the ability of soil to act as a carbon sink depends a great deal on the presence of vegetation (Ross et al. 2016). It is important to note that soil deflation represents a reduction in natural carbon sequestration infrastructure that is separate and distinct from that occurring in vegetation. Carbon is sequestered at different rates over the lifetime of a vegetation stand (Yang et al. 2018).

Land use affects soil organic C (SOC) concentrations and stocks (Khaledian et al. 2017). Losses in soil C caused by the conversion of natural vegetation to agricultural land or to urban areas are well documented (Ross et al. 2016). It is estimated that globally, 24% of the SOC stock has been lost through the conversion of forest to agricultural land (Murty et al. 2002; Wei et al. 2014) and 59% through the conversion of pasture to agricultural land (Guo and Gifford 2002). It is reported that

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during this conversion the terrestrial carbon pool can be greatly reduced by human induced activities (Lal 2004; Pan 2008). However so far there are no reports specifically on the conversion of forest to botanical garden in elsewhere typically under tropical ecosystems.

Botanical gardens are established for the purpose of maintaining documented collections of living plants used in scientific research, conservation, display and education (Groover and Dosmann 2012). Due to their large collections of plants from wide areas, botanical gardens play a central role in plant biology research (Groover and Dosmann 2012) and conservation of most threaten plants species due to climate change (Krishnan and Novy 2016). The process of urban greening through the establishment of botanical gardens will be vital for enhancing urban soil health while improving air quality as a result of the removal of excess CO_2 from the atmosphere. Therefore, studies on climate change mitigation through soil C sequestration will provide further avenues of improvement that might be suitable for the development of botanical gardens in the future. As the forests do not exist and home gardens are limited, botanical gardens have a major role in reducing CO_2 from the urban environment. Based on our review no studies have been reported on the soil C sequestration capacities of different thematic areas of a botanical garden in the tropics. Therefore, the aim of this work is to study the changes in soil properties with a special emphasis on soil C storage after the establishment of a botanical garden.

In line with the above, the current investigation was carried out with the objective of studying C storage capacity and availability of macro nutrients in different thematic areas of the Hambantota tropical botanical garden of Sri Lanka 10 years after its establishment hypothesizing that the disturbances to the soil do not make changes to the organic C fractions or nutrients.

Materials and methods

Study area

The study was carried out in a botanical garden located in the dry zone of Sri Lanka (6° 7′ 27″ N, 81° 7′ 21″ E, 6.124167, 81.1225) that was established in 2006 (Figure 1). The garden extends over 121 ha of land. The soil type of the area is known locally as Reddish Brown Earth (USDA Soil taxonomy order: Alfisols; Word reference base Major group: Luvisols). Terrain is characterized with undulating terrain which is common in the defined dry zone catena of Sri Lanka (Panabokke 1996). It is a neutral soil (pH = 7) in nature and cation exchange capacity is in between 10–20 meq 100 g^{-1} hence it is considered as a fertile soil (De Silva and Dassanayake 2010). Base saturation of the soil is more than 50%. Calcium percentage is higher and soils can get eroded easily. Primary vegetation of the area was a dry zone forest with small trees and shrubs. Dominant trees present were included *Sapindusi marginata, Feronia limonia, Dichrostachys cinerea, Carissa spinarum, Cassipourea ceylanica* etc.

The botanical garden was composed of 7 thematic areas such as Arboretum part A (HARA), Arboretum part B (HARB), Ethanobotanical garden (HEBG), Herbal garden (HHG), Ornamental shrub garden (HOSG), Student garden (HSG) and Valley path (HVP). A patch of primary vegetation of the area before the establishment of the botanical garden was left undisturbed within the botanical garden for study purposes and known as Natural shrub garden (NSG). A detailed description of each thematic area is provided in Table 1.

Management practices

No chemical fertilizers were added, and only organic fertilizers were used to grow the plants during its establishment. The organic fertilizer was added as a mixture of cow dung, sand and forest topsoil in 1:2:3 ratios during the establishment. Thereafter, only cow dung was added as a fertilizer to HHG, HOSG and HSG whenever required. During the initial 3-year period, the plants were irrigated daily using row water. Thereafter, the plants were irrigated only during the dry season at 2-week intervals. The thematic areas were protected against disturbances and human interference. Natural plant litter and residues added were not removed from the soil other than the roads and paths inside the garden.

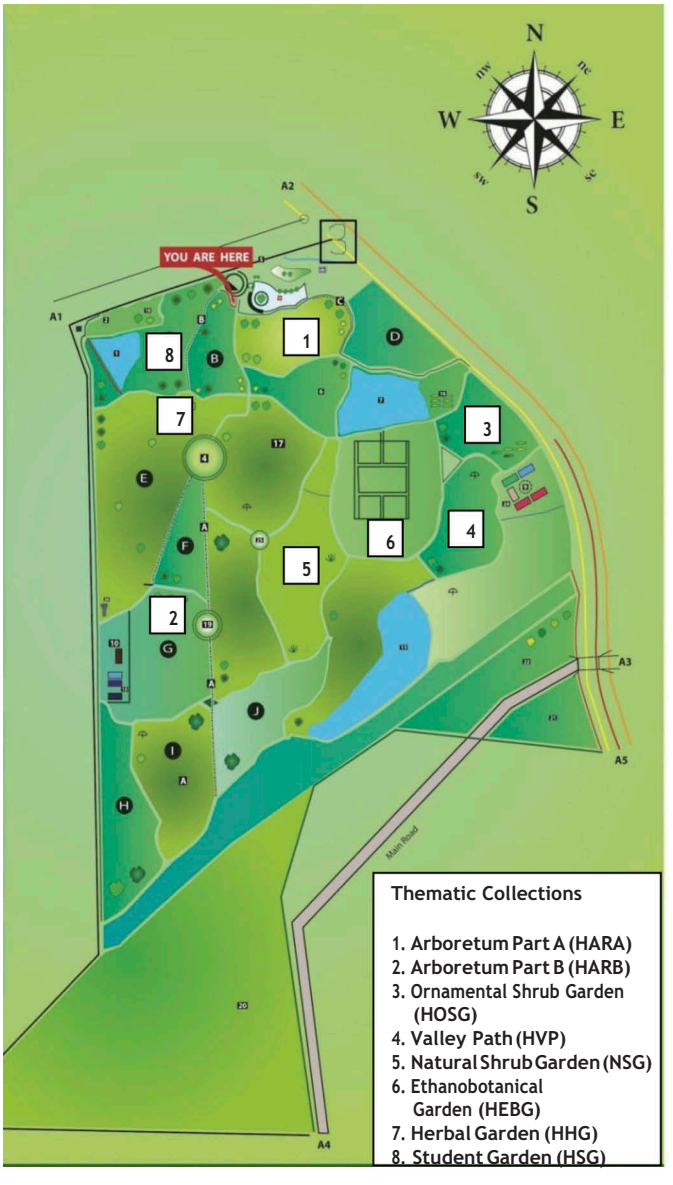

Figure 1. Study area of Dry Zone Botanical Garden in Hambantota, Sri Lanka including different thematic collections (Source: Hambantota Dry Zone Botanical Garden, Sri Lanka).

Climate

The annual temperature varied between 28 and 32 °C, while the mean annual rainfall in the area was recorded as 50–190 mm (< 800) (Figures 2 and 3).

Soil sampling

A random sampling scheme was adopted to obtain soil samples from two depth levels: 0–0.15 m and 0.15–0.30 m. Samples were collected using a soil core of 5 cm width after removing the surface litter layer. Total of 144 samples were collected from two depth levels and pooled to form 48 composite samples for the study site. Finally, from all thematic areas 48 samples were used for the analysis.

Table 1. Description of the study locations of the garden.

Thematic area	location	Composition of plants
Arboretum part A (HARA)	232276 East 106143 North	*Large trees* *Azadirachta indica, Salvadora persica, Limonia acidissima*
Arboretum part B (HARB)	232145 East 105694 North	Large trees *Diospyros ebanum, Glycyrrhiza glabra, Ziziphus mauritiana*
Ornamental shrub garden (HOSG)	232846 East 105970 North	Ornamental Shrubs *Nerium oleander,* *Acacia cornier* *Barleria prionitis*
Valley path (HVP)	232882 East 105801 North	Ornamental plants *Calotropis gigantean* *Cassia fistula*
Ethano botanical garden (HEBG)	233005 East 105842 North	Shrubs and trees *Salvadora persika* *Manilkara hexandra* *Asclepias eriocarpa*
Herbal garden (HHG)	232495 East 106031 North	Herbs & Small trees *Memozylum umbelatum* *senna auriculata, Strychnos potatorum*
Student garden (HSG)	232234 East 106162 North	Shrubs *Carissa spinarum Capparis zeylanica Ziziphusoenoplia*
Natural shrub garden (NSG)	232556 East 105841 North	Thorny shrubs & trees *Sapindusi marginata Dichrostachys cinerea* *Cassipourea ceylanica*

HARA = Arboretum part A; HARB = Arboretum part B; HEBG = Ethanobotanical garden; HHG = Herbal garden; HOSG = Ornamental shrub garden; HSG = Student garden; HVP = Valley path; NSG = Natural shrub garden.

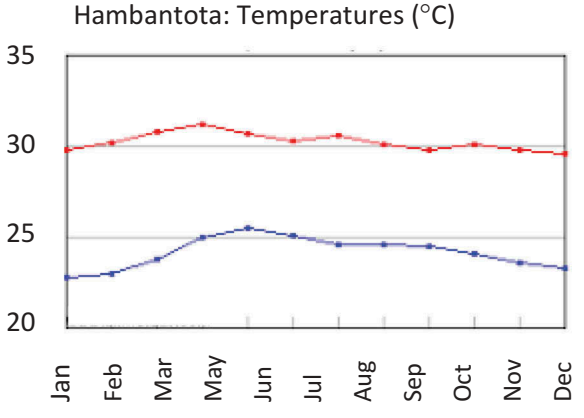

Figure 2. Average minimum and maximum temperatures in Hambantota, Sri Lanka during 2016 (Source: https://eldoradoweather.com/climate/sri%20lanka/Hambantota.html.

Soil preparation and analysis

Soil core samples collected in black polythene bags were brought to the laboratory for further processing. All visible organic debris, stones, and plant roots were removed from these samples. Large soil aggregates were crushed and sieved using a 2 mm mesh sieve. Soil pH, electrical conductivity, moisture content, bulk density, available nitrogen, phosphorus and microbial biomass carbon (MBC) were analyzed using this fresh soil. The remaining soil samples were air dried and ground (0.15 mm) using a grinder (M20 IKA, WERAKE) for further analysis (Anderson and Ingram 1993) such as SOC fractions ($KMnO_4$ oxidizable carbon (POC) and water soluble organic carbon (WSC)), soil PO_4^{3-}content, soil NO_3 content, soil NH_4^+ content and available macronutrients (K, Ca and Mg). Additional soil

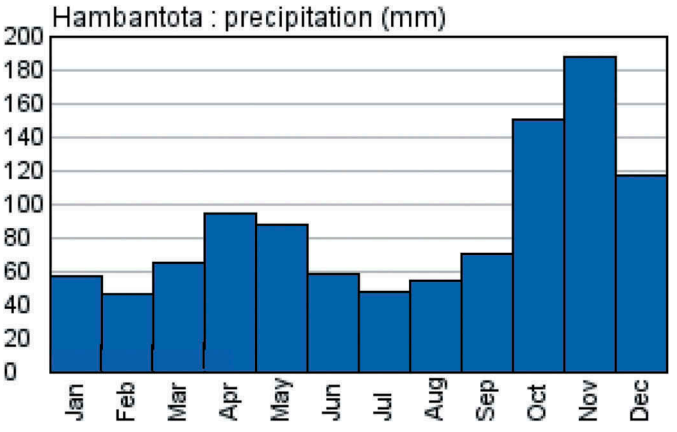

Figure 3. Average precipitation (rain/snow) in Hambantota, Sri Lanka during 2016 (Source: https://eldoradoweather.com/climate/sri%20lanka/Hambantota.html).

samples were taken from each site by core sampling method and analyzed for gravimetric water content and bulk density (Blake and Hartge 1986). The samples obtained for bulk density measurements were free from roots, stones and debris. Microbial biomass carbon (MBC) was determined using the chloroform fumigation and extraction method (Vance et al. 1987). After fumigation, the microbial biomass C was extracted using 0.5 M K_2SO_4 and quantified using the titration method with acidified ferrous ammonium sulphate (Anderson and Ingram 1993). The determination of TOC was carried out using acidified dichromate of organic carbon with the modified Walkley's oxidation method (Baker 1976). In this study, TOC was considered to be equal to SOC. The labile fraction of SOC, mainly coming from the active carbon pools, was determined using the $KMnO_4$ oxidizable carbon stimation method (Weil et al. 2003). Water soluble organic carbon (WSC) was extracted with water after shaking at 200 rpm for 30 min and filtering using Whatman 42 ashless filters. The extract was analyzed for carbon by titration with ferrous ammonium sulphate after dichromate oxidation in acidic medium.

Determination of available macronutrients

Macronutrients (K, Ca, and Mg) were extracted using modified Morgan extractant (NH_4OH/CH_3COOH) (Mc Intosh 1969) and were analyzed using an atomic absorptionspectrophotometer (GBC 933 AA). Soil PO^{3-} content was measured using the molybdenum blue method (Watanabe and Olsen 1965). Soil available $N{:}NO_3$ (Cataldo et al. 1975) and NH_4 (Lenore et al. 1989) were determined calorimetrically.

Calculation of soil carbon stocks

Carbon stocks were calculated using the following equation (Benbi et al. 2015):

$$\text{C stock } (\text{t ha}^{-1}) = \text{C content } (\%) \times \text{bulk density } (\text{Mg m}^{-3}) \times \text{depth } (\text{m}) \times 100$$

Statistical design and analysis

A general linear model (GLM) analysis was conducted in Minitab 16 to detect statistically significant differences in variables across the study area at the 0.05 probability level. The available nitrogen, available phosphorus, magnesium, copper and iron concentration data were natural log transformed to approximate a normal distribution. Other variables were tested without transformation.

A Pearson correlation analysis was performed to investigate the relationships between variables. Simple regression analyses were also performed to evaluate the relationships between the measured variables. A GLM was used to study the interactions between the studied variables. The selection criteria for the regressions were based on the R^2 and p values.

Results

Soil organic carbon fractions and stocks

The SOC fractions and stocks varied significantly with respect to the primary land use NSG. The total organic carbon (TOC) was significantly differed ($p < 0.05$) between the 2 soil depths and varied between 0.62 and 0.90% in the top soil layer of the different thematic areas (Figure 4) and between 0.63 and 1.06% in the 15–30 cm soil layer (Figure 4). The MBC ranged between 0.01 and 0.04% in the 0–15 cm soil depth (Figure 5). The water soluble C (WSC) significantly differed ($p < 0.05$) with soil depth and thematic area, showing variation of between 0.007 and 0.025% in the upper soil layer and between 0.006 and 0.916% in the lower soil layer respectively (Figure 6). The NSG showed the lowest MBC content and lowest WSC content. The $KMnO_4$ oxidizable carbon (POC) content varied across the different thematic areas and soil depths, showing variation of between 410.77 and 598.79 mg kg^{-1} in the upper soil layer and between 409.09 and 527.61 mg kg^{-1} in the lower soil layer respectively (Figure 7). The highest carbon stocks in the 0–15 cm layer were shown by thematic areas such as Arboretum Part B (13.04 t ha^{-1}), Herbal Garden (12.5 t ha^{-1}) and Valley path (13.23 t ha^{-1}) in comparison with the primary land use NSG (7.3 t ha^{-1}). A similar pattern was shown by the C stocks in the 15–30 cm layer as well (Figure 8).

Soil available nutrients

The soil available nitrate content significantly differed with soil depth and thematic area ($p < 0.05$). It ranged between 0.16 and 1.21 µg g^{-1} in the upper soil layer and between 0.06 and 0.31 µg g^{-1} in the lower layer. The highest nitrate content was recorded in the upper layer of NSG. The available NH_4^+ content of the soil significantly differed across the thematic areas and with soil depth, and the values varied between 1.23×10^{-5} µg g^{-1} and 5.12×10^{-4} µg g^{-1} in the upper soil layer and

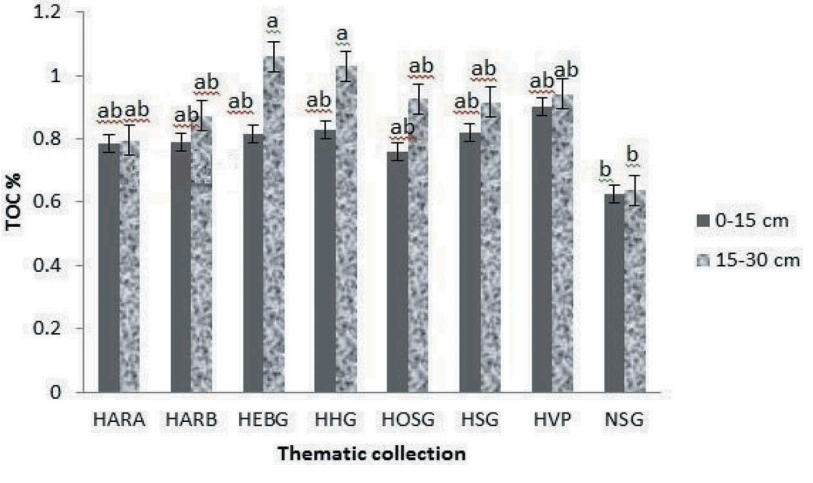

Figure 4. Variation of total organic carbon (TOC) in different thematic collections of the botanical garden, Arboretum part A (HARA), Arboretum part B (HARB), Ethanobotanical garden (HEBG), Herbal garden (HHG), Ornamental shrub garden (HOSG), Student garden (HSG), Valley path (HVP), Natural shrub garden (NSG). Means denoted by the same letter are not significantly different ($p < 0.05$).

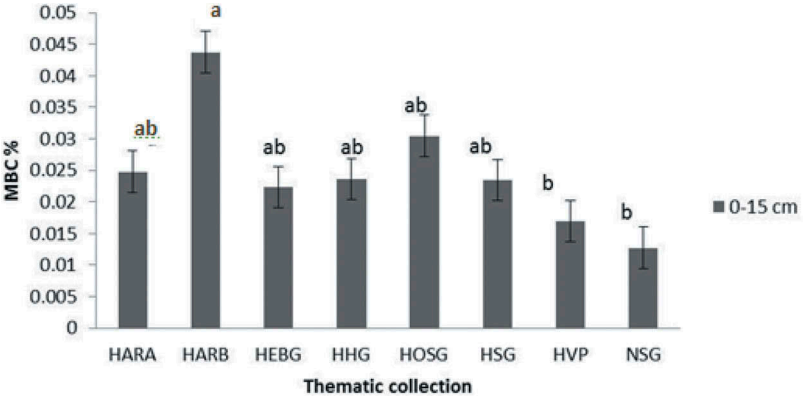

Figure 5. Variation of soil microbial biomass carbon (MBC) in different thematic collections of the botanical garden, Arboretum part A (HARA), Arboretum part B (HARB), Ethanobotanical garden (HEBG), Herbal garden (HHG), Ornamental shrub garden (HOSG), Student garden (HSG), Valley path (HVP), Natural shrub garden (NSG). Means denoted by the same letter are not significantly different ($p < 0.05$).

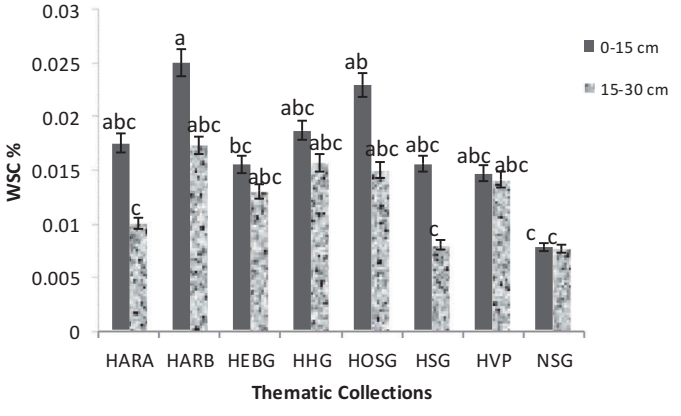

Figure 6. Variation of water soluble carbon (WSC) in different thematic collections of the botanical garden, Arboretum part A (HARA), Arboretum part B (HARB), Ethanobotanical garden (HEBG), Herbal garden (HHG), Ornamental shrub garden (HOSG), Student garden (HSG), Valley path (HVP), Natural shrub garden (NSG). Means denoted by the same letter are not significantly different ($p < 0.05$).

between 2.7×10^{-5} and 3.1×10^{-4} µg g^{-1} in the lower soil layer. The study showed that NSG contained the highest NH_4^+ content, while the lowest was found in HOSG. These results indicate that the changes in nutrients showed a different pattern compared to the organic C fraction. The contents of macronutrients (K, Ca, Mg) significantly differed across the different thematic areas and between the two soil layers. The K, Ca and Mg contents ranged between 21.22 and 36.62 mg kg^{-1}, 80.5 and 161.5 mg kg^{-1} and 27.79 and 82.36 mg kg^{-1}, respectively (Table 2).

Soil pH and electrical conductivity

In this study, the pH decreased with soil depth, and significant differences ($p < 0.05$) were found in the soils of all thematic areas (Figure 9). The soil pH in the top soil layer (0–15 cm) ranged from 5.98 to 7.93 and from 5.93 to 7.84 in the bottom layer. The EC of the soils significantly differed ($p < 0.05$) among the soils of the thematic areas (Figure 9). The EC ranged between 30.41 and 79.85 µS cm^{-1} in the upper soil layer and between 27.01 and 78.24 µS cm^{-1} in the lower soil layer.

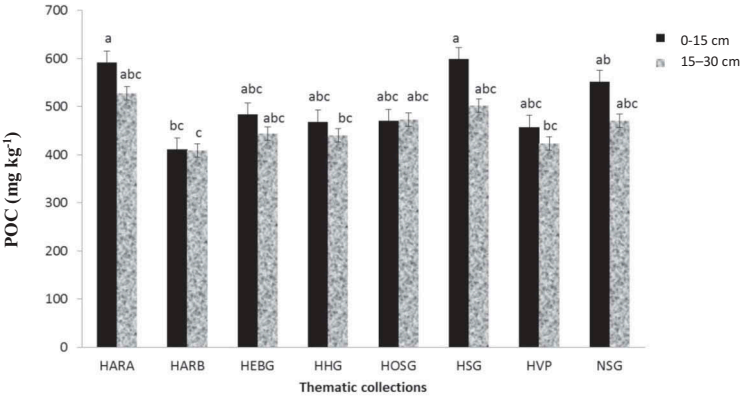

Figure 7. Variation of $KMnO_4$ oxidizable carbon (POC) in different thematic collections of the botanical garden, Arboretum part A (HARA), Arboretum part B (HARB), Ethanobotanical garden (HEBG), Herbal garden (HHG), Ornamental shrub garden (HOSG), Student garden (HSG), Valley path (HVP), Natural shrub garden (NSG). Means denoted by the same letter are not significantly different ($p < 0.05$).

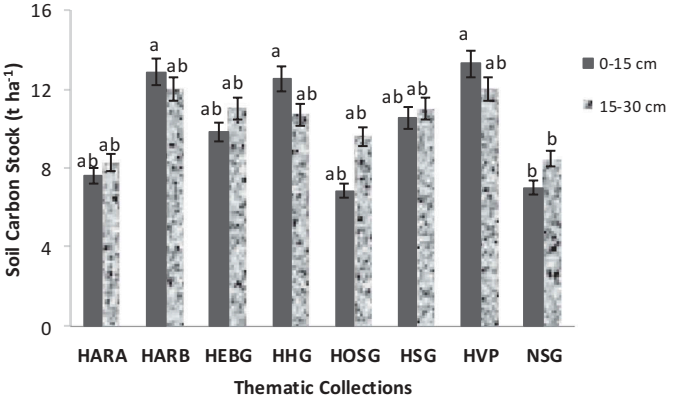

Figure 8. Soil carbon stock (t ha^{-1}) in different thematic collections of the botanical garden, Arboretum part A (HARA), Arboretum part B (HARB), Ethanobotanical garden (HEBG), Herbal garden (HHG), Ornamental shrub garden (HOSG), Student garden (HSG), Valley path (HVP), Natural shrub garden (NSG). Means denoted by the same letter are not significantly different ($p < 0.05$).

Soil physical properties

HARB showed the highest value of bulk density (1.00 g cm^{-3}) (Table 2). The lowest bulk density value was observed in NSG (0.68 g cm^{-3}). HEBG, HSG and HVP showed the same bulk density value, which was 0.80 g cm^{-3}. The soil moisture content significantly varied between the 2 layers: 2.77–9.61% for the 0–15 layer and 3.20–7.13% for the 15–30 cm layer.

Discussion

Generally, in commercial agriculture, continuous cultivation is practiced with conventional tillage and inorganic fertilizer without the addition of organic manure. Such cultivation practices lead to land degradation, which is mainly due to the acceleration of the decomposition of SOM (Pan 2008; Ratnayake et al. 2017), reduction in the quantity of plant inputs into the soil and increasing erosion rates (Albaladejo et al. 2013; Assis et al. 2010; Sousa et al. 2012). However, in the current study the botanical garden was maintained with some sustainable land use practices and selected plant

Table 2. Soil available K, Mg, and Ca concentrations in different thematic collections.

Thematic collection	Layer (cm)	K	Ca (mg kg^{-1})	Mg
HARA	0–15 cm	36.09ab	130.13ab	82.36a
HARA	15–30 cm	36.62ab	161.50a	73.09ab
HARB	0–15 cm	29.54ab	133.28ab	52.90abcd
HARB	15–30 cm	27.64ab	97.72b	46.85bcd
HEBG	0–15 cm	31.25ab	115.28ab	39.39cd
HEBG	15–30 cm	25.40b	151.55b	40.06cd
HHG	0–15 cm	23.67b	115.25b	55.03abcd
HHG	15–30 cm	21.22b	127.05b	62.18abc
HOSG	0–15 cm	28.78ab	153.55ab	41.04cd
HOSG	15–30 cm	30.86ab	141.60ab	52.14bcd
HSG	0–15 cm	27.44ab	94.90b	43.98bcd
HSG	15–30 cm	28.75ab	80.50b	27.79d
HVP	0–15 cm	25.96ab	92.25b	42.15cd
HVP	15–30 cm	25.48b	104.70b	48.44bcd
NSG	0–15 cm	34.98a	102.10b	54.60abcd
NSG	15–30 cm	31.36ab	90.73b	49.84bcd

HARA = Arboretum part A; HARB = Arboretum part B; HEBG = Ethanobotanical garden; HHG = Herbal garden; HOSG = Ornamental shrub garden; HSG = Student garden; HVP = Valley path; NSG = Natural shrub garden. Values in the same column followed by the same letter are not significantly different at $p < 0.05$.

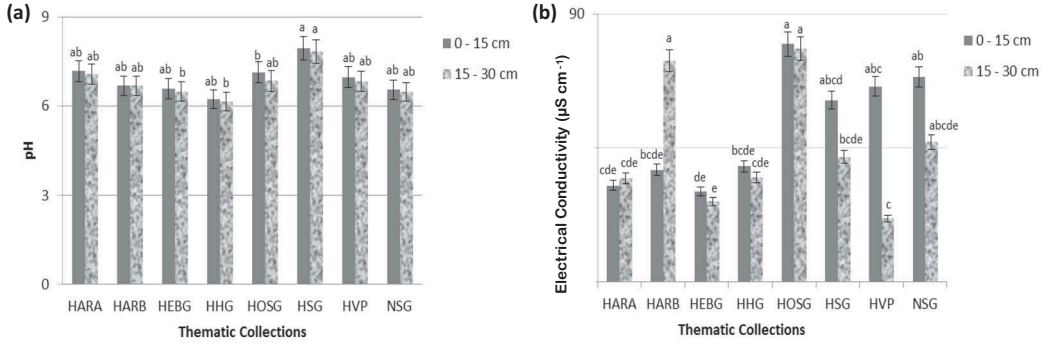

Figure 9. Variation of (a) pH (b) Electrical Conductivity (µS cm^{-1}) in different thematic collections of the botanical garden, Arboretum part A (HARA), Arboretum part B (HARB), Ethanobotanical garden (HEBG), Herbal garden (HHG), Ornamental shrub garden (HOSG), Student garden (HSG), Valley path (HVP), Natural shrub garden (NSG). Means denoted by the same letter are not significantly different ($p < 0.05$).

species resulting a significant increase in C sequestration (Campbell et al. 2001) compared to the primary vegetation of the area. The primary vegetation of the area was a dry zone forest composed of thorny shrubs small trees and very few large trees. Carbon fractions and TOC content of the soils of the thematic areas of the botanical garden was significantly higher with compared to the primary land use as dry zone forest experiences high temperatures throughout the year, and thereby increase decomposition rate of the organic matter in soil (Darmaparakrama et al. 2009).

The increase in C storage capacity of the soils of the botanical garden attributed to more soil C gain from aboveground litter and belowground roots. Minimum soil C loss from erosion due to the proper land management within the botanical garden has also contributed for this increase (Chang et al. 2011). Minimal/no surface litter removal in the botanical garden has led to conclude that residues of above ground and below ground are the major source of carbon contributing to SOC improvement (Smith 2008). The results of the current study also showed that the types of vegetation have a significant effect on the SOC storage as reflected by different thematic areas (Yang et al. 2018).

Microbial biomass is the most active part of SOM (Behera and Sahani 2003). Microbial biomass and particularly its ratio to organic carbon are early indicators of changes in the carbon status of the soil (Insam and Domsh 1988; Powlson et al. 2011). High MBC in thematic areas compared to NSG is due to the addition of organic fertilizer and maintaining soil moisture by irrigation. Usually, in topsoil, organic inputs (Santos et al. 2012) as well as high soil moisture and O_2 levels (Fierer et al. 2003) can determine the MBC content. A high microbial population can usually be expected in soils when there is high organic matter content (Six et al. 2006). Grassland soils are reported to have more soluble C (Lu et al. 2011), as seen the WSC in HARB, which was also covered by a thick and continuous grass layer (lawn). The lowest WSC content was reported in NSG, as a result of the increased erosion rates (Assis et al. 2010) in the dry zone forests. The $KMnO_4$ oxidizable carbon (POC) content varied in small amounts. The $KMnO_4$ oxidizable carbon (POC) content is considered as an indicator of soil quality (Weil et al. 2003) and showed small variations in different thematic areas of the garden. The soil carbon stocks were significantly differed ($p < 0.05$) across the soil depths and thematic collections.

The pH and EC of the soil significantly varied among the different thematic areas and between the two soil depths. The natural shrub garden (NSG) showed a fairly alkaline pH compared to the other sites as it was covered by grasses making the soil alkaline (Sharma et al. 2008). The soil pH and EC largely depend upon the leaching regime (Syed et al. 2013). The leaching regime of the soils in this study may vary according to the vegetation cover, which would have caused differences in the pH and EC, as reported by Syed et al. (2013). The pH of the soil was moderately alkaline, as also shown in a study conducted in a botanical garden at GC University, Lahore (semi-arid zone) (Syed et al. 2013). Soil moisture content is an important parameter for soil carbon sequestration, as it regulates soil respiration and plant biomass production (Chemura et al. 2014). The soil moisture content varied across the thematic areas and soil depths. The highest soil moisture content was reported in the upper layer (0–0.15 m) of the botanical garden, showing that the soil moisture is much higher in the top soil layer than in the lower soil layers (Fierer et al. 2003).

Soil NO_3^- and NH_4^+ contents were significantly low in all thematic areas compared to the primary land use as there was no irrigated water supply for leaching. The potassium content did not significantly differ ($p < 0.05$) across the thematic collections and between depths. The Ca and Mg contents were significantly differed ($p < 0.05$) across the different thematic collections and soil depths. Both Ca and Mg availability were highest in HARA. The study showed that nutrient availability was strongly affected by fertilization, soil tillage and irrigation practices used in the maintenance of the garden (Sartori et al. 2007).

The botanical garden was not established to serve the purpose of enhancing C storage capacity. In addition, there was a belief that the soil conditions could be further degraded by the establishment of this botanical garden, as the garden is mostly composed of herbs rather than woody perennials. However, the study confirmed that the establishment of botanical garden improved the C storage capacity to a significant level compared to the primary land use of the area. There are few studies available on the contribution of botanical gardens as urban green spaces, particularly in the tropics. Therefore, this study provided useful information to understand the value of botanical gardens as urban green spaces and the benefits in terms of C storage in soil.

Conclusion

In overall the establishment of the botanical garden has created a significant improvement of the soil properties with compared to the soils of the primary vegetation of the area. Plant species composition and some of the management practices used in maintaining this botanical garden such as organic fertilizer application, pruning techniques, litter management and irrigation practices, may have affected the soil organic C status. The study provides valuable information on soil carbon sequestration due to the establishment of botanical gardens in order to reduce atmospheric carbon dioxide levels in urban environments. The study also provides baseline information

that could be useful in future C trading programs. As we hypothesized, the results showed that the establishment of the botanical garden has enhanced the natural balance, soil organic C fractions, C stocks and nutrients. The present study showed that the botanical garden established in dry zone of Sri Lanka has enhanced the natural balance, soil organic C fractions, C stocks and available nutrients. The establishment of this botanical garden has confirmed its suitability to improve urban soils and mitigate climate change.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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