FACTORS AFFECTING CARBON SEQUESTRATION IN TREES

Muhammad Afzal* and Aqeela Mobeen Akhtar**

ABSTRACT

A study was conducted at Punjab Forestry Research Institute, Faisalabad, Pakistan during the year 2009-10. The objective was to determine the factors that affect carbon sequestration in trees. For this purpose 773 trees of 75 species were selected from the arboretum of Punjab Forest Department at Changa Manga. On an average these trees were of 40 years age. The results revealed that standing above and below ground biomass of these trees possessing average diameter of 36 cm and height of 13 meter sequestered total 849554 kg (ca. 850 tons) of CO_2. Among species, *Eucalyptus botryoides* tree with maximum diameter of 65.02 cm having 53 years age and 15.18 meter height sequestered maximum CO_2 (3527 kg) while *Robinia pseudoacacia* with minimum diameter of 4.57 cm having 46 years age and 3.05 meter height sequestered only 6 kg CO_2. Similarly, *Pinus roxburgii* tree with maximum height of 20.91 meter having 51 years age and 55.12 cm diameter stood second (3492 kg CO_2). So diameter and height of trees had significant effect on CO_2 sequestration. The data further showed that *Eucalyptus melanopholia* with maximum age of 56 years having 35.81 cm diameter and 14.9 meter height sequestered 1090 kg CO_2 while *Leueaena leucocephala* with minimum age of 17 years having 23.11 cm diameter and 8.69 meter height sequestered 428 kg CO_2 indicating non-significant effect of age on CO_2 sequestration. The overall results showed that crop density proved to be non-significant while diameter proved to be the most significant factor affecting carbon sequestration in trees.

KEYWORDS: Carbon dioxide; carbon sequestration; emissions; global warming; Pakistan.

INTRODUCTION

Emission of carbon dioxide, a greenhouse gas, accumulates in the atmosphere and is a major cause of rising temperatures. CO_2 emissions are what economists call a “negative externality”- emitters do not bear the full cost of damage that they cause. There is no global government to regulate excessive CO_2 emissions, and countries are tempted to leave remedies to

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***Director, **Research Officer, Punjab Forestry Research Institute, Faisalabad, Pakistan.**

others. Humans are responsible for this newly emerging CO_2 enriched world because since the pre-industrial time, CO_2 concentration has increased from 280 ppm to 380 ppm due to deforestation, massive use of fossil fuels, etc. (10). Scientists predict that climate change will cause severe disruptions, such as weather-related natural disasters, droughts and famines, which may lead to enormous loss of life. Global warming between 1.6 and 2.8 degrees Celsius over the next three decades would raise sea levels by half a metre. That is a conservative estimate, and if warming proceeds more rapidly due to loss of reflectivity of Arctic ice and release of CO_2 and methane from thawing permafrost, rising sea levels could lead to submersion of low-lying islands and hence may threaten the survival of entire nations. At the same time, in Africa and Central Asia, water will become more scarce, and drought will reduce food supplies. External shocks brought about by climate change will directly affect advanced economies. If rising sea levels flood the Maldive Islands, the effects of climate change would be as devastating as a nuclear bomb, and even for the United States and Europe, the damage to, say, Florida or the Netherlands could be just as costly. Climate change is increasingly recognised as one of transnational challenges with the greatest environmental, economic and security implications, and a powerful global environmental movement constantly highlights its importance (5).

Carbon sequestration is a geo-engineering technique for the long term storage of carbon dioxide or other forms of carbon, for mitigation of global warming. Trees are amongst the most significant elements of any landscape, both due to biomass and diversity. Trees are important sinks for atmosphere CO_2 since 50 percent of their standing biomass is carbon itself (7). It is estimated that the world's forests store 283 Gt of carbon in their biomass alone (1). Reviving forest cover and finding low cost methods to sequester carbon are emerging as a major international policy goal. Perlack *et al.* (6) reported that agro-forestry, if adopted at a rate of 2 to 4 percent annually, could reduce annual carbon emission by about 38 to 66 million tons. Moreover, converting one-tenth of high and medium productivity land back to forest each year could result in CO_2 sequestration of about 11 to 18 million tons annually. It is well known that trees, in common with all vegetation, absorb carbon dioxide (one of the principal greenhouse gases) and release oxygen during the process of photosynthesis. The carbon absorbed by trees in this process is stored in the wood. It is estimated that through conservation and sustainable use of existing forests, emission from deforestation and forest degradation can be reduced by 3.76 Gt CO_2e (carbon dioxide equivalent) per year indicating a reduction potential of 77 Gt CO_2e until 2030 (8). So determination of biomass and carbon stock of trees has gained importance as a result of Climate Conventions and Kyoto Protocol. Extraction and storage of excess carbon from the atmosphere into forests is being considered as one of the mechanisms for mitigating climate change. The present study was conducted to determine the factors that affect carbon sequestration in trees.

MATERIALS AND METHODS

An arboretum was established by Punjab Forest Department at Changa Manga during early fifties of 20th century on an area of 9.5 acres. About 75 species, indigenous and exotic have been raised there. Data regarding height and diameter (at breast height) of trees were collected during 2009-10 and analysed at Punjab Forestry Research Institute, Faisalabad. Layout plan is given below:-

Total No. of plots	=	165
Number of blank plots	=	69
Plot size	=	12.19 x 15.24 m (40 x 50')
Plant to plant distance	=	3.05 x 3.05 m (10 x 10')
Number of plants/plot	=	20 (required)
Average No. of plants/plot	=	8 (existing)

Calculation of CO_2 sequestered in a tree per year

It is estimated that agro-forestry trees, planted in tropical climates, will sequester atmospheric carbon dioxide at an average of 50 pounds of carbon dioxide per tree per year. The rate of carbon sequestration depends on the growth characteristics of tree species, the conditions for growth where the tree is planted and density of tree's wood. It is more at younger stages of tree growth, between 20 to 50 years (www.rcfa-cfan.org/english/issues). Further complicating the issue is the fact that far less research has been done on tropical tree species as compared to temperate tree species. The process of CO_2 calculation was got from two educational websites i.e. www.ncsec.org/cadre2/team18_2/students/purpose and www . shodor . org / succeedhi / succeedhi / weightree / teacher / activities which requires the determination of total (green) weight of tree, dry weight of tree, weight of carbon in tree and weight of CO_2 sequestered in tree per year.

Total (green) weight of tree: Total green weight of tree was calculated according to algorithm (3) as given below:-

$$W = 0.25D^2H \ (D<11)$$
$$W = 0.15D^2H \ (D\geq 11)$$

where W = Above ground weight of tree (pounds)
D = Diameter at breast height (inches)
H = Height of tree (feet)

The root system weighs about 20 percent as much as the above-ground weight of tree. Therefore, to determine the total green weight of tree, above-ground weight of tree was multiplied with 120 percent.

Wx120% = Total green weight of tree including roots (lbs)

Dry weight of tree: This was based on an extension publication from the University of Nebraska. The average tree is 72.5 percent dry matter and 27.5 percent moisture (4). Therefore, Wx120%x72.5%= Dry weight of tree (lbs).

Weight of carbon in tree: The average carbon content is generally 50 percent of tree's total volume (2). Therefore, W x 1205 x 72.5% x 50% = Weight of carbon in tree (lbs).

Weight of carbon dioxide sequestered/tree

Wx120 x72.5%x50%x3.6663 = Weight of CO_2 sequestered in tree (lbs)
(3.6663 is the ratio of CO_2 to C).

RESULTS AND DISCUSSION

Carbon dioxide sequestered by different tree species having different age, diameter and height was calculated through the above mentioned formula (Table 1). The data showed that *Eucalyptus botryoides* tree with maximum diameter of 65.02 cm having age and height of 53 years and 5.18 meter, respectively sequestered 3527 kg CO_2 while *Robinia pseudoacacia* with minimum diameter of 4.57 cm having age and height of 46 years and 3.05 meter, respectively sequestered 6 kg CO_2, These results indicated that diameter had significant effect on carbon sequestration. *Pinus roxburghii* tree with maximum height of 20.91 meter having age and diameter of 51 years and 55.12 cm, respectively sequestered 3492 kg CO_2 while *Robinia pseudoacacia* with minimum height of 3.05 meter sequestered 6 kg CO_2 as stated above. It indicated that height also had significant effect on carbon sequestration. The results further showed that *Eucalyptus melanophloia* tree with maximum age of 56 years having diameter and height 35.81 cm and 14.9 meter, respectively sequestered 1060 kg of CO_2 while *Leucaena leucocephala* tree with minimum age of 17 years having diameter and height of 23.11 cm and 8.69 meter, respectively sequestered 428 kg of CO_2 showing non-significant effect of age on CO_2 sequestration.

Table 1. Carbon sequestration of different tree species.

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S. No.	Species	Age (year)	Av. Dia (cm)	Av. height (m)	Total trees	CO_2 seq./ tree (kg)	Total CO_2 seq. (kg)
1	*Acacia catechu*	53	30.23	10.64	8	533	4264
2	*Albizzia lebbek*	53	47.5	15.48	4	1928	7712
3	*Albizzia procera*	54	52.32	20.7	9	3123	28107
	"	38	45.97	19.42	3	2251	6753
4	*Alstonia scholaris*	44	31.5	11.86	24	646	15504
5	*Artocarpus lakoocha*	22	50.04	15.94	4	2191	8764
6	*Bauhinia variegata*	38	33.02	11.06	3	661	1983
	"	44	29.21	11.52	17	538	9146
7	*Bischofia javanica*	54	49.78	17.04	16	2327	37232
8	*Bombax cieba*	53	53.59	17.65	9	2805	25245
9	*Butea frondosa*	43	26.42	5.58	4	359	1436
10	*Cassia fistula*	52	33.27	12.71	3	771	2313
11	*Catalaphyllia sp.*	38	31.5	13.14	17	721	12257
12	*Cedrela toona*	52	55.88	17.71	7	3048	21336
13	*Celtis australis*	44	48.77	16.34	10	2133	21330
14	*Ceratonia siliqua*	46	27.94	9.6	2	687	1374
	"	46	26.42	8.84	2	562	1124
15	*Cordia myxa*	47	38.61	13.59	7	1110	7770
16	*Dillenia indica*	22	18.8	4.57	3	150	450
17	*Diospyros cordifolia*	20	46.48	12.04	2	1437	2874
	"	20	14.99	6.58	18	136	2448
18	*Ehretia accuminata*	52	33.27	11.73	11	720	7920
	"	47	32	12.31	22	691	15202
19	*Emblica officinalis*	53	29.21	12.04	7	562	3934
20	*Erythrina blakei*	22	20.83	8.02	16	323	5168
21	*Erythrina suberosa*	47	36.32	12.04	6	880	5280
22	*Euc. botryoides*	53	65.02	15.18	4	3527	14108
23	*Euc. camaldulensis*	38	59.18	15.58	11	3004	33044
	"	52	56.9	19.6	4	3489	13956
24	*Euc. citriodora*	55	44.45	19.45	11	2123	23353
25	*Euc. cloeziana*	46	27.94	10.36	5	448	2240
26	*Euc. hemiphloia*	53	51.56	20.57	4	3027	12108
27	*Euc. hybrid*	43	38.35	19.2	7	1550	10850
28	*Euc. melanophloia*	56	35.81	14.9	12	1060	12720
	"	38	30.73	14.94	1	778	778
29	*Euc. microtheca*	38	33.78	11.64	6	736	4416
	"	48	34.04	9.08	9	582	5238
	"	38	36.58	16.25	7	1194	8358
30	*Euc. rudis*	53	56.39	13.59	5	2385	11925
31	*Euc. tereticornis*	38	41.66	16.15	3	1537	4611
	"	38	36.07	12.89	4	920	3680
32	*Euc. umbellata*	53	54.36	19.23	9	3124	28116
33	*Euc. torreliana*	43	44.7	17.37	5	1925	9625
34	*Ficus benjamina*	22	28.45	10.97	3	486	1458
35	*Ficus glomerata*	41	58.93	16.98	7	3256	22792
36	*Ficus microphylla*	22	37.34	12.5	2	955	1910
37	*Ficus retusa*	22	30.23	11.49	3	578	1734

Table contd…

38	*Fraxinus americana*	47	35.56	13.84	5	*958*	*4790*
39	*Gleditsia tricanthos*	43	21.08	9.21	5	380	1900
40	*Grevillea robusta*	46	36.83	14.97	18	1116	20088
41	*Hetero. adenophyllum*	22	26.42	9.6	2	611	1222
	"	38	32.51	12.68	12	733	8796
	"	28	34.29	12.41	10	810	8100
42	*Jacaranda ovalifolia*	47	33.53	12.1	13	748	9724
43	*Kigelia pinnata*	22	58.17	15.54	1	2909	2909
44	*Lager. flosreginae*	51	25.65	10.21	17	616	10472
45	*Leu. leucocephala*	17	23.11	8.69	10	428	4280
	"	21	34.29	10.58	12	687	8244
	"	22	26.42	9.66	13	615	7995
46	*Ligustrum lucidum*	38	22.1	8.93	10	397	3970
47	*Liquidambar styraciflua*	43	45.21	15.85	5	1782	8910
48	*Madhuca latifolia*	22	26.16	10.21	4	639	2556
49	*Mangifera indica*	54	37.34	13.66	5	1055	5275
50	*Mimusops elengi*	20	19.3	8.81	18	298	5364
51	*Morus alba*	48	40.13	10.36	3	922	2766
	"	47	33.27	8.53	1	518	518
52	*Paulownia tomentosa*	18	45.21	13.72	1	1552	1552
53	*Pinus roxburghii*	53	41.15	16.95	14	1584	22176
	"	51	43.69	16.83	9	1773	15957
	"	51	55.12	20.91	5	3492	17460
54	*Poincirus trifoliate*	41	6.6	3.96	5	16	80
55	*Pongamia glabra*	48	28.7	9.11	14	412	5768
56	*Ptero. acerifolium*	46	30.48	11.83	30	609	18270
57	*Robinia pseudoacacia*	46	4.57	3.05	5	6	30
58	*Salix tetrasperma*	53	49.02	14.42	3	1917	5751
59	*Sapindus mukrussi*	21	27.43	9.6	8	667	5336
	"	40	30.99	10.52	4	558	2232
	"	21	24.38	7.22	6	396	2376
60	*Saraca indica*	22	28.45	8.99	2	398	796
61	*Schinus terebinthifolius*	46	22.35	8.47	4	392	1568
62	*Schleichera trijuga*	22	32	11.58	5	650	3250
63	*Sophora japonica*	38	27.69	11.8	12	825	9900
64	*Sterculia discolor*	22	41.66	13.32	3	1267	3801
65	*Sterculia platanifolia*	22	31.24	10.88	6	583	3498
66	*Sterculia rupestris*	52	24.13	9.45	9	504	4536
67	*Swietenia mahagoni*	21	24.64	10.09	16	562	8992
68	*Syzygium cumini*	54	31.75	13.08	17	727	12359
	"	28	29.72	10.97	4	537	2148
69	*Tecoma undulate*	47	20.83	9.05	6	364	2184
70	*Tectona grandis*	52	39.12	14.36	11	1212	13332
71	*Terminalia arjuna*	53	44.45	16.06	9	1745	15705
72	*Terminalia belerica*	22	21.84	9.97	7	440	3080
	"	53	34.29	12.8	15	833	12495
73	*Terminalia tomentosa*	53	48.77	17.77	8	2337	18696
74	*Trewia nudiflora*	43	53.09	16.7	12	2586	31032
75	*Zizyphus mauritiana*	53	37.08	14.84	3	1123	3369
	Total	3862	3438.2	1220.2	773	114266	849554
	Average	40.2	35.8	12.7	8.1	1190.3	8849.5

Carbon sequestered was regressed against age, diameter, height and crop density to estimate the effect of each independent variable. The model developed is quite satisfactory with Adj. R^2 0.881 and F-value 176.326 (Table 2).

Table 2. Estimated Model for different variables.

Independent variables	Regression coefficients	Standard errors	t-values	Significance
Constant	-1551.396	139.895	-11.090	0.000
Age (A)	1.248	2.939	0.425	0.672
Diameter (D)	58.523	5.523	10.597	0.000
Height (H)	49.067	17.386	2.822	0.006
Crop Density (CD)	-3.496	6.080	-0.575	0.567
Adjusted R^2 = 0.881, F = 176.326				

Dependent Variable: CO_2 sequestered per tree.

Individual curves for age, diameter, height and crop density versus carbon sequestration were also estimated which are depicted as Fig. 1 to Fig. 4. Age and crop density proved to be non-significant at 5 percent level of significance with 15.49 percent (R^2=0.1549) and 3.42 percent (R^2=0.0342)

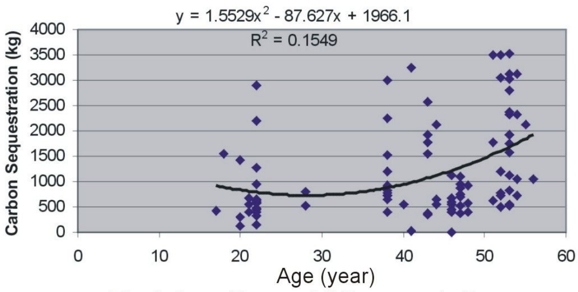

Fig. 1. Age of tree and CO2 sequestration.

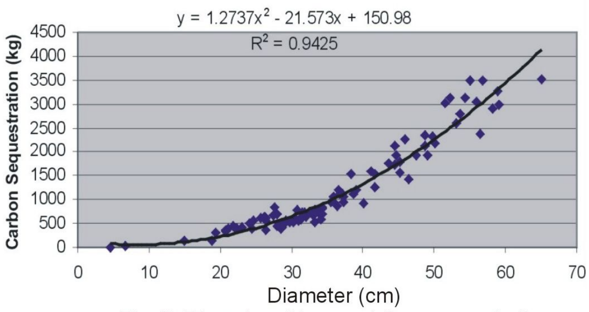

Fig. 2. Diameter of tree and Co2 sequestration

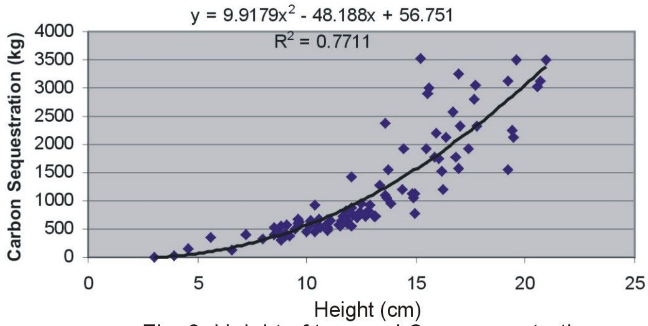

Fig. 3. Height of tree and Co_2 sequestration.

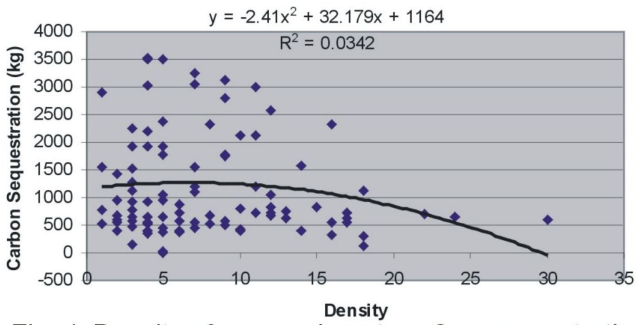

Fig. 4. Density of crop and per tree Co_2 sequestration.

contribution towards carbon sequestration, respectively. Several researchers have concluded that tree biomass is primarily a function of DBH and is relatively insensitive to tree height and consequently have incorporated only DBH as independent variable in their biomass models.

CONCLUSION

The study concludes that standing above and below ground biomass of 773 trees of 75 different species with an average age of 40 years, diameter 36 cm and height of 13 meter, sequestered 849554 kg (ca. 850 tons) of CO_2. Among different variables tested for carbon stocking, diameter proved to be highly significant factor affecting carbon sequestration in a tree.

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