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Estimation of carbon sequestration potential of *Azadirachta indica* from different provenances in South Eastern Rajasthan

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Abstract
To comprehend and emphasize the function of vegetation in neutralizing carbon emissions at local level, the carbon sequestration capability of Neem trees selected from various provenances was studied. 30 candidate plus trees of *Azadirachta indica* was selected from each location covering three districts of South Eastern Rajasthan *viz.*, Jhalawar, Kota, and Baran. The study has shown significant variation in carbon sequestration potential in CPT's of *Azadirachta indica.* Baran location exhibited greater values of height, and girth along with higher values of BGB, Total Biomass, Carbon dioxide (CO_2) content, and Carbon Equivalent [EQ] (kg). The leaf area and Carbon Equivalent [EQ] (Tons) from the Jhalawar region was found highest. The girth, Bark thickness, AGB, BGB, TB, Carbon dioxide (CO_2) content, Carbon Equivalent [EQ] (kg), and Carbon Equivalent [EQ] (tons) was lowest in Kota. Neem harbors a moderate carbon pool on earth and also acts as a major source of carbon sinks in nature, this study assessed the carbon sequestration potential of neem among different provenances and selected CPT'S will be useful for carbon sequestration in local area, Baran provenance acted as a good carbon sink for neem tree. This database will be useful for planning carbon sequestration programme in the given locality.

Keywords: *Azadirachta indica*, carbon emissions, carbon equivalent, carbon sequestration, total biomass

Introduction

Neem tree which belongs to family Meliaceae grows to a height of 12 to 15 meters (and sometimes up to 25 meters) with a short, robust bole that varies in height from 3 to 7.5 meters and girth from 190 to 280 centimeters. The tree typically branches out early, forming a wide crown of vivid green leaves with a massive, round crown that can have a diameter up to 10–20 m. In general, it never loses leaves, although on occasion during the dry season, it may shed leaves (Orwa *et al*., 2009; Puri, 1999) [20, 24]. Mature leaves are glabrous, dark glossy green, alternate, petiolated, clustered at the terminals of branches, and have 10–20 leaflets apiece. The leaflets are somewhat denticulate, sickle-shaped, and measure 5 to 10 cm in length and 1 to 4 cm in width (FAO, 2015; Orwa *et al*., 2009; Puri, 1999) [10, 20, 24].

Carbon sequestration, as defined by Gaziolu *et al*. (2015) [12] and Gaziolu and Okutan (2016) [11], is the process of removing carbon dioxide (CO_2) from the atmosphere in order to slow down global warming. Terrestrial carbon sequestration is one of the processes of converting atmospheric CO_2 into biomass components like shrubs, trees, and soil organic matter (SOM). This is achieved through the process of photosynthesis and assimilation of biomass into the soil as humus, which involves the successful storage of atmospheric CO_2 in these components of biomass (Chavan and Rasal 2010) [7].

The ability of forests to store substantial amounts of carbon in their biomass makes them a potential tool for mitigating the negative effects of climate change, which are brought on by the greenhouse effect and the global warming that carbon dioxide (CO_2) causes (Houghton, 2005) [13]. According to Food and Agricultural Organization (FAO), deforestation accounts for 70% of emissions and destroys large carbon sinks that are crucial for global climate stability because they are now removing CO_2 from the atmosphere (FAO, 2005) [10]. But rapid deforestation, especially in the tropics, increases atmospheric CO_2 concentrations, which could jeopardize the atmosphere by raising temperatures and resulting in climate change (Lewis, 2009) [17].

At the moment, the most recommended technique for sequestering and storing carbon is plantation forestry. The *Azadirachta indica* plantation offers several benefits to the environment in addition to lumber production. Neem tree reduces the effects of greenhouse gases, soil erosion, salinity by halting the rise of the saline water table, and establishing shelter belts for crops and pastures (Peter and Stanley, 2003) [22].

The efficiency of neem in fixing CO_2 is relatively high. It can fix CO_2 at a rate of more than 14 micromoles per m^2 per second. Because of its substantial leaf surface area and dense leafy canopy, it provides an excellent substitute for maximal CO_2 fixation and functions as a barrier against other pollutants, particularly SO_2. It is a tree known for its numerous purposes, neem is used as a toothbrush in rural areas, feeds goats, lambs, and other animals, provides wood for homes and seeds, and its oil acts as nematicide, fungicide, and insecticide. Moreover, Neem grows best in semi-arid and arid areas, which are the ones that require carbon sequestration the most (Prasad *et al*., 2007) [23]. Neem contains a large number of volatile organic compounds (VOCs) that may filter the air around the tree in addition to creating oxygen during the day, like most trees and plants do (Prasad *et al*., 2007) [23].

The first step in any mass multiplication program and genetic improvement of a tree species is the selection of a good phenotype based on desired attributes (Clark and Wilson, 2005). Utilizing this varied phenotypic diversity is crucial for the identification and selection of plus trees for their bulk multiplication. By merely collecting the seeds and growing plantations from them, one can acquire 10- 15% genetic gain in the first generation by selecting the superior phenotype in natural stands (Wright, 1976) [30].

Neem is a tree that thrives in dry and semi-arid climates and can significantly aid in air conditioning, halting desertification, capturing carbon, and lowering the generation of nitrous oxide and nitrate leaching from agricultural areas. Neem can so significantly contribute to the betterment of the environment as a whole. Only very less studies have been conducted till date to assess the carbon sequestration capacity of trees, even though the ability of wooded areas in contributing to carbon sequestration is well studied (Prasad *et al*., 2007) [23]. Considering these facts an attempt has been made to assess the carbon sequestration potential among CPTs of *Azadiracta indica.*

Materials and Methods

Site characteristics

The study area is composed of South Eastern Rajasthan covering three districts of *viz*., Jhalawar, Kota, and Baran. The South Eastern Rajasthan generally experiences a tropical climate with warm humid monsoon,a little mild winters and fairly intense summers. Maximum temperature in summer is as high as 45.72 ºC and minimum during winter is 4.14 ºC. The normal yearly precipitation within the region is almost 954.7 mm mainly received from the South-West monsoon a midst June to September. Some showers in the midst winter season were observed occasionally.

Survey and selection of candidates plus trees of *Azadirachta indica.*

Thorough surveys were carried out in multiple sites where *Azadirachta indica* grows naturally to identify the CPTs of selected tree species and Jhalawar, Kota, and Baran region were selected for the study. Naturally occurring *Azadirachta indica* plants desirable traits that were close to the habitat, farm boundaries, and woodland region were chosen. For this study thirty CPTs were selected. The selection was made of only those trees that had age more than half of the rotation age of neem. The individual tree selection method and independent culling method explained by Surendran *et al*. (2003) [32] was applied for CPT selection. To avoid genetic relatedness or inbreeding population 1 km distance was kept between individual (Turnbull, 1975) [29]. The tree which are having healthy stems, strong growth qualities, well-formed crown, natural pruning capacity and free from pests and diseases (Zobel and Talbert, 1984) [31]. For CPT selection the trees were screened based on visual scores given for various parameters like tree height, branch angle, stem straightness, cylindrical clear bole, and Girth at breast Height (GBH) and the above average performers were selected (Sharma, 2020) [27]. The trees with a bole height below 5 m and a GBH of 55 cm was not selected for the study.

Measuring Tree Parameters

The Geocoordinates of the tree were recorded using Garmin GPS. Tree height, clear bole height was measured using a Ravi altimeter. Girth at Breast Height (GBH) was measured using a measuring tape. Bark thickness measured by Swedish bark gauge (Chaturvedi and Khanna, 1994) [6]. The crown diameter was measured in East-West and North-South direction and the mean were calculated to obtain the crown diameter. Trees having a branch angle less than 90^0 were selected for the study. The Leaf area was measured using the graph paper method. The data recorded were subjected to descriptive statistical analysis (Table 1 and 2)

Estimation of Above-ground Biomass (AGB) and Below-ground Biomass (BGB).

An estimation of the total biomass and carbon sequestered by *Azadirachta indica* has been made using a non-destructive technique. The carbon sequestration potential was calculated for each region under study from the data recorded for the 30 CPTs. Above-ground and below-ground biomass were calculated using allometric formulas and field measurements of the tree's (GBH) (MacDicken, 1997) [18]. Total biomass and carbon content of individual trees was calculated by the equations suggested by Sharma *et al.* (2021) [26].

Results and Discussions

Above Ground Biomass

For the Jhalawar region, the minimum value obtained for Above Ground Biomass is 1574 kg and the maximum value is 47292 kg. For Kota, the minimum value is 5057.50 kg and the maximum value is 24770 kg and for Baran, the minimum value obtained for AGB is 1571 kg and the maximum value was obtained as 9509967 kg. The highest mean value of AGB is found in trees selected from Baran (606500) kg followed by Jhalawar (12861 kg) and the lowest value for AGB was obtained in trees selected from Kota (11869 kg).

Below Ground Biomass

For the Jhalawar region, the minimum value obtained for BGB is 236 kg and the maximum value is 7094 kg. For Kota, the minimum value is 759 kg and the maximum value is 3715 kg and for Baran, the minimum value obtained for BGB is 1370 kg and the maximum value was obtained as 63399793 kg. The highest mean value of BGB is found in trees selected from Baran (3982263 kg) followed by Jhalawar (1929.05 kg) and the lowest value for BGB was obtained in trees selected from Kota (1780.4 kg).

Total biomass

For the Jhalawar region, the minimum value obtained for Total Biomass is 1809 kg and the maximum value is 279099 kg. For Kota, the minimum value is 5816 and the maximum value is 28486 kg and for Baran, the minimum value obtained for Total Biomass is 1694 kg and the maximum value was obtained as 729097624 kg. The highest mean value of Total Biomass is found in trees selected from Baran (4587654 kg) followed by Jhalawar (29724 kg) and the lowest value for Total Biomass was obtained in trees selected from Kota (13650 kg).

Carbon dioxide (CO_2).

For the Jhalawar region, the minimum value obtained for CO_2 (kg) is 904 kg and the maximum value is 88745 kg. For Kota, the minimum value is 2908 and the maximum value is 14243 and for Baran, the minimum value obtained for CO_2 (kg) is 3097 kg and the maximum value was obtained as 36454881 kg. The highest mean value of CO_2 is found in trees selected from Baran (2459449 kg) followed by Jhalawar (11941 kg) and the lowest value for CO_2 was obtained in trees selected from Kota (6825 kg).

Carbon Equivalent [EQ] (kg)

For the Jhalawar region, the minimum value obtained for EQ (kg) is 3316 kg and the maximum value is 99706 kg. For Kota, the minimum value is 10663 kg and the maximum value is 52224 kg and for Baran, the minimum value obtained for EQ (kg) is 11357 kg and the maximum value was obtained as 133667897 kg. The highest mean value of EQ was found in trees selected from Baran (8409341 kg) followed by Jhalawar (270229 kg) and the lowest value for EQ was obtained in trees selected from Kota (25025 kg).

Carbon Equivalent [EQ] (Tons)

For the Jhalawar region, the minimum value obtained for EQ is 10.12 tons and the maximum value is 100 tons. For Kota, the minimum value is 10.66 tons and the maximum value is 32.22 tons and for Baran, the minimum value obtained for carbon. equivalent is 11.35 tons and the maximum value was obtained as 92.52 tons. The highest mean value of EQ is found in trees selected from Jhalawar (43.12 tons) followed by Baran (35.60 tons) and the lowest value for EQ was obtained in trees selected from Kota (25 tons).

Table 1: Quantitative growth characters of selected 30 CPTs of *Azadirachta indica* from the Jhalawar region

Location	Descriptive statistics	Height (m)	Girth (cm)	Cl.Bl.Ht (m)	Bark thickness (mm)	Cl.Bl.Ht:Th (m)	Crown diameter (m)	Leaf area (cm^2)
Jhalawar region	MAX	16.00	274.00	8.00	5.00	0.50	19.90	15.50
	MIN	10.00	54.80	2.10	1.00	0.18	8.20	5.00
	AVG	12.59	133.39	3.92	2.38	0.31	14.08	10.11
	STDEV	0.71	8.49	0.85	0.07	0.05	1.70	2.47
	CV%	5.62	6.36	21.64	2.98	16.11	12.05	24.48
Kota region	MAX	17.00	188.00	8.10	3.20	0.79	28.00	14.00
	MIN	9.00	82.00	3.20	1.00	0.23	13.50	3.50
	AVG	12.60	126.56	4.91	2.07	0.40	19.59	7.83
	STDEV	0.42	21.92	0.07	0.07	0.01	3.61	1.06
	CV%	3.37	17.32	1.44	3.41	1.76	18.41	13.55
Baran region.	MAX	17.00	213.00	6.00	3.50	0.25	21.20	13.50
	MIN	10.00	54.80	2.70	1.00	0.08	1.80	3.00
	AVG	12.92	132.65	4.01	2.22	0.19	16.53	7.43
	STDEV	1.91	32.31	0.07	0.28	0.03	0.35	0.71
	CV%	14.78	24.36	1.76	12.76	15.26	2.14	9.51

Table 2: Carbon estimates of selected 30 CPTs of *Azadirachta indica* from the Jhalawar region

Location	Descriptive Statistics	AGB (kg)	BGB (kg)	TB (kg)	Carbon content (kg)	CO_2 EQ. (Kg)	CO_2 EQ. (Tons)
Jhalawar Region	Max	47291.60	*7093.70*	279099.05	88744.90	99706.50	99.71
	Min	1573.09	*235.90*	1809.06	904.50	3316.60	10.12
	Avg	12860.60	1929.05	29724.17	11941.22	27229.01	43.12
	STDEV	2212.68	331.85	175073.63	1272.23	4665.00	4.66
	CV%	17.21	17.20	588.99	10.65	17.13	10.82
Kota Region	Max	24770.30	3715.54	28485.84	14242.92	52224.04	52.22
	Min	5057.50	*758.62*	5816.09	2908.04	10662.82	10.66
	Avg	11869.90	1780.47	13650.31	6825.15	25025.57	25.02
	STDEV	4912.34	736.85	5649.18	2824.59	10356.84	10.36
	CV%	41.38	15.00	41.39	41.38	41.39	41.42
Baran Region	Max	9509969.0	63399793.3	72909762.4	36454881.1	133667897.3	92.52
	Min	1571.00	1370.10	6194.10	3097.00	11355.60	11.35
	Avg	606499.70	3982262.71	4587654.17	2459449.51	8409341.44	35.60
	STDEV	15847.75	2377.15	18224.83	9112.44	33412.21	33.41
	CV%	2.61	0.06	0.40	0.37	0.40	93.84

Max- Maximum, Min- Minimum, Avg -Average, STDEV-Standard Deviation, CV%- Coefficient of Variation

In the study of variation in the carbon sequestration potential of *Azadirachta indica* from different provenances; the area Baran exhibited greater values of height, and girth along with higher values of BGB, Total Biomass, (CO_2) content, [EQ] (kg). The leaf area of the Jhalawar region was found highest along with the highest value of [EQ] (Tons). This is similar to the findings of Skovsgaard and Vanclay, (2008) [28]. The girth and Bark thickness have the lowest value in Kota along with the lowest AGB, BGB, TB, Carbon dioxide (CO_2) content, [EQ] (kg), and [EQ] (tons). The report of this study is consistent with Segura and Kanninen (2005) [25]; Carlos *et al*., (2015) [5], and Ostadhashami *et al*., (2014) [21] who used diameter at breast height to predict AGBin different countries. This finding of the study is also similar with the results of study of Karmacharya and Singh (1992) [15], Buvaneswaran *et al*., (2006) [3], Nandeswar *et al*., (1996) [19], Leith *et al*., (1986) [16] and Bohre *et al*., (2012, 2013) [2, 1].

The study has shown that there are variations in the amount of carbon sequestration potential assessed in the *Azadirachta indica*. A high positive correlation was found between the tree heights and the biomass in this study. In the study of variation in the carbon sequestration potential of *Azadirachta indica* from different provenances the area Baran exhibited greater values of height, and girth along with higher values of BGB, Total Biomass, Carbon dioxide (CO_2) content, [EQ] (kg). The leaf area of the Jhalawar region was found highest along with the highest value of [EQ] (Tons). The girth and Bark thickness have the lowest value in Kota along with the lowest AGB, BGB, TB, Carbon dioxide (CO_2) content, [EQ] (kg), and [EQ] (tons).

Conclusion

The study has revealed that Neem (*Azadirachta indica*) harbors a moderate carbon pool on earth and also acts as a major source of carbon sinks in nature, therefore, stakeholders and forest managers should cultivate the habit of conserving the forest for carbon sustainability, posterity and for climate change mitigation.

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