BIOMASS, CARBON STOCKS AND CO_2 SEQUESTRATION IN THREE DIFFERENT AGED IRRIGATED *POPULUS DELTOIDES* BARTR. EX MARSH. BUND PLANTING AGROFORESTRY SYSTEMS

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Abstract. Carbon sequestration needs to be accompanied by socio-economic enhancements, especially, in developing countries like Pakistan. Agroforestry has been considered as an ancient practice throughout the country but the knowledge about its impacts on tree and soil carbon storage is minimal. Growth, biomass, carbon stocks and CO_2 sequestration rate in three different age classes of *Populus deltoides* Bartr. Ex Marsh. planted in linear patterns along boundaries (bund planting) were estimated in three subdivisions (Tehsils) of district Chiniot (Bhawana, Chiniot and Lalian) of Punjab, Pakistan. For estimating tree biomass and carbon stocks, allometric equation was used and soil organic carbon (SOC) was assessed at two depths (0-15 and 15-30 cm). The diameter at breast height (DBH) and height of trees were higher at 4-6 years as compared to 2-4 years and the plant biomass was found the maximum (90.55 Mg ha^{-1}) in Tehsil Lalian at 6 years. Total carbon stocks and CO_2 sequestration rate varied from 0.89 Mg ha^{-1} and 1.63 Mg ha^{-1} yr^{-1} at 2 years to 43.54 Mg ha^{-1} and 26.58 Mg ha^{-1} yr^{-1} at 6 years, respectively, across all Tehsils. Total SOC stocks were maximum (43.73 Mg ha^{-1}) at 6 years in Tehsil Lalian while minimum 27.92 Mg ha^{-1} in Tehsil Bhawana at 2 years. Overall, soil + tree carbon stocks increased with age and was maximum at 6 years: 61.54 Mg ha^{-1}, 80.76 Mg ha^{-1}, and 87.27 Mg ha^{-1} in Tehsil Bhawana, Chiniot, and Lalian, respectively. The above results encouraged the establishment of *P. deltoides* planting along farm crops as an important possibility for increased carbon storage and mitigation of atmospheric accumulation of CO_2.
Keywords: *agroforestry, climate change, tree biomass, carbon capture, agriculture, environment*

Introduction

The agriculture sector of Pakistan is at risk and facing diverse challenges such as diminution of natural resources (agriculture, forests and water) and severe climatic changes due to increasing population pressure and growing needs of food, feed, fodder, pulp, fuel wood and timber (Saifullha, 2017). Being a less developed country, Pakistan is ranked 7th among the most vulnerable countries in the world (Kreft et al., 2017). Therefore, to ensure sustainability in agriculture and to fulfill the food requirements of the enormous population, suitable methods of climate change mitigation have to be adapted by the country (Nawaz et al., 2017b).

The contribution of agriculture in the anthropogenic emissions of greenhouse gases (GHGs) ranges from 10-12% around the globe (Smith et al., 2008). However, tree crop combination (agroforestry) has been documented by UNFCCC (United Nations

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Framework Convention on Climate Change) as GHG mitigation opportunity because of its high carbon sequestering potential and fast growth rate of farm trees (Watson et al., 2000; Updegraff et al., 2004; Chauhan et al., 2009). Planting of trees and shrubs along crops or on grazed pastures on the same land area is known as agroforestry (Nair et al., 2009). In developing countries, like Pakistan, agroforestry has recently attained growing attention for mitigating GHG emissions. Agroforestry systems can store the higher amount of carbon as compared to conventional plantations (Hergoualc'h et al., 2012).

In recent years, agroforestry has got attention as a portion climate-smart-agriculture and is repeatedly declared as a prospective source to mitigate the adverse climatic conditions (Ajit et al., 2014). In Pakistan, agroforestry provides fuelwood, timber, fodder, fertilizer, fiber and contribute in the provision of food, maintain livelihoods, cope to overcome poverty and promotes the prolific and irrepressible cropping and agricultural environment, thus playing a vital role in the daily life of rural population of the country (Nawaz et al., 2016). Moreover, agroforestry has been getting noteworthy considerations by the researchers as well as by policymakers for its apparent ability to sequester carbon, alleviation of poverty, economic growth (DAC, 2014) and considered as an important part of 'Green Pakistan' movement in the country.

Poplar (*Populus deltoides* Bartr. Ex Marsh.) based agroforestry system has received a wide recognition throughout the globe, covering an area of 1.5 million ha (Kutsokon et al., 2015). The area is supposed to increase up to many folds in near future by planting the poplar in marginal agricultural lands to fullfil the needs of fuel and timber in developing regions of the world (Nielsen et al., 2014; Jha, 2018). Because of its fast growth rate, compatibility with crops and high industrial demand, poplar has got a wide acceptance by the farmers of Pakistan, especially, in Punjab during the last two decades. The branches, leaves and sometimes roots are used as fuelwood by the local dwellers while timber of the tree is used in plywood industries of the country. The tree has an enormous potential to store carbon and sequester CO_2 owing to its fast growth habit and wider adaptability throughout the country (Arora et al., 2014; Qureshi, 2005).

A number of studies have been documented on biomass, productivity, functioning, structure and carbon stocks of Poplar throughout the world (Das and Chaturvdi, 2005; Fang et al., 2007; Rizvi et al., 2011; Arora et al., 2014). Most of these studies were carried out in plantations and/or under different agroforestry systems, however, the studies in bund planting based agroforestry system under semiarid climate are rare. Moreover, in Pakistan, the information regarding biomass, productivity, carbon stock and rate of CO_2 sequestration of bund planted poplar based agroforestry by age under the set of local environmental conditions is scanty. Keeping in mind the above situation, the study was formulated to investigate the hypothesis that *P. deltoides* (poplar) planted linearly along field bunds (bund planting) store significant amount of carbon and thus mitigate CO_2 from the environment. The second hypothesis was that site factor can play a significant role in c sequestration owing to minor climatic differences and/or different agroforestry practices. The study was performed in three Tehsils of District Chiniot: Bhawana, Chiniot, and Lalian, with the major objective to estimate the growth, biomass, carbon storage and its dissemination in the various carbon pools (above ground biomass and belowground biomass + soil) among three different age classes of *P. deltoides*.

Materials and methods

Ethics statement

The current study was carried out in three administrative subdivisions (Tehsils) of District Chiniot (*Fig. 1*). Tree inventory and soil sampling were carried out in rural areas of these Tehsils with special permission from the farmers. It is confirmed that during sampling no harm was done to the farm crops and/or farm trees (*P. deltoides*).

Site description

The studied district shared boundary with four districts: Faisalabad on the south-east, Hafizabad on the north, Jhang on the south and Sargodha on the west. The whole district was comprised of three subdivisions (Tehsils): Bhawana, Chiniot, and Lalian, with a total area of 1,020 square miles. Geographically, this region is divided into two surface levels, i.e. low-level river valley in the center along river Chenab and old Sandal Bar area present along the extreme east. Areas near River Chenab experience severe floods during monsoon season. The region experiences very long summers and short severe winters. The dry period starts from early October and lasts until mid-July (Nawaz et al., 2016). The annual rainfall ranges from 345 mm (Tehsil Lalian) to 324 mm (Tehsil Bhawana). The mean annual temperature ranges from 24 to 24.3 °C with an average June high of 34.3 °C and January low of 11.8 °C among all three Tehsils of District Chiniot. (https://en.climate-data.org).

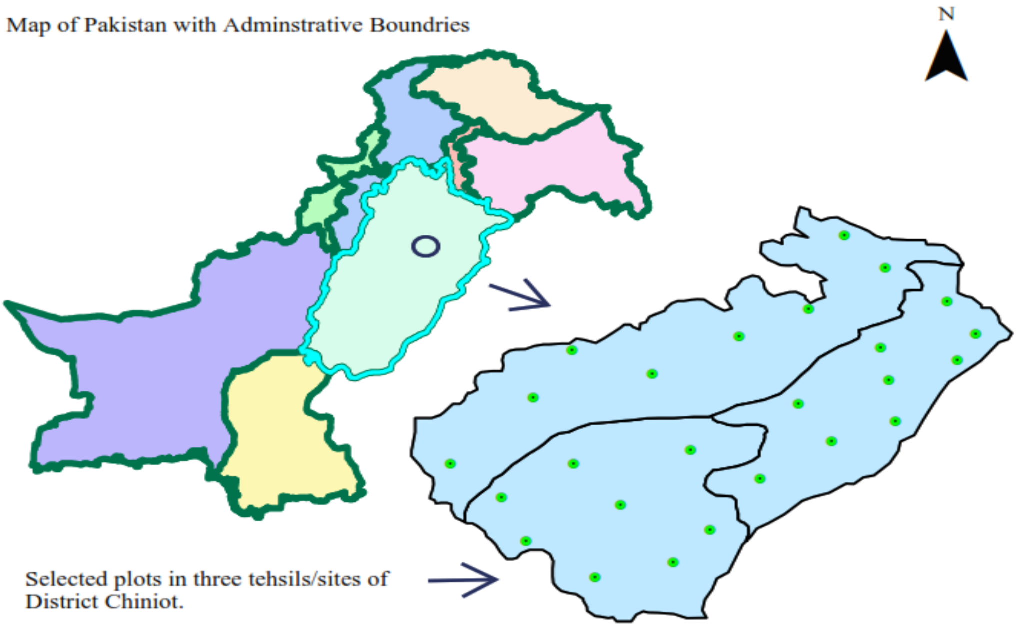

Figure 1. *Map of Pakistan with administrative boundaries and study area map showing the distribution of sampled plots in three Tehsils of District Chiniot*

Biomass sampling, carbon stocks, and CO_2 sequestration

A nondestructive approach was used to estimate the tree above and belowground biomass. Inventory data was collected from selected villages of each Tehsil. For that purpose, field visits were carried out during April 2016 and 2 plots of 0.405 ha (1 acre)

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for each age group, which have *P. deltoides* planted linearly along croplands were randomly selected from each village (Nawaz et al., 2018; Murthy et al., 2013). The height and diameter at breast height (DBH) of all the *P. deltoides* trees planted by farmers on each plot were measured. The aboveground biomass was measured by using species-specific allometric equation from the literature (Arora et al., 2014). The belowground biomass was assumed to be 26% of the aboveground biomass (Cairns et al., 1997). Inventory parameters: DBH and height were then used to calculate the individual tree biomass of each age group which was then converted to biomass per plot. Carbon stock for each age group was calculated by assuming that the dry mass is 48.1% carbon of biomass (Thomas and Martin, 2012). The calculated weight of carbon content was then converted to CO_2 sequestered by trees of each age group by multiplying with 3.6663 (Afzal and Aqeela, 2013).

Soil sampling and soil carbon stocks

Soil sampling was done randomly at 5 places for each age group of *P. deltoides* at two depths (0-15 cm and 15-30 cm). Samples were collected in cardinal directions under the tree canopy as well as outside the tree canopy. To get a composite sample, these collected samples were then mixed together for each depth. Overall, 90 samples (3 ages × 3 Tehsils × 2 depths × 5 replicates), 10 for each age class and 30 from each Tehsil were collected. All of the soil samples within the same soil depth were pooled together and air dried. The Walkley Black method was used to calculate the soil organic carbon (Walkley and Black, 1934). Metal core having a height of 4 cm and an internal diameter of 5 cm was used to determine the bulk density at two depths (0-15 cm and 15-30 cm) by a procedure described by (Arora et al., 2014). Soil carbon per hectare was calculated by multiplying the values of bulk density, soil depth and %age of organic carbon content (Joa Carlos et al., 2001).

Statistical analysis

Descriptive statistics and the data regarding soil carbon and bulk density was analyzed for each age group by using two-way analysis of variance (ANOVA). The mean comparison was carried out by least significant difference test (LSD) at ($p \leq 0.05$) by using SAS 9.4 & Statistica 10 statistical softwares.

Results

Tree growth and biomass

The growth parameters indicated the increasing trend with increased age, a steady increase in DBH and height was noted among all three Tehsils of District Chiniot (*Table 1*). The DBH and height of *P. deltoides* increased from 1.98 cm and 1.83 m at the 2 years to 24.57 cm and 20.89 m at the 6 years, respectively. Among all the Tehsils, the maximum mean DBH (6.84 ± 1.58 cm, 12.46 ± 2.20 cm, and 20.43 ± 4.08 cm) was noted in Tehsil Lalian at the 2, 4 and 6 years, respectively. Whereas, for 2-year-old age, maximum mean height (5.52 ± 1.23 m) was calculated in Tehsil Bhawana and for 4 and 6 years, maximum mean height (9.28 ± 1.85 m and 13.45 ± 1.86 m) was estimated in Tehsil Lalian. Positive and significant relationship between tree age and DBH (r = 0.92, $p < 0.001$), tree age and Height (r = 0.60, $p < 0.001$) illustrate that both the parameters were responsible for biomass increment of *P. deltoides*. The AGB (aboveground

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biomass), BGB (belowground biomass), and PB (plant biomass) recorded for different age classes of the *P. deltoides* viewed in the order: 6 > 4 > 2. Across all the three age classes of the *P. deltoides* bund agroforestry plantation, higher biomass proportion was noted in stem biomass as compared to the other parts. The AGB and BGB of the *P. deltoides* was increased with increasing age among all three Tehsils with maximum in Tehsil Lalian: 1.89 Mg ha^{-1} and 0.49 Mg ha^{-1} (2 years), 17.67 Mg ha^{-1} and 4.60 Mg ha^{-1} (4 years), and 71.85 Mg ha^{-1} and 18.68 Mg ha^{-1} (6 years), while minimum in Tehsil Bhawana 1.47 Mg ha^{-1} and 0.38 Mg ha^{-1} (2 years), 9.15 Mg ha^{-1} and 2.38 Mg ha^{-1} (4 years), and 37.80 Mg ha^{-1} and 9.85 Mg ha^{-1} (6 years), respectively. The plant biomass of the *P. deltoides* in the study district increased from 1.86 Mg ha^{-1} at the 2 years age to 90.55 Mg ha^{-1} at the 6 years plots, with the maximum increase found in the 4-6 years age (*Table 2*).

Table 1. *The general status of three age classes of Populus deltoides planted linearly along crops among three Tehsils of District Chiniot (mean ± SD)*

Tree age (years)	Measured parameters	Tehsils/sites								
		Bhawana			Chiniot			Lalian		
		Mean±SD	Mini.	Max.	Mean±SD	Mini.	Max.	Mean±SD	Mini.	Max
2	DBH (cm)	5.50±1.44	2	8.66	4.45±1.26	1.98	8	6.84±1.58	4.45	10.11
	Height (m)	5.52±1.23	1.98	7.86	4.71±1.34	1.83	8.56	5.16±1.52	1.88	9.29
	Tree density ha^{-1}	28.01±9.59	17.32	39.54	66.23±23.14	34.60	88.96	23.6±7.67	14.83	39.53
4	DBH (cm)	11.85±1.72	6.38	15.87	11.50±2.16	5.98	18.11	12.46±2.20	6.98	19.02
	Height (m)	8.27±1.48	4.94	12.19	8.87±1.91	4.96	12.77	9.28±1.85	5.88	13.83
	Tree density ha^{-1}	25.77±15.15	9.88	54.36	46.6±31.27	21.47	77.87	49.24±20.30	17.30	79.19
6	DBH (cm)	15.45±2.49	15.76	21.51	17.44±3.70	16	22.67	20.43±4.08	17.98	24.57
	Height (m)	13.05±1.86	7.4	17.03	12.86±2.18	8.68	18.5	13.45±1.86	9.44	20.89
	Tree density ha^{-1}	26.19±3.74	22.24	32.12	36.71±12.05	19.77	56.84	41.48±16.70	24.71	67.19

DBH: Diameter at breast height. Mini: Minimum. Max: Maximum

Table 2. *Biomass (Mg ha^{-1}) distribution in P. deltoides by age among three Tehsils of District Chiniot*

Biomass (Mg ha^{-1})									
Age (years)	Tehsils/sites								
	Bhawana			Chiniot			Lalian		
	AGB	BGB	PB	AGB	BGB	PB	AGB	BGB	PB
2	1.47	0.38	1.86	1.65	0.43	2.08	1.89	0.49	2.38
4	9.15	2.38	11.53	15.70	4.08	19.79	17.67	4.60	22.27
6	37.89	9.85	47.75	64.27	16.71	80.98	71.85	18.68	90.55

AGB, BGB and PB refer to aboveground biomass, belowground biomass and plant biomass, respectively

Tree carbon stocks and CO_2 sequestration

Tree carbon stocks and CO_2 sequestration was estimated at Tehsil level in three different age classes of the *P. deltoides* planted along the farm crops on bunds by farmers. Across all age groups, the aboveground carbon stocks (AGCS), belowground carbon stock (BGCS), total plant carbon stock (TPCS), CO_2 sequestration and CO_2

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sequestration rate were highest at the 6-year-old plots and the lowest at the 2-year-old plots given in *Table 3*. A positive and significant linear relationship was found between plot-level tree carbon stock and tree basal area with R^2 = 0.98 as represented in *Figure 2*.

Table 3. *Carbon stock (Mg ha^{-1}), CO_2 sequestration (Mg ha^{-1}) and CO_2 sequestration rate ha^{-1} yr^{-1} in P. deltoides by age among three Tehsils of Distirct Chiniot*

Carbon stock (Mg ha^{-1}), CO_2 sequestration (Mg ha^{-1}) and CO_2 sequestration rate ha^{-1}yr^{-1}															
Age (years)	Tehsils/sites														
	Bhawana					Chiniot					Lalian				
	AGCS	BGCS	TPCS	CO_2 Seq.	CO_2 Seq. rate	AGCS	BGCS	TPCS	CO_2 Seq.	CO_2 Seq. rate	AGCS	BGCS	TPCS	CO_2 Seq.	CO_2 Seq. rate
2	0.71	0.18	0.89	3.27	1.63	0.80	0.21	1	3.67	1.83	0.91	0.24	1.14	4.19	2.09
4	4.40	1.14	5.55	20.31	5.08	7.44	1.96	9.52	34.86	8.72	8.50	2.21	10.71	39.24	9.81
6	18.23	4.74	22.97	84.13	14.02	30.91	8.04	38.95	142.68	23.78	34.56	8.99	43.54	159.50	26.58

AGCS, BGCS and TPCS refer to aboveground carbon stock, belowground carbon stock and total plant carbon stock, respectively

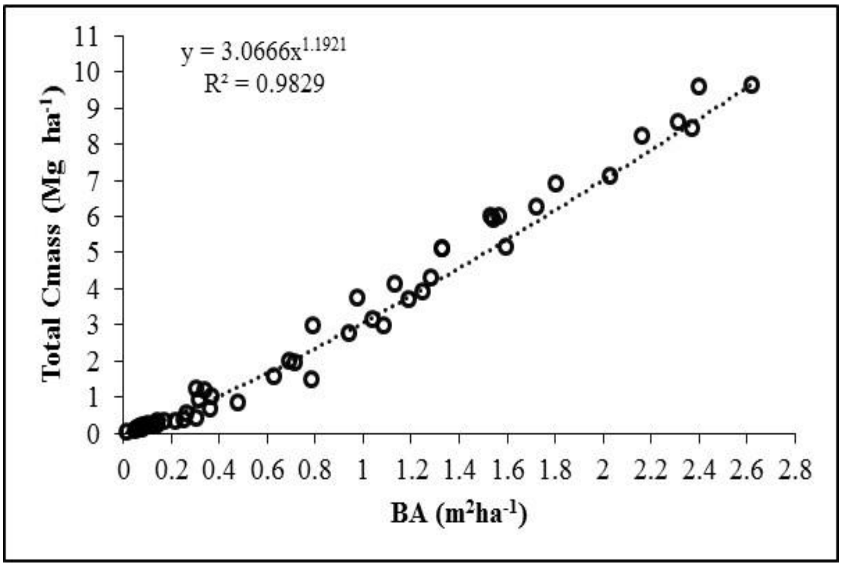

Figure 2. *Allometric model representing relationship between total carbon mass (Mg ha^{-1}) and tree basal area (BA m^2 ha^{-1}) for inventory plots of P. deltoides planted linearly along farm crops in District Chiniot*

Across all three Tehsils, the above and belowground carbon stocks at the 2-year-old plots were increased from 0.71 Mg ha^{-1} and 0.18 Mg ha^{-1} to 0.91 Mg ha^{-1} and 0.24 Mg ha^{-1}, with minimum values in Tehsil Bhawana and maximum in Tehsil Lalian. Similar trends were noted about the above and belowground distribution of carbon contents at the 4 and 6-year-old plots, maximum values accounted for Tehsil Lalian (8.50 Mg ha^{-1}, 2.21 Mg ha^{-1} and 34.56 Mg ha^{-1}, 8.99 Mg ha^{-1}), followed by Chinot (7.44 Mg ha^{-1}, 1.96 Mg ha^{-1} and 30.91 Mg ha^{-1}, 8.04 Mg ha^{-1}), while minimum carbon stocks were estimated in Tehsil Bhawana (4.40 Mg ha^{-1}, 1.14 Mg ha^{-1} and 18.23 Mg ha^{-1}, 4.74 Mg

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ha^{-1}), respectively. The total plant carbon stocks increased from 0.89 Mg ha^{-1} at the 2 years age class (Tehsil Bhawana) to 43.54 Mg ha^{-1} at the 6 years (Tehsil Lalian) with a maximum increase occurred in the 4-6 years age class. There was a positive and significant correlation was observed between biomass carbon and tree age ($r = 0.42$, $p < 0.001$). The CO_2 sequestration and CO_2 sequestration rate was increased from 84.13 Mg ha^{-1} and 14.02 Mg ha^{-1} yr^{-1} at 2 years of and reached up to a maximum of 159.50 Mg ha^{-1} and 26.58 Mg ha^{-1} yr^{-1} at 6 years in this study.

Soil organic carbon and carbon stocks

Soil organic carbon (SOC %) revealed a decreasing trend with the increase of soil depth across all age classes in the three Tehsils: SOC was higher in upper soil (0-15 cm) as compared to the sub-soil (15-30 cm). The difference in soil organic carbon because of age was significant (*Table 4*). SOC, in upper soil, was 36.97% greater in Tehsil Bhawana, 32.52% in Tehsil Chiniot and 38.28% in Tehsil Lalian in the 6 years as compared to the 2 years of *P. deltoides*. Bulk density (BD) showed antagonistic results as compared to SOC. However, BD increased with tree age across all the Tehsils. For all age classes, bulk density was more in the subsoil as compared to the upper soil surface (*Table 4*). It decreased from 1.50 g cm^{-3} at 2 years to 1.28 g cm^{-3} at 6 years in surface soil (0-15 cm).

Table 4. *Organic carbon (%) and bulk density (g cm^{-3}) in P. deltoides by age planted linearly among three Tehsils of District Chiniot*

Age (years)	Tehsils/sites	Organic carbon %		Bulk density (g cm^{-3})	
		0-15 cm	15-30 cm	0-15 cm	15-30 cm
2	Bhawana	0.75±0.07^{f}	0.51±0.03 ^{f}	1.47±0.02 ^{ab}	1.48±0.03 ^{bc}
	Chiniot	0.83±0.05^{e}	0.57±0.04 ^{def}	1.43±0.04 ^{bc}	1.51±0.02 ^{ab}
	Lalian	0.79±0.07^{ef}	0.53±0.06 ^{ef}	1.50±0.07 ^{a}	1.53±0.06 ^{a}
4	Bhawana	0.91±0.04^{cd}	0.59±0.03 ^{de}	1.31±0.04 ^{efg}	1.44±0.06 ^{cd}
	Chiniot	0.86±0.05^{de}	0.62±0.06 ^{cd}	1.40±0.04 ^{cd}	1.41±0.02 ^{cde}
	Lalian	0.95±0.06^{c}	0.66±0.05 ^{c}	1.37±0.05 ^{cde}	1.44±0.05 ^{cd}
6	Bhawana	1.19±0.04^{b}	0.78±0.06 ^{b}	1.28±0.04 ^{g}	1.34±0.06 ^{f}
	Chiniot	1.23±0.03^{ab}	0.86±0.05 ^{a}	1.31±0.03 ^{fg}	1.36±0.02 ^{ef}
	Lalian	1.28±0.03^{a}	0.85±0.06 ^{a}	1.35±0.03 ^{def}	1.39±0.03 ^{def}

n = 5 for each age class and values are mean with standard deviation. Means having same letters are not significantly different at a probability level of 5%

With the increase in tree age soil organic carbon stocks (SOCS) increased, regardless of soil depth across three Tehsils of District Chiniot (*Table 5*). In surface soil, SOCS were increased maximum 36.33% in Tehsil Chiniot while minimum 28.01% in Tehsil Bhawana at 6 years than in 2-year-old trees. At 15-30 cm depth, SOCS were decreased from 11.37 Mg ha^{-1} at the 2-year-old trees (Tehsil Bhawana) to 17.76 Mg ha^{-1} at 6-year-old trees. Tree age and SOC indicate a positive and significant correlation at both soil depths ($r = 0.86$ and $r = 0.80$, $p < 0.001$). The carbon sequestration rate (CSR) at 0-30 cm soil was greater in Tehsil Lalian (2.27 Mg ha^{-1} yr^{-1}) as compared to other two Tehsils at 6-year-old trees.

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Table 5. *Effect of three age classes of P. deltoides on soil organic carbon stock among three Tehsils of District Chiniot*

Age (years)	Tehsils/sites	Soil organic carbon stock (Mg ha^{-1})	
		0-15 cm	**15-30 cm**
2	Bhawana	16.55±1.88 ^{e}	11.37±0.66 ^{e}
	Chiniot	17.78±1.39 ^{de}	13.01±1.09 ^{d}
	Lalian	17.87±1.59 ^{de}	12.22±1.53 ^{de}
4	Bhawana	19.20±0.66 ^{cd}	12.67±0.79 ^{de}
	Chiniot	18.19±1.27 ^{cd}	13.29±1.43 ^{cd}
	Lalian	19.58±1 ^{c}	14.49±1.28 ^{bc}
6	Bhawana	22.99±0.9 ^{b}	15.58±1.28 ^{b}
	Chiniot	24.24±0.88 ^{b}	17.57±1.20 ^{a}
	Lalian	25.97±0.74 ^{a}	17.76±1.20 ^{a}

Total carbon stocks

Keeping in mind the guidelines of Intergovernmental Panel on Climate Change (IPCC), total carbon stock was (biomass + soil) calculated by considering the soil C up to 30 cm soil depth. The amount of total carbon increased with an increase of tree age in all three Tehsils (*Table 6*). The maximum total carbon stock at 2-year-old trees was estimated in Tehsil Chiniot (31.98 Mg ha^{-1} whereas at 4 and 6-year-old age trees higher total carbon stocks (44.75 Mg ha^{-1} and 87.27 Mg ha^{-1}) were estimated in Tehsil Lalian. Overall the total carbon stock increased from 28.81 Mg ha^{-1} at 2 years of age to 87.27 Mg ha^{-1} at 6 years of age among all three Tehsils. A significant and positive correlation was studied between total carbon stock and age of the *P. deltoides* trees ($r = 0.90$, $p < 0.001$).

Table 6. *Total carbon stock (tree + soil) in P. deltoides by age among three Tehsils of District Chiniot*

Age (years)	Tehsils/sites	Total carbon stock (Mg ha^{-1})		
		Total biomass carbon	**Soil organic carbon (0-15 cm + 15-30 cm)**	**Total carbon**
2	Bhawana	0.89	27.92	28.81
	Chiniot	1	30.98	31.98
	Lalian	1.14	30.09	31.23
4	Bhawana	5.55	31.87	37.42
	Chiniot	9.52	31.48	41
	Lalian	10.71	34.04	44.75
6	Bhawana	22.97	38.57	61.54
	Chiniot	38.95	41.81	80.76
	Lalian	43.54	43.73	87.27

Discussion

The present study supports our hypothesis that biomass and carbon stocks in *P. deltoides* increased markedly in both above and belowground parts with tree age among

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three Tehsils of District Chiniot. For example, Tehsil Lalian has the highest biomass than other two Tehsils because of higher tree density and greater DBH of all age classes. This can be attributed to better climatic conditions: slightly higher rainfall (345 mm annually) as compared to Tehsil Chiniot and Bhawana or there may be other factors such as agroforestry awareness and agroforestry practices. Similar trends of growth of *P. deltoides* planted in agroforestry and plantations have been reported in various studies (Jain et al., 2017; Chauhan et al., 2011; Kanime et al., 2013). Moreover, *P. deltoides* at 6 years age, accumulate more biomass in all Tehsils (47.75 Mg ha-1 to 90.55 Mg ha-1) than a 7 years old *E. camaldulensis* (62.35 Mg ha^{-1}) and 6 years old *S. siamea* (45.39 Mg ha^{-1}) described by Harmand et al. (2004). Though, the results of our study concerning aboveground biomass fall in line to those described by Rizvi et al. (2011) for *P. deltoides* in agroforestry systems. Overall, the findings of the biomass of the present study are comparable to other agroforestry trees such as *E. camaldulensis* hybrid, 95 Mg ha^{-1} at 7 years and *D. sissoo*, 50.3 to 122.7 Mg ha^{-1} (Negi and Sharma, 1985; Lodhiyal and Lodhiyal, 2003). The findings of the present study different as compared to previous studies might be because of climatic conditions, growth pattern, site quality, species density, age and cultural plus management practices.

In the present study we have quantified the above and belowground carbon stock in bund planted *P. deltoides* based agroforestry system at early growth stages. The findings of present study are based on bund planted agroforestry system while the previous studies were mostly carried out in different plantations and agroforetsry systems under different climatic conditions. For instance, mean carbon stock in a *P. deltoides* based agroforestry system in temperate region has been reported 15.1 t C ha^{-1} at 111 trees ha^{-1} (Peichl et al., 2006). The amount of carbon found by Fang et al. (2010) in 5 years old *P. deltoides* trees was only 7.8 t C ha^{-1}, far lesser as compared with our findings. The present estimates of total carbon stocks were maximum at 6 years of age across all Tehsils (22.7 Mg ha^{-1} to 43.54 Mg ha^{-1}), much higher as compared to the findings of Chauhan et al. (2010) for *P. deltoides*, Nawaz et al. (2017a) for *E. camaldulensis*. The potential of agroforestry systems to stock and sequester CO_2 are extremely inconsistent (0.29 to 15.21 t C ha^{-1} yr^{-1}) relying on several aspects including site characteristics, type of species, land use type, the age of trees and cultural practices (Nair et al., 2009). Traditional tree crop combination in Africa stock more carbon because of their greater DBH and height than the abandoned land and improved agroforestry systems which were comparatively young (Takimoto et al., 2008). Gera (2012) recommended that differences among carbon stocks can be credited to mean annual increment of trees which differed with nature of planting stock, site, age and tree density. In the present study, largest carbon amount was accounted for stem (about half) from above tree biomass, which is identical with different results for distinctive species (Redondo, 2007; Fonseca et al., 2012).

In agroforestry systems, the soil is considered as an important subsystem for lowering CO_2 levels in the atmosphere. Nair et al. (2009) compare SOC contents among different land use practices and found the trend in the order of forests > agroforestry > plantations > arable crops. A few studies from Africa demonstrated that tree carbon sequestration will not quickly hold soil carbon equivalent to the baseline level (Kaya and Nair, 2001). In the current study, higher organic carbon concentrations and SOC stocks were noted with increase in tree age at both depths. The higher SOC stocks in the upper soil surface are credited to more noteworthy carbon input from tree litter, dead roots, and root exudates (Kaushal et al., 2012; Nawaz et al., 2014; Yasin et al., 2016).

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Poplar trees in agroforestry systems by and large increase 3.5 Mg ha^{-1} of litter fall each year (Kaushal et al., 2012). Higher SOC was observed with increase in tree age in upper soil layer 0-15 cm and was 18% higher under 3-year-old tree stand when compared with 1-year-old tree stand and it further increases by 18.5% at 0-15 cm layer of soil under 6-year-old tree stand (Gupta et al., 2009). The CSR (Carbon sequestration rate) in the soil across all Tehsils varied from 1.77 Mg ha^{-1} yr^{-1} to 2.27 Mg ha^{-1} yr^{-1} in 6-year-old trees which is slightly higher to the findings (1.18 Mg ha^{-1} yr^{-1} to 1.81 Mg ha^{-1} yr^{-1}) of Arora et al. (2014).

Conclusions

Carbon sequestration through woody vegetation is a sustainable and efficient approach. In the present study, it was found that the carbon sequestration ability of *P deltoides* increases with age and, when planted as bund planting in agroforestry systems, it differs from other patterns of tree planting such as compact plantations. The species is sequestering the exceptional amount of carbon in the limited span of time, thus creating an option for farmers to get extra revenue in terms of carbon credits. Moreover, *P deltoides* fulfill the demand of plywood industry and fuel because of its fast growth and higher biomass accretion of the country. Therefore, our study suggests planting *P. deltoides* in various agroforestry systems act as a feasible alternative for higher biomass production and carbon stocks to mitigate climate change. Along with carbon capturing and sequestration these systems could develop into technological alternative to reduce deforestation rates in the country. Therefore, further studies should be carried out to explore the potential impact of various bund planted tree based agroforestry systems in climate change mitigation through carbon sequestration.

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APPENDIX

ANOVA table of bulk density at 0-15 cm depth

Source	DF	SS	MS	F	P
Age	2	0.17472	0.08736	44.57	0.0000
Tehsil	2	0.02192	0.01096	5.59	0.0077
Age*Tehsil	4	0.02289	0.00572	2.92	0.0344
Error	36	0.07056	0.00196		
Total	44	0.29010			

ANOVA table of bulk density at 15-30 cm depth

Source	DF	SS	MS	F	P
Age	2	0.17330	0.08665	51.75	0.0000
Tehsil	2	0.00995	0.00498	2.97	0.0639
Age*Tehsil	4	0.01804	0.00451	2.69	0.0463
Error	36	0.06028	0.00167		
Total	44	0.26156			

ANOVA table of soil organic carbon at 0-15 cm depth

Source	DF	SS	MS	F	P
Age	2	418.368	209.184	157.07	0.0000
Tehsil	2	22994	11.497	8.63	0.0009
Age*Tehsil	4	16.788	4.197	3.15	0.0255
Error	36	47.943	1.332		
Total	44	506.093			

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ANOVA table of soil organic carbon at 15-30 cm depth

Source	DF	SS	MS	F	P
Age	2	168.401	84.2005	89.82	0.0000
Tehsil	2	27.036	13.5179	14.42	0.0000
Age*Tehsil	4	9.909	2.4771	2.64	0.0494
Error	36	33.748	0.9374		
Total	44	239.093			

ANOVA table of organic carbon at 0-15 cm depth

Source	DF	SS	MS	F	P
Age	2	1.57667	0.78834	307.41	0.0000
Tehsil	2	0.01995	0.00998	3.89	0.0295
Age*Tehsil	4	0.03889	0.00972	3.79	0.0113
Error	36	0.09232	0.00256		
Total	44	1.72783			

ANOVA table of organic carbon at 15-30 cm depth

Source	DF	SS	MS	F	P
Age	2	0.65154	0.32577	147.93	0.0000
Tehsil	2	0.03127	0.01564	7.10	0.0025
Age*Tehsil	4	0.02304	0.00576	2.62	0.0512
Error	36	0.07928	0.00220		
Total	44	0.78512			

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