THE ROLE OF DOMESTIC LAWNS AND ROADSIDE VERGES IN CARBON SEQUESTRATION: A CASE STUDY FROM SAHIWAL CITY (PAKISTAN)

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Abstract. Plants and soils of domestic lawns and roadside verges are significant components of urban green infrastructure and provide a range of ecosystem services including carbon sequestration. This study was aimed at assessing the potential of domestic lawns and roadside verges for carbon sequestration and was performed in the city of Sahiwal in Pakistan. The soils had around 8 pH; bulk density was higher in domestic lawn that of roadside verge soils. The soil depth had no significant effect on pH and bulk density. Organic matter in domestic lawn soils was 1.48% and 1.2% in roadside verges soils. In grass turf soils surface samples had higher organic matter and organic carbon content, as did subsurface samples under trees. There were considerable variations in soil organic carbon from both domestic lawn and roadside verges, and the highest organic carbon values were observed in lawns at a depth of 11–20 cm and the lowest at roadsides at depth of 0–10 cm. The results suggest that both habitats can play an important role in carbon storage, a true ecosystem service in times of ongoing climate change, especially in cities with dry and warm climates.
Keywords: *green infrastructure, organic carbon, roads, soil, urban infrastructure*

Introduction

There is a growing interest in the search for methods to reduce the concentration of greenhouse gases in atmosphere to mitigate adverse impacts of climate change. A common method for reducing CO_2 concentration in the atmosphere is the capture and storage of CO_2 by plants and soils, also known as terrestrial carbon sequestration. The need of carbon sequestration in cities (Sarkar et al., 2018; Chen et al., 2021) is more necessary because urban areas are prone to adverse effects of climate change such as warming, heat island effect, spread of infectious diseases and pollution (Kumar and Saroj, 2014; Du et al., 2019; Beesley et al., 2020; Kumar et al., 2021; Wei et al., 2022).

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All modern cities, despite their geographical and cultural differences possess the same type of urban green infrastructure habitats such as lawns, roadside verges and parks etc. (McKinney, 2006; Mexia et al., 2018). Plants of domestic lawns and roadside verges constitute a major part of “green infrastructure” in our cities and are considered as important resources for the maintenance of urban biodiversity (Petrova et al., 2022) and provision of multiple ecosystem services. But now, scientists are discovering that growing plants on urban roadside verges or in domestic lawns are important not only for their role in improving urban ecology but also for their ability to moderate the impacts of climate change and urban heating (Chen, 2015; Velasco et al., 2016; Arilouma et al., 2020; Wei et al., 2022).

Urban green spaces (lawns, gardens, parks, roadside verges, railway lines and canal banks etc.) have the potential to capture CO_2 and “store” that carbon over time in soil. Carbon sinks inside and outside city boundaries have been suggested as a means of mitigating the negative impacts of climate change in cities (Churkina et al., 2010; Lorenz and Lal, 2015).

The soils are the third largest global carbon sink after oceans and geologic formations (Batjes, 2014) and these have four times the C present in plants on earth. Soils therefore are viewed as a potential C reservoir that could support mitigation of impacts of climate change by facilitating CO_2 sequestration. The interest in the potential of vegetation of lawns and roadside verges and soils to capture and store atmospheric CO_2 is increasing (Pouyat et al., 2009; Rangel et al., 2019; Lindén et al., 2020). In cities which are major contributors of greenhouse gases such as CO_2, urban soils can serve as a sink for carbon thus helping in improving the quality of urban environment and mitigating threats of natural disasters (Keeley et al., 2013).

Soil carbon storage in urban soils is affected by various physical, biological and anthropogenic factors (Lv et al., 2016; Zhai et al., 2017; Mexia et al., 2018; Kucuk et al., 2019). Promoting carbon sequestration (maximizing carbon storage and minimizing carbon loss) by adopting appropriate land use, soil, nutrient, water and plant management is an effective strategy for reducing atmospheric CO_2. Accurate assessment of urban soil carbon levels are imperative to understand dynamics of urban carbon sequestration and the role of different urban habitats in carbon sequestration.

Pakistan is among the top ten countries vulnerable to impacts of climate change (Eckstein et al., 2021). It is rapidly urbanizing and its cities are already facing multiple impacts of global warming such as heat waves, urban flooding, epidemics and deterioration of air quality. The dynamics of carbon pools in urban soils of different habitats in Pakistan has not received much attention and there is lack of studies on carbon sequestration in urban soils. The main goal of this research was to determine organic carbon stocks in soils of domestic lawns and roadside verges. Then the effects of grass turfs and trees on soil carbon levels in both habitats were investigated. In addition to this, relationships of soil pH and depth on carbon storage in soils were also assessed during this investigation.

Materials and methods

Study area

This study was carried out in the city of Sahiwal, Pakistan (30°39’52.16” N latitude and 73°06’30.54” E longitude) (*Fig. 1*), with a population of half million (FAO, 2020). It is located in a semi-arid flat alluvial plain formed by the rivers Ravi and Sutlej. These

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plains are irrigated by the world's largest canal-irrigation system built by the British in the sub-continent. Its height above sea level is 152 m. The climate tends to have hot, sometimes extremely hot, summers and mild warm winters. The soil and climatic characteristics support short or scrubby vegetation which can be termed as open and pronouncedly of xerophytic nature in which thorny leguminous species predominate (FAO, 2020). Works on the localities were carried out in 2022.

Figure 1. *Orientation map, the red arrow points to the city where this research was carried out*

Field survey design

Forty sites (20 domestic lawns and 20 roadside verges) were randomly selected to have some reasonable data for statistical analysis and surveyed. Out of twenty domestic lawns ten were with trees and ten were with grass turf. Similarly, twenty roadside verges were divided into two groups (10 with trees and 10 with grass turf). At each site, a list of plant species was made. Vascular plants nomenclature accords with The Angiosperm Phylogeny Group (2016).

In domestic lawns, fifteen common species of trees, shrubs and herbs were recorded (*Table 1*). The notable species among these were *Cynodon dactylon*, *Euphorbia prostrata*, *Trianthema portulacastrum*, *Morus alba*, *Melia azedarach*, *Mangifera indica*, *Roystonea regia* and *Punica granatum*. Twenty plant species were recorded on roadside verges (*Table 1*). The frequent species of roadside verges were *Dalbergia sissoo*, *Syzygium cumini*, *Eucalyptus camaldulensis Azadirachta indica*, *Bombax ceiba*, *Cynodon dactylon*, *Trianthema portulacastrum*, *Vachellia nilotica*, *Achyranthes aspera* and *Parthenium hysterophorus*.

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Table 1. *Common plants of domestic lawns and roadside verges*

Plants	Domestic lawns	Roadside verges
Acacia nilotica	No	Yes
Achyranthes aspera	No	Yes
Alternanthera sessilis	No	Yes
Amaranthus viridis	No	Yes
Azadirachta indica	No	Yes
Bombax malabarica	No	Yes
Capparis aphylla	No	Yes
Citrus limon	Yes	No
Cynodon dactylon	Yes	Yes
Dactyloctenium aegyptium	No	Yes
Dalbergia sissoo	No	Yes
Eucalyptus camaldulensis	No	Yes
Eucalyptus lanceolatus	No	Yes
Eugenia jambolana	Yes	Yes
Euphorbia prostrata	Yes	Yes
Ficus elastica	Yes	No
Chenopodium album	No	Yes
Launea nudicaulis	No	Yes
Mangifera indica	Yes	No
Melia azedarach	Yes	No
Morus indica	Yes	No
Ocimum basilicum	Yes	No
Oreodoxa regia	Yes	No
Parthenium hysterophorus	No	Yes
Phoenix dactylifera	No	Yes
Pinus roxburghii	Yes	No
Psidium guajava	Yes	No
Punica granatum	Yes	No
Rosa indica	Yes	No
Trianthema monogyna	Yes	No
Trianthema monogyna	No	Yes
Ziziphus jujuba	No	Yes

Soil sampling and analysis

From each site, two soil samples were collected with a chrome plated soil corer at two depths per core (0–10 cm and 11–20 cm). Soil samples were sieved through 2 mm sieve and any plant parts or residue fragments were removed manually.

Soil pH was determined by a pH meter (Hana USA) using 1:5 solution of soil in deionized water. Due to high levels of salinity, soils of the region have pH around 8 (Imran et al., 2010).

The bulk density (gcm^{-3}) was determined by heating soil in an oven (Orient Pakistan) at 600°C to a constant mass and then taking its weight.

The soil organic matter (%) was determined by loss on ignition method (heating 10 g of soil at 1400°C for 8 h) in a muffle furnace (Haoyue Shanghai, China).

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Soil organic carbon (%) was calculated as a multiple soil organic matter × 0.58 (Gough and Elliot, 2012). Soil carbon mass (gCm^{-2}) was estimated by multiplying bulk density with carbon percentage concentration and subtracting volume of any coarse fragments (Huyler et al., 2014).

Statistical analysis

The logarithms of the obtained characteristics were taken first, and then statistical analysis was used with STATISTICA software (StatSoft Inc, 2013) at the significance level of 0.05. One-way analysis of variance (ANOVA) was taken as a technique to compare means of obtained samples. A series of Tukey's honestly significant difference tests were run to answer the pair comparisons question. The Principal component analysis (PCA) was carried out to explain variation in the data.

Results

The summary of analyses of different parameters of soils is presented in *Table 2*. In the study area, nearly all soil samples were neutral to basic in reaction with pH ranging from 7.4 to 8.0. In lawns and roadside verges, pH under grass and trees sites, decreased with increase in depth. Between habitats, the pH value in surface soils was lower in grass dominated soils than trees because higher contribution of biomass by grasses.

Table 2. *Soil characteristics measured at different locations and depths are presented. Mean, standard deviation (SE) and Tukey's honestly significant difference tests are presented (different letters indicate significant difference P < 0.05)*

Parameters		Soil pH	Bulk density (g cm^{-3})	Soil organic matter (%)	Soil organic carbon (%)	Soil carbon mass (gCm^{-2})
Site type	Soil depth (cm)	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
Lawns grass	0 - 10	7.8 ± 0.1^{abc}	1.13 ± 0.06^{a}	1.73 ± 0.11^{bc}	0.99 ± 0.06^{bcf}	897 ± 14.3^{a}
	10 - 20	7.6 ± 0.1^{b}	1.15 ± 0.07^{a}	1.49 ± 0.12^{abcdefg}	0.87 ± 0.07^{abcdefg}	795 ± 13.9^{ab}
Lawns trees	0 - 10	8 ± 0.1^{a}	1.19 ± 0.04^{a}	1.13 ± 0.06^{adefg}	0.66 ± 0.03^{adefg}	623 ± 21.2^{b}
	10 - 20	7.8 ± 0.1^{abc}	1.16 ± 0.05^{a}	1.57 ± 0.08^{cf}	0.92 ± 0.05^{cf}	853 ± 23.1^{ab}
Roadside grass	0 - 10	7.9 ± 0.04^{abc}	1.12 ± 0.03^{a}	1.19 ± 0.07^{efg}	0.69 ± 0.05^{efg}	616 ± 17.8^{b}
	10 - 20	7.7 ± 0.1^{abc}	1.20 ± 0.03^{a}	1.17 ± 0.07^{g}	0.68 ± 0.04^{g}	650 ± 11.8^{b}
Roadside trees	0 - 10	8.0 ± 0.1^{ac}	1.11 ± 0.04^{a}	1.16 ± 0.08^{defg}	0.67 ± 0.05^{defg}	598 ± 23.7^{b}
	10 - 20	7.8 ± 0.1^{abc}	1.15 ± 0.05^{a}	1.34 ± 0.07^{fg}	0.78 ± 0.04^{fg}	650 ± 16.7^{ab}

Soil bulk density in the study area varied from 1.13 g cm^{-3} to 1.19 g cm^{-3} with a mean value of 1.15 g cm^{-3}. It did not vary significantly among sites for any of the depth or vegetation type.

In domestic lawns, the amount of organic matter was (1.73%) higher than roadside verges (1.19%). Between grass and trees covered area organic matter varies from 1.73 to 1.13% in lawns and from 1.12 to 1.11% in roadside soils.

Table 2 shows distribution of soil carbon for all sites in parameters: soil organic carbon and soil carbon mass. In the study area, soil carbon mass ranged from 598 gCm^{-2} to 897 gCm^{-2}. However, most of the samples contained soil carbon in the range of 598–795 gCm^{-2}. In lawns with trees, a significant increase in soil carbon was observed from

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surface layer (0–10 cm) to deeper layer (11–20 cm) whereas in grass dominated lawns, a decrease in soil carbon was observed with increase in depth. In roadside soils, similar pattern of variation was recorded. In case of tree-dominated sites, presence of large roots and increased microbial activity may be the reason of higher amounts of carbon in the deeper zones of the soil. *Table 3* indicates the eigenvalues of four PCA axes and these axes account for 100% variation in the data. The first axis has 69.53% variance and the second axis accounts for 21.8% of variation with a combined variance score of 91.34%. Three variables (organic matter, organic carbon and carbon mass) explain most of the variation along the first PCA axis with scores of 0.527, 0.528 and 0.527 respectively (*Table 4; Figs. 2* and *3*). Bulk density had the highest score (0.92). It shows that about 96% of 166 variation in the quantity of C stock in soil is due to combined influence of organic matter, 167 soil carbon and bulk density.

Table 3. *Percentage of variance and eigenvalues of PCA axis*

Axes	Axis 1	Axis 2	Axis 3	Axis 4
Eigen values	3.47	1.09	0.43	0.001
Percentage variance of axis				
For each axis	69.53	21.81	8.63	0.04
Cumulative	69.53	91.34	99.97	100

Table 4. *Coefficient values of five soil components with the two PCA axis*

Component No.	Component	Axis 1	Axis 2
1	Soil pH	–0.39781	–0.36299
2	Bulk density	–0.07213	0.92087
3	Soil organic matter	0.52759	–0.09975
4	Soil organic carbon	0.52883	–0.09166
5	Soil carbon mass	0.52776	0.04385

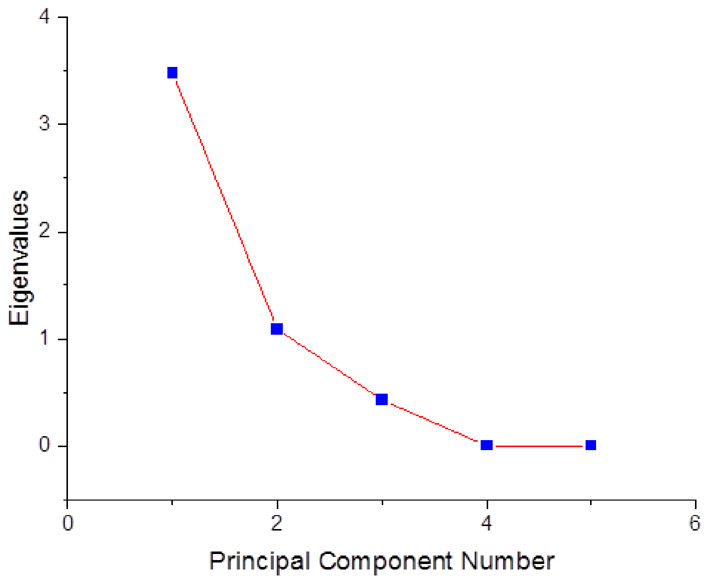

Figure 2. *Scree plot for measured soil components (eigenvalues)*

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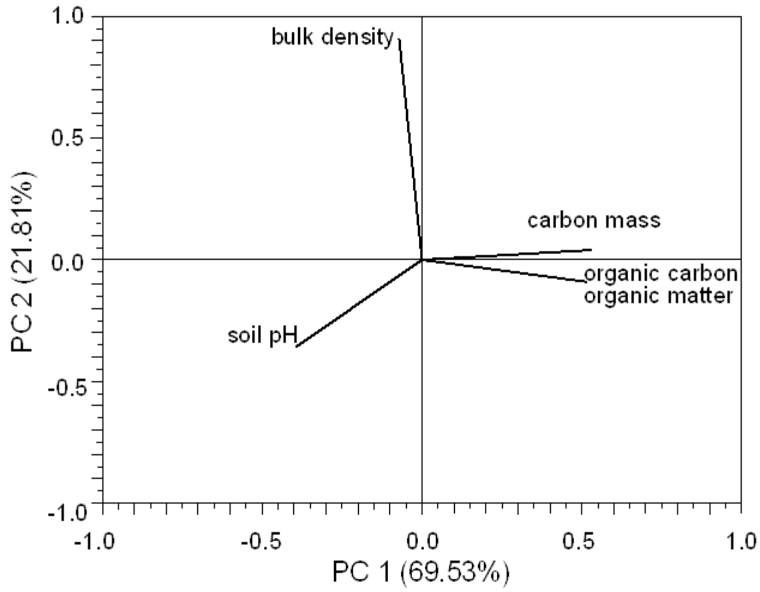

Figure 3. *Biplot distribution of soil factors in the first two PCA axis*

Discussion

This research work has shown that green infrastructure in study area on both sites (domestic lawns and roadside verges; *Table 1*) might have the potential to sequester organic carbon and contribute towards mitigation of impacts of climate change (Wang et al., 2022). This impact is obvious by changing soil characteristic on both studies areas. This was more pronounced in case of domestic as compared to roadside verges. The soils pH changes from neutral to basic (7.4 to 8.2) indicates the increase in organic matter (1.73%), organic carbon (0.99%) and carbon mass (897 gCm^{-2}). Similar results were reported by Contosta et al. (2020). This ultimately enhanced the production of different humic substances. It may be due to better management (fertilization, irrigation) practices in domestic lawns than roadside soils. Further, it can be attributed to the increase in organic matter of the soils at deeper zones with enhanced microbial degradation and production of different humic acids (Song et al., 2014). Bulk density remained same among sites for any of the depth or vegetation type. It should be mentioned that the different bulk densities, and therefore carbon storage, of the investigated urban soils can influence the possible dispersion of metals and arsenic, as found in the Liverpool city study (Beesley et al., 2020).

This study supports other investigations of role of plant and soils of urban lawns and roadside vegetation in carbon sequestration (Jobbagy and Jackson, 2000; Velasco et al., 2016; Sapkota et al., 2020). In case of tree-dominated sites, presence of large roots and increased microbial activity may be the reason of higher amounts of carbon in the deeper zones of the soil as discussed by Rolando et al. (2021). The soils in the study area have low soil organic matter because of arid climate and high (98°C) temperature. These levels exceed the normal limits of soil organic matter (0.8–1.0%) found in the region (Bajwa, 1990). Scanty plant cover and low microbial degradation of biomass contribute towards low fertility of soils (Lal, 2004; Jobbágy and Jackson, 2000). Our study confirmed that these habitats are also important for carbon storage. It is therefore important that domestic lawns and roadside verges are managed and maintained with vegetation cover (Wei et al., 2022).

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The survey and sampling in this research was carried out in early summer when precipitation is low and season was dry for few months. In the Punjab, the major part of rain fall occurs in monsoon season (July–October), and there is possibility of enhanced growth of herbaceous flora in the region. Zubair et al. (2022) suggests that assessment of carbon sequestration in different seasons may be affected by varying seasonal factors such as rainfall, temperature variation and plant growth patterns. So, carbon sequestration may have varying rates and levels during a year (Chen et al., 2021). To achieve an objective and realistic assessment, itis proposed to have a more detailed and long-term studies on carbon sequestration in urban ecosystems.

Another factor affecting soil carbon storage is the nature and composition of urban flora of domestic lawns and roadside verges. According to Li et al. (2022) in warm and arid regions, herbaceous plants and grass species have high root to shoot ratio and possess greater fine, shallow root system which add organic matter and biomass to soil.

In this study, roadside verges showed lower levels of soil organic matter and organic carbon. In roadside habitats, disturbance is a major factor affecting roadside plant and soils. Due to various factors such as physical disturbance, pollution, invasive species and lack of management, carbon sequestration may be hampered in roadside verges.

Conclusion

Greater focus on the ecological service of green structures are obvious in the present time. To address this issue, we measured carbon in soils from different functional green structures in Sahiwal city. Soil samples were collected from domestic lawns and roadside verges at two depths separately (0–10 cm, 11–20 cm) with data of trees and grass cover. The soil samples were analyzed for soil pH, bulk density, organic matter, organic carbon, and carbon mass. The soils pH was around 8 indicating their alkaline nature. Bulk density was higher in lawn soils that of roadside soils. The soil depth had no significant effect on pH and bulk density. Organic matter in lawn soils ranged from 0.8 to 2.0% (mean 1.48%) and in roadside soils, it ranged from 0.7 to 1.9% (mean 1.2%). In grass turf soils surface samples had higher levels of organic matter and organic carbon whereas, under trees sub-surface samples had higher amount of organic matter and soil organic carbon. There was considerable variation in soil organic carbon from both habitats and the highest organic carbon values were observed in lawns at 15 cm depth and lowest in the surface soils of roadside verges. Overlooked habitats of green structures such as lawns and borders appear to be important for soil carbon accumulation.

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