# A perceptive study on carbon sequestration potential of *Acacia catechu* in the Mukundara National Park Rajasthan

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**Abstract**

***The carbon sequestration potential of an unmanaged and previously unstudied Acacia catechu in the Mukundara National Park Rajasthan, by estimating the total aboveground biomass contained in the forest. It turned into observed that the biomass, above ground comprising of stems, branches, and foliage, holds a total of 200 tons per hectare, foremost to a valued 100 tons of carbon being deposited per hectare aboveground. Acacia species consequently has the potential to play a significant function within the mitigation of climate change. The relation among the biomass, M, of each component (stems, branches, and foliage) and the diameter d, of the plant become also studied, by means of fitting allometric equations of the form $M = \alpha d^{\beta}$. It was observed that all components fit this power law relation very well ($R^2 > 0.7$), chiefly the stems ($R^2 > 0.8$) and branches ($R^2 > 0.9$) for which the relation is found to be almost linear.***

**Keywords:** ***Carbon sequestration, Acacia catech, Forest ecosystem***

## Introduction

Carbon sequestration is the route through which agricultural and forestry practices eliminate carbon dioxide ($CO_2$) from the atmosphere. The word “sinks” is also used to describe agricultural and forestry lands that fascinate $CO_2$, the most prominent global warming gas released by human activities. Agricultural and forestry practices can also discharge $CO_2$ and other greenhouse gases to the atmosphere. Sequestration activities can help prevent global climate change by enhancing carbon storage in trees and soils, preserving existing tree and soil carbon, and by reducing emissions of $CO_2$, methane ($CH_4$) and nitrous oxide ($N_2O$). Thus carbon can be sequestered biologically in the forest ecosystem first into the plants and then to the animals. Carbon sequestration in forests occurs in living biomass of above ground and soil.

Forest ecosystem is one of the most essential components of terrestrial ecosystems and the biggest carbon pool, occupying an integral position in global carbon cycle of terrestrial ecosystems (Liu et al. 1997; Wang et al. 2001; Kuuluvainen and Gauthier 2018; Zhao et al. 2019). The world’s total forest area was became approximately four billion hectares, similar to about 31% of the total land area (FAO 2011, 2016). Over 86% of the global vegetation carbon pool and over 73% of the global soil carbon pool are stored in forest ecosystem (Dixon et al. 1994). Forest ecosystem has higher output than any other terrestrial ecosystems, with its fixed carbon accounting for more than two-thirds of the total amount in terrestrial ecosystems per year (Fang et al. 2001a, b). The forest area of India is among the top five globally and covers 20.36% of the country’s total area. As researched, Indian forests have served as a carbon sink during the last few many years, which changed into frequently because of big-scale afforestation efforts in India, where the forest area increased by two million hectares per year in the 1990s and by an average of three million hectares per year since 2000. Forest ecosystem carbon storage mainly includes forest vegetation carbon storage, soil carbon storage, and litter carbon storage (Lafleur et al. 2018; Lee et al. 2014; Herault and Piponiot 2018). Precise estimation of forest ecosystem carbon storage is a major concern that has drawn extensive attention of scientist in the area of global climate change. In countries with innovative forestry tools, such as the United States (Tian et al. 2015; Domke et al. 2016, 2017), Canada (Sage et al. 2019), Europe (Neumann et al. 2016; Vanguelova et al. 2016; Rodríguez Martin et al. 2016) and Russia (Warnant et al. 1994; Krankina et al. 1996; Filipchuk et al. 2018 a super deal of research has been conducted on the estimation of forest ecosystem carbon storage. According to Marzluff, (2008) urban is defined in environmental sciences in terms of dominant land cover whereas it is associated with population density in social sciences. Climate change and Global warming resulting from emissions of $CO_2$ and other GHGs are causing the environment and atmosphere to degrade significantly (Kant and Anjali, 2020). Fossil fuel burning - Land use changes - Industrial effluents are some of the main human induced activities responsible for increasing $CO_2$ emissions in the atmosphere. Slow response of climate towards these changes in $CO_2$ levels amply indicates that global mean temperature would keep rising even though carbon emissions are stopped today, and even then other climate impacts would keep increasing for next few decades or centuries. The rate at which carbon is deposited into residing organisms isn't always the same as the rate it is returned to our planet (Gruber et al, 2004). $CO_2$ is dominant amongst GHGs (Lal and Singh, 2000) and trees act as sink which fixes carbon through photosynthesis and stores excess carbon as biomass (Ravindranath and Ostwald, 2008). In the present scenario of continuously increasing concentration of $CO_2$, growing interest is being witnessed in studying the potential of increasing carbon storage in terrestrial vegetation through forest conservation, and through afforestation – reforestation - land use change – land cover management. IPCC's special report on land use changes and forestry suggests that there is huge untapped potential to sequester an additional 87 Pg C by 2050 in global forests alone (IPCC, 2000). However, carbon sequestration, an activity to store carbon or its other forms for global warming mitigation which was one of the important clauses of erstwhile Kyoto Protocol, is considered significant in urban areas also because of the greater net savings in carbon emissions achieved by urban vegetation's. Globally, climate negotiations have highlighted the importance of land use sectors in mitigating the climate change. According to Intergovernmental Panel on Climate Change, (2007), agriculture alone accounts for 10-12% of the total global anthropogenic emissions of GHGs with an estimated non-$CO_2$ GHG emission of 5120-6116 $MtCO_2$ eq/yr in 2005. Due to the fact that agricultural lands are often intensively managed, they provide possibilities to beautify agronomic practices, nutrient and water control, land use practices to suit the land managers' targets of carbon sequestration. The overall carbon sequestration potential of worldwide croplands is 0.75-1Pg/yr or approximately 50% of the 1.6-1.8 Pg/yr misplaced because of deforestation and other agricultural activities (Lal and Bruce, 1999).

The emphasis of land use systems that have higher carbon content than current plant community can help to attain net gains in carbon, precisely and major increases in carbon storage can be achieved by moving from lower biomass land uses (e.g. grasslands, crop fallows, etc) to tree based systems such as forests, plantation forests and agroforestry (Roshetko et al, 2007). Agroforestry provides a unique possibility to combine the twin goals of weather exchange model and mitigation. Although agroforestry structures are not normally designed for carbon sequestration, there are numerous recent research that substantiate the proof that agroforestry systems can play a main function in storing carbon in aboveground biomass (Verchot et al, 2007) and in soil (Nair et al, 2009) and in belowground biomass (Nair et al, 2009). A number of the earliest checks of national and international terrestrial carbon dioxide sinks monitor two beneficial attributes of agroforestry systems (a) direct close to term garage (decades to centuries) in timber and soils and (b) the capability to offset on the spot GHG emissions associated with deforestation and subsequent moving cultivation (Dixon, 1995) In this paper, I present a view of carbon sequestration potential of agroforestry systems, particularly India and highlight the need for more studies estimating the potential of agroforestry systems given the multiple benefits of such systems and the potential to provide synergy between climate change mitigation and adaptation by way of decreasing the vulnerability of communities to climate risks and climate change in the long run.

In this work, I study the carbon sequestration properties of an unmanaged and previously unstudied ***Acacia catechu*** in the Mukundara National Park is a national park in Rajasthan. I only take into account the carbon stored in the aboveground biomass (stems, branches, and foliage), although as mentioned earlier, it should be born in mind that a large fraction of the total carbon is stored in the soil.

India has also conducted extensive research in this field since the 1950s. However, various statistics sources, extraordinary estimation techniques and one of a kind scale of study area have led to substantial variations in the estimation of forest area carbon storage. This work ought to offer references for more correct estimation of forest carbon storage. The paper is organized as follows. Firstly, I describe the ***Acacia*** species that I studied (***Acacia catechu***) and the site of the research (Mukundara National Park). Then I describe our experimental method and present the results of the aboveground biomass measurements, estimation of the carbon content, and the construction of allometric equations relating biomass to a plant's diameter. Finally, I summarize and draw our conclusions.

## Review of literature

Manhas et al. (2006) assessed total carbon stored by Indian forests as11085.16 Mt and 1083.81 Mt for the year 1984 and 1994, respectively. The order of carbon contribution stocked for the major forests is: miscellaneous forest› shorea robusta forest› Tectona grandis forests› temperate forests› tropical forests ›Bamboo forest, etc. The values predicted by different authors range from 1,083.81 Mt C (Manhas et al., 2006) for the year 1984 to 3,907.67 MtC (Chhabra et al., 2002) for the year 1994. Estimated rate of Carbon flux in selected planted forests in India, Raizada et al. (2003) revealed that - i) Planted forests of short rotation tree species with regular leaf shedding patterns have more capacity for C sequestering in litter, ii) Fast growing conifers may produce slow decomposing litter leading to accumulation on forest floor, hence risk for fire damage and decline in ground flora diversity, iii) Mixed planted forests of exotic and native species could be more efficient in sequestering carbon than monocultures and fast growing hardy species like Eucalyptus would be ideal choice for wasteland afforestation. Forest ecosystems act as source and sink of atmospheric carbon dioxide ($CO_2$) and are one of the most faithful options for carbon sequestration and play a crucial role in regulating global carbon cycle. Local, regional, and national carbon inventories of source and sinks of carbon are indispensable to assess the prospective role of various carbon sequestration pools for reducing atmospheric $CO_2$ accumulation, and therefore it is a pioneer step for preventing global warming. The studies also important for developing of systems / markets for national and international carbon credit / emission trading as well as in reducing emission from deforestation and forest degradation ($REDD^+$) programs in developing countries (Han et al. 2007; NEFA 2002; Kale et al. 2004). Article 2.1 of Kyoto Protocol addresses the issues related to global warming and asked to own responsibility to signatory countries to protect the sinks and reservoirs of greenhouse gases and increase afforestation, reforestation, and promote sustainable forest management (Yavaşli, 2012). India is also one of the signatory in Kyoto Protocol; hence, various studies have been carried out at different parts of the country. However, the data is patchy and sporadic. Precise assessment of $CO_2$ emissions as a result of land use changes, forest fire, degradation, and other anthropogenic activities are a few challenging issues for understanding global carbon cycle and hence for making policies. Therefore, latest researches specifically focus on biomass assessment to trim down uncertainties related to carbon cycle and emissions.

Knowledge of spatial distribution of biomass is a prerequisite to find out the sources and sinks of carbon (C) as a result of forest to degraded land and vice versa as well as their temporal variations (Yavaşli, 2012). Forests play a critical role in global carbon flux and act as carbon sink by storing large quantities of carbon for a long period of time. This storage of organic rely in biomass presents a lag for entire carbon emission because of breathing, more than 40% of the global primary production in forest area ecosystem is done with the aid of tropical and subtropical forests (Beer et al. 2010). India is 8$^{th}$ among the top 10 most biodiverse countries (Butler, 2016), with 21.05% (692,027 $km^2$) of its geographical area (3,287,263 $km^2$) under forest and tree cover (FSI, 2011). Near approximately 173,000 villages are labeled as forest fringe villages, and their dependency on forest resources is obviously large. Subsequently, it is very much important to assess the likely impact of forest degradation on projected climate change. In view of this, carbon / biomass inventory studies play an important role in relation to broaden and enforce edition rules for each biodiversity conservation, protection, future sustainable utilization of forest resources, safeguarding the livelihoods of forest structured humans, and lowering stress on forest ecosystems (Kishwan et al. 2009). In step with fourth assessment record of the Intergovernmental Panel on climate change (IPCC 2007), limited data is available concerning the biomass, carbon stock / sequestration at countrywide and nearby level. This is especially real for India as a few and sporadic forest biomass/carbon studies are to be had for carbon dioxide mitigation assessment (Ravindranath and Ostwald, 2008). Another shortcoming is that, these estimates of carbon sequestration potential and stock are done without taking consideration of regional variations in species distribution, growth rates, and carbon sequestration rates. Nevertheless, such estimates are useful in formulating strategies for reducing $CO_2$ emissions with the help of $REDD^+$ in global climate negotiations as a mitigation option (Gibbs et al. 2007; Murthy et al. 2012).

Unrestricted utilization of forest area sources, rapid populace increase, and industrial development are manifested in land use adjustments, thereby reducing the volume and area of forests especially in tropical countries like

India. A huge range of plants/forest types occur in India because of substantial climatic and edaphic variations. Therefore, all feasible forest types ranging from alpine to very dry forests are occurring at extraordinary locations. In view of the above variability, comprehensive data on biomass and carbon storage are lacking at local,

regional, and national level as required for millennium ecosystem assessment (MEA 2005) to workout strategies and policies for mitigating atmospheric $CO_2$ through organizing and conserving different forest vegetation's. The present paper aims to evaluate carbon sequestration potential of ***Acacia catechu*** in the Mukundara National Park Rajasthan in relation to quantification methods and biomass estimates. No systematic information is available on research on biomass / carbon of different regions and styles of forests and uniform estimation method of Indian forests at one region. Even though, a number of researches had been finished on biomass/carbon storage estimations in India, they're sporadic and patchy with regards to precise forest atmosphere and technique.

## Background information

***Acacia catechu***

| | |
|---|---|
| **Kingdom-Plantae** | Plante |
| **Subkingdom** | Viridiplantae |
| **Infrakingdom** | Streptophyta |
| **Super division** | Embryophyta |
| **Division** | Tracheophyta |
| **Subdivision** | Spermatophytina |
| **Class** | Magnoliopsida |
| **Superorder** | Rosanae |
| **Order** | Fabales |
| **Family** | Fabaceae |
| **Genus** | Acacia Mill. |
| **Species** | Acacia catechu (L. f.) Willd. – Black cutch |

## Chemical constituents

Main chemical constituents of ***Acacia catechu*** are catechin, (-) epicatechin, epigallocatechin, epicatechin gallate, epigallocatechin gallete rocatechin, phloroglucin, protocatechuic acid, quercetin, poriferasterol glucosides, poriferasterol, acyglucosides, lupenone, lupeol, procyanidin AC, kaempferol, dihydrokaemferol, L - arabinose, D - galactose, D - rhamnose andaldobiuronic acid, afzelchin gum and mineral. Another important constituent is taxifolin. Catechin is biologically highly active. It is used as a haemostatic. Taxifolin has antibacterial, anti-fungal, antiviral, anti-inflammatory, and antioxidant activity. The medicinal properties of ***Acacia catechu*** are due to the antioxidant properties of these constituents.

## Study area

Mukundara National Park is a national park in Rajasthan, India with an area of 759.99 $km^2$ (293.43 sq mi). It was established in 2004 and consists of three wildlife sanctuaries: Darrah Wildlife Sanctuary, National Chambal Sanctuary, and Jawahar Sagar Wildlife Sanctuary. It is located in the Kathiawar - Gir dry deciduous forests.

Mukundara National Park is mountainous and has a variety of plants, trees and animals. It has grasslands in between and also many dry deciduous trees. There are four rivers that flow in this location; the rivers are, Kali River, Ahu River, Ramzan River. Tree species in the forests of Mukundara National Park include ***Acacia nilotica***, ***Anthocephalus***, ***Atrocarpus heterophyllus***, ***Aegle marmelos***, ***Azadirachta indica, Bombax ceiba, Cassia*** *fistula, Citrus aurantifolia, Delonix regia, Dalbergia sissoo, Phyllanthus emblica,* Eucalyptus, Ficus religiosa, Ficus glomerata, Ficus benghalensis.

## Material and results Estimation of plant density

Several species of ***Acacia*** were found in the study site but only the predominant one was included in this study. The population was determined by taking a sample in an area equivalent to 2,500 $m^2$, then extrapolating to a hectare (10,000 $m^2$). The result was a population density of 1,125 culms in 2,500 $m^2$, equivalent to 4,500 culms $ha^{-1}$.

## Estimation of the carbon content

Using a confidence level of 95% and an error of 20%, the initial sample size was calculated to be 25. With the total population in the study region being 1,125, the significant sample size was 24 plants, which was used to estimate the biomass and carbon content. Measurements of the plants' dimensions yielded a range of heights between 24.35feet with an average of 86.71 feet.

The aboveground biomass consists of stems, branches, and foliage, which constitute the 'green material'; its weight is called the 'green mass'. Measurements of the green mass were performed for each of the 24 plants in the sample, weighing each component separately. The total average green mass for a plant was 99.50 kg, consisting of 87.14 kg (88%) in stems, 8.41 kg (8%) in branches, and 3.95 kg (4%) of foliage. The minimum mass per plant was 87.80 kg and the maximum 114.10 kg*These numbers are summarized in Table 1.*

**Table : -1 The average height, average CBH and average age (yrs) relationship in *Acacia catechu* in all four directions**

| | |
|---|---|
| **Average number of tress (in round figure)** | **357** |
| **Average height (feet)** | **24.35** |
| **Average CBH (cms)** | **86.71** |
| **Average age (yrs)** | **23.92** |

After the water content has been removed from the green material, the remainder is called the 'dry material'. If only the green mass of ***Acacia catechu*** is known, the dry mass can be determined using the following mathematical relation developed by Riano & Londono (2002):

**Dry mass = - 1.0007 + 0.467 x green mass**

The 24 samples which had been weighed manually were used to test this relation. To confirm its accuracy, a small sample of these weighed plants was taken to the laboratory to remove the water content by drying the material in an oven at 75°C until a constant weight was obtained, following the method of Castaneda et al. (2004). The summarized results are shown in Table 3.

**Table 2: - Ranges and average values for plant heights, diameters**

| | **Height (feet)** | **Diameter (cm)** | **Total mass (kg)** |
|---|---|---|---|
| **Minimum** | **19** | **15** | **87.8** |
| **Maximum** | **24.3** | **19.3** | **114.1** |
| **Average** | **21.3** | **16.8** | **99.5** |

To obtain the carbon content, the dry mass must be multiplied by a figure between 0.45 and 0.55, with the value depending on the particular plant. In the absence of this specific information, a value of 0.5 is generally used (Brown, 1997), as in this study. Using this estimate and the figure obtained earlier for the plant density, I can estimate the density of carbon stored in aboveground biomass by ***Acacia catechu.*** The final value of 100.0 t ha $^{-1}$ is close to the value obtained by Castaneda et al. (2004).

| **Table 3: - Measurements of aboveground dry mass and carbon density, obtained via three different methods (see text for details).** | **Riano & Londono (2002), formula** | **Average** |
|---|---|---|
| **Average above-ground dry mass per plant (kg)** | **44.33** | **44.43** |
| **Above-ground dry mass density (tons ha-1)** | **200.5** | **200** |
| **Above-ground carbon density (tons ha-1)** | **100.3** | **100** |

Castaneda et al. (2004) also took into account the ages of the plants, estimating the average carbon capture rate to be 25.92 t $ha^{-1}$ $year^{-1}$. However, they found that the annual contribution to carbon capture was not uniform – younger plants absorb more carbon than older plants. In the current work, it was not possible to include the effect of age since the study was conducted in a natural forest with no previous studies undertaken; therefore there is no way to determine the age of the plants. As a result, the data contained here cannot provide any information about the age - dependence of a plant's carbon sequestration ability. However, implementing the relation proposed by Castaneda et al. (2004), Mukundara National Park Rajasthan, study area have a carbon-fixing potential of approximately 27.53 t $ha^{-1}$ $yr^{-1}$.

I stress that this is a number purely for reference and that further studies would be needed to confirm its accuracy. The amount of carbon expelled by each plant through respiration should also be accounted for; the amount of carbon stored by plants exceeds the amount released during respiration and rotting (Schlesinger, 1997) but approximately one third of the carbon which is absorbed during photosynthesis is released through respiration, with the amount dependent on climatic conditions, soil moisture, and other factors (Schneider & Childers, 1941).

## Allometric equations for component and total biomass

Assuming a power-law relation between the dry mass of each component i (stems, branches, foliage), $\mathbf{M_i}$, and the diameter, d, of the plant, which I choose to measure at a reference point of 1.3 m above the ground, I have: $\mathbf{M_i = \alpha_i d^{\beta i}}$ , where $\boldsymbol{\alpha_i}$ and $\boldsymbol{\beta_i}$ are parameters to be determined for each component. Linearizing the equation by taking logarithms, I obtain:

$$\ln M_i = \ln \alpha_i + \beta_i \ln d.$$

As suggested by Baskerville (1972), an adjustment should be included to eliminate the bias associated with the logarithmic transformation of the model

$$M_i = \exp(\alpha_i + \beta_i \ln d - \sigma_i / 2) \text{ (Wiant \& Harner, 1979)}$$

where $\mathbf{M_i}$ is the dry mass of the $i^{th}$ component (stems, branches, foliage) and $\boldsymbol{\sigma_i}$ is the mean square error for that component. The regression analysis was performed using Grahpad prism - 6 for the dry masses obtained for each of the components by the three different measurement methods. The values obtained for each of the three methods are shown in detail in Table 4. $\boldsymbol{\sigma_i}$ is the same for all measurement methods.

It can be seen that the laboratory measurements produce very similar results; the analytic method from Riano & Londono (2002) shows a larger discrepancy. The values obtained for the scaling parameter, α, are more spread than the values obtained for the exponent β. The $R^2$ value for the stems is very large (0.95), showing an almost perfect, near-linear relation ($\beta \approx 0.94$) between the mass of the stems and the plant diameter. The correlation between the mass of the branches and the plant diameter is also very strong ($R^2 = 0.87$) and nearly linear ($\beta \approx 1.01$). For the foliage, the value of α is considerably smaller than for the other components since foliage constitutes only around 4% of the total plant mass (see previous section); this may be a region in which the equation from Riano & Londono does not hold. The laboratory measurements find a value of β which is close to 2, but the analytic method shows a large discrepancy. However, the $\mathbf{R^2}$ value for all experiments exceeds 0.7.

**Table 4:- Fit parameters and R2 values for the allometric equations relating the dry mass of each of the $i^{th}$ components (stems, branches, foliage) obtained by three different measurement methods, with the plant diameter: $M_i = \alpha_i d^{\beta i}$.**

| | $\alpha_i$ | $\beta_i$ | $\sigma_i$ | $R^2$ |
|---|---|---|---|---|
| **Stems** | **2.6896** | **0.961** | **0.0478** | **0.9524** |
| **Branches** | **0.051** | **1.443** | **0.1214** | **0.8762** |
| **Foliage** | **9.46 x 10-6** | **4.027** | **0.3665** | **0.7153** |
| **Total** | **2.2311** | **1.059** | **0.0508** | **0.948** |

## Summary and conclusions

In this study I have measured the aboveground biomass contained in an unmanaged and previously unstudied ***Acacia catechu*** in the Mukundara National Park Rajasthan. I have found that the plant density of this forest is 4,500 culms $ha^{-1}$ and contains around 200 t of aboveground biomass $ha^{-1}$, leading to an estimated aboveground carbon sequestration density of 100 t ha-$^{1}$. I have also fitted equations relating the mass of each component (stems, branches, foliage) to the plant's diameter, finding that a power-law relation of the form $\mathbf{M_i = \alpha_i d^{\beta i}}$, where $\mathbf{M_i}$ is the mass of each component and d is the diameter of the plant, fits all the components very well ($R^2 > 0.7$), particularly for the stems ($R^2 > 0.8$) and branches ($R^2 > 0.9$) for which the relation is found to be almost linear.

The relatively large amount of carbon stored by ***Acacia catechu*** means that it has the potential to contribute as significantly to carbon sequestration as some other species of trees. This will be the case if plantations are set up and carefully managed and the mature culms are harvested and turned into durable products that will store carbon for several decades; the flexibility and durability of ***Acacia*** make it an ideal building material for several structures, as well as being suitable for a wide range of furniture and decorative products. If this path is followed, care must be taken to ensure that the plantations are appropriately situated, taking into account the growing requirements of the species; that the plantations are properly managed; and to take into account potential undesirable effects on the environment such as species invasiveness. Once these factors have been properly considered, the large biomass density and fast growth rate of ***Acacia catechu*** make it an ideal species for commercially viable carbon sequestration that can help to mitigate climate change.

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