Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345 (Online)
An Open Access, Online International Journal Available at http://www.cibtech.org/jls.htm
2016 Vol. 6 (2) April-June, pp. 40-46/Tripathi
Research Article

CARBON MANAGEMENT WITH URBAN TREES

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ABSTRACT
The global phenomenon of urbanization and development has severely hit the towns and cities of Indian sub- continent including Delhi, the capital of India. This new form of growth has resulted into utter chaos in the city. Uncontrolled population growth coupled with infrastructure development, industrial and vehicular emissions has resulted into a complete butchering of the urban environment. Carbon emission due to fossil fuel burning seems to be the fundamental cause escalated by deforestation and denudation. In addition, carbon emission by rich and growing class has made the situation even more grim. The air quality is deteriorating which is equally hitting different components of the urban ecosystem including human health and sanity. Though, Delhi boasts of 20.22% of the total geographical area under forest and tree cover, it seems the efforts are not enough to negate the environmental damage. The urban forests in Delhi comprise of Delhi Ridge, mini forests maintained by government agencies and a larger fragmented green area which is non- forested but tree dominated. Such green area occurs in patches which include trees in parks, gardens, avenue trees, trees within the premises of historical monuments, University/Institute/Educational campuses, landscapes, posh office areas, places of beautification etc. Considering the harmful effects of increased carbon emissions in Delhi particularly vehicular pollution it became imperative to evaluate the role played by such fragmented green areas in carbon mitigation. Thus, a carbon sequestration study was conducted at National Zoological Park (a non- forested and tree dominated area) in a 3 ha land consisting of 1225 individuals belonging to 20 tree species selected randomly. The role played by urban trees in carbon offsetting was analyzed. Tree density was calculated as 408.33 stems/ha. Total Organic Carbon stored by 1225 trees came out to be 182.12 Tons/species. The average DBH of trees was calculated as 29.73 cm indicating that the trees are moderately mature to accumulate and store good amount of carbon in the form of its standing biomass.

Keywords: *Urbanization, Carbon Emission, Deforestation, Non- Forested and Tree Dominated Area, Carbon Offsetting*

INTRODUCTION
In this modern and developing world carbon management is a serious concern with respect to urban environment. India is urbanizing at a brisk pace and the distance between villages and towns/cites is shrinking. At the moment big cities are over burdened with population pressure resulting into imbalance in the urban ecosystem. Due to overcrowding for all well-known reasons land, water and air quality of the cities is being rapidly deteriorating which has become the ultimate challenge for urban planners. Since, increasing urbanization is inevitable, the challenge is to live with it and its environmental impacts. Though, lots of efforts are being made to improve the quality of urban environment by maintaining and enhancing forest and tree cover, rejuvenating polluted water bodies and upgrading urban population management skills but it seems that efforts are not too much to combat the unavoidable shift in the climate.
Though, urban areas continue to expand and urban forests play a significant role in environmental quality and human health, relatively little is known about this resource in terms of ecosystem services. As urban forests both sequester CO_2 and affect the emission of CO_2 from urban areas, urban forests can play a critical role in helping combat increasing levels of atmospheric CO_2 (Novak and Crane, 2002). Realizing the importance of urban trees environmentalists and urban planners throughout the world are working towards the concept of eco cities. Trees in urban areas play a vital role in maintaining the ecological

balance of crowded and polluted environment. Non- forested but tree dominated areas in the name of parks, gardens, avenue trees, landscapes, within historic monuments, university premises and open spaces because of their proximity to generation of vehicular emissions are important in reducing atmospheric carbon. These tree laden green areas are recognized for their social, cultural, recreational and aesthetic values apart from conserving the biodiversity, of the region (Chaudhary *et al*., 2011) and performing carbon storage and sequestration activity (Ugle *et al*., 2010)**.**

Delhi, the capital city of India is also facing the brunt of human need and greed. At present, the National Capital Territory of Delhi stands as the world's second largest urban area with 25 million people (United Nations, 2014). Ruthless population growth coupled with urbanization and deforestation since past few decades has completely changed the ecological dynamics of the city. Uncontrolled carbon emissions (particularly vehicular and industrial) has emerged as a menace in the recent years and if concrete steps not taken now, the consequences would be grave for present as well as future generations.

For urbanized and polluted cities like Delhi carbon mitigation through urban forest management is one of the prime ways to store and sequester carbon for long periods. In spite of heavy infrastructure and developmental projects Delhi is still able to maintain its Forest and Tree Cover around 20.22% of its total geographical area (SFR, 2015)**.** Trees are considered to be a major capital assets in cities for their multipurpose benefits as ecosystem services.

Carbon now being considered as a tradable commodity under the Clean Development of the Kyoto Protocol, more and more studies are coming up evaluating the role of trees in carbon sequestration under different environmental conditions. As urban environment is highly stressful hence growth, development and carbon sequestration ability of such trees greatly varies in such areas. The urban forest is therefore a unique ecosystem experiencing different combinations of stresses. It therefore requires a site-specific research in addition to special strategies and policies to govern its management and design (Kiran and Kinnary, 2011)**.**

Immense work has been done on forest flora of Delhi since past few decades (Parker, 1918; Parker, 1920; Mukherjee, 1953; Maheshwari, 1963; Sharma, 1997; Naithani *et al*., 2006). In the recent years some interesting work on various aspects of Delhi urban greenery has also attracted attention among the scientific fraternity (Khera *et al*., 2009; Bhattacharya *et al*., 2010; Bhalla *et al*., 2015) but estimation of carbon stocks and carbon sequestration rate of urban trees with respect to urban environment has not been evaluated till date though some work has been initiated recently (Tripathi and Joshi, 2015; Tripathi, 2015)**.** Thus, a study was carried out at *National Zoological Park (NZP)*, commonly called as *"Chidia Ghar"* evaluating the role of urban trees in carbon mitigation in a non- forested and tree dominated area. The entire place is spread in an area of approximately 71 ha consisting of animal and bird enclosures dominating the entire space apart from moderate/thick tree vegetation. The biodiversity in this region is conserved by strict monitoring and management of trees by the local staff. *NZP* is an abode of around 132 different tree species which are acclimatized to semi arid and sub tropical climate of Delhi and can sustain high temperatures and scarcity of water. Old and matured trees mostly dominated the *NZP* area. Potential of trees in carbon sequestration was analyzed by non destructive methods i.e. without harming and felling the tree. It is strongly felt that a comprehensive program should be launched to map all non- forested but tree dominated trees within Delhi/NCR for their potential role in carbon mitigation and management.

MATERIALS AND METHODS

Study Area: Delhi is located at 28°37'N 77°14'E/ 28.61°N 77.23°E and lies in north India. The city has a humid sub tropical climate. Temperature ranges from 5-40°C, annual mean temperature is 25°C. Delhi receives an annual rainfall ranging between 600-800 mm. Vegetation of Delhi is tropical thorn forest group which is peculiar to arid and semi-arid region (Champion and Seth, 1968). The total geographical area of Delhi is around 1483 Km^2 of which 299.77 Km^2 is under forest and tree cover (20.22%) and per capita green space is around 0.002 ha (SFR, 2015). Delhi has a continental climate due to its distance from the coast and location with respect to mountain ranges. The Yamuna river and terminal part of the Aravali hill range are the two main geographical features of the city. The Aravali hill range is covered with forests and is called the Ridges and they are the city's lungs and help maintain its environment (Krishen, 2006). The Yamuna river in Delhi is the source of drinking water. Apart from Delhi ridge and mini- city forests maintained by Government agencies, there are other fragmented green spaces in Delhi/NCR which are non- forested but tree dominated and plays a crucial role in carbon offsetting.

Thus, the potential role of trees in carbon sequestration growing in a non- forested area was evaluated with respect to urban environment. The study was conducted at *NZP* on a 3 ha land. 1225 individuals belonging to 20 tree species were investigated for measuring the carbon stocks (above and below ground). 50 (0.06 ha) plots were used for sampling the entire vegetation. Initially cbh was measured using measuring tape which was later converted to corresponding DBH values. The circumference of the tree was measured at the circumference at breast height (CBH), 1.3 m above ground surface.

Figure 1 (a): Forest Cover Map of Delhi (*SFR, 2015); (b): National Zoological Park (*Google Satellite Image)

Height of the trees was measured by pole method or considering heights of electric poles within the premises. The allometric model proposed by Brown *et al.*, (1989) to estimate the above ground biomass has been used in the present investigation. The literature revealed that this method is non destructive and is most suitable method (FAO, 1997). The selection of the appropriate allometric equation is a crucial step in estimating aboveground tree biomass (AGTB). Allometric equations for biomass usually include information on bole diameter at breast height (DBH) (in cm), total tree height (in m) and wood density (in gm/cm^3). Ignoring variations in wood density results in poor overall prediction of the stand (AGB) (Baker *et al.*, 2004). Therefore, wood density is an important predictive variable in the regression model. The use of tree height as a predictive variable also improves the quality of the allometric equation. Hence, the allometric equations enable AGTB to be easily estimated, provided that diameter, total height and wood density of the trees are available.

$$\mathbf{Y = exp\ [-2.4090 + 0.9522\ In\ (D^2\ H\ S)]}$$

Where Y= Above ground Biomass in Kg and D is Diameter at Breast Height in cm, H is height of the trees in meters and s is the wood density in gm/cm^3. Wood density (gm/cm^3) value for the species obtained from web (www.worldagroforestry.org). Below ground Biomass (BGB) was calculated by using simple default value of 25% of the aboveground biomass (IPCC, 2006). Total Biomass was measured as sum of above and below ground biomass (Sheikh *et al.*, 2011). Carbon was considered as 50% of its biomass (Pearson *et al.*, 2005).

RESULTS AND DISCUSSION

A total of 1225 individual trees belonging to 20 species were sampled and evaluated from an area of 3 ha using 50 (0.06 ha) plots. Tree density came out to be 408.33 stems/ha. Details of individual tree species i.e. number of trees per individual, mean dbh, mean height, mean basal area, mean above ground carbon (Tons/Tree), mean belowground carbon (Tons/Tree), mean organic carbon (Tons/Tree), total carbon stocks (Tons/species) and carbon sequestration rates (Tons/year) has been depicted in Table 1 and 2. Moreover, mean organic carbon (Tons/Tree) of 20 tree species was also compared (Figure 2). Maximum organic carbon was stored by *F. religiosa* (31.45 Tons/species, n = 15) followed by *F. benghalensis* (29.60 Tons/species, n= 23) and *F. virens* (9.57 Tons/species, n= 12) Minimum organic carbon was stored by *A. nilotica* (1.04 Tons/Tree, n = 50). Total Organic Carbon stored by 1225 individuals was calculated as 182.12 Tons/specie.

Table 1: Field Data from the Study Site

S No.	Scientific Name	Number of Trees	Mean D (cm)	Mean H (m)	Mean BA (cm^2)
1	*Albizia lebbeck*	35	27.8	18.6	298.5
2	*Acacia nilotica*	50	13.85	9	150.58
3	*Alstonia scholaris*	62	15.92	8.5	198.96
4	*Azadirachta indica*	116	26.5	11	551.27
5	*Bombax cieba*	57	21.5	10	362.87
6	*Butea monosperma.*	45	17.62	11.6	243.72
7	*Cassia fistula*	94	12.26	6.7	117.99
8	*Delonix regia*	68	13.31	9.5	139.07
9	*Eucalyptus tereticornis*	30	24.66	21	477.37
10	*Ficus benghalensis*	23	80.5	15	5086.1
11	*Ficus religiosa*	15	97.7	17	7493.05
12	*Ficus virens*	12	69.8	13.5	3824.55
13	*Mangifera indica*	76	24.71	11	479.3
14	*Morus alba*	67	20.01	7.5	314.31
15	*Pithocellobium dulce*	81	15.94	8.8	199.46
16	*Polyalthia longifolia*	85	26.58	13	554.6
17	*Pongamia pinnata*	105	20.99	8.8	345.86
18	*Prosopis juliflora*	32	30.5	14	730.25
19	*Tamarindus indica*	95	22	13.9	379.94
20	*Syzgium cumini*	**77**	12.43	9	121.23
	Total	1225			22068.98

The average DBH of all the tree species came out to be 29.73 cm indicating that the trees are mature enough to accumulate and store reasonable amount of carbon in the form of their biomass.
There are a wide variety of stresses which a growing tree has to face in an urban environment, mentioning few of them: insufficient or excessive light exposure, high temperatures (urban heat island), air pollution, soil nutrient deficiency, water stress, water logging, extremes in humidity, restricted root spacing etc. An urban tree has to interact with all such stresses in order to grow and survive.
As Delhi climatic conditions are sub- tropical and semi- arid hence mostly mesophytes and semi-xerophytes dominates the vegetation and have successfully acclimatized to such conditions with minor/major adjustments to its morphological, anatomical and physiological characteristic. Some adjustments may include extensive and deep tap root system with strong network of adventitious and fine roots, enlarged rhizosphere, effective symbiotic and mycorrhizal associations, short life cycle, reduced leaf area (for efficient heat and moisture transfer outside the leaf), cuticle on leaf surface, short to medium sized thick bole, bole covered with bark, trees mostly deciduous in nature.

Table 2: Total Carbon Stocks (above and below Ground) and Carbon Sequestration Rates in 20 Different Tree Species

S No.	Scientific Name	MAGOC (Ton/Tree)	MBGOC (Ton/Tree)	MOC (Ton/Tree)	OC Stored (Tons)	Carbon Seq (Tons/year)
1	*Albizia lebbeck*	0.274587	0.06864675	0.34323375	12.01318125	0.240263625
2	*Acacia nilotica*	0.0167075	0.004176875	0.020884375	1.04421875	0.020884375
3	*Alstonia scholaris*	0.025365	0.00634125	0.03170625	1.9657875	0.03931575
4	*Azadirachta indica*	0.158983	0.03974575	0.19872875	23.052535	0.4610507
5	*Bombax cieba*	0.0483035	0.012075875	0.060379375	3.441624375	0.068832488
6	*Butea monosperma*	0.0271625	0.006790625	0.033953125	1.527890625	0.030557813
7	*Cassia fistula*	0.011755	0.00293875	0.01469375	1.3812125	0.02762425
8	*Delonix regia*	0.0139825	0.003495625	0.017478125	1.1885125	0.02377025
9	*Eucalyptus tereticornis*	0.09954	0.024885	0.124425	3.73275	0.074655
10	*Ficus benghalensis*	1.029528	0.257382	1.28691	29.59893	0.5919786
11	*Ficus religiosa*	1.6770845	0.419271125	2.096355625	31.44533438	0.628906688
12	*Ficus veriens*	0.637984	0.159496	0.79748	9.56976	0.1913952
13	*Mangifera indica*	0.1165125	0.029128125	0.145640625	11.0686875	0.22137375
14	*Morus alba*	0.0283725	0.007093125	0.035465625	2.376196875	0.047523938
15	*Pithocellobium dulce*	0.02128	0.00532	0.0266	2.1546	0.043092
16	*Polyalthia longifolia*	0.082055	0.02051375	0.10256875	8.71834375	0.174366875
17	*Pongamia pinnata*	0.072504	0.018126	0.09063	9.51615	0.190323
18	*Prosopis juliflora*	0.2288515	0.057212875	0.286064375	9.15406	0.1830812
19	*Tamarindus indica*	0.1503785	0.037594625	0.187973125	17.85744688	0.357148938
20	*Syzgium cumini*	0.0135975	0.003399375	0.016996875	1.308759375	0.026175188
	Total	4.734534	1.1836335	5.9181675	182.1159813	3.642319625

Some important physiological features which enhance carbon-di-oxide uptake, photosynthetic efficiency and carbon sequestration and assimilation may include: Tree foliage (crown cover), phyllotaxy, number and orientation of stomata on leaf surface, availability of CO_2 around stomata, stomatal aperture and conductance etc. Studies of C_3 plants growing in a wide variety of plant communities and environments and representing a diversity of life forms repeatedly shows strong relationship between maximum photosynthetic capacity and leaf nitrogen content. The physiological basis of this relationship could be the role of nitrogen in enzymes and pigments necessary for photosynthesis namely rubisco and chlorophyll. Perhaps, this is the reason that this region is dominated by trees which have nitrogen fixing ability (NFA). Though, urban trees in due course of evolution have made several adjustments during its life cycle to negate climate change but still there are few critical drawbacks as well which restricts photosynthetic efficiency and carbon uptake in growing trees when placed in a typical urban environment. The hydraulics of water movement affects tree height and thus the overall rate of carbon sequestration and allocation. The increase in hydraulic resistance with greater height increases water stress in leaves thus closing stomata and reducing carbon gain during photosynthesis. This could be the probable reason that Delhi trees mostly have short to medium sized and thick bole as perhaps water stress could have restricted tree growth and carbon uptake. Further greater respiration at warm temperatures contributes to decline in net photosynthesis.

In C_3 pathway, plants loose some of the CO_2 they fix in a light- enhanced process called photorespiration. This occurs because, rubisco which catalyzes CO_2 fixation by RuBP, also catalyzes the oxidation of RuBP by O_2. This reaction consumes oxygen and release CO_2 so that the net CO_2 uptake during photosynthesis is reduced by 30-50% (Barbour *et al.*, 1999). Though, photorespiration helps in photo-

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protection of the chlorophyll and enzymes participating in photosynthesis and thus, is useful to plants under high light intensities and hot weather conditions but when photorespiration operates for long it becomes harmful to plants probably because photorespiration competes with photosynthesis and results in net carbon loss.

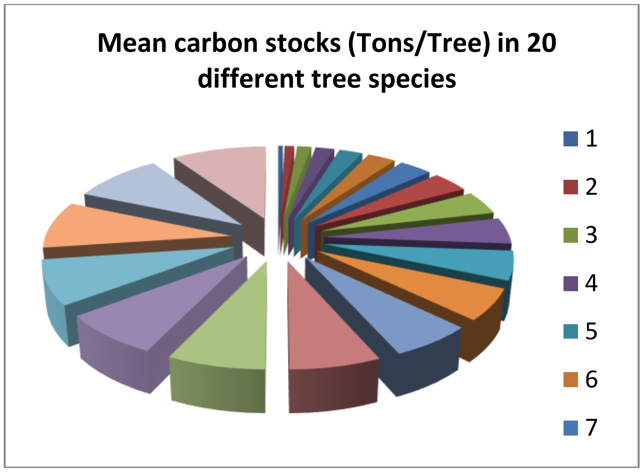

Figure 2: Mean Organic Carbon Stocks (Tons/Tree) in 20 Different Tree Species

Thus, we see that in spite of acute challenges which a growing tree has to face in an urban environment still it survives under all adversaries and helps in maintaining the carbon balance of the crowded and polluted cities, though the rate of photosynthesis and carbon sequestration varies from site to site. Urban trees within Delhi/NCR play a pivot role in carbon offsetting and thus a comprehensive and holistic approach should be needed for its monitoring and management within the city framework. Moreover, studies related to specific sites within an urban environment should be conducted for a better understanding of the tree- carbon dynamics so that urban trees can be engineered in the future for maximum carbon uptake and enhanced photosynthesis.

Conclusion

In the present scenario, urbanization is inevitable so development of eco cities is the need of the hour. The fragmented green pockets such as trees in parks, gardens, avenue trees, trees within the premises of historical monuments, University/Institute/Educational campuses, landscapes, posh office areas, places of beautification etc acts as lungs for the city infrastructure which provides a wide range of ecosystem services to the society including carbon storage and sequestration. So, such green pockets should be managed and conserved scientifically. As urban trees faces different stresses which is peculiar to that site hence site- specific monitoring and management is required. Moreover, such trees should be evaluated critically for their role in carbon mitigation. A comprehensive carbon sequestration program should also be launched for Delhi, mapping the entire trees within the green pockets. This approach might be a small step forward in allocating the carbon budget of the city and to plan our afforestation programs in the future in a more professional way.

ACKNOWLEDGEMENTS

Author would like to sincerely thank the field staff for assistance in collecting the ground data. The encouraging role played by the Head of the Department is deeply acknowledged. Moreover, sincere thanks to Prof. Hema Joshi for helping in giving the manuscript a final shape.

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