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Assessment of phytomass and total carbon stock of multipurpose trees species *Populus deltoides, Grevillea robusta and Albizzia lebbeck* under rain-fed conditions in Islamabad, Pakistan

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Abstract

This study was designed to assess the total phytomass (Kg ha^{-1}) and their total carbon stock (Mg C ha $^{-1}$ yr^{-1}) of three multipurpose tree species i.e. *Grevillea robusta* (silver oak), *Populus deltoids* (poplar), *Albizzia lebbek* (siris), under rain-fed conditions in three selected areas of Islamabad. Phytomass was measured through allometric equation by measuring height and diameter at breast height (DBH). Carbon stock was measured using universal conversion factor. Physical parameters of the soil samples (pH, electrical conductivity, texture, soil inorganic carbon and soil organic carbon) were also measured in soil physics lab in Land Resource Institute (LRRI), NARC. Maximum phytomass 73.39 Kg ha^{-1}yr^{-1} and total Carbon stock 40.15 Mg C ha^{-1}yr^{-1} was found in the *Populus deltoides* than 55.36 Kg ha^{-1}yr^{-1} phytomass and 31.42 Mg C ha^{-1}yr^{-1} of Carbon stock by *Albizzia lebbeck* and 23.18 Mg C ha^{-1}yr^{-1} Carbon stock and 39.26 Kg ha^{-1}yr^{-1} phytomass was calculated in *Grevillea robusta.* National Institute of Health (NIH) site ranked recorded the maximum Carbon stock and phytomass followed by National Agriculture Research Institute (NARC) and Rose and Jasmine Garden (RJG). Mixed fast growing MPTS with high Carbon Stock ability will help to achieve the forested area cover of 25% in a country along with carbon sequestration to combat global warming and climate change on a global level.

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Introduction

Carbon stock (CS) and phytomass of selected three multipurpose tree species (MPTS) at three different locations in Islamabad were estimated in the present study. Non-destructive methods (no harm or felling of trees and environment) were used to find the Phytomass and carbon stock by a combination of field work and allometric equations. *Grevillea robusta, Populus deltoides and Albizzia lebbeck* were the MPTS under study at National Agriculture Research Centre (NARC), National Institute of Health (NIH) and Rose and Jasmine Garden (RJG), Islamabad.

Carbon sequestration involves the capture and storage of the carbon from the atmosphere. Naturally, plants capture CO_2 by the process of photosynthesis. They take in CO_2, sequester it as sugars, and finally add organic matter in the soil (Kumar *et al.*, 2009).

Therefore, evaluation of this carbon content both in vegetation and in soil becomes vital to compute the carbon sequestration potential. Later on, the glucose is diverted to other tree components for storage after converting it to other types of food. Initially the carbon accumulation rate in above ground biomass is linear in a permanent stand but it declines because of the saturation effect (Rathore, 2013). Phytomass is the total amount of biomass in one area that includes the photosynthesizing part of the vegetation (leaves) and the stems (Ramage, 2012).Multipurpose trees (MPTs) and shrubs are defined as woody (or firewood) trees that are deliberately grown and managed for greater than one significant benefaction such as goods or services to the people and the land-use systems in which they are cultivated (wood and Burley, 1991; Foroughbakhch *et al.,* 2009).

As the term indicates they are used for more than one purpose that is they may supply food, wood, forage, firewood, and nitrogen to the soil providing habitat, shade or soil improvement. The trees selected in this study are also multipurpose tree species. *Populus deltoids,* being MPTs and a fast growing species, in addition to the main role in carbon cycle, are used in paper manufacturing, inexpensive hardwood timber (plywood), electric guitars and drums, in snowboards industry leather tanning etc. it has been recommended to be used in rich soil and near to water courses. *Albizzia lebbeck* is also used for multipurpose such as forage, production of timber and it has been used in medicines traditionally, e.g. medicines used to treat eyes, lung, flu, pectoral problems and abdominal tumors. *Grevillea robusta* is also used in furniture making, fences, cabinetry, external window joining, and ornamental purposes and as timber resource.

Pakistan has limited timber and wood resources. The total land area of Pakistan is 87.98 m ha and area covered by forests is nearly 4.4 m ha (4.96%) compared to required level of 25%, considered crucial for sustainable economic development of any country (Zaman & Ahmad, 2012). Since Pakistan has confined forest capital, it has to import wood and wood products to accomplish the escalating demands. Pakistan forests encompass heterogeneity due to variance in physiographic, climatic and edaphic aspects. Deforestation and forest degradation contributes in increasing carbon dioxide concentration in the atmosphere. Carbon dioxide (CO_2) acts as a major greenhouse gas. Food and Agriculture Organization (FAO, 2015) reported that globally, forest area has been decreased from 31.6 percent in 1990 to 30.6 percent in 2015, particularly due to anthropogenic activities thereby contributing to global climate change.

Alternatively, afforestation and forest restoration activities abate Green House Gas (GHG) emissions from forest ecosystem. (FAO, 2015) estimates that with decline in deforestation rate between 2001 and 2015, the carbon emissions from forests have been decreased by more than 25 % globally.

Along the forest resources that play important role in CS is trees outside forest (TOF). TOF, in general means the trees on cultivated land, alongside roads, waterways, railways, orchards, ponds, homestead and gardens. FAO defines TOF as trees present on areas which is not designated as 'forests' or 'other woody lands'. TOF make a significant support to sustainable agronomy, food and countryside domestic markets; they deliver many goods and facilities similar to forests, they also shield soil and crops from wind and water erosion hence contending drought and desertification and guarding water resources (Singh and Chand 2012). They also play role in environmental services for example conservation of biodiversity and carbon sequestration.

Soil-vegetation system perform a vital role in the global carbon cycle. Organic carbon is around three times greater in soil than in flora and around two fold the carbon that exists in atmosphere, it means that vegetation is second in sequestering C next to soil (Mehta *et al*, 2013). At present, 40% of global CO_2 emissions by anthropogenic activities are absorbed by terrestrial flora and soil (Sheikh and Kumar, 2010). The observations described by Rathore (2013), revealed that the wood stores maximum amount of carbon and is the maximum portion of total biomass while the different types of life forms when compared stocks carbon in order of conifers > deciduous > evergreen > bamboos. Asian Disaster Preparedness Centre (ADPC., 2009) estimated that in worldwide C emissions Pakistan only emits 0.04%. However, Pakistan is among the most susceptible countries list going to be impacted by climate change intensely. Climate change disturbs livelihoods severely; therefore, it is critical to consider climate change in development process. According to the report given by (IPCC., 2010) prime consideration has been given to forests accounting about 45% of terrestrial carbon pool and are responsible for 17% of yearly radiative constraints via deforestation. Nevertheless, it is noteworthy that because of the spatial degree, trees in other land use systems such as farmlands have greater potential for emission/sequestration because of their spatial extent. Fast growing trees on farmland have a vital share in mitigating the effects of climate change. Both soils and trees are significant. Their impact needs to be researched further to investigate other dynamics and interlink ages that will effectively and accurately measure the carbon storage potential of fast growing trees.

The data of total CS (M t) of the whole country, Pakistan, is presented in Global Forest Resources Assessment (GFRA) 2005. Though scientific work on actual measurements of biomass and CSs was not done in any type of forest of Pakistan until 2017, remote sensing tool was used for the data in GFRA (2005) estimates which may be error prone.

In Pakistan, still presentable data regarding to biomass and carbon pool of fast growing trees are not available. Therefore, it is a need and necessity to have accurate and reliable estimates regarding biomass and CS of fast growing multi-purpose trees. Hence, this study was designed to evaluate the total phytomass and the total carbon pool of three fast growing MPTS under rain fed condition in Islamabad and which is the real solution to combat the various carbons in our atmosphere.

Material and methods

Study area

The present research was administered in three sites of Islamabad. The latitude of Islamabad, Pakistan is 33.73N and the longitude is 73.08 E. These sites include field area of RRI (Range Research Institute) in National Agricultural Research Center (NARC) at latitude 33.6701° N, 73.1261° E longitude, Islamabad, Rose and Jasmine garden near Abpara at latitude 33.70 °N and longitude 73.08 °E, National Institute of Health (NIH) at 33.68° N latitude and 73.14° E longitude, Islamabad. All these sites are situated at the edge of Pothwar plateau at the end of the Margalla hills in the Federal Islamabad Capital Territory.

Sampling

Three MPTS (*Grevillea robusta, Albizzia lebbek, and Populus deltoides*) of an even aged group were selected. There were three blocks/ replicates selected at three location in Islamabad. In each block there were ten number of a species earmarked for determination of phytomass and their CS.

Age of the selected plants were measured with the help of an instrument Pressler borer by counting their annual rings.

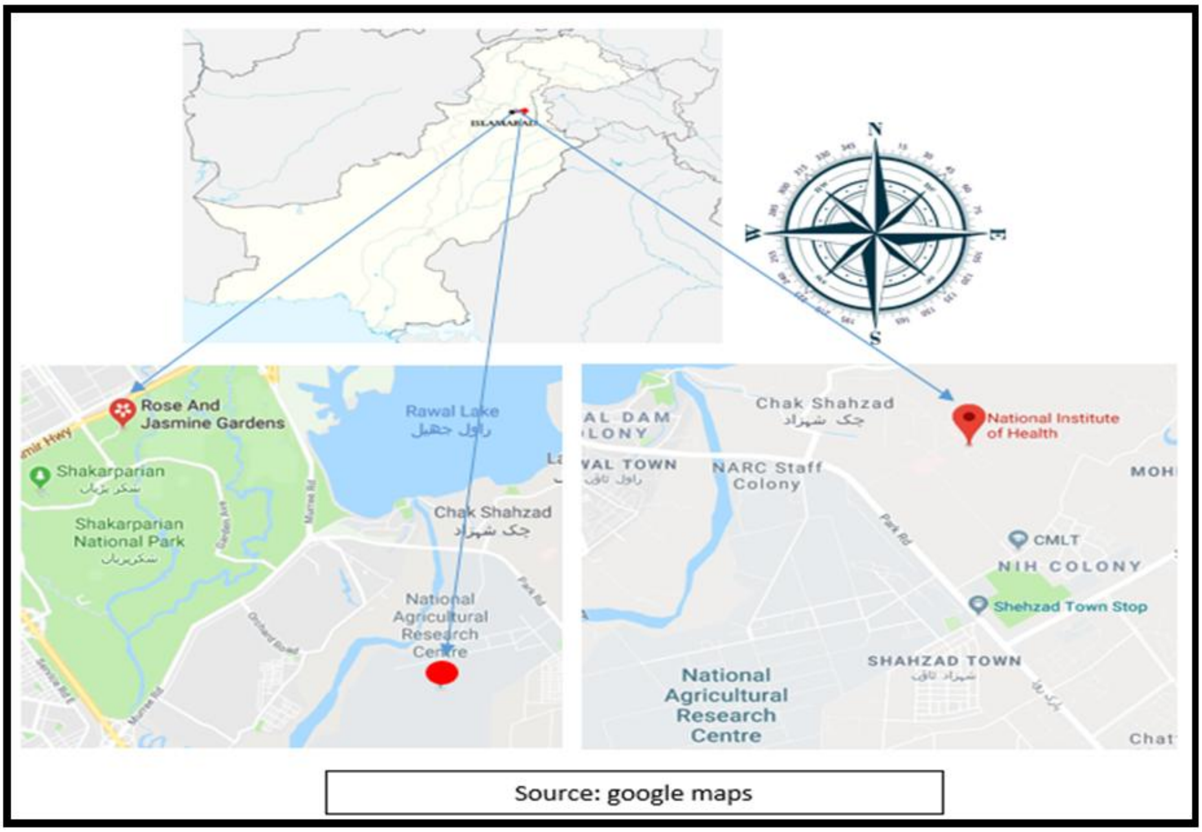

Fig. 1. Study Area Map.

In the same piece of land composite soil samples were also collected with the help of an auger at three depths (0-20,20-40,40-60 cm) for pH, Electrical conductivity (EC), texture, soil inorganic carbon (SIC) and soil organic carbon (SOC). Composite soil sample were made by mixing the samples taken at three depths of a site. Further, the composite soil samples were air-dried, to get a fine sample.

These samples were ground by mortar and pestle first and then a 2mm sieve was used to sieve the soil sample and used for further analysis.

Parameters

Phytomass was calculated from height (ft) and diameter (ft) at breast height (DBH). The height was measured with the help of an instrument Abneys Level. It gives correct measurement and probably the best instrument for height measurement among other instrument like Haga altimeter, Blume leiss altimeter etc. Diameter tape was used for DBH measurement. Hence, total thirty plants in one block were observed for height, DBH, total phytomass (TP) and total Carbon Stock (TCS).

Analysis

Tree phytomass was calculated by the following formula:

Volume (ft^3) = $(DBH/4)^2$ x L x FF

Volume (m^3) = volume (ft^3) 35.315

(AGP) Above ground Phytomass (Mg) =

$$\frac{\text{Volume } (m^3) \times \text{BWD } (kgm^{-3}) \times \text{BEF}}{1000}$$

Where DBH = Diameter at Breast Height, L= Height, FF= form factor i.e. 0.6, BWD = Bulk wood Density i.e. 700 taken from literature, BEF = Biomass Expansion Factor whose value was 1.5.

(BGP) Below ground phytomass (Mg) = AGP x 0.26 (Bala *et al* 2006; Siraj and Teshome 2017).

For the assessment of CS, the AGP and BGP were multiplied with conversion factor of 0.50 (50% of the phytomass), which is used worldwide (Malhi *et al.*, 2004; Nizami 2012; Ahmed and Nizami 2015; Siraj and Teshome 2017).

Aboveground Carbon Stock (AGCs) = AGP x 0.50

Belowground Carbon Stock (BGCs) = BGP x 0.50.

The Total Carbon Stock (TCS) Mg C ha^{-1} was measured by adding AGCs and BGCs.

Soil analysis

Soil samples were analyzed for texture (Gee and Bauder, 1982), pH (Mclean, 1982), EC (Richards, 1954), soil organic matter (Nelson and Sommers, 1982) and soil inorganic matter.

Statistical analysis

The data was arranged in MS excel. One way ANOVA was used for analysis. The technique used was two-factor factorial design under Randomized Complete Block Design. Software used was statistics 8.1.

Results

Above ground phytomass, below ground phytomass and total Phyto-masses of selected species at selected sites are given in table 1-4.

The tables 1, 2, 3, 4 illustrates that phytomass (AGP, BGP, TP in $Mgha^{-1,}$ TP in $Mgha^{-1}$ yr^{-1} respectively) of all the tree species are significantly different from one another. Hence, it means that at various sites the species of same age have different phytomass.

Table 1. Above Ground Phytomass (AGP in $Mgha^{-1}$) of the species at selected sites.

Species / Site	*Populus deltoides*	*Albizzia lebbeck*	*Grevillea robusta*	Site Mean
NARC	879.06 ^{b}	676.07 ^{a}	436.79 ^{ac}	663.97^{b}
NIH	896.56 ^{a}	764.55 ^{b}	432.00 ^{c}	697.70^{a}
RJG	845.63 ^{c}	536.58 ^{c}	533.36 ^{bc}	638.52^{c}
Species mean	873. 75	659.07	467.38	666.73

$LSD_{0.01}$ (Least Significant Difference) for species = 73.424

$LSD_{0.01}$ (Least Significant Difference) for sites = 114.66

$LSD_{0.01}$ for site x species = 127.17

Numbers sharing different letters are statistically at P<0.5.

The highest phytomass ($Mgha^{-1}$ yr^{-1}) of *Populus deltoides* was observed at NIH followed by the tree species at NARC and then the least phytomass were at the RJG. Phytomass pattern of *Albizzia lebbeck,* was found similar to the *Populus deltoides*, it was the highest for the trees at NIH followed by the species at NARC and the least phytomass of *Albizzia lebbeck* were at RJG. Phytomass of the *Grevillea robusta* showed a more different pattern among the three species. The AGP of *Grevillea robusta* at RJG was the highest, controverting to the other two species being lowest at this site. The phytomass of *Grevillea robusta* at NIH was lower than RJG (highest), but higher than NARC species. The lowest AGP by *Grevillea robusta* among these sites was at NARC.

Table 2. Below Ground Phytomass (BGP in $Mgha^{-1}$) of the species at selected sites.

Species / Site	*Populus deltoides*	*Albizzia lebbeck*	*Grevillea robusta*	Site Mean
NARC	228.55^{b}	175.78 ^{b}	113.57 ^{b}	172.63^{b}
NIH	233.11 ^{a}	198.78 ^{a}	112.32 ^{bc}	181.40^{a}
RJG	219.86 ^{c}	139.51^{c}	138.67^{a}	166.02^{c}
Species mean	227.17	171.36	121.52	173.35

$LSD_{0.01}$ (Least Significant Difference) for sites = 29.811

$LSD_{0.01}$ (Least Significant Difference) for species = 19.090

$LSD_{0.01}$ for site x species = 33.065

Numbers sharing different letters are statistically at P<0.5.

Table 5 as below, shows the means of TCS (above ground and below ground C Stocked in Mg C ha-1) by the selected three tree species at the selected sites.The result shows that the mean total Carbon stocked by all three species are significantly different from one another. It means that these three species have different ability to stock carbon in them. *Populus deltoids* has the highest ability to stock carbon. Secondly, *Albizzia lebbeck* can stock more than the *Grevillea robusta*.

Table 3. Total Phytomass (AGP + BGP) t ha^{-1} of the species at selected sites.

Species / Site	*Populus deltoides*	*Albizzia lebbeck*	*Grevillea robusta*	Site Mean
NARC	1107.6 ^{b}	851.8 ^{b}	550.4^{b}	836.61^{b}
NIH	1129.7^{a}	963.3^{a}	544.3 ^{bc}	879.10 ^{a}
RJG	1065.5 ^{c}	676.1^{c}	672.0 ^{a}	804.54 ^{c}
Species mean	1100.9	830.4	588.9	840.08

$LSD_{0.01}$ (Least Significant Difference) for species = 144.47

$LSD_{0.01}$ (Least Significant Difference) for sites = 92.514

$LSD_{0.01}$ for site x species = 160.24

Numbers sharing different letters are statistically at P<0.5.

It was observed that the phytomass and carbon stock were directly proportional, higher the phytomass, higher would be the carbon stock and vice versa.When comparing the CS of *Populus deltoids* at three sites, CS by trees at NIH is the highest, that of CS by *Populus deltoids* at NARC ranked second and the least among them was stocked by the trees at RJG and is significantly different from NARC and NIH. CS by *Albizzia lebbeck* at different sites also showed the same pattern as that of the *Populus deltoids*. The AGCS by *Albizzia lebbeck* at NIH is the highest, that of CS by *Albizzia lebbeck* at NARC ranked second; and the *Albizzia lebbeck* at RJG stocked the least among them and all of them are significantly different from each other. *Grevillea robusta* showed a more different pattern among the three species.

Table 4. Total Phytomass (AGP+BGP) t ha^{-1} yr^{-1} of the species at selected sites.

Species / Site	*Populus deltoides*	*Albizzia lebbeck*	*Grevillea robusta*	Site Mean
NARC	73.841^{bc}	56.790^{b}	36.691^{b}	55.774^{b}
NIH	75.311 ^{a}	64.222^{a}	36.288 ^{bc}	58.607^{a}
RJG	71.033 ^{c}	45.073^{c}	44.802^{a}	53.636 ^{bc}
Species mean	73.395	55.362	39.260	56.006

$LSD_{0.01}$ (Least Significant Difference) for species = 6.167

$LSD_{0.01}$ (Least Significant Difference) for sites = 9.6313

$LSD_{0.01}$ for site x species =10.683

Numbers sharing different letters are statistically at P<0.5.

The CS by it at RJG was the highest, contradicting to the other two species being lowest at this site. The CS by the trees of *Grevillea robusta* at NARC was lower than RJG (highest) but higher than NIH species. The lowest AGCS by *Grevillea robusta* among these sites was at NIH. The results of above and below ground CS at different sites indicates that the C Stocked by tree species in the selected different sites do not have significant difference in it. It may be because all the sites are located in the same topographic region having similar rainfall patterns and are in the same environmental conditions. Table 6 depicts that the SC (Mg C ha^{-1}) is highest under the *Albizzia lebbeck* at RJG followed by the *Grevillea robusta* and then in the *Populus deltoides* at the same site. The result showed that the SC under remaining species at the other two sites were not significantly different from one another, but were significantly different from all species at the RJG. The order of SC is *Populus deltoides* at NARC > *Grevillea robusta* at NARC > *Albizzia lebbeck at NARC* > *Grevillea robusta* at NIH > *Populus deltoides* at NIH >*Albizzia lebbeck* at NIH. Considering SC under species, SC was highest in the soil under *Albizzia lebbeck, Grevillea robusta* ranked second and the least among them was in the soil under *Populus deltoides*. When compared, the SC for the sites, RJG had highest SC, NARC being second and NIH third in stocking Carbon in their soil. Soil analysis done for pH, EC, Soil Inorganic Carbon (SIC) and SOC depicts the results shown in table 7-9. While soil texture determined gave the result to be clay loamy.

Table 5. Total Carbon Stock Mg C ha^{-1} (AGCS+BGCS) for Site and Species.

Species / Site	*Populus deltoides*	*Albizzia lebbeck*	*Grevillea robusta*	Site Mean
NARC	553.81^{b}	425.92^{c}	275.18^{a}	418.30^{b}
NIH	564.83^{a}	481.67^{a}	272.16^{ba}	439.55^{a}
RJG	532.75^{c}	338.05^{b}	336.02^{c}	402.27^{c}
Species mean	550.46	415.21	294.45	420.04

$LSD_{0.01}$ (Least Significant Difference) for species = 46.257
$LSD_{0.01}$ (Least Significant Difference) for sites = 72.235
$LSD_{0.01}$ for site x species = 96.743
Numbers sharing different letters are statistically at P<0.5.

The highest pH of soil was recorded at NIH under the *Populus deltoides* and *Albizzia lebbeck*. Followed by the soil at RJG under *Populus deltoids* > NARC under *Populus deltoids* > RJG under *Albizzia lebbeck* > NIH under *Grevillea robusta* > NARC under *Grevillea robusta* > NARC under *Albizzia lebbeck* >RJG under *Grevillea robusta*. The soil pH under species was of the order *Populus deltoids* > *Albizzia lebbeck* > *Grevillea robusta*. The soil pH at the sites has the order NIH > RJG > NARC.

Table 6. Soil Carbon (SC) Mg C ha^{-1} for Site and Species.

Species / Site	*Populus deltoides*	*Albizzia lebbeck*	*Grevillea robusta*	Site Mean
NARC	49.71^{b}	46.43^{bc}	47.72^{bc}	47.95^{bc}
NIH	42.08^{c}	41.88^{c}	42.43^{c}	42.13^{c}
RJG	63.88 ^{a}	80.15^{a}	69.98^{a}	71.34^{a}
Species mean	51.89	56.15	53.38	53.81

$LSD_{0.01}$ (Least Significant Difference) for species = 3.33
$LSD_{0.01}$ (Least Significant Difference) for sites = 6.38
$LSD_{0.01}$ for site x species = 7.88
Numbers sharing different letters are statistically at P<0.5.

The above table for comparison of soil EC shows that the soil at RJG under the *Grevillea robusta* has the highest value of EC and hence it becomes the highest EC site and species followed by the species *Albizzia lebbeck* and *Populus deltoides* at the same site. The soil EC for other species and sites had the order *Populus deltoides* at NARC> *Grevillea robusta* at NARC > *Grevillea robusta* at NIH>*Populus deltoides* at NIH> *Albizzia lebbeck* at NIH and least in *Albizzia lebbeck* at NARC. The EC of soil under tree species was of the order *Grevillea robusta* > *Populus deltoids* > *Albizzia lebbeck*. The soil EC at the sites has the order RJG > NARC> NIH.

SOC and SIC in the soil samples of the selected sites and species are shown in the table 8. The statistically higher SOC was present at RJG under the *Populus deltoids* except at NIH under *Grevillea robusta*. *Populus deltoids* at NARC had the second highest SOC followed by the *Albizzia lebbeck* at NIH > *Albizzia lebbeck* at RJG, *Populus deltoids* at NIH > *Albizzia lebbeck* at NARC > *Grevillea robusta* at NARC > *Grevillea robusta* at RJG. The SOC under tree species was of the order *Populus deltoids* > *Grevillea robusta* > *Albizzia lebbeck*.

Table 7. Soil pH and EC (dS/m) for Site and Species.

Sites \ Species	*Populus deltoides*		*Albizzia lebbeck*		*Grevillea robusta*		Site Mean	
	pH	EC	pH	EC	pH	EC	pH	EC
NARC	8.03^{c}	287.3^{b}	7.71^{c}	192.1^{c}	7.81^{b}	258.7^{a}	7.85^{c}	246.02^{b}
NIH	8.14^{a}	223.7^{c}	8.15^{a}	201.0^{b}	7.83^{ab}	252.3^{ba}	8.04^{a}	225.66^{c}
RJG	8.11^{ba}	311.7^{a}	7.90^{b}	326.7^{a}	7.62^{c}	1362.0^{c}	7.88^{bc}	666.78^{a}
Species mean	8.09	274.22	7.92	239.9	7.75	624.33	7.92	379.49

$LSD_{0.01}$ (Least Significant Difference) for species = 0.05*, 43.87**

$LSD_{0.01}$ (Least Significant Difference) for sites = 0.07*, 33.22**

$LSD_{0.01}$ for site x species =0.10*, 63.81**

Numbers sharing different letters are statistically at P<0.5.

The SOC at the sites has the order NIH > RJG > NARC. The statistically higher SOC was present at RJG under *Populus deltoids* followed by *Albizzia lebbeck* at RJG > *Grevillea robusta* at RJG > *Grevillea robusta* at NARC > *Populus deltoids* at NARC, *Albizzia lebbeck* at NARC > *Populus deltoids* at NIH > *Albizzia lebbeck* at NIH> *Grevillea robusta* at NIH. The SIC under tree species was of the order *Populus deltoids* > *Albizzia lebbeck*> *Grevillea robusta*. The SIC at the sites has the order RJG > NARC> NIH.

The results gave the similar trend in TCS, TP, AGP and BGP and each of them had highest value at NIH, in *Populus deltoides* followed by NARC in *Albizzia lebbeck and* RJG in *Grevillea robusta* except TCS in RJG to be followed in *Albizzia lebbeck* then at NARC in *Grevilea robusta*. *Whereas* SC, had a different pattern both in species and site. SC gave the highest value in RJG under *Albizzia lebbeck*, followed by the site at NARC under *Grevillea robusta* and then at NIH under *Populus deltoides*, it was because of the SIC which also showed such pattern. It has been observed that when there is high soil inorganic carbon then the phytomass and CS by trees will be less and vice versa.

Discussion

The role of trees in C sequestering to decrease the accumulation of CO_2 in the atmosphere has been documented (Houghton *et al.,* 2001, Jangra *et al.*, 2010). Nearly, 88% of total biomass of trees is stored in the trunks of trees as AGB in systems of agroforestry and other plantations, remaining being stored as belowground biomass (Sharrow and Ismail, 2004).Several studies have been done on CS and carbon sequestration by different tree species in various parts of the world. Jangra *et al.,* 2010 stated the total CS in 2006 to be 151.356 Mg C ha^{-1} and 158.869 Mg C ha^{-1} in plantation of *Grevillea robusta* of 25 years old in India, which is lower than the result of this study (249-344 Mg C ha^{-1}). While SOC in soils at 0-100 cm depth was found to be 0.96-0.12% which is comparable to findings of this study (1.5-1.8%), the organic and inorganic CS was 48.058 Mg C ha^{-1} and 28.698 Mg IC ha^{-1} respectively. Total phytomass calculated was 324.198 $Mgha^{-1}$, which is near to the findings of this study (499-689 $Mgha^{-1}$).Siraj and

Teshome 2017, marked *Grevillea robusta* as the first ranked species on CS performance amongst the selected species (*Cupresuss lusitanica, Grevillea robusta, Pinus radiate, Eucalyptus gtandis, Pinus patella)* of their study. A single plant on yearly basis can stock carbon on average about 44.61 tons. The maximum sequestration is 140.8 with a minimum of 9.47 tons. It was considered as the most dominant species, which can enhance sequestration performance if treatments of silviculture combined with suitable environment is given.

The result of phytomass of *Grevillea robusta* in the present study AGP = 221–546 kg, BGP = 33-201 kg, was much similar to their research results i.e AGB =120.21kg - 1780.04kg, BGB 31.26-462.81 kg.

Table 8. Soil Organic Carbon (SOC) and Soil Inorganic Carbon (SIC) for Site and Species.

Species / Sites	*Populus deltoides*		*Albizzia lebbeck*		*Grevillea robusta*		Site Mean	
	SOC	SIC	SOC	SIC	SOC	SIC	SOC	SIC
NARC	1.74^{b}	4.70^{b}	1.59^{b}	4.59^{b}	1.57^{b}	5.17^{b}	1.63^{c}	4.82^{b}
NIH	1.67^{cb}	2.84^{c}	1.69^{a}	2.58^{c}	1.80^{a}	1.82^{c}	1.72^{b}	2.41^{c}
RJG	1.86^{a}	13.56^{a}	1.69^{a}	11.44^{a}	1.52^{cb}	10.58^{a}	1.69^{a}	11.86^{a}
Species mean	1.76	7.03	1.66	6.20	1.63	5.85	1.68	6.36

$LSD_{0.01}$ (Least Significant Difference) for sites = 0.07*, 2.04**

$LSD_{0.01}$ (Least Significant Difference) for species = 0.07*, 0.81**

$LSD_{0.01}$ for site x species = 0.12*, 2.33**

*SOC, **SIC

Numbers sharing different letters are statistically at $P<0.5$.

Kaul *et al.,* 2010 identified that amongst the species (*Eucalyptus tereticornis, Populus deltoides marsh, Tectona grandis linn. f., Shorea robusta gaertn. .f.)* they studied *Populus deltoides marsh* has the maximum potential to sequester carbon. The carbon stock by fast growing short rotation *Populus deltoides marsh* to be 55 Mg C ha^{-1} yr^{-1}, and soil C as 67 Mg C $ha^{-1}yr^{-1}$. These results are close to the results the present study i.e. TCS =35-48 $Mgha^{-1}yr^{-}$, SC = 44-53 $Mgha^{-1}yr^{-1}$. *Populus deltoides* was found to be the highest carbon stocking species of the present study as well.The findings of the present study was also in harmony with the research of Ahmad and Nizami, *(2015*), i.e. TP = 460.9-829 $Mgha^{-1}$ is close to the present study (499.8-1356 $Mgha^{-1}$), TCS = 28.62-486.6 Mg C ha^{-1} is in range of the findings 283.94-731.69 Mg C ha^{-1} of this research.

Comparing results with the coniferous forest in Dir Kohistan KPK, Pakistan study done by Ahmad *et al., (2015)* the mean input of biomass C stock was 1.65 Mg C ha^{-1} yr^{-1}. Total biomass gained by the forest was 3.31 Mg $ha^{-1}yr^{-1}$, the result of the present study are higher than their results. Other studies of same type in Dir KPK district Pakistan, by Ahmad *et al., (2014)* and Haq *et al., (2017*), estimated mean biomass 258.98 t ha^{-1}, mean CS 129.49 Mg C ha^{-1} and mean of 29 Mg C ha^{-1} for CS and tree biomass was 59 t ha^{-1} respectively. The results of present research are higher than their results, which is contradictory to what is reported earlier that coniferous trees can store C more than other trees. However, they reported the reason of the lower values. The trees selected for their study omitted the plants having less than 15cm diameter, which can increase the results and range from180- 230 $Mgha^{-1}$, considering this range the results are comparable to the present study. Another reason is that, the coniferous plants are slow growing plants and need more time to become an adult about 80 years though they can sequester more C but have to wait for a long period. Whereas the broad-leaved fast growing species selected in this study needs maximum 15 years to be adult and sequester C in less time. Gonzalez and Laird in (*2003)* stated that the key process that regulates the quality of soil is the conversion of plant residues into stable clay humic complex and describes the soil as a net source and sink of carbon. Jobbagy and Jackson in (*2000*) stated vertical distribution of soil carbon from several research studies. In their study based on CS in *Grevillea robusta* plantation reported high potential for carbon sequestration and hence CS of SIC at increasing soil depth and SOC at upper soil surface till 60cm depth. The pH of soil under *Grevillea robusta* of 15 years old (mean = 7.757 at 0-60cm) in presented study was in accordance with the study by Jangra *et al., (2010*), having value ranging from 7.11 to 8.65 at 0-100 cm soil depth and 25 year old plantation area. Their study indicated that there was an increase in soil pH with an increase in soil depth. It was observed in the presented study that plants had high phytomass and CS when the pH of its soil sample was higher.

Pakistan has limited forested area combined with the catastrophic effects of Climate change though a negligible portion of Carbon is emitted; hence, planting MPTS that can stock maximum Carbon such as *Populus deltoides, Albizzia lebbeck, Grevillea robusta* etc is a good option. Proper prior planning and management should be undertaken with the involvement of stakeholders and community for planting trees over an area. Sustainable long-term political policies by the government should be made to ensure protection of the forested land. Further research in carbon stock potential of other MPTS in other regions of Pakistan can be done. There is a proposed plan of present government to plant billions trees all over Pakistan. Henceforth, other researches like the presented one will help the government, semi government, NGOs and linked departments to plan accordingly.

Conclusion

Global warming and climate change, the hot and global issue, can only be solved naturally by sequestration and stocking of Carbon in trees. The present study was a small step to find out the best tree that can stock the most C while providing humans with other benefits expected from them. It is concluded from the present research that trees ability to grow, accumulate phytomass, sequester and stock carbon is entirely dependent on its species kind, age, climatic conditions, soil type and the region where it has been grown. The results showed that *Populus deltoides* having highest phytomass (Mgha^{-1}yr^{-1}) has the highest ability to stock carbon (Mg C ha^{-1}yr^{-1}) *Grevillea robusta* being the second and *Albizzia lebbeck* stand third. Fast growing, MPTS, have maximum potential to stock carbon helps lessen the effects of climate change and global warming such as *Populus deltoides, Albizzia lebbeck* and *Grevillea robusta.*

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