ESTIMATION OF CARBON STORAGE STATUS AND POTENTIAL IN IRRIGATED FOREST PLANTATIONS OF PUNJAB

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ABSTRACT:

Climate change has become one of the most important environmental issues globally. It has remarkable results on plant production, water use and transport patterns. The risks to bio-diversity are growing with the passage of each day. The destruction of natural habitat, decline in biological diversity, conversion of forests land into arable lands, excessive use of natural resources, rising sea levels, increase in the concentration of carbon dioxide and greenhouse gas emissions in the atmosphere, gradual increase in the earth's average temperature and dominance of existing habitat by exotic species are some of the major consequences of climate change. By keeping in mind the current situation, the present study was designed in order to assess the carbon stocks and potential of carbon sequestration in irrigated forest plantations of southern Punjab, Pakistan. The main objective of the study was to check the current status of carbon sequestration and carbon stocks in different forestry combinations and potential of trees grown under different forestry systems for CO_2 sequestration in the Districts Bahawalpur and Lodhran. The practical surveys were done in the selected study Districts to collect the data. Study findings showed that the quantity of above-ground and below-ground tree carbon stocks and the sequestration of CO_2 was little varied relying on the calculating procedure, climatic situations and distribution of tree species in the study region. District Bahawalpur had the highest (25.88 Mg ha^{-1}) and (83.75 Mg ha^{-1}) total tree carbon stocks and tree sequestration of CO_2 in comparison with the District Lodhran having (10.69 Mg ha^{-1}) and (39.42 Mg ha^{-1}) respectively. Between all the two selected districts, relied on the area, District Bahawalpur had highest (2090641.2 Mg) and (6181613.6 Mg) total estimated tree carbon stocks and the sequestration of CO_2 as compared to District Lodhran having (221434.6 Mg) and (647257.63 Mg) respectively. In addition, District Bahawalpur had the highest (186634.34 Mg) and (3163287.76 Mg) total

potential tehsil carbon stock and total potential tehsil CO_2 Sequestration in comparison with District Lodhran having (1194670 Mg) and (2927022.2 Mg) respectively. The findings of that research recommend that the amount of the carbon stocks and also the potential of the trees to sequester atmospheric CO_2 can be easily enhanced by increasing the tree cover in our country as trees have the greater ability to sequester atmospheric carbon and store carbon stocks in larger amounts.

Keywords: Carbon Sequestration, Climate Change, Carbon Stock

1. INTRODUCTION

The biologists have been seeking various approaches to reduce global warming and climate change by minimizing Green House Gas emissions. Amidst each environment, a particular heed is given to forest ecosystems that have a special part in capturing the environmental CO_2 in the shape of tree biomass carbon (Dunne *et al*., 2019; Ketiem *et al*., 2017; Field *et al*., 2015). Forests can stock 20-50 times extra carbon stocks in comparison with fallow fields (Abdulazeez *et al*., 2014) because of their woody kind (Kebede *et al*., 2015; Adedotun, 2010). Trees after reaching a certain age of their growth sequester atmospheric CO_2 by their food making process and stock that carbon in the shape of tree biomass and soil organic matter in the forest environments (Ozor and Nnaji, 2011). Forest trees have the potential to store big quantities of carbon up to hundreds of tons ha^{-1} in their lifetime (Chija, 2013).

Human actions i.e. uncontrolled alterations in the land usage methods, cutting down of forests and consumption of fossil fuels are responsible for continual emissions of environmental CO_2, causing climate change throughout the world (Dasgupta *et al*., 2014). CO_2 is regarded as a main greenhouse gas and biggest distinct cause (>70%) to global warming because of its quick enhance in the atmosphere after the start of urbanisation (Allen *et al*., 2011). About 3.5 ppm of CO_2 has been accumulating in the air on an annual basis that is causing actual dangers to our earth globally (Porter *et al*., 2014). If that rate persists until the upcoming centennial, our globe temperature may increase up to 2 ^{0}C leading to 20 to 30% deterioration of earth environment globally (UNFCCC, 2021; Asrat and Simane, 2018; Abdul-Razak and Kruse, 2017). Irrigated forest plantations are considered a best way of increasing the environmental resources produced by farm fields.

Irrigated forest plantations are regarded a best methods to reduce the effects of climate change throughout the world (Morton, 2017) because trees grown near the edges of the agricultural lands considerably increase the potential of these patterns to sequester and reserve carbon (Sallawu *et al*., 2020; Stanturf *et al*., 2011). It was observed that farm fields have greater than 10% forest trees across the world (Limantol *et al*., 2016; Fosu-Mensah *et al*., 2012). These forestry patterns are providing several advantages to about 1.2 billion people from the tropics and under-developed nations across the globe (Yaro *et al*., 2015). That land usage pattern is presently reserving approximately 45.3 Pg carbon, from which >75% is collected in the woody vegetation (Nilsen, 2019; Bauer and Stewart, 2013). In addition, forestry patterns can store approximately 6.3 Gt of environmental carbon by 2050 having a sequestration rate of more than 600 Mt C yr^{-1} (Smith *et al*., 2014) causing those patterns a best way of carbon sequestration in a large quantity in comparison with the other land usage systems (Delonge *et al*., 2016; Calo, 2017).

Moreover, the following forestry tree species i.e. *A. nilotica* and *D. sissoo* are acknowledged the main source of increasing the rate of carbon sequestration and its storage across the world as these have early growth, little rotation period and can be planted in many geo-graphic areas worldwide (Dudley and Alexander, 2017; Mateo-Sagasta *et al*., 2018). Likewise, In Punjab, Pakistan, these forestry tree species are being widely grown along the edges of farm fields as shelterbelts in Punjab, Pakistan and doing their best to fulfill the needs for firewood and rural furniture across the country (Medina *et al*., 2020). A very much little focus has been given to forestry patterns in comparison with the forestry pattern (Paudel and Crago, 2021).

Various forestry experts in the world have accepted the role played by *A. nilotica* and *D. sissoo* tree species based forestry patterns for the mitigation of climate change by the sequestration of CO_2 in various areas of the world (Gilbert, 2015; Newell and Taylor, 2017) Still, a very little data is available for forestry potential regarding the storage of carbon in Pakistan. So, the major aim of the current study was to give a criterion regarding farther research for observing and evaluating the present carbon stocks in various irrigated-forestry combinations of the country and to recognize elements that could be supervised to increase carbon sequestration in those patterns.

2. MATERIALS AND METHODS

2.1. Study Sites and Sampling Methodology

The study was carried out in the two semi-arid districts situated in the similar environmental area in Punjab province of Pakistan: Bahawalpur and Lodhran. The climate is hot in both districts. The mean rainfull is 336 mm in Bahawalpur, 346 mm in Lodhran annually. The mean temperature is 23.8 ^{0}C in Bahawalpur and 24.2 ^{0}C in Lodhran annually. Inventory data was gathered from 16 rural union councils and 80 villages from 8 tehsils of the above given districts to measure carbon in tree biomass and soil. 400 quadrate plots each of 0.405 ha (1 acre) having irrigated-forestry patterns were chosen randomly for sampling purposes. The tehsil and the union councils are bureaucratic components of the Pakistani government. The tehsil is 4th bureaucratic component that comes after district and consisting of small towns and big union councils. The union council is the 5th bureaucratic component after tehsil and consists of 5 to 7 villages only.

2.2. Above and Belowground Biomass Carbon Measurement

Practical surveys were conducted from April 2020 to October 2022 to collect inventory data. The girth at 1.37 m above the ground level and tree end height was estimated and documented for a tree in every 0.405 ha plot. Age of trees was known by interviewing with the landholder of the said plot. The tree biomass was estimated by using the allometric equations (Table 1) and corrected for log bias where deemed suitable. Likewise, where allometric equations to measure tree belowground biomass were not accessible, below-ground tree biomass was supposed to be 26% of the above-ground tree biomass (Bassett and Fogelman, 2013; Rose and Chilvers, 2018). After that, tree biomass of each tree was then scaled to biomass per plot, biomass per hectare, and carbon stock per hectare. The carbon contents were measured from tree biomass by supposing that the trees dry biomass was 48.1% carbon (Clapp *et al*., 2018). By using linear regression, the relation among plot level tree basal area and carbon contents was examined.

2.3. Total and Potential Carbon Pools

The entire tree carbon at tehsil level was measured by multiplying the per hectare carbon from sampled plots by the total area of the said tehsil. The following below given equation was used for calculating the potential tree carbon stocks in study area:

Potential carbon stock = Potential tree density/current tree density × actual carbon stock ha^{-1} (1)

Where the present tree density (trees ha^{-1}) is the mean tree density from field sampling and potential tree density (trees ha^{-1}) is the mean highest desired tree density stated by the farmer's interviews in the study districts. In every union council (sub-division of the tehsil, as given earlier), if the mean higher desired tree density stated by farmers during questioning was little in comparison with the biggest calculated plot tree density in such union council, then, the calculated value was taken as potential tree density.

That method permitted our measure of potential tree density to be affected by farmers' acumen and logistical and bio-physical restrictions showed in the higher calculated tree density (Gosnell *et al*., 2020; Clapp *et al*., 2018). Unpredictability in our measure of potential tree density were demonstrated as standard deviation of farmers' reply to the question, "What is higher tree density that you would plant on your field?". Standard deviations for potential average tree carbon stock and potential tehsil carbon stock were then scaled properly from the standard of deviation of potential tree density.

Table 1: Allometeric equations for the calculation of above and belowground biomass in the selected districts

Species	Component	Allometeric Equations	Source	R^2	MSE
Acacia nilotica	AGB BGB	LogY = -1.0646+0.9098×logD^2H LogY = -1.3952+0.8253×logD^2H	Zhang *et al*., 2016 Zhang *et al*., 2016	0.96 0.92	- -
Albizia Lebbek	AGB BGB	LnY = -3.1114+0.9719×ln D^2H BGB = AGB×0.26	Anitha *et al*., 2015 Chave *et al*., 2014	0.97 -	0.1161 -
Azadirachta indica	AGB BGB	LnY = -3.1114+0.9719×ln D^2H BGB = AGB×0.26	Anitha *et al*., 2015 Chave *et al*., 2014	0.97 -	0.1161 -
Bombax ceiba	AGB BGB	LnY = -3.1114+0.9719×ln D^2H BGB = AGB×0.26	Anitha *et al*., 2015 Chave *et al*., 2014	0.97 -	0.1161 -
Ziziphus mauritiana	AGB BGB	LnY = -3.1114+0.9719×ln D^2H BGB = AGB×0.26	Duncanson *et al*., 2015 Chave *et al*., 2014	0.97 -	0.1161 -
Eucalyptus camaldulensis	AGB BGB	LnY = -2.2660+2.4663×ln D^2H BGB = AGB×0.26	Picard *et al*., 2012 Chave *et al*., 2014	0.99 -	- -
Melia Azedarach	AGB BGB	Y = 42.321 + 9.52×10^{-5} × D^2H BGB = AGB×0.26	Anitha *et al*., 2015 Chave *et al*., 2014	0.74 -	- -
Morus alba	AGB BGB	LnY = -3.1114+0.9719×ln D^2H BGB = AGB×0.26	Tashi *et al*., 2017 Tashi *et al*., 2017	0.97 -	0.1161 -
Dalbergia sissoo	Bole Branch Twig Leaf	Tree age <4 Y = -0.367+1.3457×DBH Y = -1.4581+0.7708×DBH Y = -0.2932+0.1461×DBH	Chave *et al*., 2005 - - -	0.97 0.94 0.94 0.94	- - - -

		Y = -0.4501+0.283×DBH			
Syzygium cumini	AGB BGB	LogY = -1.2066+0.9872×logD^2H BGB = AGB×0.26	Anitha *et al*., 2015 Chave *et al*., 2014	0.97 -	- -

- ❖ Above ground biomass (AGB)
- ❖ Below ground biomass (BGB)

3. RESULTS AND DISCUSSION

3.1. Tree Inventory

(Figures 1, 2, 3, 4) sum ups the essential inventory data that is height (m), DBH (diameter at breast height, cm) and age of a tree (years) in the two selected districts at the tehsil level. Inter-planting forestry and straight plantation methods were noticed between the entire study regions. There was not any alteration in the values between each parameter. We noticed nearly same kinds of tree species in each tehsil of the two selected districts. The important tree species liked by the farmers regarding forestry were *A. nilotica*, *D. sissoo*, *E. camaldulensis*, *M. Azedarach*, *A. indica*, *M. alba*, *B. ceiba*, *Z. mauritiana* etc. where *A. nilotica* and *D. sissoo* tree species were most preferred by the farmers. *A. nilotica* and *D. sissoo* tree species were found dominant tree species in comparison with other tree species. Further, *A. nilotica* tree species was planted for commercial purposes in all the two selected study districts.

Tehsil Bahawalpur in the district Bahawalpur had highest (13.41 cm) average diameter at breast height and (8.75 m) height in comparison with each other tehsil in the two selected study districts. The average highest (3.33 years) age of a tree was noticed in tehsil Bahawalpur in Bahawalpur district and (7.83 years) in tehsil Kahror Pakka in Lodhran district. Ahmadpur East tehsil had highest (0.90 m^2 ha^{-1}) average tree basal area in district Bahawalpur followed by Lodhran tehsil (0.83 m^2 ha^{-1}) in district Lodhran whereas each other tehsil had slightly different basal area.

3.2: Estimation of tree Carbon Stock

3.2.1: District Bahawalpur

The mean, minimum and maximum values of inventory data of District Bahawalpur at Tehsil level is summarizes in (Tables 2, 2a). The data indicated that in all Tehsils species like *D. sissoo*, *E. camaldulensis*, *A. nilotica* and *B. ciebea* were mostly preferred by the farmers for timber and fuelwood purposes. Species like *M. alba*, *A. lebbeck*, *M. azedarach* and *Z. mauritiana*

were planted in small numbers mostly for fuel wood and fodder purposes. It was noted that Tehsil Khairpur Tamewali has more *D. sissoo*, *E. camaldulensis* and *B. ciebea* trees as compared to Tehsil Ahmadpur East, Yazman, Hasilpur and Bahawalpur.

The mean maximum (11.78±5.65 cm) DBH of *D. sissoo* was estimated in Tehsil Khairpur Tamewali East with an average height of 6.98±2.76 m. The age of the trees ranged from 1 to 10 years with an average of 4.87±1.68 years. Tehsil Ahmadpur East has a slightly higher (14.67±6.42 cm) *M. azedarach* mean DBH with an average height (6.59±1. m) and age (4.42±1.39 years) as compared to Tehsil Yazman, while Bahawalpur showed slightly a different mean height (8.75 ±3.23 m) a with DBH range (1.91-23.50 cm) in *E. camaldulensis*. The mean maximum (13.25±6.47 cm) DBH of *A. nilotica* was observed at Hasilpur with the age ranges from 2-9 years. Species like *M. alba*, *M. azedarach* and *A. lebbeck* had maximum (10.41±4.13 cm), (13.07±3.54 cm) and (07.61±2.54 cm) mean DBH and maximum (6.23±1.47 m), (6.67±2.21 m) and (4.79±1.97 m) mean height in Tehsil Bahawalpur as compared to Tehsils Ahmadpur East and Yazman.

3.2.2: District Lodhran

The mean, minimum and maximum values of inventory data of District Lodhran at Tehsil level are summarizes in (Table 3). The data indicated that in all Tehsils species like *A. nilotica*, *D. sissoo*, *E. camaldulensis* and *B. ciebea* were mostly preferred by the farmers for timber and fuelwood purposes. Species like *M. alba*, *A. lebbeck*, *M. azedarach* and *Z. mauritiana* were planted in small numbers mostly for fuel wood and fodder purposes. It was noted that Tehsil Dunyapur has more *D. sissoo*, *E. camaldulensis* and *B. ciebea* trees as compared to Tehsil Kahror Pakka and Lodhran.

The mean maximum (14.71±4.73 cm) DBH of *B. ciebea* was estimated in Tehsil Dunyapur East with an average height of (7.51±3.73 m). The age of the trees ranged from 1 to 08 years with an average of (5.07±2.04 years). Tehsil Kahror Pakka had a slightly higher (19.31±3.07 cm) *E. camaldulensis* mean DBH with an average height (8.05±2.67 m) and age (2.67±1.74 years) as compared to Tehsil Lodhran.

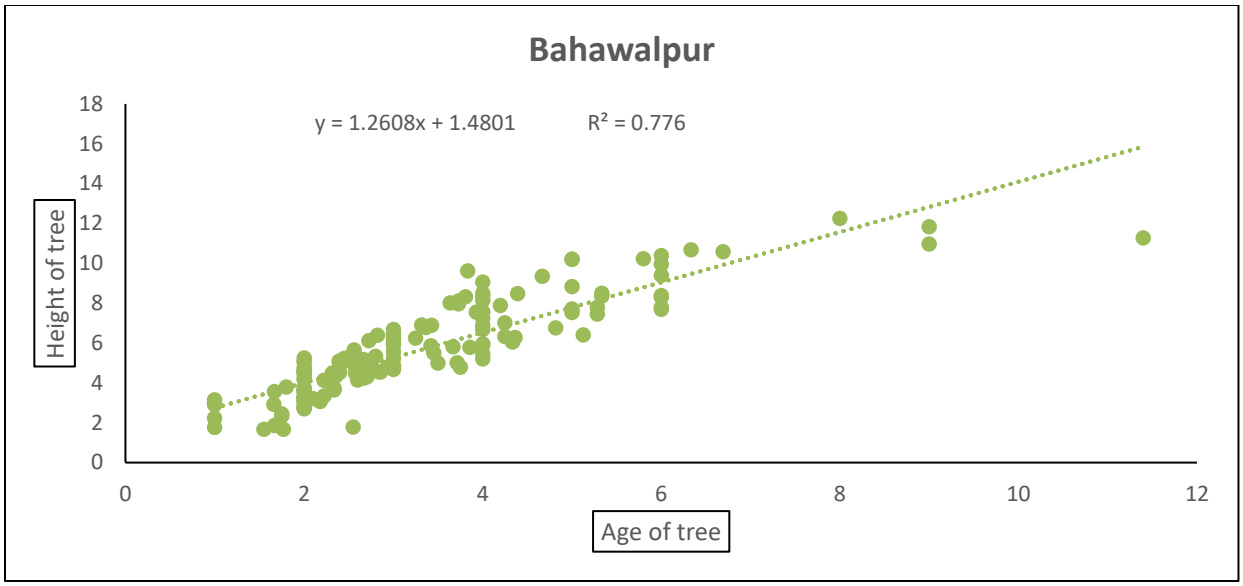


Figure 1: Relationship between tree age and DBH (cm) at plot level district Bahawalpur.

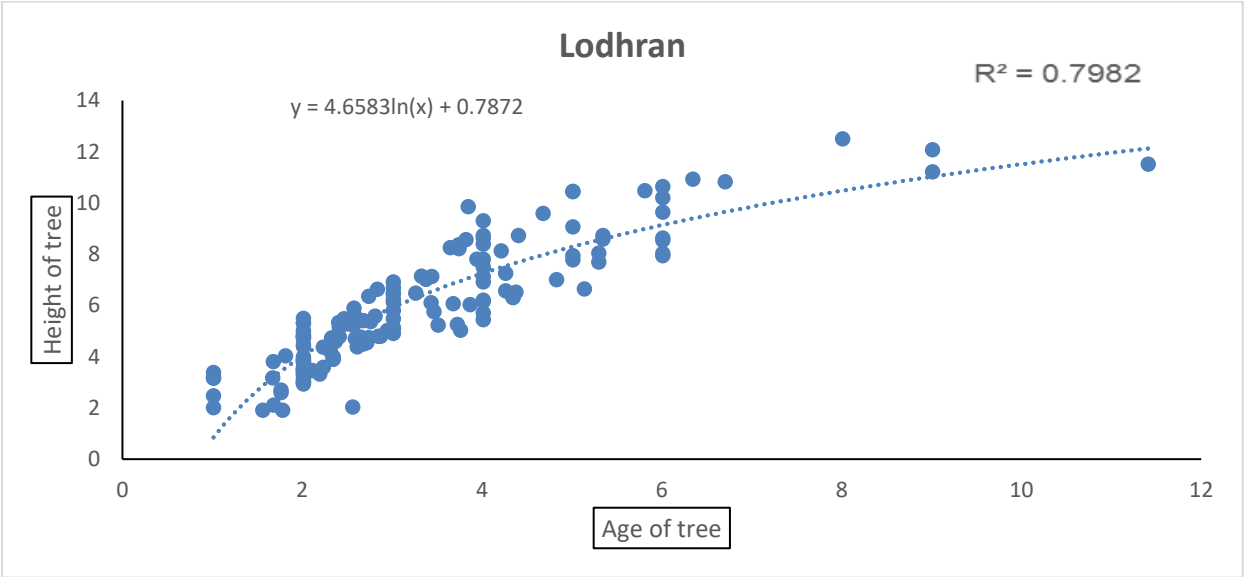
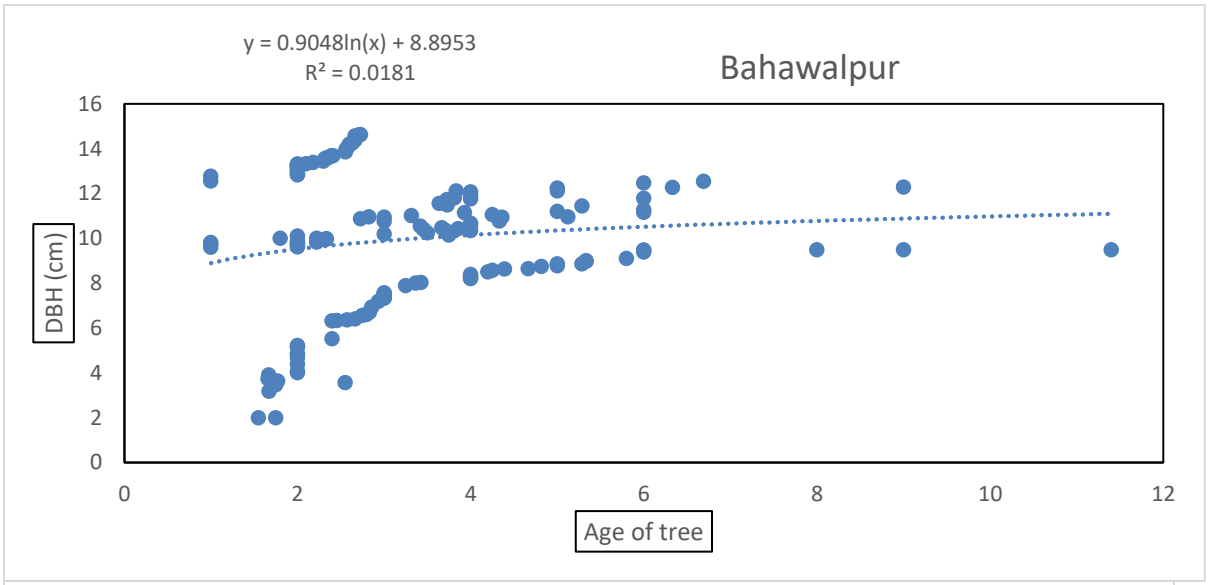


Figure 2: Relationship between tree age and DBH (cm) at plot level district Lodhran.

Figure 3: Relationship between tree age and height (m) at plot level district Bahawalpur.



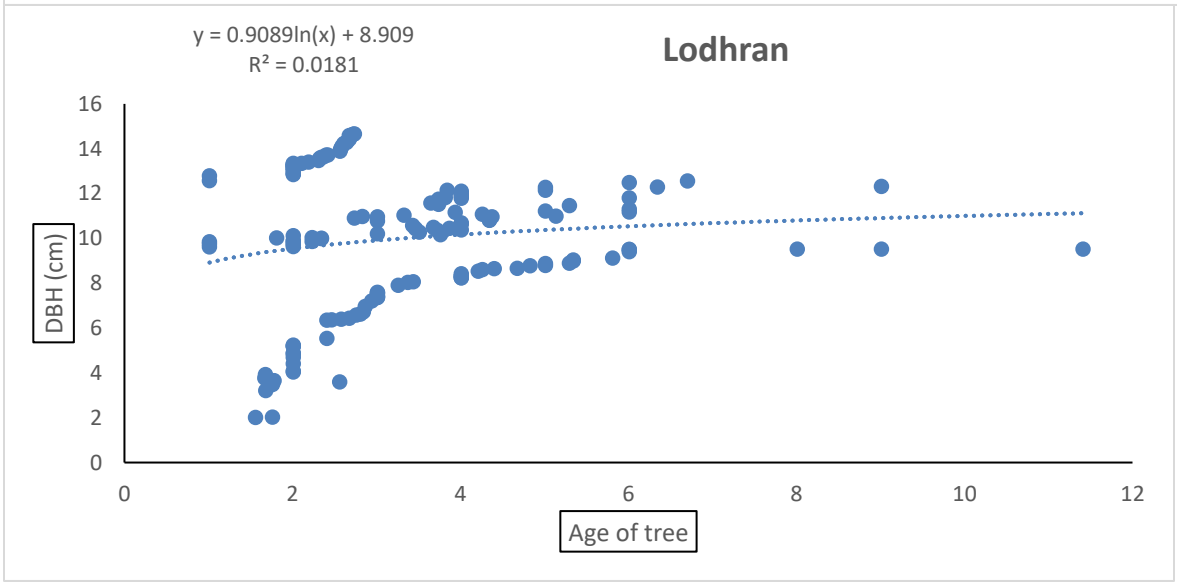


Figure 4: Relationship between tree age and height (m) at plot level district Lodhran

Table 2: Summary of tree diameter at breast height (DBH), tree height and tree age at tehsil level of District Bahawalpur

District	Tehsil	Plots (0.405) hectare	Species	Frequency	DBH (cm)			Height (m)			Tree Age		
					Mean	Range	SD	Mean	Range	SD	Mean	Range	SD
Bahawalpur	Khairpur Tamewali	50	*A. nilotica*	27	11.37	2.56-23.450	3.57	5.98	2.71-11.25	3.43	5.21	3-8	3.07
			D. sissoo	345	11.78	1.67-30.96	5.65	6.98	2.87-14.27	2.76	4.87	1-10	1.68
			E. camaldulensis	41	9.76	2.25-27.53	6.31	8.79	2.36-17.75	5.58	3.64	3-5	1.95
			B. ceiba	47	11.37	6.55-25.37	4.37	6.55	3.27-10.67	2.07	4.34	2-7	1.57
			A. lebbeck	23	7.87	3.67-13.89	2.78	4.63	1.97-7.57	1.76	2.89	1.8	1.29
			M. azedarach	13	10.57	3.76-18.68	5.43	5.23	3.21-8.07	2.17	3.07	2-5	0.89
			M. alba	41	8.34	2.07-14.21	2.75	4.32	2.37-6.57	0.97	2.85	1-5	0.95
			Z. mauritiana	137	10.47	1.81-26.37	5.39	6.18	0.83-16.37	3.27	3.57	2-8	1.57
			S. cumini	15	7.78	2.38-16.41	2.56	5.77	4.57-9.73	1.38	4.57	3-7	0.89
	Ahmadpur East	50	*A. nilotica*	63	10.75	3.64-22.87	3.42	4.35	1.97-11.33	1.95	5.45	2-9	2.61
			D. sissoo	9	11.28	7.27-12.56	1.88	5.97	4.37-7.89	1.67	4.77	3-7	0.78
			E. camaldulensis	85	11.67	2.78-21.57	2.69	7.98	2.05-11.98	2.89	7.69	3-15	1.27
			B. ceiba	234	10.67	1.07-27.33	4.33	5.32	1.04-14.56	2.57	4.07	2-10	1.76
			A. lebbeck	89	9.89	2.17-17.23	3.47	5.37	2.67-11.25	1.57	3.47	1-6	0.77
			M. azedarach	26	14.67	2.51-26.20	6.42	6.59	2.65-9.63	1.88	4.42	2-7	1.39
			M. alba	86	8.43	2.04-15.65	3.85	5.34	1.54-9.03	1.75	4.02	2-5	1.47
			Z. mauritiana	27	8.97	1.87-30.87	2.46	4.97	2.67-14.97	2.19	3.58	3-7	0.87
			S. cumini	19	7.56	2.17-13.15	2.67	3.97	2.56-6.78	1.24	3.49	2-8	0.94
	Yazman	50	*A. nilotica*	48	11.67	2.74-23.67	4.56	6.36	2.05-12.04	2.56	4.36	1-10	2.04
			D. sissoo	379	11.37	2.43-28.57	4.77	5.67	0.76-13.78	2.45	3.65	2-9	1.77
			E. camaldulensis	185	10.53	1.76-20.52	5.07	8.12	1.57-13.57	2.59	3.21	1-6	0.97
			B. ceiba	212	15.62	2.45-28.56	4.67	5.67	2.43-16.57	2.67	6.78	2-13	2.43
			A. lebbeck	7	10.67	8.37-12.67	2.57	5.37	3.57-7.96	1.56	4.33	3-6	1.65
			M. azedarach	41	11.03	2.12-17.53	3.21	6.02	3.05-7.89	1.63	3.78	2-7	1.26
			M. alba	57	9.33	1.36-18.97	3.45	5.02	2.33-8.75	1.79	3.48	2-8	1.35
			Z. mauritiana	14	9.64	3.56-12.78	4.67	5.03	2.67-7.56	1.57	3.17	2-5	0.87
			S. cumini	15	8.27	3.01-12.69	2.67	4.78	2.59-5.89	1.43	2.89	2-6	0.68

Table 2a: Summary of tree diameter at breast height (DBH), tree height and tree age at tehsil level of District Bawhawalpur

District	Tehsil	Plots (0.405) hectare	Species	Frequency	DBH (cm)			Height (m)			Tree Age		
					Mean	Range	SD	Mean	Range	SD	Mean	Range	SD
Bahawalpur	Bahawalpur	200	*A. nilotica*	146	12.01	1.25-23.57	3.67	7.07	1.45-12.43	2.72	3.33	2-10	1.97
			D. sissoo	412	9.65	2.07-13.67	3.88	4.87	2.44-7.89	1.60	1.61	2-7	1.42
			E. camaldulensis	378	9.97	1.91-23.5	4.67	8.75	3.5-16.43	3.23	2.96	2-11	1.87
			B. ceiba	195	13.41	2.47-21.75	2.57	7.59	2.24-12.53	2.37	2.48	3-12	1.45
			A. lebbeck	41	7.61	1.95-13.56	3.23	4.79	2.67-7.97	1.97	2.07	2-8	1.43
			M. azedarach	109	13.07	2.07-15.08	3.54	6.67	2.07-12.03	2.21	3.07	1-10	2.07
			M. alba	131	10.41	0.97-17.41	4.13	6.23	1.27-10.21	1.47	2.75	2-9	1.79
			Z. mauritiana	125	11.82	0.81-19.40	4.12	6.35	1.22-10.21	2.20	2.20	1-9	1.98
			S. cumini	47	10.07	2.73-20.67	3.67	7.17	3.25-10.69	1.67	1.97	1-7	2.15
	Hasilpur	50	*A. nilotica*	107	12.77	3.76-14.25	3.45	8.05	1.97-13.27	1.79	6.17	2-9	1.87
			D. sissoo	79	8.68	2.15-27.89	3.76	5.79	3.07-12.79	2.53	3.45	2-8	1.53
			E. camaldulensis	48	11.22	4.27-15.73	3.37	7.87	4.67-10.57	1.67	3.67	2-5	1.73
			B. ceiba	185	12.64	2.57-21.75	3.75	6.98	2.65-11.87	2.43	2.78	2-10	1.79
			A. lebbeck	48	7.95	1.75-13.07	3.67	4.87	2.06-7.06	1.35	3.87	1-6	1.27
			M. azedarach	109	12.07	2.65-23.67	4.31	4.69	1.95-11.07	2.07	2.47	1-10	1.56
			M. alba	124	11.23	1.08-17.56	4.78	5.97	1.76-11.89	2.09	3.79	1-9	1.89
			Z. mauritiana	65	10.75	0.98-17.57	2.56	5.77	1.57-8.63	1.78	2.46	1-6	1.37
			S. cumini	15	11.78	2.57-12.77	1.78	4.78	2.57-7.76	0.67	4.65	1-8	1.89

Table 3: Summary of tree diameter at breast height (DBH), tree height and tree age at tehsil level of District Lodhran

District	Tehsil	Plots (0.405) hectare	Species	Frequency	DBH (cm)			Height (m)			Tree Age		
					Mean	Range	SD	Mean	Range	SD	Mean	Range	SD
Lodhran	Dunyapur	50	*A. nilotica*	29	12.75	2.65-24.57	2.67	6.07	2.83-12.05	2.83	5.67	3-9	2.27
			D. sissoo	351	12.08	3.07-31.51	4.57	5.54	2.97-15.07	3.05	6.07	2-10	1.83
			E. camaldulensis	43	10.06	2.69-29.38	5.61	9.04	3.05-18.53	4.37	4.41	2-5	1.97
			B. ceiba	49	14.71	7.05-26.75	4.73	7.51	3.71-11.73	3.73	5.07	1-8	2.03
			A. lebbeck	25	8.03	4.71-14.09	3.37	3.97	2.03-8.17	2.06	3.91	2-9	1.49
			M. azedarach	15	13.01	4.07-19.07	3.59	4.75	3.57-9.21	2.83	3.71	1-6	1.93
			M. alba	43	7.89	2.71-15.37	2.51	4.57	3.07-7.71	1.75	3.05	1-6	1.05
			Z. mauritiana	143	11.27	2.25-27.67	3.41	5.81	1.13-17.23	3.71	4.03	2-7	1.71
			S. cumini	17	8.23	3.05-17.56	2.17	6.23	5.08-10.35	2.05	3.03	3-8	1.57
	Kahror Pakka	50	*A. nilotica*	65	13.47	4.07-23.79	2.78	5.23	2.07-12.25	2.11	5.35	2-11	1.75
			D. sissoo	11	12.83	6.78-13.14	2.07	5.73	4.72-8.07	1.75	5.03	2-8	1.07
			E. camaldulensis	87	19.31	3.07-31.15	3.07	8.05	2.17-12.03	2.67	7.83	2-11	1.74
			B. ceiba	237	11.37	2.05-28.07	3.07	5.73	1.67-15.67	3.01	5.03	3-7	2.07
			A. lebbeck	91	10.11	2.57-18.33	2.71	4.35	3.03-12.17	2.03	4.01	2-8	1.37
			M. azedarach	28	15.03	3.17-27.67	3.39	5.78	2.73-13.78	2.21	4.51	3-7	1.43
			M. alba	89	9.39	3.41-16.57	2.53	5.13	2.03-10.03	1.88	3.67	2-6	1.71
			Z. mauritiana	29	9.01	2.05-31.73	2.63	5.03	3.05-15.05	2.21	3.56	3-8	1.07
			S. cumini	21	8.63	2.27-14.23	2.73	4.05	2.78-7.51	1.43	361	2-9	1.43
	Lodhran	200	*A. nilotica*	49	12.03	3.05-24.71	4.65	6.61	2.53-13.41	2.65	4.65	2-11	1.64
			D. sissoo	384	12.07	2.57-29.73	4.75	6.07	1.67-14.86	2.57	3.57	3-10	1.79
			E. camaldulensis	188	11.31	2.65-21.23	4.73	7.37	2.73-14.75	2.33	3.37	2-7	1.73
			B. ceiba	217	16.27	3.52-29.61	3.97	6.03	3.31-17.73	2.07	7.08	3-10	1.67
			C. lebbeck	11	11.05	8.73-13.03	3.05	6.17	3.75-8.03	1.68	4.57	3-7	1.87
			M. azedarach	43	11.37	3.21-18.37	3.11	6.22	3.53-7.93	1.77	4.83	3-7	1.63
			M. alba	59	10.27	2.26-19.05	3.25	5.27	2.43-9.33	1.85	4.05	3-9	1.53
			Z. mauritiana	17	9.89	3.67-13.87	3.74	4.75	3.07-8.65	1.87	4.31	2-7	1.73
			S. cumini	11	7.86	3.31-13.95	2.75	5.05	2.67-6.07	1.57	3.95	3-8	1.86

3.2.1.1: Tree Carbon Stock, Total Tree Carbon Stock, Total Soil Carbon Stock and the sequestration of CO_2 at Tehsil level of District Bahawlpur

District Bahawalpur has five Tehsils: Bahawalpur, Hasilpur, Khairpur Tamewali, Ahmadpur East and Yazman. The findings concerning tree carbon stock, total tree carbon stock, total soil carbon stock and the sequestration of CO_2 at Tehsil level of District Bahawalpur have been illustrated in (Tables 4, 4a). The highest (1.79-2.95 $Mgha^{-1}$) and (4.27-8.93 $Mgha^{-1}$) total tree carbon stock ha^{-1} and total tree sequestration of CO_2 ha^{-1} in all tehsils of District Bahawalpur were observed. The total tree carbon stock ha^{-1} and the sequestration of CO_2 ha^{-1} were greater in Tehsil Bahawalpur in comparison with Tehsil Hasilpur, Khairpur Tamewali, Ahmadpur East and Yazman. The average highest (2.74 $Mgha^{-1}$) and (6.05 $Mgha^{-1}$) total tree carbon stock and total tree sequestration of CO_2 were measured in tehsil Hasilpur followed by tehsil Ahmad Pur East (2.12 $Mgha^{-1}$ and 4.27 $Mgha^{-1}$), tehsil Yazman (2.45 $Mgha^{-1}$ and 7.67 $Mgha^{-1}$) while tehsil Khairpur Tamewali had (1.79 $Mgha^{-1}$ and 6.39 $Mgha^{-1}$ total tree carbon stock and total tree CO_2 sequestration.

Bahawalpur tehsil had maximum tree species with greater DBH and height in comparison with other tehsils. In tehsil Bahawalpur, the maximum (0.63 $Mgha^{-1}$) mean tree carbon stock was calculated for *A. nilotica* with a range of (0.07 $Mgha^{-1}$ to 4.43 $Mgha^{-1}$) and minimum for *E. Camaldulensis* having (0.57 $Mgha^{-1}$). In Hasilpur tehsil, maximum (0.45 $Mgha^{-1}$) mean tree carbon stock was estimated for *A. nilotica* and minimum for *S. cumini* having (0.43 $Mgha^{-1}$). Likewise, in Khairpur Tamewali tehsil, the maximum (0.59 $Mgha^{-1}$) mean tree carbon stock was calucalted for *D. sissoo* and minimum for *E. camaldulensis* having (0.49 $Mgha^{-1}$). Further, in tehsil Ahmadpur East, the maximum (0.93 $Mgha^{-1}$) mean tree carbon stock was found for *B. ceiba* followed by *S. cumini* having (0.93 $Mgha^{-1}$). In tehsil Yazman, the maximum (0.97 $Mgha^{-1}$) mean tree carbon stock was estimated for *B. ceiba* and minimum for *S. cumini* having (0.78 $Mgha^{-1}$). The estimated tree carbon stock in *M. alba*, *M. azedarach*, *A. lebbeck* and *Z. mauritiana* was minimal in all Tehsils because of fewer number of trees with lesser DBH and height as compared to other species.

Bahawalpur tehsil had highest (1202135.6 Mg), (2843045 Mg) and (4403237 Mg) total estimated tehsil tree carbon stock, tehsil soil carbon stock and tehsil CO_2 sequestration. Whereas, the minimum (15936.2 Mg), (1799934 Mg) and (582239.5 Mg) total tehsil tree carbon stock

tehsil soil carbon stock and tehsil CO_2 sequestration was calculated for Yazman tehsil. (Figure 24) indicated a strong linear relationship between total carbon mass per plot and tree basal area. Regression analysis revealed high (0.9002) recorded R^2 for the tehsil Ahmadpur East and the minimum for Bahawalpur tehsil having (0.7638). The slope of the relationship was greater for the tehsil Ahmadpur East in comparison with all the other tehsils. The slope of the Bahawalpur tehsil differed statistically in comparison with Khairpur Tamewali, Ahmadpur East, Yazman and Hasilpur tehsils.

3.2.2.2: Tree Carbon Stock, Total Tree Carbon Stock, Total Soil Carbon Stock and the sequestration of CO_2 at Tehsil level of District Lodhran

Dominant tree species and tree density was different in each Tehsil of District Lodhran. An effective and close relationship was observed regarding total carbon mass per plot and basal area. Regression analysis revealed high (0.8339) recorded R^2 for the tehsil Lodhran (Figure 6). The slope line was higher for the Tehsil Lodhran as compared to other tehsils. Highest (0.95 $Mgha^{-1}$) and (3.45 $Mgha^{-1}$) total tree carbon stock and total tree sequestration of CO_2 were estimated in tehsil Lodhran having average values of (0.001 $Mgha^{-1}$ and 4.35 $Mgha^{-1}$) (Table 5). The lowest (0.75 $Mgha^{-1}$ and 2.73 $Mgha^{-1}$) total tree carbon stock and the sequestration of CO_2 were recorded in Tehsil Kahror Pakka. *B. ceiba* had highest (1.17 $Mgha^{-1}$) carbon stock in Tehsil Lodhran and (0.71 $Mgha^{-1}$) in Dunyapur while in Tehsil Kahror Pakka lowest (0.63 $Mgha^{-1}$) carbon stock was recorded as trees growing in Tehsil Lodhran and Kahror Pakka were taller having higher DBH in comparison with trees present in Tehsil Dunyapur. The highest (0.39 $Mgha^{-1}$) average carbon stock of *D. sissoo* was found in Tehsil Lodhran followed by Tehsil Kahror Pakka (0.39 $Mgha^{-1}$). Similarly, *E. camaldulensis* had highest (0.65 $Mgha^{-1}$) carbon stock in Tehsil Dunyapur followed by Tehsil Lodhran (0.50 $Mgha^{-1}$) and Tehsil Kahror Pakka (0.29 $Mgha^{-1}$) subsequently. The carbon stock of following tree species i.e. *Melia Azedarach, Morus alba, Ziziphus mauritiana, and Syzygium cumini* was found from 0.002-1.54 $Mgha^{-1}$ as these trees were present in little numbers in comparison with tree species like *Acacia nilotica, Dalbergia sissoo* and *Eucalyptus camaldulensis* that were present in large numbers in all the Tehsils of District Lodhran.

The total tree carbon stock and the sequestration of CO_2 were measured by multiplying the total average values of tree carbon stock ha^{-1} and CO_2 sequestration ha^{-1} with the total area of

that Tehsil. Likewise, the total soil carbon stock was measured by multiplying the estimated soil carbon with the area of that Tehsil. Tehsil Lodhran had enough forest cover in comparison with the other tehsils of the District Lodhran. Due to this, Tehsil Lodhran had the highest (99567.5 Mg), (1831257 Mg) and (362789.4 Mg) total measured tree carbon stock, soil carbon stock and total sequestration of CO_2 followed by Tehsil Kahror Pakka having (72545.3 Mg), (1664178 Mg) and (265789.7 Mg) total carbon stock, total soil carbon stock and total CO_2 sequestration. The lowest (49321.8 Mg), (1329645Mg) and (18678.53 Mg) total tree carbon stock, total soil carbon stock and total sequestration of the CO_2 were estimated in Tehsil Dunyapur.

Table 4: Tree Carbon stock, total tree Carbon Stock, total tree CO_2 sequestration, total estimated tehsil tree, soil Carbon Stock and CO_2 sequestration at tehsil level (Khairpur Tamewali, Ahmadpur East and Yazman) within Bahawalpur district in Punjab, Pakistan.

District	**Bahawalpur**		
Tehsils	**Khairpur Tamewali**	**Ahmadpur East**	**Yazman**
No. of Plots Measured (0.405 ha)	**50**	**50**	**50**
Tree Carbon Stock/ha ($Mgha^{-1}$)	**Mean (Min-Max)**	**Mean (Min-Max)**	**Mean (Min-Max)**
Acacia nilotica	0.37 (0.007-1.21)	0.39 (0.003-1.11)	0.38 (0.00-1.39)
Albizia lebbeck	0.06 (0.004-0.10)	0.07 (0.005-0.012)	0.05 (0.003-0.013)
Bombax ceiba	0.35 (0.06-0.97)	0.93 (0.003-4.84)	0.97 (0.02-7.95)
Dalbergia sissoo	0.59 (0.07-1.64)	0.36 (0.008-1.37)	0.49 (0.005-4.02)
Eucalyptus camaldulensis	0.49 (0.03-1.35)	0.46 (0.008-1.65)	0.63 (0.004-4.75)
Melia azedarach	0.11 (0.08-0.17)	0.25 (0.08-0.63)	0.13 (0.07-0.27)
Morus alba	0.08 (0.002-0.26)	0.19 (0.005-0.74)	0.16 (0.003-0.53)
Syzygium cumini	0.41 (0.09-1.13)	0.93 (0.10-3.63)	0.78 (0.17-2.15)
Ziziphus mauritiana	0.08 (0.03-0.17)	0.05 (0.009-0.17)	0.07 (0.03-0.18)
Total tree Carbon Stock /ha ($Mgha^{-1}$)	0.62 (0.009-2.83)	0.81 (0.002-5.35)	1.47 (0.03-8.85)
Total tree CO_2 Sequestration/ha ($Mgha^{-1}$)	2.23 (0.04-10.35)	2.62 (0.005-18.21)	5.13 (0.04-23.25)
Total Tehsil Area (Km^2)	1,014	18,491	19,160
Total Estimated Tehsil tree Carbon stock (Mg)	37923.5	606567.4	15936.2
Total Estimated Tehsil Soil Carbon stock (Mg)	1078125.3	1352232	1799934
Total Estimated Tehsil tree CO_2 Sequestration (Mg)	138684.5	222063.2	582239.5

Table 4a: Tree Carbon stock, total tree Carbon Stock, total tree CO_2 sequestration, total estimated tehsil tree, soil Carbon Stock and CO_2 sequestration at tehsil level (Hasilpur and Bahawalpur) within Bahawalpur district in Punjab, Pakistan.

District	**Bahawalpur**	
Tehsils	**Hasilpur**	**Bahawalpur**
No. of Plots Measured (0.405 ha)	**50**	**200**
Tree Carbon Stock/ha ($Mgha^{-1}$)	**Mean (Min-Max)**	**Mean (Min-Max)**
Acacia nilotica	0.45 (0.03-1.93)	0.63 (0.07-4.43)
Albizia lebbeck	0.004 (0.01-0.13)	0.006 (0.02-0.13)
Azadirachta indica	0.35 (0.05-1.003)	0.47 (0.09-1.003)
Bombax ceiba	0.27 (0.03-0.49)	0.10 (0.007-5.64)
Dalbergia sissoo	0.27 (0.03-1.12)	0.42 (0.03-2.47)
Eucalyptus camaldulensis	0.15 (0.008-1.74)	0.57 (0.003-2.81)
Melia azedarach	0.13 (0.07-0.15)	0.25 (0.08-0.53)
Morus alba	0.25 (0.07-0.73)	0.15 (0.003-0.47)
Syzygium cumini	0.43 (0.010-1.05)	0.51 (0.08-1.81)
Ziziphus mauritiana	0.16 (0.005-1.63)	0.23 (0.0004-1.78)
Total tree Carbon Stock /ha ($Mgha^{-1}$)	0.41 (0.03-2.04)	0.99 (0.0005-6.81)
Total tree CO_2 Sequestration/ha ($Mgha^{-1}$)	1.51 (0.05-6.89)	3.73 (0.002-25.05)
Total Tehsil Area (Km^2)	239	246
Total Estimated Tehsil tree Carbon stock (Mg)	228078.5	1202135.6
Total Estimated Tehsil Soil Carbon stock (Mg)	1900204	2843045
Total Estimated Tehsil tree CO_2 Sequestration (Mg)	835389.4	4403237

Table 5: Tree Carbon stock, total tree Carbon Stock, total tree CO_2 sequestration, total estimated tehsil tree, soil Carbon Stock and CO_2 sequestration at tehsil level (Dunyapur, Kahror Pakka and Lodhran) within Lodhran district in Punjab, Pakistan.

District	**Lodhran**		
Tehsils	**Dunyapur**	**Kahror Pakka**	**Lodhran**
No. of Plots Measured (0.405 ha)	**50**	**50**	**200**
Tree Carbon Stock/ha ($Mgha^{-1}$)	**Mean (Min-Max)**	**Mean (Min-Max)**	**Mean (Min-Max)**
Acacia nilotica	0.95 (0.003-3.35)	0.71 (0.05-2.51)	0.51 (0.008-1.93)
Albizia lebbeck	0.09 (0.004-0.31)	0.04 (0.0005-0.11)	0.11 (0.005-0.35)
Bombax ceiba	0.71 (0.02-3.51)	0.63 (0.01-1.25)	1.17 (0.03-2.85)
Dalbergia sissoo	0.37 (0.03-1.37)	0.12 (0.04-1.25)	0.39 (0.03-0.91)
Eucalyptus camaldulensis	0.65 (0.002-3.66)	0.29 (0.07-0.87)	0.50 (0.008-2.72)
Melia azedarach	0.31 (0.07-0.77)	0.43 (0.06-0.83)	0.55 (0.07-1.21)
Morus alba	0.35 (0.009-1.19)	0.21 (0.004-0.75)	0.31 (0.007-1.54)
Syzygium cumini	0.43 (0.04-0.96)	0.13 (0.007-0.63)	0.63 (0.006-1.47)
Ziziphus mauritiana	0.31 (0.002-0.57)	0.07 (0.005-0.63)	0.09 (0.01-0.36)
Total tree Carbon Stock /ha ($Mgha^{-1}$)	0.86 (0.002-2.87)	0.75 (0.008-3.47)	0.95 (0.001-4.35)
Total tree CO_2 Sequestration/ha ($Mgha^{-1}$)	2.25 (0.06-12.07)	2.73 (0.001-11.57)	3.45 (0.006-15.78)
Total Tehsil Area (Km^2)	889.0	778.0	1,790
Total Estimated Tehsil tree Carbon stock (Mg)	49321.8	72545.3	99567.5
Total Estimated Tehsil Soil Carbon stock (Mg)	1329645	1664178	1831257
Total Estimated Tehsil tree CO_2 Sequestration (Mg)	18678.53	265789.7	362789.4

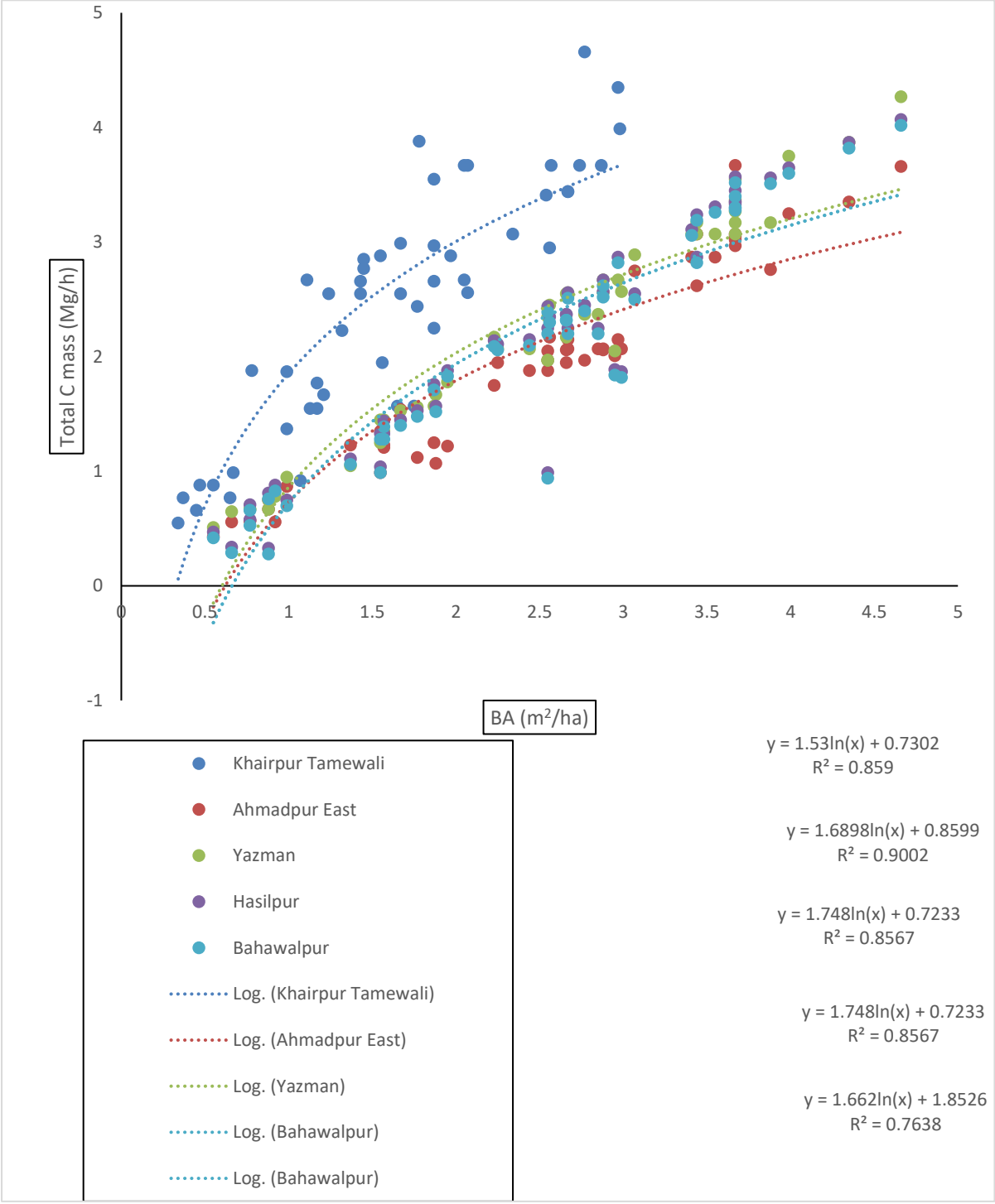


Figure 5: Relationship between total C mas (Mg/ha) and total basal area of (m^2/ha) at tehsils of district Bahawalpur.

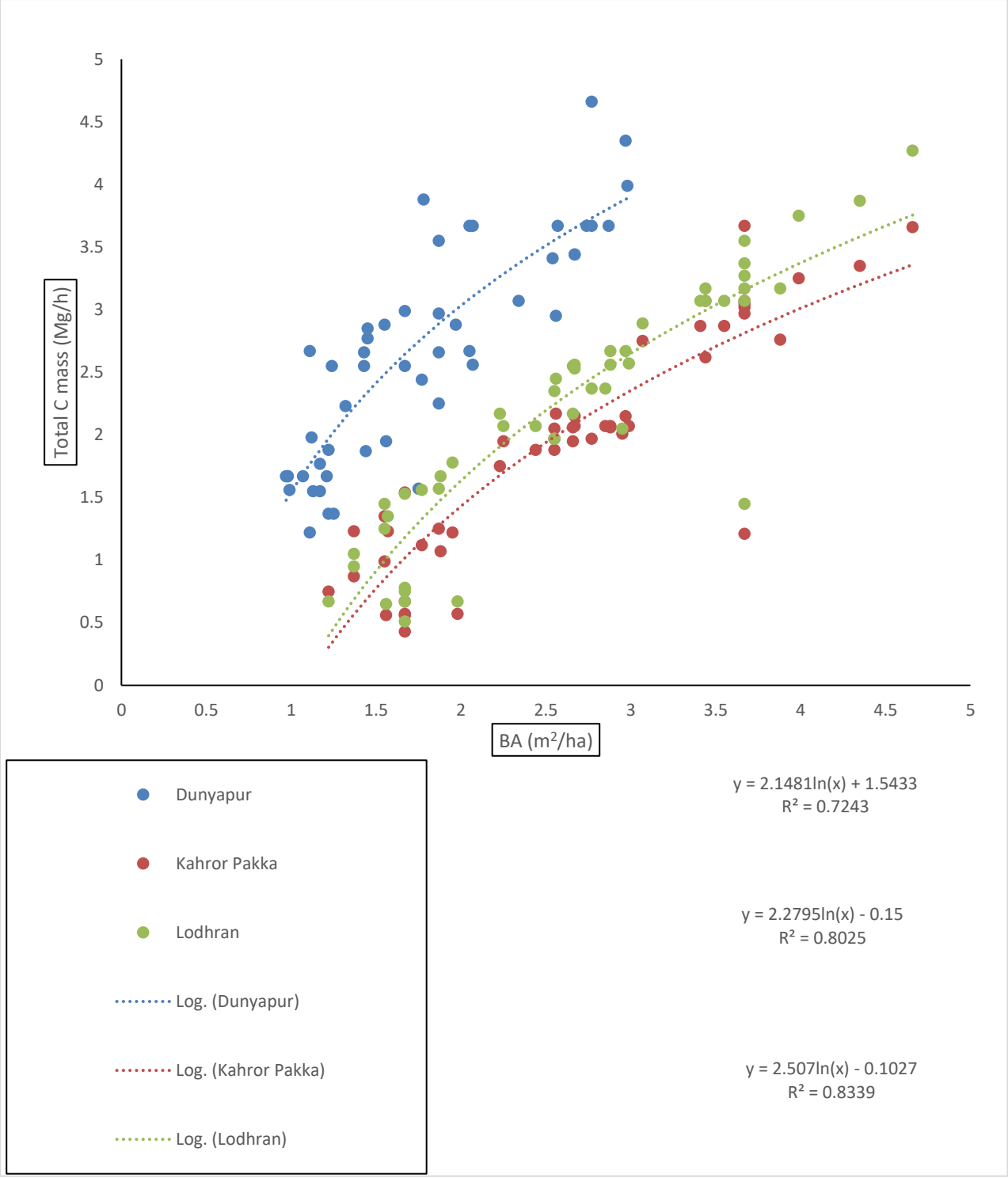


Figure 6: Relationship between total C mas (Mg/ha) and total basal area of (m^2/ha) at tehsils of district Lodhran.

Table 6: Analysis of Covariance to test the difference in slope between Districts in regression between total carbon per hectare vs BA/ha

District	a (Intercept)	b (Slope)
Bahawalpur	0.1187	1.6825 (a)
Lodhran	0.0895	1.5537 (b)

3.3: Potential tree carbon stock, CO_2 sequestration, potential carbon stock and the sequestration of CO_2 at Tehsil level in the two selected Districts of Punjab

The carbon sequestration potential is about the capacity of the quantity of carbon and CO_2 that can be sequestered by farm trees. In order to measure the potential of trees to capture carbon, tree density was determined. Tree Density was obtained from the farmer's interviews that how much trees they plant on their agricultural lands and was analyzed statistically. After that, the average was calculated of these trees planted on one hectare basis. The number and kind of tree species were almost same in all the tehsils of the selected districts. The area of every Tehsil also has an important part in enhancing the potential of carbon stocks and its sequestration.

3.3.1: District Bahawalpur

District Bahawalpur has five tehsils. Between all tehsils of District Bahawalpur, tehsil Bahawalpur had highest (69 ha^{-1}) tree density with higher (2.39 $Mgha^{-1}$) and (8.80 $Mgha^{-1}$) values of tree carbon stock and CO_2 sequestration followed by tehsil Hasilpur (2.16 $Mgha^{-1}$ and 7.97 $Mgha^{-1}$) whereas the lowest (0.91 $Mgha^{-1}$ and 3.36 $Mgha^{-1}$) values were estimated in tehsil Khairpur Tamewali (table 7).

3.3.2: District Lodhran

In District Lodhran, highest (83.38 ha^{-1}) tree density was observed in tehsil Lodhran followed by Kahror Pakka (71.25 ha^{-1}) and the lowest (63.06 ha^{-1}) tree density was noticed in tehsil Dunyapur. The data showed that Tehsil Lodhran had the greater potential to sequester carbon and CO_2 in comparison with Tehsil Kahror Pakka and Dunyapur as illustrated in (table 8). Findings exhibited that Tehsil Lodhran had the greater (2.84 $Mgha^{-1}$and 10.49 $Mgha^{-1}$) potential to sequester carbon and the sequestration of CO_2 subsequently. Among all the tehsils, Dunyapur had the lowest potential to sequester carbon and CO_2. Similarly, the highest (318811.2 Mg) and (1175758 Mg) total potential of carbon stock and total sequestration of CO_2 was recorded for tehsil Lodhran followed by Tehsil Kahror Pakka while lowest (108572.7 Mg) and (404339.8 Mg) total

potential of carbon stock and total sequestration of CO_2 was observed for Dunyapur tehsil.

Table 7: Potential Carbon stock and CO_2 sequestration at tehsil level within Bahawalpur district in Punjab, Pakistan.

District	Bahawalpur						
Tehsil	**Tree Density (trees/ha)**	**Potential Tree Density (trees/ha)**	**Potential Tree C stock (MgC/ha)**	**Potential Tree CO_2 Sequestered ($MgCO_2$/ha)**	**Tehsil Area (Km^2)**	**Total Potential Tehsil C stock (Mg)**	**Total Potential Tehsil CO_2 Sequestration (Mg)**
Khairpur Tamewali	27.96	87.44	1.79	6.39	1,014	132487.5	3537395.9
Ahmadpur East	24.56	71.25	2.12	4.27	18,491	157618.9	4532156.4
Yazman	39.23	83.38	2.45	7.67	19,160	318811.2	1286453.5
Hasilpur	35.75	76.57	2.74	6.05	239	214579.6	2325867.3
Bahawalpur	19.67	63.06	2.95	8.93	246	109674.5	4134565.7
Average	**29.434**	**76.34**	**2.41**	**6.662**	-	-	-
Total	-	-	-	-	**39,150**	**186634.34**	**3163287.76**

Table 8: Potential Carbon stock and CO_2 sequestration at tehsil level within Lodhran district in Punjab, Pakistan.

District	Lodhran						
Tehsil	**Tree Density (trees/ha)**	**Potential Tree Density (trees/ha)**	**Potential Tree C stock (MgC/ha)**	**Potential Tree CO_2 Sequestered ($MgCO_2$/ha)**	**Tehsil Area (Km^2)**	**Total Potential Tehsil C stock (Mg)**	**Total Potential Tehsil CO_2 Sequestration (Mg)**
Dunyapur	28.78	67	2.34	7.55	889.0	124567.7	345673.6
Kahror Pakka	26.77	64	2.28	6.67	778.0	414367.4	435673.9
Lodhran	16.65	51	1.43	4.21	1,790	655734.9	2145674.7
Average	**24.07**	**60.67**	**2.02**	**6.14**	-	-	-
Total	-	-	-	-	**3457**	**1194670**	**2927022.2**

4. Conclusions

Our thorough sampling in the two selected districts exhibited that irrigated forest plantations in the Punjab province of Pakistan presently reserve adequate quantities of carbon in the soil and plants as well. Relying upon farmer's readiness in order to enhance the tree stocking rate, the two selected study districts have the ability to enhance the tree carbon storage from 107.45% to 150.51%. In this regard, the farmers of the Punjab can help Pakistan to easily fulfill the promises made in the Paris Climate Accord by just adopting appropriate alterations in the growing pattern of trees on existing forestry systems if the reasonable incentives are given to them.

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