Short Communication

Range Mgmt. & Agroforestry 41 (2) : 381-385, 2020

ISSN 0971-2070

Biomass production and carbon sequestration potential of neem (*Azadirachta indica A. Juss)* under dryland environment

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Received: 22nd December, 2019 Accepted: 4th November, 2020

Abstract

Neem (*Azadirachta indica* A. Juss*)* is a fast-growing evergreen tree species adopted to wide range of climatic condition and especially suitable for dryland areas. A study was conducted to quantify its potential for carbon sequestration. The study concentrated on estimating biomass and carbon stock of 10-year-old *Azadirachta indica* plantation under different diameter classes. Biomass production of neem was recorded maximum in root (258.1 t ha^{-1}) followed by primary branch, secondary branch, stem and leaf under 20-30 cm diameter class. The 10-year-old neem plantation showed carbon sequestration potential of about 31.82 kg C $tree^{-1}$ (88.15 t C ha^{-1}) in above ground biomass and 17.97 kg C $tree^{-1}$ (49.78 t C ha^{-1}) in below ground biomass. The maximum average CO_2 equivalent was recorded in root followed by primary branch, secondary branch and stem. The carbon dioxide equivalent showed an increasing trend with increased diameter classes.

Keywords: *Azadirachta indica*, Biomass, Carbon stock, Climate change

Carbon dioxide (CO_2) is one of the major greenhouse gases responsible for global warming. It contributed about 72% in total global warming and about 78% of the total GHG emissions during 1970 to 2010. Its level in atmosphere is increasing rapidly due to expanding use of fossil fuel, land use changes, deforestation and conversion of forest lands to other activities. Recent past has contributed more, as about half of the anthropogenic CO_2 emissions between 1750 and 2011 have occurred in the last 40 years (IPCC, 2014). Since the beginning of industrial revolution, level of CO_2 has increased from pre-industrial level of 280 ppm to present level of more than 400 ppm.

Carbon sequestration is becoming potential options for reducing CO_2 concentration in the atmosphere to mitigate global warming and climate change (Ghosh and Mahanta, 2014). Large scale, plantation of tree is being viewed as potential option to meet the need of C-sequestration (IPCC, 2014; Bhadwal and Singh, 2002). Trees capture CO_2 during photosynthesis and stored it in the form of biomass for long duration. As trees grow, they sequester carbon proportionate to the amount of tree biomass increases, eventually reduces atmospheric CO_2 concentration (Dyson, 1977). It has reported that terrestrial vegetation and soil can contribute to reduce atmospheric CO_2 concentration which currently absorbs 40 per cent of global carbon dioxide emission from human activities (Adam, 2001). Such kind of carbon storage can be encouraged by carbon trading and Clean Development Mechanism (CDM) under Kyoto protocol.

In India, there is very good scope for carbon sequestration by raising plantation through afforestation. Government of India policy also promotes tree plantation and committed to bring 33% of total land under forest. It has reported that forest plantation and Indian forests together can able to remove 0.12 Gt of carbon dioxide from the atmosphere (Lal and Singh, 2000). The total carbon stored in forests, including soil in India is estimated to be 7083 Mt (FSI, 2017). India has also about 68.35 million ha waste land that can be utilised for mass tree plantation and carbon sequestration (Balasubramanian, 2015).

However, selection of tree is most important factor for C-sequestration. The C-sequestration potential for trees varies with species and climatic condition. Further, carbon content also varied among different tree species and among wood types within a single tree (Lamlom and Savidge, 2003; Chauhan *et al*., 2009) indicating the need to estimate biomass and carbon content for each species and each tree component for enhancing the accuracy of measurement. Further, productivity of any vegetation system mainly depends on biomass production and carbon storage potential in their different components, which are affected by nature and age of plant, and other factors (Chaturvedi *et al.,* 2016). Hence, there is a need to identify potential tree resources for sequestrating the atmospheric carbon and its suitability for Indian condition to mitigate climate change through a systematic research program.

Neem (*Azadirachta indica* A. Juss), a native tree of Indian subcontinent, is one of the most suitable tree species for arid dryland areas of India. It is fast growing and evergreen tree species and tolerant to nutrient poor soil and harsh climatic condition. It has multipurpose use like fuel wood, timber, pharmaceuticals, livestock fodder, nitrification of soils for various agricultural crops, and pest control (Koul *et al.,* 1990). Due to its nature to tolerate nutrient poor soil, harsh climate, fast growth and multiple use it can be good tree species for mass plantation for C-sequestration and other beneficial use. Many studies have been reported about beneficial use of neem trees and its products, however, no studies have been conducted for estimation of biomass carbon stock and CO_2 equivalent mitigation potential in *Azadirachta indica* especially in dry land condition. Thus keeping in view the growing interest in quantifying the ability to sequester atmospheric carbon, an attempt was, therefore, made to estimate the biomass and carbon stock of *Azadirachta indica* under dry lands of Hyderabad, India.

This study was conducted at ICAR-Central Research Institute for Dryland Agriculture in Hyderabad, India during 15th November, 2014 to 15th February, 2015 in winter season. It is located at $17^0 27'$ N latitude, $78^0 35'$ E longitude with above mean sea level of 515 m. The mean annual temperature was 13.5°-38.6°C and the mean annual rainfall was 755 mm. The experimental soil represented Alfisol soil order (Typic Haplustalf), with pH slightly acidic to neutral (6.4) and EC-0.085 dS m^{-1}. The soils were low in available nitrogen (145 kg ha^{-1}), medium in available phosphorus (13.0 kg ha^{-1}) and available potassium (175 kg ha^{-1}). The ten-year-old neem plantations were selected for carbon sequestration study with 6 m X 6 m spacing. The entire field was divided in to plots of equal size and within each plot, 25% of the trees were marked representing the population. Entire plantation was divided into three diameter classes *viz.,* 0-10 cm, 10-20 cm and 20-30 cm which were in same plot or field for measuring the growth parameters. Nine representative trees in the respective diameter class were selected for destructive sampling. Growth variables *viz*., tree height, basal diameter, diameter at breast height (DBH), crown height and crown width were measured as per established procedure before felling of trees.

The above ground and below ground biomass estimation was done by destructive sampling method. The collected samples were dried at 80 °C till constant weight was obtained. The oven dry weight of the whole sample was calculated using the formula given below (Gnana Mathuram, 2009). From the oven dried weight carbon content in the tree biomass was computed. Oven dried biomass samples were grounded in Willey Mill and ash per cent was determined by the procedure given by Allen *et al.* (1986). Carbon per cent in above ground biomass and below ground biomass was estimated using the formula given below (Negi *et al.,* 2003; Dhruw *et al.*, 2009).

Carbon % = 100% - {Ash % + Molecular weight of O_2 (53.3 %) in $C_6H_{12}O_6$}

The carbon stock in the above ground biomass and below ground biomass was computed by using the formula; Carbon = Biomass × Carbon per cent, while the carbon dioxide equivalent was calculated as per the equation; Carbon dioxide equivalent = Carbon stock × 3.66.

The data revealed that the targeted diameter classes varied significantly. The growth variables *viz.,* tree height, basal diameter, DBH, crown height and crown width were maximum for neem tree under higher diameter class, whereas these were minimum under lower diameter

Table 1. Biomass of *Azadirachta indica*

Basal diameter class	Leaf biomass	Stem biomass	Primary branch biomass	Secondary branch biomass	Above ground biomass	Below ground biomass/root biomass	Total biomass
	t ha^{-1}	t ha^{-1}	t ha^{-1}	t ha^{-1}	t ha^{-1}	t ha^{-1}	t ha^{-1}
0-10	3.767	11.96	17.68	33.37	66.78	28.78	95.56
10-20	6.523	28.72	51.30	51.41	137.9	71.23	209.1
20-30	10.54	99.02	194.5	149.4	453.5	258.1	711.6
Mean	6.946	46.57	87.84	78.08	219.4	119.3	338.8

Table 2. Biomass carbon stock of *Azadirachta indica*

Basal diameter class	Leaf C		Stem C		Primary branch C		Secondary branch C		Above ground biomass C		Below ground biomass/root C		Total C	
	kg tree^{-1}	t ha^{-1}	kg tree^{-1}	t ha^{-1}	kg tree^{-1}	t ha^{-1}	kg tree^{-1}	t ha^{-1}	kg tree^{-1}	t ha^{-1}	kg tree^{-1}	t ha^{-1}	kg tree^{-1}	t ha^{-1}
0-10	0.444	1.231	1.758	4.870	2.725	7.550	4.542	12.58	9.469	26.23	4.333	12.00	13.80	38.23
10-20	0.770	2.133	4.220	11.69	7.908	21.90	6.997	19.38	19.89	55.10	10.72	29.70	30.61	84.81
20-30	1.245	3.449	14.55	40.30	29.98	83.06	20.34	56.34	66.11	183.1	38.85	107.6	104.9	290.7
Mean	0.820	2.271	6.843	18.95	13.54	37.50	10.62	29.43	31.82	88.15	17.97	49.78	49.79	137.9

Table 3. Co_2 equivalent of *Azadirachta indica*

Basal diameter class	Leaf CO_2 equivalent		Stem CO_2 equivalent		Primary branch CO_2 equivalent		Secondary branch CO_2 equivalent		Above ground biomass CO_2 equivalent		Below ground biomass/ root CO_2 equivalent		Total CO_2 equivalent	
	kg tree^{-1}	t ha^{-1}	kg tree^{-1}	t ha^{-1}	kg tree^{-1}	t ha^{-1}	kg tree^{-1}	t ha^{-1}	kg tree^{-1}	t ha^{-1}	kg tree^{-1}	t ha^{-1}	kg tree^{-1}	t ha^{-1}
0-10	1.627	4.508	6.435	17.82	9.977	27.63	16.62	46.05	34.65	96.00	15.85	43.92	50.51	139.9
10-20	2.818	7.807	15.44	42.78	28.94	80.17	25.60	70.93	72.80	201.6	39.24	108.7	112.0	310.3
20-30	4.557	12.62	53.25	147.5	109.7	304.0	74.45	206.2	242.0	670.3	142.2	393.9	384.2	106.4
Mean	3.001	8.313	25.04	69.37	49.55	137.2	38.89	107.7	116.4	322.6	65.77	182.1	182.2	504.8

class. The range of tree height (m), DBH (cm), crown height (m), crown width (m) and number of branches (numbers/tree) were 4.4 to 6.75, 8.8 to 22.5, 1.0 to 2.3, 1.8 to 7.6 and 14 to 44, respectively in the plantation. The result presented on biomass production of neem indicated that biomass increased with a corresponding increase in diameter class (Table.1) and was recorded maximum in leaf biomass (10.54 t ha^{-1}), stem biomass (99.02 t ha^{-1}), primary branch biomass (194.5 t ha^{-1}), secondary branch biomass (149.4 t ha^{-1}) and root biomass (258.1 t ha^{-1}) under 20-30 cm diameter class. The average total biomass of neem tree was recorded as 338.8 t ha^{-1}. Among the fractionated plant parts, the roots were exhibited maximum average biomass (119.3 t ha^{-1}) followed by primary branch biomass, secondary branch biomass, stem biomass and leaf biomass. The average total biomass and above ground biomass of neem tree were recorded as 338.8 t ha^{-1} and 219.4 t ha^{-1}, respectively. These findings were in conformity with the findings of Singh and Lodhiyal (2009), Uma *et al.* (2011) and Fonseca *et al.* (2012). Similar results were observed in *Tectona grandis* and *Dalbergia sissoo* by Dhruw *et al.* (2009), in *Melia azadirach* by Singh and Gill (2014) and in *Simarouba glauca* by Noor *et al.* (2016a).

Among the fractionated plant parts of targeted species neem highest average carbon stock values of 17.97 kg tree^{-1} and 49.78 t ha^{-1} were recorded in root followed by primary branch (13.54 kg tree^{-1}). The average total carbon stock, above ground carbon stock and below ground carbon stock values were 49.78 kg tree^{-1} and 137.9 t ha^{-1}, 31.82 kg tree^{-1} and 88.15 t ha^{-1} and 17.97 kg tree^{-1} and 49.78 t ha^{-1} respectively. The carbon stock of neem tree components increased from lower diameter class (0-10 cm) to higher diameter class (20-30 cm) (Table.2). The above ground, below ground and total biomass of neem expressed higher carbon stock under 20-30 cm diameter classes. Kumar *et al.* (2009), Yadava (2010) and Juwarkar *et al.* (2011) also reported that the lower DBH tree would sequester less carbon, while higher DBH trees would accumulate more carbon during the initial stages of growth. Hence it was concluded that carbon stock is more in higher diameter class as compared to lower diameter class. Further many researchers indicated that stem had more biomass and the quantity of biomass was directly correlated to total carbon content of tree (Jana *et al.*, 2009; Dhruw *et al.*, 2009; Chauhan *et al.*, 2009; Noor *et al.*, 2016b).

The maximum average CO_2 equivalent was observed in root followed by primary branch, secondary branch and stem (Table.3). The maximum CO_2 equivalent was recorded under 20-30 cm diameter class in tree components of root biomass (142.2 kg tree^{-1} and 393.9 t ha^{-1}) followed by primary branch biomass when compared with other diameter classes. Average total CO_2 equivalent was recorded as 182.2 kg tree^{-1} and 504.8 t ha^{-1} in the targeted species. The highest average CO_2 equivalent was exhibited in root (65.77 kg tree^{-1} and 182.1t ha^{-1}) followed by primary branch (49.55 kg tree^{-1} and 137.2 t ha^{-1}), secondary branch (38.89 kg tree^{-1} and 107.7 t ha^{-1}) and stem (25.04 kg tree^{-1} and 69.37 t ha^{-1}). The lowest average CO_2 equivalent was recorded in leaf biomass (3.001 kg tree^{-1} and 8.313 t ha^{-1}). Average total, above ground and below ground biomass CO_2 equivalent under higher diameter (20-30 cm) was 384.2 kg tree^{-1} and 1064 t ha^{-1}, 242.0 kg tree^{-1} and 670.3 t ha^{-1} and 142.2 kg tree^{-1} and 393.9 t ha^{-1}, respectively. Yadava (2011) and Noor *et al.* (2016c) also reported that higher diameter class generally sequestrate more CO_2 as compared to lower diameter class and more biomass fixes more CO_2 from the atmosphere. This is the one of the important attributes in determining the potential of a tree species to mitigate the major green house gas, carbon dioxide. These results were conformity with the findings of Noor *et al.* (2016b; 2016c) and Yadava *et al.* (2011).

The study revealed that the carbon stock of neem tree components increased from lower diameter class (0-10 cm) to higher diameter class (20-30 cm). The above ground, below ground and total biomass, carbon stock and CO_2 equivalent of neem was higher under 20-30 cm diameter classes. Thus the different components of neem tree had substantial mitigation potentials. Therefore, growing of such trees with better carbon sequestration potentials will improve carbon stocks and mitigate the carbon dioxide in the atmosphere.

Acknowledgement

The authors would like to thank Director, ICAR-CRIDA, Hyderabad and Director, ICAR-CAZRI, Jodhpur for giving opportunity to take up research in dry land region of India during the professional attachment training at ICAR-CRIDA, Hyderabad. It is a pleasure to express our sincere and respectful thanks to Dr. G. Rajeshwar Rao, Principal Scientist, CRIDA, Hyderabad for his coveted guidance, constant encouragement and personal interest during the course of investigations.

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