Comparing the Early Stage Carbon Sequestration Rates and Effects on Soil Physico-Chemical Properties after Two Years of Planting Agroforestry Trees

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Abstract: Farm friendly and fast growing trees are the sustainable, cheaper and efficient source of carbon sequestration and carbon stock, however, their carbon sequestration potential vary among tree species depending upon several factors. This study was conducted to determine the carbon sequestration potential and carbon storage difference among different tree species at early stage. Second objective of this study was to observe the effects of trees on the physico-chemical properties of soils. Seedlings of fifteen widely planted farm trees species were planted under same set of climatic and soil conditions. Employing tree biomass after two year of planting (2014-2016), carbon stocks and carbon sequestration rates were calculated. Soil samples were collected under each tree species at two depths: 0-15cm and 16-30 cm, to determine the physico-chemical properties of soils such as pH, EC, N, P, K, C and organic matter (O.M.). It was found that *Populus deltoides* contained the highest carbon stocks (7.21 ± 1.31 kg C) and sequestered the CO_2 at the highest rate of 13.21 ± 0.84 kg C/year as compared to all other fourteen tree species. O.M. (%) and Carbon (mg/kg) were also the highest in the soils under *P. deltoides* (2.29 ± 0.42 and 3.8 ± 0.2 respectively) as compared to and all other tree species. Nitrogen contents (%) were found the maximum in the soils under *D. sissoo* (0.063 ± 0.04) > *Acacia nilotica* (0.058 ± 0.008) and *Albizia lebbeck* (similar to *Acacia nilotica*). Such information enhances our capacity to better predict the carbon sequestration potential and carbon stock in different trees.

Keywords: Agroforestry, climate change, Carbon dioxide, Global warming, Carbon sequestration.

INTRODUCTION

Climate change is the major environmental issue and its mitigation has become a real global challenge in the current energy deficient scenario [1, 2]. Increased industrialization to fulfil the demands of rising population and enhanced fossil fuel burning to meet the energy shortage are the major causes of climate change since last century as both activities are resulting in the increase of atmospheric Green House Gases (GHGs), especially, the CO_2 [3]. From 2010 to 2012 the increase in CO_2 emissions were 4.4 Pg C/year and it was reported that emissions of CO_2 from fossil fuel burning were much more as compared to deforestation and/or soil degradation [2, 4]. Persistent increase in global atmospheric CO_2 levels despite combined human efforts in term of conventions and agreements [5] necessitate the use of all available cheaper, sustainable and efficient resources such as trees to offset the outward flux of CO_2 [6]. Trees planted in the form of forests, urban forests, plantations, agroforests *etc*. can sequester and stock massive amounts of atmospheric CO_2 in various parts such as wood (stem and branches), leaves, bark and root [7, 8], however, planting of trees on agricultural lands (agroforestry) can sequester more carbon than single crop or trees in forests [9, 10].

Agroforestry systems (AFS) are very well recognized for their economic, environmental and agricultural importance [11, 12]. Although, the main purpose of the AFS is not the carbon sequestration, but modern research and studies provides us the evidences that sufficient carbon can be stored in above ground and below ground biomass [13, 14]. Currently, AFS are sequestering from 0.29 to 15.21 Mg C/ha/year above ground and from 30 to 300 Mg C/ha upto 1 m soil depth [4, 9, 10]. It is estimated that by 2050, AFS has the potential of stocking 6.3 GT of carbon [15] and can sequester the atmospheric carbon at the rate of more than 600 Mt C yr^{-1} [4]. So, AFS potential for carbon sequestration is the greatest than any other land use options.

In AFS, the carbon sequestration rate differs among various tree species depending upon its age, density, cropping pattern and soil conditions as well as other management and environmental factors [16]. Fast growing tree species grown on agricultural lands under tropical humid climate can sequester more atmospheric carbon as compared to slow growing trees species planted on degraded lands under arid or temperate climatic conditions [9, 17]. This difference is due to

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difference in biomass production by a species under the set of external (environmental and anthropogenic) and internal factors (physiological and genetic) [10, 18]. While sequestration C in above ground and below ground biomass, trees not only increase the soil organic carbon (SOC) but also improves other physico-chemical properties of soils and these beneficial effects are conspicuous even after first year of plantation [17, 19]. It has also been intensively reported in literature that trees capable of fixing atmospheric nitrogen (Family Fabaceae) can enhance the soil fertility many times and they can reduce the tree-crop competition [20].

Keeping in view the forest status of Pakistan with only 2.2 % forest cover, its forest resources are not sufficient to meet the demands of 20 million population [21]. Furthermore, owing to high deforestation rate and harsh climatic conditions it seems impossible to increase its cover up to recommended proportion of 25% as desired for any country to attain the economic and environmental sustainability [22]. So, agroforestry and promotion of farmlands trees can be only potential future solution for Pakistan to attain self sufficiency in wood demands [23]. Furthermore, planting of high carbon sequestering and soil fertility booster farmland trees will not only help to maximize the wood biomass production but they will also result in environmental and agricultural beneficial outcomes [24, 25].

Normal rotation times of farm trees are from 5 to 10 years. Early comparison of the performance, carbon sequestration rate and tree soil interactions of agroforestry trees under local set of climatic factors will help us to understand the nature of trees and in taking decisions for objective oriented future farm tree plantings. The objectives of this study were to compare the carbon sequestration rates of 15 widely planted agroforestry trees and their effects on physico-chemical properties of soil after 2 years of planting.

MATERIAL AND METHODS

Study Area

This comparative study was conducted at Forestry research area, university of Agriculture Faisalabad, (longitude 73°74 East, latitude 30°31.5 North) Pakistan. Soil of the study area was organic matter deficient (less than 0.5%) with loamy texture. The climate of study area is sub-tropical with an annual average precipitation of 364 mm of which 50% is received in July and August. The average maximum temperature in summer recorded as 41 ºC and the average minimum temperature in winter is 4 ºC. Faisalabad is 184 meters (604 ft) above sea level and is situated in the rolling flat plains of northeast Punjab.

Site Preparation

Land was ploughed and levelled in the April, 2014 to plant the trees for experimental purpose. Fifteen widely planted multipurpose agroforestry tree species belonging to different families were selected for experiment after the comprehensive survey of the farmlands and consulting the available literature. Among these tree species includes *Acacia ampliceps, Acacia nilotica, Terminalia arjuna, Bombax ceiba, Albizia lebbeck, Populus deltoids, Salix tetrasperma, Dalbergia sissoo, Morus alba, Moringa oleifera, Leucaena leucocephala, Acacia jacquemontii, Cordia myxa, Syzygium cuminii, Cassia fistula*. After the judicious division and marking of prepared land, three to five months old disease free and healthy seedlings of selected trees with uniform morphological characteristics were transplanted in 50 cm^3 by pit planting method. 10 plants of each species were planted at a same distance of 4.5 m (row to row) and 2 m (plant to plant) in May, 2014. A water channel was made for each row to irrigate each plant. Except during early days after transplanting where more frequent irrigations were carried out, the trees were irrigated weekly in both summer and winter but in rainy season (July and august) no artificial water was given. The plants were not fertilized with any fertilizer or organic manure.

Estimation of Carbon

After 2 year of planting, in May, 2016 all the trees were measured for various parameters. The heights of tree were determined by Graduated pole (15 ft) and Hega altimeter depending upon the suitability. Their girths were measured by diameter tape at breast height. Height and girth measurements were employed to measure the tree volume at breast height by using cylindrical formula [26]. Then 2 trees per species were harvested to calculate the true volume with the help of Samalian's formula. By this method, correction factor was obtained. Calculated volume at breast height was multiplied with this correction factor to determine the true volume of each tree [26].

Carbon stock and CO_2 sequestration rate were determined by using the standard methods in the literature after determining the tree biomass while employing the true tree volume and wood density [26-29]. Wood density was measured from extracted tree cores obtained from harvested trees. The below ground root mass was supposed 20% of above ground biomass, so, it was added into above ground biomass and dry biomass was calculated by deleting 27.5% moisture. Carbon was estimated about 45-50% of dry biomass of the trees (hardwoods) [26, 30].

Physico-chemical Properties of Soils

Three soil samples were taken underneath each species between plants at a depth of 0-15 cm and 16-30 cm to determine the physico-chemical properties of soils. Saturated soil paste was made by adding distilled water in 250 g soil sample, then pressure was applied with a filter paper and extract was obtained from saturated soil. To prevent salts's precipitation, one drop per 25 mL sodium hexametaphosphate (1%) solution was added. The soil pH was determined from saturated soil paste, electrical conductivity (EC) from soil extract, total nitrogen by Ginning and Hibbard's method, available phosphorus and potassium by a model PFP.7 Jenway flame spectro photometer, and soil organic matter and soil carbon was determined by Walkley and Black method. Sodium and calcium were found under detection limit in soil samples. Average and standard deviations were calculated for all the analysed parameters.

RESULTS AND DISCUSSION

The results of this study (Figures **1-3**) represent the dependence relations (regression) between the tree growth and carbon allocation in 15 tree species. It was found that relations between tree diameters and heights were not highly interrelated with r^2 value of only 0.5 (Figure **1**). Similarly, the relations between heights (m) of the tree and carbon stocks (kg) were more interrelated as compared to relations between height and diameter (r^2 = 0.62) but not highly dependant as compared to relations between carbon stocks and diameter (r^2 = 0.89) as shown in Figure **2** and **3**. It was found that under agroforestry conditions where spacing between is more as compared to natural forest conditions, secondary growth (diameter increment) of tree is more linked with carbon sequestration as compared to primary growth (height increment). It is widely reported that with increment in the spacing between trees there is more increase in tree diameters [4, 15].

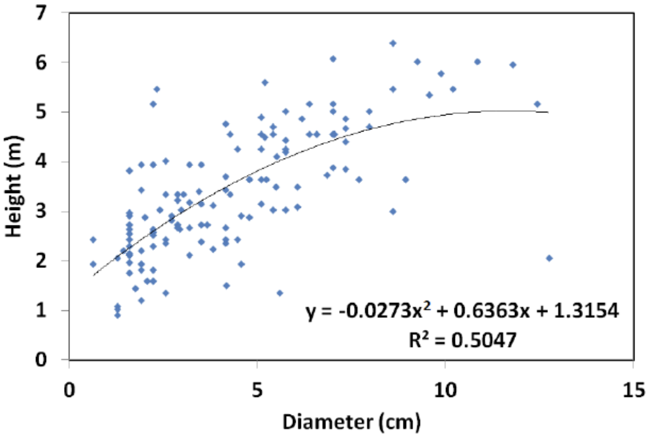

Figure 1: Relation of diameter and height for 15 agroforestry tree species.

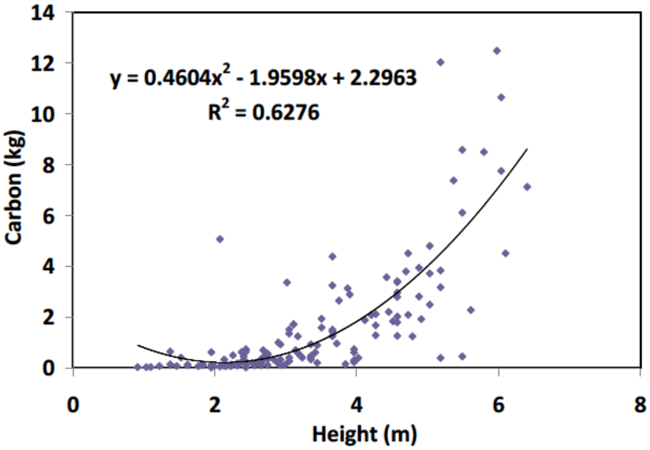

Figure 2: Relation of height and carbon stocks for 15 agroforestry tree species.

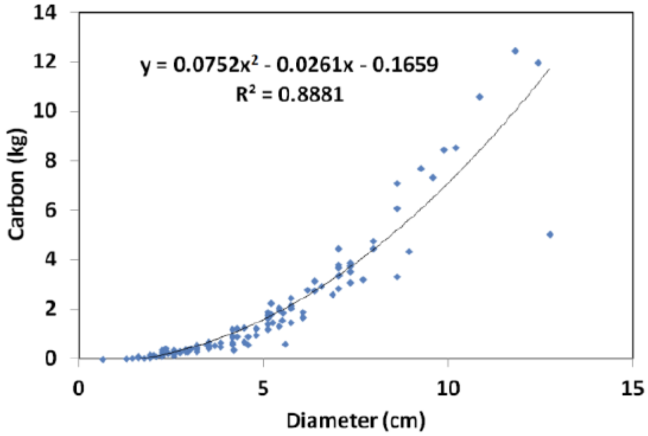

Figure 3: Relation of diameter and carbon stocks for 15 agroforestry tree species.

Species wise allocation of carbon stocks and carbon dioxide sequestration rate is presented in Table **1**. It was found that 2 years after transplanting, *Populus deltoides* contained the highest carbon stocks (7.21 ± 1.31 kg C) and sequestered the CO_2 at the highest rate of 13.21 ± 0.84 kg C/year as compared to all other fourteen tree species. Ranking of tree species was carried out according to carbon stocks in specific time and given in Table **1**. After *Populus deltoides*, second tree species with highest carbon stocks and carbon sequestration rate was *Acacia ampliceps* with 4.26 ± 0.37 kg C and 7.80 ± 0.63 kg C/year respectively. Other five tree species with carbon stocks more than 1 kg includes *Albizia lebbeck* (3.03 ± 0.98) > *Acacia nilotica* (2.75 ± 1.12) > *Bombax ceiba* (2.14 ± 0.90) *Dalbergia sissoo* (1.85 ± 0.75) > *Terminalia arjuna* (1.11 ± 0.72). All other eight tree species contained the carbon stocks less than 1 kg C. The results depict that among 15 tree species under given set of climatic and edaphic conditions, *Populus deltoides* exhibited the maximum primary and secondary growth as compared to other tree species that resulted in the more carbon stocks and higher carbon sequestration rates. Results of this study are in agreement with previous studies on agroforestry, which reported that fast growing tree species sequester more carbon as compared to slow growing trees and *Populus deltoides* is a fast-growing tree species where water is not a limiting factor [9, 20].

Table **2** describes the effects of various tree species on the soil physico-chemical properties after 2 years of transplantation at the depth of 0-15 cm. It was found that after two years, change in the pH and electrical conductivity (EC) of the soils under various tree species was not significant. Though, other physico-chemical properties like organic matter, phosphorous, potassium, nitrogen and carbon were significantly different and were dependent on the tree species. It was found that generally organic matter (O.M.) contents of soils were very low but O.M. was the highest in the soils under *Populus deltoides* (2.29 ± 0.42 %) as compared to *Bombax ceiba* (1.5 ± 0.03 %) and all other tree species. Other three species with high organic matter (%) among all tree species includes *Dalbergia sissoo* (1.18 ± 0.1) > *Albizia lebbeck* (1.1 ± 0.2) > *Morus alba* (0.81 ± 0.09) respectively. Phosphorus contents (ppm) and potassium (%) showed the similar trends as O.M with the highest concentration in *Populus deltoides* (6.75 ± 0.9 for phosphorus and 100 ± 14.1 for potassium respectively). Carbon (mg/kg) was found maximum under *Populus deltoides* (3.8 ± 0.2) as compared to *Albizia lebbeck* (2.9 ± 0.4) and *Dalbergia sissoo* (2.9 ± 0.1) and all other tree species. *P. deltoides*, *B. ceiba*, *D. sissoo*, *A. lebbeck* and *M. alba* are the deciduous trees and like other deciduous trees they shed their leaves during dormant season [31]. Fast growing deciduous trees produce more biomass and shed more biomass accordingly that results in the increment of organic matter contents along with other macro and micro elements in the soils [17]. So, organic matter contents, potassium and phosphorus under the soils of *P. deltoides* were found more as compared to other tree species and overall they were found more under deciduous trees as compared to evergreen trees.

Table 1: Carbon Stocks and Carbon Sequestration Rates of Agroforestry Trees During Early Ages

Sr. No.	Species name	C (kg)	CO_2 (kg)	CO_2/year (kg)	Ranking
1	*Acacia ampliceps*	4.26 ± 0.37	15.61 ± 0.31	7.80 ± 0.63	2
2	*Acacia nilotica*	2.75 ± 1.12	10.07 ± 0.51	5.04 ± 1.02	4
3	*Terminalia arjuna*	1.11 ± 0.72	4.06 ± 0.43	2.03 ± 0.87	7
4	*Bombax ceiba*	2.14 ± 0.90	7.85 ± 0.32	3.92 ± 0.64	5
5	*Albizia lebbeck*	3.03 ± 0.98	11.12 ± 0.37	5.56 ± 0.75	3
6	*Populus deltoides*	7.21 ± 1.31	26.43 ± 0.42	13.21 ± 0.84	1
7	*Salix tetrasperma*	0.31 ± 0.17	1.13 ± 0.22	0.56 ± 0.44	12
8	*Morus alba*	0.60 ± 0.79	2.22 ± 0.32	1.11 ± 0.64	10
9	*Dalbergia sissoo*	1.85 ± 0.75	6.77 ± 0.21	3.38 ± 0.42	6
10	*Moringa oleifera*	0.80 ± 0.64	2.95 ± 0.30	1.47 ± 0.60	8
11	*Leucaena leucocephala*	0.22 ± 0.47	0.81 ± 0.36	0.41 ± 0.73	14
12	*Acacia jacquemontii*	0.25 ± 0.30	0.92 ± 0.33	0.46 ± 0.66	13
13	*Cordia myxa*	0.60 ± 0.52	2.19 ± 0.22	1.09 ± 0.45	11
14	*Syzygium cuminii*	0.60 ± 0.62	2.22 ± 0.27	1.11 ± 0.55	9
15	*Cassia fistula*	0.08 ± 0.09	0.27 ± 0.12	0.13 ± 0.05	15

Table 2: Physico-Chemical Properties of Soils under Agro-Forestry Trees at 0-15 cm Depth

Sr. No	Species name	Ec (mS/cm)	Soil pH	Organic matter (%)	Phosphorus (ppm)	Potassium (%)	Nitrogen (%)	Carbon (mg/kg)
1	*Acacia ampliceps*	1.26 ± 0.02	8.1 ± 0	0.82 ± 0.3	5.1 ± 1.4	20 ± 14.1	0.055 ± 0.04	1.75 ± 0.7
2	*Cassia fistula*	1.30 ± 0.1	8.15 ± 0.07	0.42 ± 0.1	2.75 ± 0.3	60 ± 0	0.022 ± 0.002	0.3 ± 0.1
3	*Acacia nilotica*	1.19 ± 0.07	8. 1± 0	0.7 ± 0.2	5.3 ± 1.1	90 ± 14.1	0.058 ± 0.008	2 ± 0.2
4	*Terminalia arjuna*	1.18 ± 0.02	8.1 ± 0	0.5 ± 0.1	3.5 ± 1.4	40 ± 0	0.04 ± 0.002	0.67 ± 0.3
5	*Bombax ceiba*	1.21 ± 0.04	8.15 ± 0.07	1.5 ± 0.03	5.9 ± 1.6	130 ± 8.9	0.012 ± 0.007	2.1 ± 0.4
6	*Albizia lebbeck*	1.18 ± 0.02	8.1 ± 0	1.1 ± 0.2	6 ± 0.1	100 ± 0	0.058 ± 0.008	2.9 ± 0.4
7	*Populus deltoides*	1.13 ± 0.007	8.1 ± 0	2.29 ± 0.42	6.75 ± 0.9	100 ± 14.1	0.014 ± 0	3.8 ± 0.2
8	*Salix tetrasperma*	1.22 ± 0.1	8.1 ± 0	0.4 ± 0.3	4.095 ± 0.7	60 ± 28.2	0.036 ± 0.007	0.7 ± 0.4
9	*Morus alba*	1.1 ± 0.02	8.1 ± 0	0.81 ± 0.09	5.15 ± 0.9	80 ± 28.2	0.017 ± 0.004	1.26 ± 0.1
10	*Dalbergia sissoo*	1.09 ± 0.04	8.15 ± 0.07	1.18 ± 0.1	6.15 ± 0.3	90 ± 14.1	0.063± 0.04	2.9 ± 0.1
11	*Moringa oleifera*	1.25 ± 0.01	8.1 ± 0	0.95 ± 0.2	5.25 ± 0.9	120 ± 0	0.031 ± 0.004	1.1 ± 0.7
12	*Leucaena leucocephala*	1.23 ± 0	8.15 ± 0.07	0.57 ± 0.1	3 ± 0.1	40 ± 0	0.057 ± 0.010	1.05 ± 0.9
13	*Acacia jacquemontii*	1.25 ± 0.09	8.05 ± 0.07	0.63 ± 0.12	5.1 ± 0.2	90 ± 14.1	0.053 ± 0.06	1.6 ± 0.5
14	*Cordia myxa*	1.21 ± 0.03	8. 1 ± 0	0.41 ± 0.2	3.375 ± 1.2	60 ± 28.2	0.031 ± 0.03	0.6 ± 0.5
15	*Syzygium cuminii*	1.18 ± 0.03	8.1 ± 0	0.56 ± 0.08	4.3 ± 0.7	60 ± 28.2	0.034 ± 0.008	0.74 ± 0.9

Similarly, soils with high O.M. have the high soil carbon. Our results support the previous findings and highest carbon contents were found under *P. deltoides*.

The results showed that the nitrogen was the growth limiting factor in these soils with very low nitrogen contents (<0.07%). Generally, nitrogen contents (%) were found the maximum in the soils under *Dalbergia sissoo* (0.063 ± 0.04) > *Acacia nilotica* (0.058 ± 0.008) and *Albizia lebbeck* (like *Acacia nilotica*). Nitrogen contents (%) were similar and significantly not different under the *Acacia ampliceps*, *Leucaena leucocephala* and *Acacia jacquemontii* as well. All the above mentioned six tree species belong to fabaceae family and due to symbiotic relations in their roots they are capable to fix atmospheric nitrogen into soils as reported in literature [22, 32]. So, occurrence of more nitrogen under these trees species is in accordance with previous findings.

At the soil depth of 16-30 cm, the results showed accordingly no change in pH and EC Table **2**. At this depth, overall no trends in physico-chemical properties of soils were observed under the influence of different tree species, however, in some cases such as *Populus deltoides*, *Dalbergia sissoo* and *Bambax ceiba* the trends were same as at upper soil layer (0-15 cm depth). At the depth of 16-30 cm, more nitrogen contents (%) were observed under the soils of *Dalbergia sissoo* (0.19 ± 0.1) and *Acacia nilotica* (0.18 ± 0.1) as compared to 0-15 cm soil depth and all other tree species. This may be attributed to more root length and/or strong root symbiotic relations in these species as compared to other tree species of same family [32].

CONCLUSION

Agroforestry is the only choice for many developing countries like Pakistan to fulfil the wood demands of rising population and to lessen the pressure on scarce natural forests. Planting the multipurpose trees in the agroforestry systems is always highly desired. Keeping in view the current challenge of reducing green house gases (GHGs) especially CO_2 to save our environment

Table 3: Physico-Chemical Properties of Soils under Agro-Forestry Trees at 16-30 cm Depth

Sr. No.	Name of Species	EC (mS/cm)	Soil pH	Organic matter (%)	Phosphorus (ppm)	Potassium (%)	Nitrogen (%)	Carbon (mg/kg)
1	*Acacia ampliceps*	1.15 ± 0.01	8.05 ± 0.07	0.3 ± 0.2	1.3 ± 0.2	50 ± 42.4	0.0087 ± 0.002	1.33 ± 0.3
2	*Cassia fistula*	1.16 ± 0.1	8.05 ± 0.07	0.6 ± 0.2	3.2 ± 0	110 ± 14.1	0.0745 ± 0.004	1.1 ± 0.9
3	*Acacia nilotica*	1.18 ± 0.1	8 ± 0	0.5 ± 0	1.95 ± 1.5	70 ± 14.1	0.1785 ± 0.1	1.8 ± 0.5
4	*Terminalia arjuna*	1.17 ± 0.07	8 ± 0	0.4 ± 0.09	1.85 ± 0.9	40 ± 0	0.028 ± 0.009	0.84 ± 0.5
5	*Bombax ceiba*	1.1 ± 0.08	8.05 ± 0.07	1.205 ± 0.1	3.65 ± 0.6	70 ± 42.4	0.056 ± 0	2.1 ± 1.8
6	*Albizia lebbeck*	1.08 ± 0.06	8.05 ± 0	0.13 ± 0.01	3.01 ± 0.2	100 ± 0	0.0605 ± 0.006	1.2 ± 0
7	*Populus deltoides*	1.14 ± 0.07	8 ± 0	2.2 ± 0.1	4.13 ± 1.5	90 ± 28.2	0.0505 ± 0.007	3.3 ± 1.5
8	*Salix tetrasperma*	1.15 ± 0.007	8.1 ± 0.14	0.385 ± 0.2	2.9 ± 0.2	100 ± 10	0.0105 ± 0	1.5 ± 0.7
9	*Morus alba*	1.10 ± 0.09	8.1 ± 0.14	0.3 ± 0.02	2.35 ± 0.3	60 ± 28.2	0.014 ± 0	1.45 ± 0.9
10	*Dalbergia sissoo*	1.19 ± 0.07	8.05 ± 0.07	1.435 ± 0.9	3.25 ± 0.6	80 ± 0	0.19 ± 0.1	2.2 ± 0
11	*Moringa oleifera*	1.13 ± 0	8 ± 0	0.84 ± 0.09	2.25 ± 0.2	90 ± 13.3	0.0415 ± 0.004	2.4 ± 0.2
12	*Leucaene leucocephala*	1.13 ± 0.03	8.05 ± 0.07	0.445 ± 0.4	3 ± 0.1	80 ± 0	0.0415 ± 0.004	0.95 ± 0.9
13	*Acacia jacquemontaii*	1.14 ± 0	8.05 ± 0.07	0.83 ± 0.01	2.75 ± 1.5	90 ± 14.1	0.0365 ± 0.007	0.74 ± 0.1
14	*Cordia myxa*	1.11 ± 0.01	8 ± 0	0.2 ± 0.2	3.15 ± 1.4	100 ± 0	0.039 ± 0.01	0.7 ± 0.7
15	*Syzygium cuminii*	1.08 ± 0.03	8 ± 0	0.2 ± 0	1.9 ± 0.5	60 ± 28.2	0.0432 ± 0.04	1.5± 0.7

from irreversible changes demands us to change our approaches and way of acting. Planting the trees, which sequester the atmospheric CO_2 at high rates and have positive effects on the soil physico-chemical properties can have many beneficial outcomes for environment and human beings. In agroforestry systems, planting fast growing trees can result in more carbon sequestration, planting deciduous trees can result in more organic matter on soil and planting the trees of fabaceae family can enhance soil fertility. Moreover, results of tree soil interactions are observable just after 2 years. It was found that *Populus deltoides*, *Delbergia sissoo*, *Acacia ampliceps*, *Albizzia lebbeck* and *Acacia nilotica* have good potential to remove GHGs from the atmosphere and to sustain the soil fertility.

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