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Research Article

Assessment of Carbon Sequestration Potential of Agroforestry System in Pothwar: Opportunities and Challenges

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ABSTRACT

Agroforestry has been recommended as a carbon sequester for the region where carbon emission is prominent. Agroforestry is acknowledged as a natural approach to carbon sequestration, playing a crucial role in enhancing carbon sinks. In Pakistan, agroforestry practices have maximized the sinks of carbon on higher level playing a vital role in mitigation of climate change. The current research work focused on the role of agroforestry systems in carbon mitigation. Agroforestry provides various opportunities to fulfill the objectives of the climate adaptation. During our research, A focused on the biomass of the trees, carbon sequestration potential in agroforestry practices at rural and urban sites. Industries and urbanization are the foremost carbon emission sources in the surroundings. Recently the nature-based solution has promoted to provide solution to the climatic adaptations. The results depicted that *Dalbergia sissoo* showed higher concentration of carbon in the urban sites (2.58, 0.56, and 4.57 Mg ha⁻¹) and outside sites from the urban vicinity. In terms of total carbon stock and carbon sequestration, *Syzygium cumini* and *Acacia nilotica* were the most prominent species within urban sites, with values of 2.82 and 10.32 Mg ha⁻¹, respectively, and 3.78 and 13.5 Mg ha⁻¹ in rural sites. Conversely, *Eucalyptus camaldulensis* exhibited higher carbon stock and sequestration values in rural vicinity sites, showing 7.83 and 28.70 Mg ha⁻¹. Sites outside the urban vicinity generally had lower carbon stock and sequestration values. Among the trees studied, *Dalbergia sissoo* was the most dominant in the urban vicinity with values of 0.97 and 3.54 Mg ha⁻¹. In Chakwal, *Ficus religiosa* showed notable values of 1.26 and 4.63 Mg ha⁻¹, while in the cosmetic industry sector, *Vachellia nilotica* had the highest values, 2.51 and 9.19 Mg ha⁻¹, compared to other species. Analysis of belowground biomass and carbon storage revealed a decrease in soil carbon with increasing depth, with the highest soil carbon stock found at a 0–20 cm depth both inside and outside the industries. The study concludes that agroforestry practices within and around various rural and urban sites hold significant potential for mitigating air emissions.

Keywords: Carbon sequestration, Air pollution, Rural, Urban, Pothwar.



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INTRODUCTION

Agroforestry is termed as the strategy of land utilization that has the potential to address the future challenges of the environment. Agroforestry is considered any land utilization practice involving the integration of crops along the forest trees. The term agroforestry comprises various systems, including agri-silviculture, silvo-pastoral, and agro-silvo-pastoral. However, most farmers fail to understand the agroforestry systems as a well-defined form of farming and land utilization. The agroforestry approach exhibits sustainability by offering ecosystem services such as climate change mitigation and benefits small-scale landholders. There is an

increasing interest in examining how non-state actors might help accelerate the adoption of agroforestry practices and their potential contributions to this process. According to the Intergovernmental Panel on Climate Change, storing carbon in soils is recognized as a significant strategy for reducing greenhouse gas (GHG) emissions (Chazdon et al., 2016). Following the widespread conversion of agricultural land in many regions, the carbon stocks have undergone significant depletion, resulting in a potential reservoir for CO₂ removal from the atmosphere. To augment the organic matter level in soil, an enhanced management practice will be required (Akpoti et al., 2019).

Agroforestry is a strategy that effectively fulfills yield requirements of the farmers and landowners while offering environmental advantages to society. According to the Asian Agroforestry Training Centre (AFTA, 2021), it can be defined as a meticulously planned land management approach that aims to maximize the advantages derived from integration of trees with the crops, thereby harnessing the potential of biological interactions. As per the USDA National Agroforestry Centre, the current agroforestry practices in North America encompass five fundamental types, including windbreaks, silvopasture, alley cropping, forest farming and riparian buffers. The range of choices offered to landowners within each agroforestry practice varies depending on their objectives. It includes the desire to optimize the yield of crops, livestock, fodder, or trees (Baig et al., 2021). The primary issue for agroforestry practitioners is to strike a balance between optimizing capacity of the farming systems and preserving the associated environmental advantages. This delicate task is crucial for promoting sustainable agriculture and agro-ecosystems (Folefack and Darr, 2021).

Carbon stocking in forest ecosystems encompasses various elements, such as biomass C and soil. The overall carbon pool inside the ecosystem is substantial and remains in a state of dynamic balance with its surrounding environment (Peichl et al., 2012). Conversion of land use leads to disturbance within the ecosystem impacting carbon flow and stocks. The conversion of forested areas into agricultural ecosystems significantly impacts various soil parameters enhancing concentration and stock of soil organic carbon. Conversion of agricultural land use consistently minimizes soil organic carbon stock often ranging from 20 to 50%. The reduction of soil organic carbon reserves can be ascribed to various factors (Dawoe, 2009).

The observed rise in atmospheric CO₂ concentration levels can be mostly attributed to the discharge of CO₂ from industrialized activities and power generation. Methods of direct carbon sequestration, such as geological injection, possess significant storage capacity. One potential strategy for mitigating emissions is biological carbon mitigation from the atmosphere (Fernandino et al., 2018). It involves (CO₂) utilization emitted from sources, such as flue gases, to foster the growth of photosynthetic autotrophic organisms. The generated biomass can be subsequently transformed into biofuels, bio-chemicals, food, or animal feed. These valuable secondary products generate income that can be utilized to fund the process of carbon mitigation (Rajkhowa and Sarma, 2021).

Various organizations working on climate change mitigation mostly prioritize tree plantation to sequester carbon from the atmosphere (Ali et al., 2024). Globally, it is observed that plantations have resulted in stream flow reduction by an average of 227 millimeters per year showing a 52% decline. Furthermore, 13% of streams experienced full drying for a minimum duration of one year (Chausson et al., 2020). The findings from regional modeling of U.S. plantation scenarios indicate counterbalancing the water losses is improbable. Plantations have the potential to contribute to groundwater regulation and recharge and upwelling processes (Pawson et al., 2013).

Agroforestry is a prominent illustration of agroecological praxis, contributing to food productivity and also offering various advantages to society in the form of multi-varied products (Sheppard et al., 2020). Agroforestry systems exemplify mixed species cropping systems that enhance "planned biodiversity" in contrast to the monocultures. Intercropping, hence influence the presence of "associated biodiversity" as well as the diversity of microbes, plants, and animals (Kassam et al., 2020).

Although restoration of damaged natural forests and carbon sequestration through afforestation have long been identified as an effective method for climate change mitigation. Agroforestry improves ecosystem resilience to the adverse effects of climate change. The effectiveness of agroforestry systems in carbon storage is influenced by both environmental conditions and socio-economic factors. Agroforestry systems can sequester over 70 Mg/ha of carbon in the top 20 cm of soil, but their capacity varies based on species, location, and the structure of its components (Mutuo et al., 2015; Newaj and Dhyani, 2008; Albrech and Kandji, 2003).

Various researcher has observed during their studies that urban tree planting is a super solution for the removal of air pollutants (Bridgewater, 2018). Agroforestry at urban sites is considered as well-reputed in contributing towards environment quality maintenance (Kabisch et al., 2018). The majority of scientists depicted that urban agroforestry practices help in maximum carbon sequestration potential and mitigation of environmental pollution and climate

change mitigation (Hewitt et al., 2020, Carstens and Amer, 2019). It is also observed that the carbon fixation potential of trees makes them effective for providing quality air due carbon sequestration (Sæbø et al., 2017, Bealey et al., 2007, Escobedo and Nowak, 2009). Various studies showed that the urban agroforestry practices have high carbon sequestration potential in the urban sites (Bealey et al., 2007, Escobedo, and Nowak, 2009). Gopalakrishnan et al. (2019) observed that agroforestry plays a vital role in eliminating NO_2 and O_3 through the absorption and diffusion process causing a gradual decrease in pollutant concentration. Escobedo and Nowak, (2009) also depicted that urban practices of planting are more feasible in the absorption of various pollutants from the atmosphere. Alonso et al. (2011) observed during their research study that urban trees work as carbon and O_3 sinks in our daily life. Moreover, the economic efficiency of agroforestry systems in urban and rural sites was compared with other conventional techniques to mitigate air pollution and understand the carbon sequestration potential (Bealey et al., 2007, Alonso et al., 2011).

Agroforestry's role in carbon sequestration around various sites has been observed by numerous scientists (McHale, 2007). However, to my understanding, the role of agroforestry in carbon sequestration at urban, peri urban, and rural sites in Pakistani context is not yet explored. The current study focuses on the carbon sequestration potential of agroforestry systems in the vicinity of rural and urban sites. The current study objectives at Pothwar regions were to quantify the agroforestry systems and amount of carbon sequestration at rural and urban agroforestry sites. Furthermore, the study aims to understand the above and below-ground biomass in rural and urban agroforestry sites. Moreover, the study aimed at the perceptions of local communities' understanding of agroforestry concepts in Pakistan.

MATERIAL AND METHODS

Due to current global warming and climatic variation, tree planting plays a vital role as a carbon sink and environment maintenance. The recent study focused on carbon sequestration potential of various plants in rural and urban sites in Pothwar plateau in order to predict the amount of stored carbon, above and below ground biomass of plants and their relationship with various sites of Pothwar plateau.

Study Area

Pothwar Plateau spans from approximately 30 to 34 degrees North latitude and 70 to 74 degrees East longitude. The region can be characterized from the climatic point of view into two major zones. The first sub-zone, termed sub-humid, covers districts Rawalpindi and Islamabad in the northern side of Punjab province (Shirazi, 2020). Islamabad region mostly receives an annual rainfall of about 500 to 1000 mm. The second sub-zone lies southwest of Islamabad and includes the districts of Attock, Chakwal, and Jhelum regions. This region experiences a semi-arid climate, with annual rainfall averaging between 300 to 500 mm. These regions are comprised of a variety of weathers including the cold season, spanning from November to March: the hot season occurs from April to June; the monsoon weather starts from July to September ranging up to 1700 mm. Sometimes the remaining two months of October and November also have a span of post monsoon rainfalls. Meteorological data on maximum and minimum temperatures (in degrees Celsius) along with rainfall amounts (in millimeters) were gathered from the meteorological station situated at PMAS AAUR. Rawalpindi district, is classified under the Köppen–Geiger system, experiences arid and semi-arid climatic conditions.

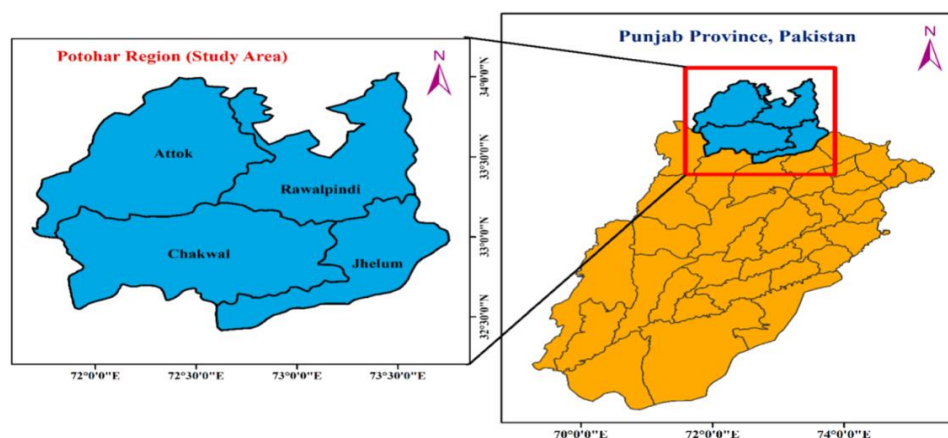


Figure 1. Study Area map (Pothwar region)

Site selection

The selected sites were chosen to evaluate the actual carbon sequestration levels in agroforestry sites, encompassing both above-ground and below-ground biomass. Two major sites were selected in each study area including Islamabad, Rawalpindi, Jehlum, Chakwal, and Attock. The rapid increase in population and urban development has led to the emergence of new housing societies surrounding the city. The study was structured to examine carbon sequestration across rural, urban, and peri-urban areas within the study sites. This mix of population growth, housing developments, and agroforestry sites prompted researchers to select these study sites to explore the roles of agroforestry and urban green spaces on a local scale in the Pothwar region.

Sampling methodology

The research study area was divided into different sites, and an initial survey was conducted to gather information on agroforestry systems in the Pothwar region. Furthermore, the study facilitated the estimation of carbon sequestration potential across the region using various methodologies. The study area was divided into four major strata i.e. Rawalpindi/Islamabad, Jhelum, Attock, and Chakwal composed of different agroforestry systems in a 500 m² radius including both urban and rural sites. The study aimed to explore the perspectives of respondents using a snowball sampling technique. The study covered several key locations including Islamabad, Rawalpindi, Attock, Chakwal, and Jhelum, further categorized into urban and rural areas. Notable individuals from each district were contacted to identify farmers actively practicing Agroforestry practices. The use of a proper sampling frame was essential to ensure that all potential respondents had an equal opportunity to be selected, thereby enhancing the validity of the findings.

Data collection and measurement

Dia and height measurement

The data collection process involved selecting trees within a 500-meter radius. An assessment of height occurred for every tree utilizing Suunto clinometer methods along with conventional measurements while steel tape assessed their girth dimensions. Soil sampling occurred across multiple depths through the use of a soil auger device.

Carbon Estimation of Above and Belowground Biomass

The study conducted field surveys to obtain measurements for species diameter and height. The study measured tree circumferences at a height of 1.37 meters from the ground level while recording the total height of trees distributed across urban and rural 500-square meter sites. The study computed tree biomass based on established allometric equations found in the literature where suitable adjustments managed logarithmic bias (refer to Table 1). All tree species demonstrated an estimated belowground biomass value amounting to 26% of their aboveground biomass (Cairns et al., 1997; Kanime et al., 2013; Akbar et al., 2014). Individual tree biomass was then aggregated into plot biomass, hectare biomass, and total carbon stock per hectare. Carbon content was determined assuming dry mass contained 48.1% carbon (0.48) (Thomas et al., 2012; Kanime et al., 2013). CO₂ sequestration was calculated by multiplying tree carbon by a factor of 3.66 (Afzal and Akeela, 2013). To estimate above-ground tree biomass in the study area, species-specific allometric equations were utilized. These equations relate DBH and height to estimate biomass. The equation used for calculating carbon sequestration in trees is as follows:

Carbon sequestration (kg/ha/year) = (tree biomass carbon + understory carbon + soil carbon) at final measurement - (tree biomass carbon + understory carbon + soil carbon) at baseline.

Table 1. Equations for estimating aboveground biomass of various tree

Species	Equation	Citation
<i>Azadirachta indica</i>	$10^{-1.0646} * D^2 H^{0.9098}$	(Ravindranath and Ostwald, 2007)
<i>Dalbergia sissoo</i>	$e^{-3.1141} * D^2 H^{0.9719}$	(Brown, et al., 1989)
<i>Vachellia nilotica</i>	$10^{-1.0646} * D^2 H^{0.9098}$	(Ravindranath and Ostwald, 2007)
<i>E. camaldulensis</i>	$e^{-2.2660} * D^{2.4663}$	(Hawkins and Biomass, 1987)
<i>Albizia lebbek</i>	$10^{-1.0646} * D^2 H^{0.9098}$	(Ravindranath and Ostwald, 2007)
<i>Syzygium cumini</i>	$10^{-1.2066} * D^2 H^{0.9872}$	(Rai et al., 2018)
<i>Moringa oleifera</i>	$e^{-3.1141} * D^2 H^{0.9719}$	(Brown, et al., 1989)

D = Diameter (cm) and H = Height (m).

Equations for estimating aboveground biomass of various tree species have been adjusted to directly calculate component biomass in kilograms. If belowground biomass equations for a species are unavailable, it is assumed that belowground biomass constitutes 26% of the aboveground biomass (Akbar et al 2014; Kanime et al., 2013).

Soil Sampling and Analysis

Soil samples were collected at two depths, 0–15 cm and 15–30 cm, near trees of which the diameter and height were identified within and outside 500 square meters of each study site from all four directions. A soil auger facilitated the collection of four samples per site to form a composite sample. In total, 300 samples were collected from both depths and stored in polythene bags for analysis at Pir Mehr Ali Shah Arid Agriculture University, Rawalpindi. Bulk density was determined using a 100 cm³ stainless steel cylinder. Following air-drying, samples were sieved through a 2mm sieve. Organic carbon content was quantified using the Walkley–Black method. Subsequently, the values for soil depth, bulk density, and organic carbon percentage were multiplied to compute the soil carbon content per hectare (Sá et al., 2001).

$$\text{SOC} = \text{OC}\% \times \text{Bulk density (g cm}^{-3}\text{)} \times \text{sampling depth (cm)}$$

Statistical Analysis

The study utilized Statistics 8.1 software and SPSS for descriptive statistics and performed a one-way ANOVA with LSD (least significant difference) tests between means, was used to assess differences among all study sites. Despite these challenges, we successfully collected, tabulated, and statistically analyzed the data using descriptive analysis i.e. frequency. After data collection from all villages, the data was organized using MS Office Excel 2013 and then analyzed using IBM SPSS 21 for descriptive statistics (Table 3.2) (Aziz et al., 2017; Yadav et al., 2016). Descriptive statistics were calculated using Statistics 8.1 software (Statistical Package). Additionally, one-way ANOVA with LSD (Least Significant Difference) was used to evaluate differences between means across all study sites (Zubair et al., 2022).

RESULTS

The current research reveals the distinct income profitability understanding between agroforestry practitioners and non-agroforestry users. The research clearly shows that agroforestry practitioners understand its advantages and trust the tangible value it delivers better than the non-agroforestry users. Firstly the study provides an overview of personal and demographic characteristics for farmers. The study evaluates agroforestry conditions while examining monetary benefits of agroforestry systems alongside the process of carbon sequestration and farmer opinions on agroforestry practices.

Demographic Information

The current study focused on demographics of the locals on prior basis. The purpose of the demographics was to assess the revenue generation of the locals and the percentage of the locals depending on agroforestry practices. When the locals were inquired regarding the land holding, first they were a bit skeptical to answer the questions, but later on when they were guaranteed that the survey is as research work then they answered properly. When the local were enquired regarding land holding sizes, most (30%) of the respondents replied that they have 20-30 Acres of land. Similarly, the remaining respondents' results showed least land holding capacity.

Table 2. Perceived responses on land holding and usage

Variable	Categories	Percentage of Respondents
Land Holding Size	10Acre	7
	10-20 Acre	23
	20-30 Acre	30
	30-40 Acre	20
	Above 40 Acre	20
Land usage	Agriculture crops only	45
	Livestock only	6
	Tree Plantation only	4
	Agroforestry	40
Tenancy Status	Owner/Cultivator	17
	Owner cum Tenacy	43
	Tenacy	23

Perceptions on Agroforestry practice

The respondents were asked regarding the locals practice of agroforestry, majority (53%) of the respondents stated that they are not practicing the agroforestry. Some 47% of the respondents stated that they practice agroforestry. Empirical evidence of people more than 40% were practicing agroforestry in their lands.

Agroforestry systems in Pothwar region

The respondents were asked about the agroforestry system that were practiced in the study sites. The respondents who were in the favor of the agroforestry practices stated that they mostly prefer to do boundary plantation on their lands. However, some of the respondents stated that they focus on alley cropping. When the locals were asked about the practice of number of trees on their local lands, most of the respondents said that they have planted more than 20 trees on their agricultural farms. The second highest amount of the trees by the local on agricultural farms was about less than 200. Some of the respondents stated that they have planted less than 100 trees on their farm lands. A least number of the respondents stated that they plant less than 50 plants on their piece of lands.

Perceptions of tree selection

The respondents were enquired for the reason of plantation of trees, majority of the respondents stated that they plant various types of trees to provide fruits and fuel wood. Additionally, it was observed that people were utilizing the trees in the croplands as feed for the animals they raised.

The locals were asked regarding their least preferring to agroforestry practices, majority of the respondents stated that the trees planted along the agricultural crops compete with the agricultural crops. Therefore, most of the locals are not in the favor of agroforestry practices. The respondents replied on the question that were not expected and were pretty new for the surveyors. They stated that don't prefer agroforestry practices because of least interest, not enough spaces, less availability, occupy land, take much time, social dispute, degrade land, too much work, less water availability, forest management, tree compete with the agricultural crop, and lack of market demand. These were major reasons that locals have mentioned for the lack of interest in agroforestry.

Table 3. Perceived responses on agroforestry practices

Variable	Categories	Percentage of Respondents
Practice of Agroforestry	Yes	45
	No	55
Agroforestry System Practiced	Boundary plantation	80
	Alley plantation	2
	Mixed plantation	12
Avg num of trees in the farmlands	<20	40
	>50	5
	>100	30
	>200	35
Reason of Planting Tree	provide shelter or shade	5
	provide food/fruit	30
	rehabilitate degrade land	5
	Provide Fuel wood	30
	Provide Timber	10
	Provide forage	20
Reasons of Not Planting	None	0
	not interested tree	5
	not enough area	10
	less availability of water	15
	occupy land for another crop	5
	take too long to grow	3
	social dispute cause browsing	3
	degrade the land	5
	too much work	2
	insufficient rainfall	5
	forest management problem	5
	tree compete with crop	25

	no guaranteed market	5
Sources of Information Regarding Agroforestry	Radio	48
	T. V	12
	Forestry Department	5
	Neighbors	35
	Social media	5

When the respondents were asked about the species preferences, the responses were quite interesting as describing the trend of trees and their status on the owner’s lands. The targeted area depicted the major use and presence of *Accacia nilotica*. About 35% of the people were planting these trees in and around the farmlands. The other major dominance was of *Euclyptus camaldulensis* and Jaman (*Syzygioum cumini*), and Shisham (*Dalbergia sissoo*) consecutively.

Some other species that were preferred by the locals on minor basis included Albizia species, Neem, Date palm, ziziphus species, and Moringa specie consecutively.

Table 4. Perceived responses on Agroforestry species

Plant species	Status of occurrence
Siris <i>Albizia lebbek</i> , <i>Albizia procera</i>	13
<i>Euclyptus camaldulensis</i> , Jaman (<i>Syzygioum cumini</i>)	25
Shisham <i>Dalbergia sissoo</i>	16
Ber <i>Ziziphus muritiana</i> , <i>Zizyphus numularia</i>	3
Kikar <i>Accacia nilotica</i>	35
Date palm, Neem	6
Moringa <i>Moringa olifera</i>	2

Impacts of Agroforestry on income

The respondents provided detailed information about the expected income from agroforestry products when asked about their estimated earnings. Among respondents (20%) we found a surprising response that demonstrated agroforestry adoption led to minor increases in their farm crops. A total of 18% of respondents noted that their animals produced more milk after adopting tree fodder as feeding material.

When the respondents were acquired regarding the impacts of agroforestry practices, majority (60%) of the locals were in the favor using forest trees as wind breaks around the agricultural crops helping to combat the strong winds, A minority of 2% from the total respondents indicated that trees enhance soil content while the others disagreed. Using agroforestry methods the majority of participants reported no income changes although 20% indicated no changes in their financial status (Table 5).

Table 5. Agro-Forestry and Perceived Income

Variable	Categories	Percentage of Respondents
Benefit Perceived from Agroforestry	Increased Crop Production	20
	Increased milk production	18
	Wind break	60
	Improves Soil fertility	2
Income Generated from Agro Forestry Practices	>20 percent	30
	>50 percent	25
	>75 percent	15
	100 percent	10
	No change	20

Agroforestry Product harvested from the farm	Fodder and Forage sale	5
	Firewood Sale	30
	Timber Sale	5
	Charcoal Sale	30
	Fruit and Vegetable sale	10

Agroforestry impacts on biotic and abiotic factors

When the respondents were enquired regarding the biotic and abiotic factors, the locals were not that much aware of the biotic and abiotic interferences. However, upon long discussion the locals' responses on the questions were outstanding. The local communities (43%) with the agroforestry practices stated that they follow agroforestry in order to get revenue from selling the forest trees in the markets.

About 27% of the respondents stated that the agroforestry practices help in carbon sequestration phenomenon. Some (19%) of the respondents stated that the agroforestry is mostly helpful in increasing the tree cover. Furthermore, a least number (7%) and (4%) of the respondents stated that agroforestry practices are helpful in land rehabilitation and conservation of soil from various types of erosion.

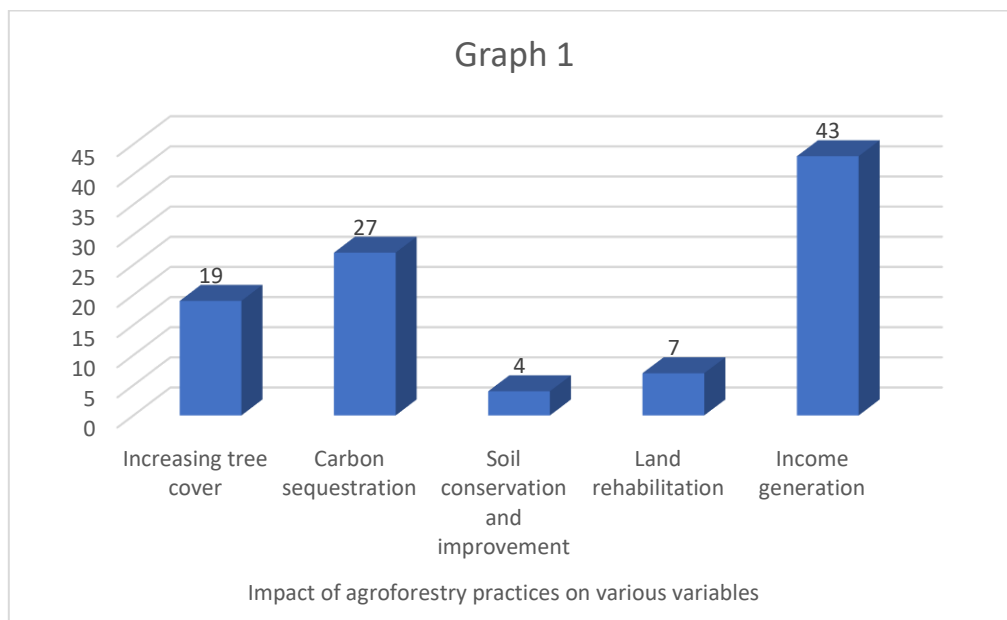


Figure 2. Perceived responses on impact of agroforestry

The total mean biomass exhibited significant variation among tree species located inside and outside the selected sites across all cities: Jhelum, Attock, Chakwal, Rawalpindi, and Islamabad (Table). Generally, the biomass of both aboveground and belowground was higher for trees situated within or near urban areas compared to those in rural areas. Inside the cities, the maximum total biomass values recorded were 3.41 Mg ha⁻¹ in Jhelum, 8.54 Mg ha⁻¹ in Chakwal, and 9.16 Mg ha⁻¹ in Attock, with the highest being 21.80 Mg ha⁻¹ for *Acacia nilotica*, *Syzygium cumini*, *Ficus* species, and *Eucalyptus camaldulensis*, respectively. Conversely, outside the cities, the total biomass ranged from 1.65 Mg ha⁻¹ to 4.91 Mg ha⁻¹ across all cities. In Jhelum, the maximum total biomass outside the city was found in *Eucalyptus camaldulensis* (2.39 Mg ha⁻¹), while the minimum was recorded for *Conocarpus erectus* (0.09 Mg ha⁻¹). Similarly, outside the cities in Chakwal, Attock, Rawalpindi, and Islamabad, higher biomass values were observed for *Syzygium cumini*, *Acacia nilotica*, and *Vachellia nilotica* (3.93, 5.22, and 5.20 Mg ha⁻¹, respectively), whereas the lowest biomass was measured for *Melia azedarach*, *Albizia lebeck* (0.45 Mg ha⁻¹, 0.59 Mg ha⁻¹, and 0.09 Mg ha⁻¹). Furthermore, the highest aboveground biomass was observed in *Eucalyptus camaldulensis* in Jhelum, Rawalpindi, and Islamabad, and the highest belowground biomass was also recorded for *Eucalyptus camaldulensis* in Jhelum, as shown in the Table 6.

Table 6. Biomass estimation of various tree species in agroforestry practices along various gradients of Jhelum, Chakwal, Attock, Rawalpindi and Islamabad rural and urban sites.

Cities	Species	Inside Urban vicinity			Outside Rural vicinity		
		AGZ.mgha 1	BGB.mgha 1	TB.mgha 1	AGB.mgha 1	BGB.mgha 1	TB.mg/ha 1
Jhelum	<i>C.erectus</i>	0.16 ^a ±0.04	0.04 ^a ±0.02	0.20 ^a ±0.08	0.07 ^a ±0.04	0.02±0.00	0.09 ±0.04
	<i>D .sissoo</i>	0.38 ^b ± 0.15	0.10 ^b ± 0.03	0.48 b ±0.21	1.62 a ±1.22	0.42 a ± 0.32	2.04 a ± 1.54
	<i>E.camaldul nsis</i>	13.94a±5. 37	4.36 ^a ±1.36	1.30a±6. 73	2.03 b± 0.51	0.36 b ± 0.13	2.39 ^b ± 0.64
	<i>A.nilotica</i>	2.88a ± 0.65	0.53 a ± 0.16	3.41 a± 0.75	1.18 ab±0.89	0.47 ab±0.27	1.65 ^{ab} ±1.1 6
	<i>M.azdarcha</i>	2.72 ^a ±1.22	0.38 ^a ±0.25	3.10 ^a ±1. 27	0.94 ^b ±0.79	0.15 ^b ±0.9	1.09 ^b ±0.8 8
	<i>Poplar species</i>	1.07 ^b ±0.86	0.38 ^b ±0.21	1.45 ^b ±1. 07	0.04 ^b ±0.02	0.03 ^b ±0.00	0.07 ^b ±0.0 0
	<i>S. cumini</i>	1.73 ^a ±0.66	0.44 ^b ± 0.17	2.19 ^a ±0. 86	1.62ab±0. 86	0.29 ab±0.22	1.91 ^{ab} ±1.0 8
Chakwal	<i>C.erectus</i>	0.18 ^a ±0.06	0.05 ^a ±0.03	0.23 ^a ±0.11	0.11 ^a ±0.05	0.02±0.01	0.13 ±0.06
	<i>D .sissoo</i>	0.66 ^{ab} ± 0.33	0.25 ^{ab} ± 0.15	0.91 ^{ab} ±0 5	0.26 ^b ± 0.22	0.13 ^b ± 0.11	0.39 ^b ± 0.33
	<i>E.camaldul nsis</i>	11.94 ^a ±5.3 5	3.16 ^a ±1.41	1.1a±6.7 6	1.13 b± 0.43	0.26 b ± 0.10	1.39 b ± 0.54
	<i>M.azdarcha</i>	0.87a±0.2 4	0.14a±0.1 3	1.01 ^a ±0. 37	0.37±0.15	0.08 ^a ±0.05	0.45 ^a ±0.2 0
	<i>Poplar species</i>	1.06 ^b ±0.84	0.48 ^b ±0.37	1.54 ^b ±1. 23	0.97 ^b ±0.80	0.27 ^a ±0.15	1.25 ^a ±0.9 5
	<i>S. cumini</i>	7.43 ^a ± 3.75	1.11 ^b ± 0.85	8.54a ±4.62	3.37 ^{ab} ±1.8 6	0.56 ^{ab} ±0.4 2	3.93 ^{ab} ±2.2 8
	<i>A. nilotica</i>	2.08 ^a ±1.33	0.98 ^a ±0.84	3.06 ^a ±0. 81	1.09 ^a ±0.85	0.67 ^a ±0.55	1.76 ^a ±1.4 0
Attock	<i>D.sissoo</i>	0.56b±0.4 3	0.17 b ± 0.12	0.73 ^b ±0.55	0.54 ^b ± 0.45	0.11 ^b ± 0.08	0.65 ^b ± 0.53
	<i>A.lebbeck</i>	0.44 ^a ±0.34	0.09 ^a ±0.03	0.53 ^a ±0. 37	0.21 ^b ±0.15	0.02 ^b ±0.01	0.23 ^a ±0.1 6
	<i>A. nilotica</i>	0.76 ^b ±0.64	0.20 ^b ± 0.14	0.96 ^b ± 0.80	4.15 a ± 3.06	1.07 a ± 0.79	5.22 a ± 3.85
	<i>A.indica</i>	0.18 b ± 0.06	0.06 b ± 0.02	0.24 ^b ± 0.08	0.22 ^b ± 0.06	0.05 b ± 0.02	0.27 b ± 0.08
	<i>T.arjuna</i>	0.78 ^b ±0.66	0.11 ^b ±0.07	0.89 ^b ±0. 72	0.35 ^b ±0.26	0.06 ^b ±0.02	0.41 ^b ±0.2 8
	<i>A.lebbeck</i>	0.95 ^a ±0.65	0.19 ^a ±0.8	01.14 ^a ±0 .77	0.47 ^a ±0.31	0.12 ^a ±0.09	0.59 ^a ±0.4 0
	<i>C.citrinus</i>	0.22 ^b ± 0.05	0.09 ^b ± 0.02	0.31 ^b ± 0.06	0.15 ^b ± 0.05	0.03 ^b ± 0.01	0.18 ± 0.06
	<i>Ficus species</i>	7.07 ^a ±3.22	2.09 ^a ±1.14	9.16 ^a ±4. 37	3.44 ^a ±1.87	0.24 ^a ±0.14	3.68 ^a ±2.01
Rawalpindi /Islamabad	<i>D.sissoo</i>	0.79 ^{ab} ± 0.64	0.16 ^{ab} ± 0.12	0.95 ^{ab} ±0.54	0.57 ^{ab} ± 0.39	0.11 ^{ab} ± 0.9	0.68 ^{ab} ± 0.48

	<i>A.lebbeck</i>	1.04 ^a ±0.76	0.41 ^a ±0.32	1.45 ^a ±0.98	0.08 ^a ±0.02	0.01 ^b ±0.00	0.09 ^a ±0.02
	<i>E.camaldulnsis</i>	18.04 ^a ±6.58	3.76 ^a ± 1.38	21.80 ^a ±7.98	4.55 ^a ±1.21	0.36 ^b ± 0.20	4.91 ^b ± 1.41
	<i>C.citrinus</i>	1.87 ^a ±0.85	0.38 ^a ±0.12	2.25 ^a ±0.95	1.03 ^a ±0.55	0.16 ^b ±0.05	1.19 ^a ±0.60
	<i>A.indica</i>	0.44 ^a ±0.24	0.09 ^a ±0.04	0.53 ^a ±0.36	0.37 ^a ±0.15	0.05 ^b ±0.00	0.42 ^a ±0.15
	<i>A. nilotica</i>	0.87 ^b ± 0.68	0.29 ^b ± 0.17	1.16 ^b ± 0.87	4.14 ^a ±3.06	1.06 ^a ± 0.79	5.20 ^a ± 3.85
	<i>Ficus species</i>	0.81 ^a ±0.67	0.33 ^a ±0.22	1.14 ^a ±0.91	1.64 ^a ±1.52	0.42 ^b ±0.05	2.06 ^a ±0.05

Means with similar letters are not statistically different at p=0.05.

ABG = Above ground biomass, BGB = Below ground biomass, D = Diameter at Breast height, d = Diameter at 0.3 m above the ground, TB = Total biomass

The aboveground biomass (AGB), belowground biomass (BGB), and total biomass (TB) metrics highlight significant variations in carbon stocks and CO₂ sequestration across different tree species within and outside selected industrial areas. Statistical analyses revealed substantial differences in the aboveground, belowground, and total carbon stocks among tree species (p ≤ 0.05), as shown in Table.

Within Jhelum, Chakwal, Attock, and Rawalpindi/Islamabad, the highest total carbon stock recorded was maximum for *Eucalyptus camaldulensis*, with values of 7.88 Mg ha⁻¹ at Jhelum, 8.83 Mg ha⁻¹ at Chakwal, and 7.83 Mg ha⁻¹ at Rawalpindi/Islamabad. In Attock, however, *Ficus* species had the maximum carbon stock at 2.09 Mg ha⁻¹. Trees such as Poplar outside Jhelum city exhibited a notable carbon stock of 0.99 Mg ha⁻¹, while *Melia azedarach* outside Chakwal showed 0.95 Mg ha⁻¹, and *Acacia nilotica* outside displayed 1.26 Mg ha⁻¹.

Overall, the highest CO₂ sequestration rates were observed for trees within the selected cities, with figures of 4.65 Mg ha⁻¹ yr⁻¹ in Jhelum, 3.09 Mg ha⁻¹ yr⁻¹ in Chakwal, 5.19 Mg ha⁻¹ yr⁻¹ in Attock, and 28.70 Mg ha⁻¹ yr⁻¹ in Rawalpindi/Islamabad. These rates were notably higher compared to those measured outside the cities, as detailed in Table 7.

Table 7. Different tree species carbon composition inside and outside various cities of Pothar regions.

		Inside Urban vicinity				Outside Urban vicinity			
Cities	Species	AGC.mg/ha1	BGC.mg/ha1	TC.mg/ha1	CO2 mg/ha	AGC.mg/ha1	BGC.mg/ha1	TC.mg/ha1	CO2 mg/ha
Jhelum	<i>C.erectus</i>	0.19b±0.08	0.07b±0.02	0.26cd±0.10	0.37b ±0.16	0.78a±0.59	0.21a±0.15	0.99a±0.74	2.65a ± 1.67
	<i>D.sissoo</i>	0.20b±0.09	0.08b±0.03	0.28cd±0.12	0.85cd±0.36	0.76a±0.56	0.19a±0.14	0.95a±0.70	3.59 a ± 2.68
	<i>Euclyptus</i>	6.24a±2.58	1.64a±0.68	7.88a±3.26	27.70a±1.81	0.53b±0.20	0.14b±0.07	0.67b±0.27	2.38 b ± 0.94
	<i>A.nilotica</i>	0.93a±0.28	0.25a±0.07	1.18a±0.35	3.80a±4.30	0.54ab±0.39	0.15ab±0.11	0.69ab±0.51	3.01 ab ± 1.62
	<i>M.azdarcha</i>	0.17b±0.08	0.03b±0.00	0.20b±0.08	0.44±0.017	0.08b±0.03	0.02b±0.00	0.10b±0.03	0.39 b ± 0.26
	<i>Poplar</i>	0.81b±0.20	0.13b±0.05	0.94b±0.25	4.71b±1.24	0.41b±0.34	0.06b±0.03	0.47b±0.37	4.65 b±1.09
	<i>S.cumini</i>	1.09a±0.26	1.34a±0.37	2.34a±0.57	3.73a±4.24	0.44ab±0.40	0.12ab±0.10	0.56ab±0.50	1.90 ab ±1.99

Chakwal	<i>C. erectus</i>	0.26a± 0.10	0.04a ±0.01	0.30a ±0.11	1.26a ± 0.98	0.13a ±0.05	0.02a ±0.00	0.15a± 0.05	0.44b ± 0.26
	<i>D. sissoo</i>	0.28ab±0 .13	0.08ab±. 03	0.36ab±0 .16	1.28ab±0. 54	0.10b± 0.06	0.04b±0. 02	0.14b±0. 08	0.40b ± 0.26
	<i>Euclyptus</i>	7.22a± 2.60	2.61a±0. 70	8.83a±3. 30	29.75a±1 1.99	0.70b ±0.22	0.25b±0. 05	0.95b±0. 27	2.34b ± 0.92
	<i>M. azdarcha</i>	1.22a±.6 1	0.51a±0. 70	1.73a±0. 68	1.17b±0.3 4	0.50b±0. 20	0.15b±0. 07	0.65b±0. 27	3.09a b ± 1.62
	<i>Poplar</i>	0.40b± 0.24	.21a± 0.10	.61a± 0.34	1.34a ± 0.34	0.20b±0. 10	0.13b± 0.05	0.33b±0. 15	0.47 b± 0.26
	<i>S. cumini</i>	0.80a±0. 35	0.22a±0. 08	1.02a±0. 43	11.32a±4. 08	0.60ab±0 .42	0.15ab±0 .11	0.75ab±0 .53	1.38 ab ± 1.85
	<i>A. nilotica</i>	1.09a± 0.65	1.30a± 0.45	1.39a± 1.19	8.36a±5.3 4	0.67ab ±0.35	0.17ab ±0.09	0.84 b±0.44	0.58 ab ± 0.85
Attock	<i>D. sissoo</i>	0.29ab±0 .13	0.08ab±. 04	0.37ab±0 .17	1.25ab±0. 95	0.10b±0. 06	0.03b± 0.01	0.13b± 0.07	0.56b ± 0.26
	<i>A. lebbek</i>	0.44 b±0.23	0.07b±0. 03	0.51b±0. 26	1.68b ±0.85	0.22b±0. 13	0.04 b±0.01	0.26b±0. 14	0.79a ± 0.78
	<i>A. nilotica</i>	0.40b± 0.22	0.19b± 0.08	0.59b± 0.30	1.56b± 0.34	0.29a± 0.16	0.11a± 0.06	0.41a±0. 22	8.19a ± 6.78
	<i>A. indica</i>	0.21ab±0 .16	0.05ab±0 .04	0.26ab±0 .20	0.99ab±0. 73	1.00a± 1.04	0.26a± 0.27	1.26a± 1.31	1.63a ± 0.80
	<i>T. arjuna</i>	0.68 b±0.30	0.11 b±0.06	0.79 b±0.36	1.32b± 1.03	0.36 b±0.17	0.06 b±0.03	0.42b±0. 20	1.44 b±0.8 8
	<i>C. citrinus</i>	0.10b ± 0.03	0.02b± 0.01	0.12b± 0.04	1.40b ±0.55	0.10b± 0.03	0.02b± 0.01	0.13b± 0.04	0.49b ± 0.18
	<i>Ficus spp</i>	1.80 a±0.80	0.29 a±0.20	2.09 a±1.00	5.23b± 1.95	0.82a±0. 65	0.20 a±0.10	1.02 a±0.75	0.88a ± 0.85
Rawalpindi /Islamabad	<i>D. sissoo</i>	0.35b±0. 20	0.10b±0. 06	0.45b± 0.26	1.34b± 0.97	0.25b±0. 13	0.11b± 0.07	0.36a± 0.20	0.98a ± 0.6
	<i>A. lebbek</i>	1.72 a±0.75	0.27 a±0.15	1.99 a±85	5.34a ±1.33	0.84 a±0.40	0.13 a±0.06	0.97 a±0.46	0.73a ± 0.47
	<i>Euclyptus</i>	6.22 a±2.57	1.61a±0. 67	7.83a± 3.24	27.10a±1 1.80	0.50b ± 0.20	0.13b± 0.05	0.63b ±0.25	2.39b ± 0.96
	<i>C. citrinus</i>	0.10b±0. 03	0.03b± 0.01	0.13 b±0.04	0.38 b±0.15	0.08b±0. 04	0.01 b± 0.00	0.9 b± 0.04	0.42 b±0.1 2
	<i>A. indica</i>	0.26 a±0.13	0.04a±0. 02	0.30 a±0.15	1.09ab±0. 73	0.13 a±0.06	0.02 a±0.01	0.15 a±0.07	0.17a ± 0.26
	<i>A. nilotica</i>	1.02a± 0.65	0.90a± 0.81	1.92a± 1.46	8.75b± 3.76	0.56ab±0 .25	0.19ab±0 .09	0.75ab±0 .34	5.19a b± 3.68
	<i>Ficus spp</i>	1.94 a±0.80	0.30 a±0.22	2.24 a±1.02	6.44 a±3.65	0.79 a±0.65	0.13 a±0.03	0.92 a±0.68	0.99a ± 0.92

Means with similar letters are not statistically different at $p=0.05$. Where first and second values represent mean and standard deviation. Moreover, AGC (aboveground carbon), BGC (belowground carbon).

DISCUSSION

Tropical forests are mostly observed on inventory purposes to understand the biomass including above and below ground (Brown and Lugo, 1992) and in Europe (Kauppi et al., 1992). Majority of the studies similar to our studies were developed with the help of finding dbh and height, depicted as common methods for the data inventory purpose (Segura and Kanninen, 2005). Considering the measurement of various trees height, Segura and Kanninen (2005) suggested to develop a specific model that can be used as a single explanatory variable to show the tree species carbon.

Carbon emission is going on the peak due to various anthropogenic activities of human beings. These anthropogenic activities have impact on the atmosphere and the process of photosynthesis mostly impacting on the leaves, branches, roots and stems. It is observed that the anthropogenic activities have high impact on the leaves falling causing impact on the photosynthesis process of plants. The process of falling leaves have high impact on the loss of carbon. However, majority of the trees in the Pothohar regions are deciduous leave causing high damage to the plants. Furthermore, some of the species that are evergreen can be highly affected of the leaf fall occurs. The loss of leaf can be recovered by the upcoming leaves. Nanotechnology enhances carbon sequestration in agroforestry systems like those in Pothwar by improving soil carbon stabilization with nano-biochar and boosting carbon capture efficiency through advanced nanomaterials (Ali et al., 2024).

According to various scientists the biomass conversion to carbon is 2:1 (Dixon et al., 1994). In 1983, Olsen et al., observed that the above ground carbon is stored in values per hectare showed in various vegetation composition. When we compared our rates of carbon sequestration with the amount of *P. caribaea*, the amount of carbon sequestered is much higher in our study as compared to the previous studies. The above ground carbon biomass was showing high concentration of carbon 59 T ha^{-1} however in our study the highest amount of carbon was showed by Shisham (*Dalbergia sissoo*) in the district of Chakwal (Schroeder, 1991).

The current research has three major objectives i.e. to assess the perceptions of local communities on the agroforestry practices. The second objective fulfilled the biomass estimation of various tree species through agroforestry practices. The study also focused on predicting the carbon sequestration potential in various rural and urban sites of the Pothohar region including Rawalpindi, Islamabad, Attock, Jhelum, and Chakwal. The study can also help in prescription of a special help to assess the amount of carbon sequestration. Ketterings et al., (2001) proved during his studies the destruction method of finding the carbon sequestration is not necessary. Therefore, the study results can be applied in other sites where agroforestry systems are applicable.

The current study focused on assessing the capability of various forest trees in agroforestry practices along rural and urban sites in capital of Pakistan and Pothohar regions to understand the role of trees in climate change mitigation. In Pakistan, various agricultural lands can be invested as agroforestry practice to introduce nature-based solutions for the control of carbon emission from various sources. The current research derived that the agroforestry practices have maximum capacity of carbon sequestration generated from various industries and vehicles. The study also perceived that the agroforestry practice in rural and urban sites helps in reduction of air pollution in the vicinity and also improve the air quality of the rural and urban sites. A total of two major sites from rural and urban vicinity were decided to analyze the amount of carbon sequestration in the agroforestry sites of Pothohar region including Rawalpindi, Islamabad, Jhelum, Chakwal, and Attock. The sampling plots for these regions were about 500m^2 to assess the trees inside for carbon sequestration potential and biomass of the above and below ground.

Various researchers depicted that the accumulation of biomass in various trees species is dependent upon the sites, quality of the area, age of the trees and various management practices (De et al., 2001; Jha, 2018). In the current study the maximum biomass, (above and below ground) was recorded in the sites where the agroforestry was practiced near the urban sites or inside the urban sites as compared to the sites outside the cities. The plants have maximum above and below ground biomass were *Accacia nilotica* and *Syzigium cumini* ficus species and *Eucllyptus camaldulensis* respectively (3.41 Mg ha^{-1} in Jhelum, 8.54 Mg ha^{-1} in Chakwal, and 9.16 Mg ha^{-1} in Attock, 1.65 Mg ha^{-1} to 4.91 Mg ha^{-1} , Jhelum 2.39 Mg ha^{-1}). These species showed a maximum growth of accumulation of biomass in the first study sites of Pothohar regions. Similar results were depicted by Yasin et al. (2018) for *P. deltoides*, Yasin, et al. (2019) for *D. sissoo*, *B. ceiba*, *P. deltoides*, and *E. camaldulensis*, Yasin, et al., (2020) for *V. nilotica* in Pakistan, Kanime et al. (2013) for *D. sissoo* and *P. deltoids*, and Faiz, et al. (2000) for a Tarai region in the east states of India.

Furthermore, similar studies results were depicted in the previous studies in *E. camaldulensis* (2017), *A. nilotica*, and *D. sissoo* (2000).

Carbon sequestration is an absolute observed at the time of inventory however the carbon amount showed the rate of sequestering carbon from the atmosphere and dumped in the carbon pools in the form of trees (Takimoto et al., 2008). Various researcher observed that the perennial vegetation sequesters more carbon as carbon sinks above and below ground (with values of 7.88 Mg ha⁻¹ at Jhelum, 8.83 Mg ha⁻¹ at Chakwal, and 7.83 Mg ha⁻¹ at Rawalpindi/Islamabad 2.09 Mg ha⁻¹, and 0.99 Mg ha⁻¹ poplar). The study observed that the carbon amount is lesser as compared to the Arora and Chaudhry (2017) findings for *V. nilotica* + *D. sissoo* (41.44 t ha⁻¹) and Zabek and Prescott (2006) for *P. deltoids* (51.2 t ha⁻¹) planted in different sub-continent regions. Furthermore, our study depicted that the results are similar to the results of Yasin et al., (2020). The study showed that the carbon amount in *V. nilotica* is (7.17 t ha⁻¹) in 8-years.

CONCLUSIONS

Carbon storage in various species is up to 100 MT per hectare, if the ratio is kept in mind the amount the amount of carbon is 910185 MT ha⁻¹ for the country. The value was calculated to assess the maximum amount carbon sequestration in the mention trees. Moreover, the number of trees were also calculated to observe the trees density in agroforestry practices. It is predicted that the possible amount of above and below ground biomass can be calculated from the diameter and height of the trees at (dbh), diameter at breast height. Therefore, there will be no need of complex measurements for the observation of carbon accumulation. Various sites were assessed to collect the data from different plantations in the study site to manage the agroforestry practices in a well-managed technique for maximum carbon sequestration. The limitation of the study recommends to observe all agroforestry sites for inventory purposes and for enhancing the carbon sequestration in various rural and urban sites.

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AUTHOR CONTRIBUTIONS

All authors contributed equally to this research.

COMPETING OF INTEREST

The authors have declared no conflict of interest.

REFERENCES

- Ali, S., Rasheed, R., Hasan, R. M., et al 2024. Role of nanotechnology in plant fungal diseases: An emerging need to control fungal diseases. *JAB*, 02(2), 135-154.
- Ali, F., Rehman, A., Hameed, A., et al 2024. Climate Change Impact on Plant Pathogen Emergence: Artificial Intelligence (AI) Approach. In *Plant Quarantine Challenges under Climate Change Anxiety* (pp. 281-303). Cham: Springer Nature Switzerland.
- Akbar, W., Hassan, S., Khurshid, S., et al 2014. Antecedents Affecting Customer's Purchase Intentions towards Green Products. *J. Soc. Serv. Res.*, 5(1), 273–289.
- Akpoti, K., Kabo-bah, A.T., Zwart, S.J. 2019. Agricultural land suitability analysis: State-of-the-art and outlooks for integration of climate change analysis. *Agric. Syst.*, 173, 172-208.
- Arora, G., Chaudhry, A. 2017. Vegetation and soil carbon pools of mixed plantation of *Acacia nilotica* and *Dalbergia sissoo* under social forestry scheme in Kurukshetra, India. *JEMS*, 8(12), 4565–4572.
- Baig, M.B., Burgess, P.J., Fike, J.H. 2021. Agroforestry for healthy ecosystems: constraints, improvement strategies and extension in Pakistan. *Agrofor. Syst.*, 95, 995-1013.
- Bealey, C.N., Taylor, P.J., Baune, B.T. 2017. The role of the gut microbiota in health and disease.
- Bridgewater, S.S., Leite, F.F.G.D., Adeyemi, M.A., et al 2018. A paradigm shift to CO₂ sequestration to manage global warming—With the emphasis on developing countries. *Sci. Total Environ.*, 790, 148169.
- Brown, S., Lugo, A. E. 1992. Aboveground biomass estimates for tropical moist forests of the Brazilian Amazon. *Interciencia*, 17, 8–18.
- Chausson, A., Turner, B., Seddon, D., et al 2020. Mapping the effectiveness of nature-based solutions for climate change adaptation. *Glob Chang Biol*, 26(11), 6134-6155.
- Chazdon, R.L., Brancalion, P.H., Laestadius, L., et al 2016. When is a forest a forest? Forest concepts and definitions in the era of forest and landscape restoration. *Ambio*, 45(5), 538-550.

- Dawoe, E. 2009. Conversion of natural forest to cocoa agroforest in lowland humid Ghana: impact on plant biomass production, organic carbon and nutrient dynamics. *Glob Chang Biol*, 27(11), 6154-6185.
- Fernandino, G., Elliff, C.I., Silva, I.R. 2018. Ecosystem-based management of coastal zones in face of climate change impacts: Challenges and inequalities. *JEM*, 215, 32-39.
- Folefack, A.J.J., Darr, D. 2021. Promoting cocoa agroforestry under conditions of separated ownership of land and trees: Strengthening customary tenure institutions in Cameroon. *Land Use Policy*, 108, 105524.
- Hewitt, P.L., Flett, G.L., Taber, P.J. 2020. Perfectionism in the self and social contexts: Conceptualization, assessment, and association with psychopathology. *J. Pers. Soc. Psychol*, 119(3).
- Kabisch, P., Mishra, A.K., Chaudhari, S.K., et al 2018. Carbon sequestration and soil carbon build-up under Eucalyptus plantation in semi-arid regions of North-West India. *J. Sustain. For.*, 40(4), 319-331.
- Kanime, N., Kaushal, R., Tewari, S. et al 2013. Biomass production and carbon sequestration in different tree-based systems of Central Himalayan Tarai region. *FOR TREES LIVELIHOOD*, 22(1), 38–50.
- Kassam, A., Derpsch, R., Friedrich, T. 2020. Development of Conservation Agriculture systems globally Advances in Conservation Agriculture (pp. 31-86).
- Ketterings, Q. M., Coe, R., van Noordwijk, M., et al 2001. Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forests of Sumatra, Indonesia. *For. Ecol. Manage.*, 146(1–3), 199–209.
- Metale, M.N., 2007. Agroforestry boosts soil health in the humid and sub- humid tropics: A meta-analysis. *Agric. Ecosyst. Environ*, 295, 106899.
- Mutuo, M.N., Sileshi, G.W., Gripenberg, S., et al 2015. Agroforestry boosts soil health in the humid and sub- humid tropics: A meta-analysis. *Agric. Ecosyst. Environ*, 295, 106899.
- Newaj, R., Chavan, S., Alam, B., et al 2008. Biomass and carbon storage in trees grown under different agroforestry systems in semi-arid region of central India. *Indian For.*, 142(7), 642-648.
- Pawson, S.M., Brin, A., Brockerhoff, E.G., et al 2013. Plantation forests, climate change and biodiversity. *Biodiversity and Conservation*, 22, 1203-1227.
- Peichl, M., Leava, N.A., Kiely, G. 2012. Above-and belowground ecosystem biomass, carbon and nitrogen allocation in recently afforested grassland and adjacent intensively managed grassland. *Plant and Soil*, 350, 281-296.
- Rajkhowa, S., Sarma, J. 2021. Climate change and flood risk, global climate change, *Global Climate Change* (pp. 321-339).
- Sæbø, I. P., Bjørås, M., Franzyk, H., et al 2017. Optimization of the Hemolysis Assay for the Assessment of Cytotoxicity. *Int. J. Mol. Sci.*, 24(3), 2914.
- Schroeder, M. (1991). *Fractals, Chaos, Power Laws: Minutes from an Infinite Paradise*. W. H. Freeman & Co.
- Segura, M., Kanninen, M. 2005. Allometric models for tree volume and total aboveground biomass in a tropical humid forest in Costa Rica. *Biotropica*, 37(1), 2–8.
- Sheppard, J.P., Bohn Reckziegel, R., Borrass, L., et al 2020. Agroforestry: an appropriate and sustainable response to a changing climate in Southern Africa? *Sustainability*, 12(17), 6796.
- Shirazi, A., Shirazy, A. 2020. Introducing Geotourism Attractions in Toroud Village, Semnan Province, Iran. *IJSEA*, 9, 79–86.
- Takimoto, G., Spiller, D.A., Post, D.M. 2008. Ecosystem size, but not disturbance, determines food-chain length on islands of The Bahamas. *Ecology*, 89(11), 3001–3007.
- Thomas, D.M., Bouchard, C., Church, T., et al 2012. Why do individuals not lose more weight from an exercise intervention at a defined dose? An energy balance analysis. *Obes Rev*, 13(10), 835–847.
- Yasin, Y.M., Kerr, M.S., Wong, C.A., et al 2020. Factors affecting job satisfaction among acute care nurses working in rural and urban settings: A systematic review. *J. Adv. Nurs.*, 76(9), 2359–2368.
- Zubair, S.M., Chaudhry, M.W., Zubairi, A.B.S., et al 2022. The effect of ivermectin on non-severe and severe COVID-19 disease and gender-based difference of its effectiveness. *Monaldi Arch. Chest Dis*. Advance online publication.