REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No. 1S (2024)
http://www.veterinaria.org
Article Received: November 2023, Revised: December 2023, Accepted: January 2024

Assessment of Carbon Stock and sequestration potential by Mango Orchards in Maharashtra, India: A systematic review

Deepak S. Patil[1*], Dr. Vitthal K. Kauthale[2], and Sadashiv D. Nimbalkar[3]

[1*,2, 3] BAIF Development Research Foundation, Central Research Station, Urulikanchan, Tq. Haveli, Dist Pune 412 202 Maharashtra, India, Email: Deeppatil860@Gmail.Com

Abstract
Carbon sequestration by green plants is a suitable way to reduce atmospheric CO_2. The review reviewed and measured the aboveground and belowground carbon sequestration potential of *Mangifera indica* from different locations in Maharashtra. The total standing aboveground biomass and belowground biomass of *Mangifera indica* are 82.83 tha^{-1} and 21.54 tha^{-1} respectively, while the total standing biomass of *Mangifera indica* in 2847 hectares of Aurangabad is 104.41 tha^{-1}. The sequestered carbon stock in aboveground and belowground standing biomass of *Mangifera indica* are 44.73 tha^{-1} and 11.63 tha^{-1} respectively while the total sequestered carbon of *Mangifera indica* in 2847 hectares area is 56.36 tha^{-1}. The newly developed allometric equations for *Mangifera indica* on the diameter class basis for AGB as a function for DBH and height have shown high correlations.
A large body of literature on Mango orchards in Maharashtra still lacks a systematic understanding of its contribution to carbon sequestration. A systematic review was used to provide a quantitative and qualitative synthesis of available evidence and knowledge gap from 25 publications that met the selection criteria regarding the contribution of the Mango orchard's carbon sequestration (n = 43) in Maharashtra. Mango orchards in Maharashtra stock an average of 24.2 ± 2.8 Mg C ha^{-1} in biomass and 98.8 ± 12.2 Mg C ha^{-1} in the soil. Empirical studies are needed to understand the above better and belowground carbon stock in Mango orchards. Fewer studies reported the carbon stock and sequestration potential by *Mangifera indica*. The results show that *Mangifera indica* is a powerful climate adaptation and mitigation solution as it can increase resilience and sequester significant amounts of carbon dioxide from the atmosphere.

Keywords: Aboveground carbon, Allometric equation, belowground carbon, CDM, carbon sequestration potential, climate change, carbon stock, Total Biomass.

Introduction:
Mango is the major fruit crop grown throughout India in areas having a distinct dry and wet season. Being an evergreen and deep-rooted (1.0 m and deeper) tree, it has adapted to fix carbon under large seasonal variations of light and water. Two types of mango population occur in India, the wild polyembryonic mangoes and the cultivated grafted mangoes. Estimates of the population and area occupied by wild polyembryonic mangoes are not available but surely is a sizable area as India is the origin of mangoes. Cultivated mango occupies an area of nearly 2,263,000 ha (Statistics Agriculture 2018) and has great potential for carbon sequestration.

The area is further expected to increase given the importance given to the horticulture sector in government policies in recent years. This communication reports estimates of carbon sequestration in the Konkan region, one of the major mango belts of India. Konkan, also known as the Konkan coast, is a part of the Western Ghats having rough terrain. It is a 720 km long coastline in three of the western Indian states, viz. Karnataka, Goa and Maharashtra. Konkan includes the following districts in the three states: Maharashtra – Sindhudurg, Ratnagiri, Raigad, Mumbai, and Thane; Goa – South and North Goa and Karnataka – Dakshina Kannada, Uttara Kannada and Udupi. The cities of Mumbai and Mangalore form the two end-points of the Konkan coast.

Deforestation in the Konkan region has rendered hillslopes barren and hard rock surfaces remain exposed to heavy rainfall. These lateritic barren surfaces in the Konkan region have become degraded lands and do not fulfil their life-sustaining potential. This has resulted from inherent and imposed disabilities such as location, environment, chemical and physical properties of the soil, and financial or management constraints. (Salunkhe *et al*. 2021)
It has shown how an entirely harsh-terrain wasteland can be converted into an environmentally, economically, and socially accepted sustainable, productive system. The area under mango in the Konkan region is 106,210 ha (Table 1), of which 1 lakh/hectare area is under Konkan, Maharashtra districts which produce 50,000 MT with an average production of 3.12 t/ha.

Global emission of carbon dioxide has increased by 18% and is damaging the environment by reaching to the highest level after 1750. Its level increased per year by 1.5ppb in the years 1990-2000, by 2 ppb in 2001-2009, and by 2.3ppb in 2009-2010 which is the highest in recent decades. It is contributing to global warming and climate change as discussed in the Earth Summit held in 1992 at Rio De-Janerio, the Kyoto Protocol signed in 1997 in Japan, the Copenhagen conference in 2009 held at Denmark, the Kankun conference in 2010 held in Mexico, and Darban conference held in 2011 in South Africa (D.M., 2011). Many efforts are being made to reduce atmospheric carbon dioxide. The Kyoto Protocol, prepared by the United Nations in the Framework of Convention on Climate Change stipulates Clean Development Mechanisms (CDM) and its Joint Implementation whereby storage of carbon in various terrestrial sinks may be acceptable for insertion in national

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No. 1S (2024)
http://www.veterinaria.org
Article Received: November 2023, Revised: December 2023, Accepted: January 2024

greenhouse gas inventories of each nation. Reducing greenhouse gas emissions including carbon dioxide can be achieved by controlling emissions and avoiding unadvisable land use changes. Carbon sequestration in growing forests is known to be a

Cost-effective option for the mitigation of global warming and global climatic change. Sequestration can be defined as the net removal of carbon dioxide from the atmosphere into long-lived carbon pools. Estimates of carbon stocks and stock changes in tree biomass (above and belowground) are necessary for reporting to the United Nations Framework Convention on Climate Change (UNFCCC) and will be required for Kyoto Protocol reporting (Green *et al.* 2007).

The increasing carbon emission is of major concern for the entire world as well addressed in Kyoto protocol (Chavan, and Rasal, 2010). In recent years, global climate change mitigation has received much more attention from scientists, resource managers, and policymakers. The Intergovernmental Panel on Climate Change (IPCC), to face climate change challenges, has promoted strategies for climate change mitigation and adaptation (IPCC, 2014). Forests have the potential to reduce carbon from the atmosphere and thus mitigate climate change (Jackson and Baker 2010), Considering the carbon sequestration potential of forests, the forestry community perceived the importance of promoting different forestry practices that can provide climate change mitigation benefits (UNFCCC, 2007).

Experimental Method:
The carbon content of some selective tree species is calculated by different methods based on field survey methods, laboratory analysis, and Mathematical models. The methods used for biomass estimation are in situ and non-destructive except for laboratory analysis.

A. Study Area:
Maharashtra is located at latitude 19° 39' 47.8080" N and longitude 75° 18' 1.0548" E. Maharashtra, the third largest state with a geographical area of 3,07,713 square kilometers has a total recorded forest area of 61,952 square kilometers. This includes 50,865 sq. km of Reserved Forest, 6,433 sq. km of Protected Forest, and 4,654 sq. km of unclassed forest area. Unclassed Forest includes all forests other than Reserve Forest and Protected Forests as reported by State/UTs Forest Departments. (Ministry of Environment, Forest and Climate Change, 2022).
Mango (*Mangifera indica*) is regarded as the "king of fruits" and is the leading fruit crop of India. Mango occupies about 36% of the total area under fruits (2019-20) comprising 2.3 million hectares, with a total production of 20.44 million tons, contributing 40.50% of the total world production of mango (National Horticultural Board, 2022)
(https://www.mapsofindia.com/lat_long/maharashtra/)

Carbon sequestration potential measurements
a) Diameter over bark (D): Above and below-ground biomass of trees was estimated using non-destructive methods. Grafted mango varieties tend to form more than one trunk or main branch and there is no possibility to measure diameter at breast height (DBH). In such cases, the diameter over the bark (D) of such trees was computed by taking the square root of the sum of all squared stem diameters of primary and secondary branches (Nimbalkar *et al*., 2017).
$D = \sqrt{(a)^2 + (b)^2 + (c)^2 + (d)^2}$

Where,
a, b, c, d are the diameters of individual branches.

b) **Tree volume over the bark (VOB):** This was estimated by using the regression equation for multi-branched trees as suggested by Bohre et al., 2013.
$VOB = -0.017 + 0.003\,D + 0.0014H + 1.899 \times 10^{-5}\,D^2H$
(Coefficient of Determination R^2=0.986; Standard Error (SE) = 0.00497)
VOB = tree volume over the bark in m^3;
D = diameter of the tree in cm;
H = height of the tree in meters;

c) Above-ground biomass (AGB): Above-ground biomass (AGB) was calculated by multiplying wood volume, wood density, and biomass expansion factor (BEF)
AGB = VOB x WD x BEF x 1000
Where,
AGB = Above Ground Biomass;
VOB = Volume of the tree over bark;
WD = Wood density g cm^{-3}; Wood density of the mango was taken as 0.68 from the online database (https://www.wood-database.com/mango/)
BEF = Biomass expansion factor that includes leaves, twigs, and branches. Biomass expansion factor varies with stand age i.e. at 3 years old it was 0.93 and gradually increased to 1.63 at the age of 8 years followed by a gradual decline towards 1.12 at the age of 20 years (Ganeshamurthy *et al*., 2016).

d) Below-ground biomass (BGB): The below-ground biomass (BGB) has been calculated by multiplying above-ground biomass taking 0.26 as the root-to-shoot ratio (Ganeshamurthy *et al*., 2020).
BGB = AGB X 0.26

e) Total Biomass: Total Biomass was determined by adding the above and below-ground biomass of the respective tree.
Total Biomass =AGB + BGB

f) Total carbon content: Based on published values, the carbon content is approximately 50% of the total biomass based on dry weight (Paladinic *et al*., 2009).
Total carbon = Total biomass X 0.50

g) Carbon sequestration potential: The total carbon sequestration potential of trees was expressed in terms of equivalent CO2 tree-1 by multiplying with a factor of 3.67 (Molecular weight of CO2 to molecular weight of Carbon ratio).
Carbon sequestration potential (CO2e tree^{-1}) = Total carbon X 3.67

B. Measurement of tree height:
To estimate biomass from selective tree species it is not advisable to cut them. The biomass can be measured by mathematical models by measuring the Diameter at Breast Height (DBH) directly and the girth at DBH. Girth considered is the DBH measured at breast height at approximately 1.3 meters and the diameter of trees having a diameter above >10 cm are treated as trees and are measured. The tree height was measured by Theodolite at DBH. The angle between the tree top and eye view at breast height angle (α) is taken into consideration for tree height measurement and the height of the tree is calculated.

C. Soil sampling and laboratory analysis
Soil samples were collected at 0–15 cm depth from each site using a core sampler from January to May of the year 2023-24. Five sets of samples were collected from each study site and are mixed to form a composite soil sample, these composite samples were brought to the laboratory for further analysis. Before analysis, soil samples were sieved through a 2 mm mesh and then mixed thoroughly. Walkley and Black's method (Walkley, 1947) was used to estimate SOC. In this method, as only about 60–86% of SOC is oxidized, a standard correction factor of 1.32 was used to obtain the corrected SOC values (De Vos *et. al.,* 2007)

D. Estimation of Ground Biomass Using Regression Equations
Regression equations were used to estimate the above-ground biomass from Mango orchards. Depending upon the diameter at breast height and considering climatic conditions, regression equations developed by (FAO, 1997) were used to estimate above-ground biomass including stem, stump, branches, bark, seed, and foliage of individual Mango orchards in kg. The climatic zone of Ratnagiri district is humid. A humid region equation was applied. The regression equation used for the estimation of above-ground biomass is as follows,
Y = 42.69 - 12.800 × D +1.242 × D2
Where Y denotes above-ground biomass in kg, D denotes diameter at breast height in cm
Below ground Biomass Estimation
The below-ground biomass was determined by multiplying above-ground biomass by 0.26, where 0.26 is the root-to-shoot ratio (Ravindranath and Ostwald, 2008).

Total Biomass Estimation
The sum of above and below-ground biomass is the total biomass of Mango orchards.

TBM=AGB+BGB
Carbon Stock Estimation of Mango Orchards
Carbon was assumed to be 50% of the biomass of any plant species (Vieilledent et al. 2012) As a result, the coefficient value of 0.5 for biomass-to-carbon conversion was used (Ravindranath et al. 1997).
Biomass to carbon stock = 0.5 x total biomass of Mango orchards

Amount of CO_2 Sequestered by Mango Orchards
To calculate CO_2 assimilation by vegetation, estimated carbon stocks would be transformed into CO_2 equivalents (biomass value × 3.667) (Guleria *et al.* 2014). The amount of CO_2 sequestered by each selected village was calculated from the carbon stock values of Mango orchards.

Results:
Estimation of Above-Ground Biomass of Mango Orchards
The potential of the Mango orchard to sequester carbon depends on the age and diameter of the Mango orchard. Values of above-ground biomass in the Ratnagiri district ranged from 8.64 to 318.07 t/ha with an average of 148.22 t/ha (standard error of 8.08) (Salunkhe et al. 2021)

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No. 1S (2024)
http://www.veterinaria.org
Article Received: November 2023, Revised: December 2023, Accepted: January 2024

Estimation of below Ground Biomass of Mango Orchard
Values of below-ground biomass in the Ratnagiri district ranged from 2.25 to 82.70 t/ha with an average of 38.54 t/ha (standard error of 2.10). Below-ground biomass accumulated in each tree was 20 % of the total biomass of the tree. A similar percentage of below-ground biomass i.e. 19 % was found in moist central African forests (Ekoungoulou *et al*. 2014).

Total Biomass of Mango Orchard
Total biomass is the sum of the above and below-ground biomass of Mango. Total biomass values of Mango ranged from 10.89 to 400.77 t/ha in the Ratnagiri district. The diameter increases the value of biomass also increases. Thus, it shows that the total biomass increased with increasing diameter and ages of mango plants (Naik *et al*. 2019). A similar study shows that above-ground biomass in mango crops was 263.30 t/ha and below-ground biomass was 79.23 tha^{-1} (Kumar *et. al*. 2017).

Carbon Stock and CO_2 Sequestration of Mango Orchard
Carbon stock values for Mango orchards in the Ratnagiri district ranged from 10.89 to 200.38 t C/ha with an average carbon stock of 95.89 t C/ha (standard error of 4.92) (Table 3 and Fig. 5). Amount of CO2 sequestrated map was shown in Fig. 6. From Table 3, it is seen that carbon stock values were also increased with increase in diameter of the tree. The amount of CO2 sequestered were ranging from 19.99 to 734.81 t CO_2/ ha or with an average rate of 351.62 t CO_2/ha (standard error of 18.06). Carbon stock rate ranges from 46.21 t Cha^{-1} to 93.47 t Cha^{-1} with an average rate of 73.58 t C/ha from mango orchards in India (Ganeshamurthy *et al.* 2019).

The soil moisture (SM) percent in different land uses of Puthupet ranged from 2.45 (*Casuarina* plantation) to 8.93 (coconut plantation) up to 30 cm soil depth (Figure 1). The soil moisture percentage significantly ($P< 0.001$) varied among the study sites. Coconut plantations showed significantly ($P< 0.05$) higher soil moisture (8.93%) than the other study sites. On the other hand, the soil pH across these different land uses ranged from 5.33 (cashew nut plantation) to 7.3 (coconut plantation) up to 30 cm soil depth (Figure 1). The pH was also significantly ($P< 0.001$) greater in coconut plantations when compared with natural forest, cashew nut, *Casuarina*, and mango plantations. The soil bulk density (BD) in these different land uses ranged from 1.19 (forest) to 1.64 (wasteland) up to a depth of 30 cm. The soil bulk density was found to increase significantly ($P< 0.05$) with an increase in soil depth in all the sites except the natural forest. Wasteland and mango plantations also showed significantly ($P< 0.05$) greater bulk density than the other study sites. The soil organic matter SOM (%) in the present study ranged from 3.25 (mango plantation) to 7.12 (forest) in 0–30 cm soil depth (Figure 3). The stock of SOM (%) significantly ($P< 0.001$) decreased with an increase in soil depth in all the sites except the cashew nut plantation. (Sundarapandian *et al*. 2015).

Discussion:
The most dreaded problem of the new millennium caused by the impact of human activity is global warming. Anthropogenic activities like enhanced fossil-fuel consumption coupled with deforestation are causing serious public and political concerns about greenhouse gas (GHG) emissions and their consequences on loss of biodiversity and climate change. (Houghton 2003) (Achard *et al.* 2002). An option for augmenting the emission of GHGs is to enhance the carbon stored in perennial trees through sequestration.
Forests sink about 40% of the global carbon on land, however, perennial orchards, plantations, and agro-forestry are other alternatives for the trapping of carbon. It is considered that in the Indian context forests, agroforestry, and perennial horticultural crops trap a significant amount of carbon emitted through fossil-fuel combustion. The dynamics of this forest carbon has a significant influence on the global carbon budget. Estimates based on global or regional soil carbon densities of various forests show that Indian forests sequester about 5.3–6.7 Pg C (Dadhwal *et al*. 2012).

In the present scenario, the forest area is declining while perennial fruit orchards and plantation areas are on the increase. Generally, during the initial stage of establishment, both orchards and forests sequester similar amounts of carbon. Comparing orchards with forests is not justified as the former has a management component completely anthropogenic, while management of the latter in Asian countries is more towards silviculture and not input-backed management. Nevertheless, orchards do have the potential similar to forests but on a lower scale because of indirect C emissions associated with orchard management practices. An estimate of the carbon sequestration potential of fruit orchards in India is therefore essential for any strategic planning, offsetting GHG emissions, and for trading carbon.

Cultivated mango covers roughly 2.3 million hectares with a production of 20.82 million tons. Forest Survey of India 2019 report estimated that mango tree ranks first in tree outside forest (TOF) with a growing stock of 207.24 million cubic meter and consists of about 77.03 million tons of carbon in India. Similarly, an extensive study to map out the carbon sequestration potential of mango on country level have done by Ganeshamurthy *et al.* (2019). At the country level, mango orchards had sequestrated 285.005 million tons of carbon in woody vegetation & soils.

The study on biomass distribution and development of allometric equations for non-destructive estimation of carbon sequestration in grafted mango was carried out by Ganeshamurthy *et al.* (2016). The percent contribution of dry matter accumulation in various components of mango was 49.82 % in the bole and primary branch, 17.02 % in the secondary branch, 10.62 % in foliage, and 22.54 % in roots. The dry biomass of harvested mango trees varies from 22.47 kg $tree^{-1}$ in 3 years

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 25, No. 1S (2024)
http://www.veterinaria.org
Article Received: November 2023, Revised: December 2023, Accepted: January 2024

old to 1155.84 kg tree-1 in 85 years old. The variation in biomass and carbon stock was due to grafting, planting density and differences in site conditions like micro climate, soil, and management, etc.

Another study of Ganeshamurthy *et al.* (2019) estimated about 9.913 million tons of carbon stored in mango orchards grown over 1.06 lakh ha area in Konkan. Naik *et al*. (2019) conducted a study on mango orchards to estimate biomass and carbon stock from an age series of 2-10 years. The total biomass varied from 0.53 to 10.5 Mg ha-1 with a mean annual increment of 0.26-1.05 Mg ha^{-1} in 2–10-year-old mango orchards. The highest carbon mitigation potential of 10-year-old mango orchard was 3.0 Mg ha-1 with a corresponding carbon dioxide mitigation of 11.04 Mg ha-1 in hot and sub-humid climates. Rathore *et al.* (2021) studied biomass and carbon stocks estimation in mango-based land uses on degraded lands in Indian Sub-Himalayas. The dry biomass ranged from 1.4 to 97.7 Mg ha-1 in mango alone, 4.9-2.6 Mg ha^{-1} crops alone and 1.4-100.3 Mg ha^{-1} in mango with intercrops. The stored carbon, emitted carbon, mitigated carbon and total carbon ranged 0.7-39.7, 0.00-8.5, 0.70-31.2 and 0.70-48.20 Mg ha-1, respectively in mango and mango-based land use in humid climate. Finally, they concluded that intercropping with trees gives higher carbon storage over sole cropping of tree and crops.

Table 1. Area, production and productivity of mangoes in the Konkan region, India

Konkan districts	**State/Union Territory**	**Area (ha)**	**Production (thousand mt)**	**Productivity (t ha^{-1})**
Thane, Mumbai, Raigad, Ratnagiri, Sindhudurg	Maharashtra	100,000	50	3.12
North Goa, South Goa	Goa	4770	9.04	4.42
Uttara Kannada, Udupi, Dakshina Kannada	Karnataka	1440	5.76	4.10

Table 2: Carbon sequestered in mango orchards of India (tonnes)

State/UT	**Area (000 ha)**	**Total carbon sequestered in 1 ha orchard (t ha^{-1})**	**Total carbon sequestered in the region (mt)**
Bihar	150.64	133.385	20.09312
Chhattisgarh	73.99	143.615	10.62607
Haryana	9.42	138.503	1.304698
Himachal Pradesh	41.52	131.182	5.446677
Jammu and Kashmir	12.67	131.342	1.664103
Jharkhand	52.24	137.336	7.174433
Madhya Pradesh	40.08	135.346	5.424668
Punjab	6.85	141.242	0.967508
Rajasthan	5	118.51	0.59255
Uttarakhand	35.93	136.216	4.894241
Uttar Pradesh	264.93	134.292	35.57798
Andhra Pradesh	332.97	137.203	45.68448
Karnataka	192.61	153.539	29.57315
Kerala	69.11	122.456	8.462934
Tamil Nadu	160.94	104.404	16.80278
Telangana	180.62	134.524	24.29772
Goa	4.770	99.057	0.472502
Gujarat	153.18	91.197	13.96956
Maharashtra	157.07	104.474	16.40973
Andaman and Nicobar & LD	0.05	177.489	0.008874
Assam	5.58	116.419	0.649618
Arunachal Pradesh	0.05	177.652	0.008883
Mizoram	0.89	116.792	0.103945
Nagaland	0.64	157.572	0.100846
Odisha	199.3	105.71	21.068
West Bengal	97.93	119.187	11.67198
Tripura	11.64	114.222	1.329544
Others	6.98	89.417	0.624131
Total	2262.77	3602.283	285.005

Source: Ganeshamurthy *et.al.* 2019

Table 3. Soil C in mango orchards in India

State/UT	Soil carbon (tonne/ha)	Area (000 ha)	Total soil carbon stock (1000 tonnes)
Bihar	39.55	150.64	5957.812
Chhattisgarh	49.67	73.99	3675.083
Haryana	46.05	09.42	433.791
Himachal Pradesh	55.09	41.52	2287.337
Jammu and Kashmir	55.24	12.67	699.891
Jharkhand	43.29	52.24	2261.470
Madhya Pradesh	41.17	40.08	1650.094
Punjab	48.84	06.85	334.554
Rajasthan	26.21	05.00	131.050
Uttarakhand	59.91	35.93	2152.566
Uttar Pradesh	41.45	264.93	10981.350
Andhra Pradesh	42.09	332.97	14014.710
Karnataka	77.14	192.61	14857.940
Kerala	75.77	69.11	5236.465
Tamil Nadu	41.64	160.94	6701.542
Telangana	39.49	180.62	7132.684
Goa	52.42	4.77	250.0434
Gujarat	44.04	153.18	6746.047
Maharashtra	57.23	157.07	8989.116
Andaman and Nicobar & LD	101.12	0.05	5.056
Assam	39.98	5.58	223.088
Arunachal Pradesh	101.12	0.05	5.056
Mizoram	40.26	0.89	35.831
Nagaland	81.04	0.64	51.866
Odisha	46.50	199.3	9267.450
West Bengal	59.88	97.93	5864.048
Tripura	54.80	11.64	637.872
Others	42.00	6.98	293.160
Mean	53.67821	80.98571	3959.892

Total soil carbon stock from mango orchards in India = 110.877 mt.

Soil Organic Carbon (SOC)

Soil organic content is an important parameter of the soil and is significantly responsible for the fertility and productivity of the soil (Bandopadhayay *et al.,* 2008). Soil organic matter retains the largest terrestrial reservoir of carbon (about 1550 Pg) in the global carbon cycle. Soils store about 2.5 to 3.0 times more carbon than plant parts (Post *et al.,* 1990). As per the estimates of Lal R. (2004), India's total SOC pool is 21 Pg at 30 cm depth and 63 Pg at 150 cm depth, which is about 2-2.5 % of the world soil pool at 1 to 1 m depth. Soil carbon storage in agricultural systems receives significant importance under climate change mitigation strategies.

Gupta and Sharma (2013) estimated SOC pool under different orchards in 13 districts of Uttarakhand. They reported a maximum SOC of 80.81 Mg ha-1 in apple followed by 50.70 Mg ha-1 in Mango, 47.55 Mg ha-1, 44.93 Mg ha-1 in Litchi and lowest in Guava (40.21 Mg ha-1). The dynamic of carbon stock in soil of fruit orchard found significant enhancement over control in eastern plateau and hills regions of India (Naik *et al.,* 2021). They reported the maximum total soil organic carbon in the active stage was 36.2 Mg C ha-1 in Mango than guava (34.57 Mg ha-1) and litchi (33.97 Mg ha-1). Among Mango, Sapota, Coconut, and Teak, the organic content of soil at 0-20 cm was higher in Teak plantations (0.69-1.11%) followed by Mango (0.64-0.85%), Sapota (0.36-1.07%), and coconut (0.57-0.81%) in all the age of plantations viz. 5 to 20 years. At different depths of soil, the surface soil (0-20cm) recorded high soil organic content percentage than the sub-surface soil in all orchards and agroforests (Selvaraj *et al,* 2016). A study by Salunkhe et al. (2021) reported that soils of mango orchards of Ratnagiri district of the Maharashtra state have high organic content with an average value of 1.74% at 0-15 cm and 1.64 cm at 15-30cm soil depth.

Conclusion

The average carbon stock rate was found as 95.89 t C/ha from Mango orchards of the Ratnagiri district. It shows that carbon stock values were increased with an increase in the diameter of the tree. The mango crop area is about 60,105 ha in Ratnagiri district. Thus, the total carbon stock and amount of CO_2 sequestered in Mango orchards from the Ratnagiri district were found to be 5.76 M tonnes and 21.13 M tonnes respectively. Thus, it is also found that horticultural crops have great potential to improve carbon sequestration. (Salunkhe *et al.* 2021)

Mango orchards rose by the small and marginal farmers with the integration of horticultural crops area expansion or rural employment guarantee schemes are less recognized for their carbon sequestration potential. Irrespective of the eco-geographical region of the varieties, crown spread, and light penetration to the ground level varied which can be attributed to the normal cultivar growth habit. At the age of 10 years, grafted mango varieties had mean carbon sequestration potential ranging between 1.072 to 3.493 e-CO_2 metric ton tree^{-1}. This study demonstrated that mango-based tree farming benefits the smallholder's livelihoods as well as mitigating climate change. (Murali V *et. al,* 2022)

Acknowledgement

The authors are thankful to the Research Coordination Committee (RCC), BAIF Development Research Foundation, Pune, for providing technical and financial support to publish this review article and thankful to the scientists at BAIF Central Research Station, Urulikanchan, Ta. Haveli, Dist. Pune 412 202 M.S. (India) for cooperation and guidance.

References

1. Achard, Frédéric et al. 2002. "Determination of Deforestation Rates of the World's Humid Tropical Forests." Science 297(5583): 999–1002.
2. Bandopadhayay BK, Burman D, Pal D. (2008) Management of soil fertility for sustaining crop productivity in coastal agro ecosystem in India. J Indian Soc. Coastal agric. Res;26(2):102-110.
3. Bohre P, Chaubey OP, Singhal PK. Biomass accumulation and carbon sequestration in Linn and Gmelina arborea Roxb. International Journal of Bio-Science and Bio-Technology. 2013;5(3):153-174.
4. Murali V, Gowthami P, and Prashanth A Kumar. 2022. "Carbon Sequestration Potential of Different Mango Cultivars in the Tropical Hot and Semi-Arid Climate of Deccan Plateau, India." ~ 441 ~ The Pharma Innovation Journal 11(11): 441–45. www.thepharmajournal.com.
5. Chavan, B., Ganesh R. 2012. "Total Sequestered Carbon Stock of Mangifera Indica." Environment and Earth Science 2(1): 37–49.
6. Dadhwal, V. K. et al. 2012. "Recent Results From Eo Studies on Indian Carbon Cycle Assessment." The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XXXVIII-8/(February 2014): 3–9.
7. Ganeshamurthy AN, Ravindra V, Venugopalan R, Mathiazhagan M, Bhat RM. Biomass distribution and development of allometric equations for non-destructive estimation of carbon sequestration in grafted mango trees. Journal of Agricultural Science. 2016; 8(8):201.
8. Ganeshamurthy, A. N., V. Ravindra, and T. R. Rupa. 2019. "Carbon Sequestration Potential of Mango Orchards in India." Current Science 117(12): 2006.
9. Ganeshamurthy AN, Kalaivanan D, Rajendiran S. Carbon sequestration potential of perennial horticultural crops in

Indian tropics. In Carbon Management in Tropical and Sub-Tropical Terrestrial Systems. Springer, Singapore; c2020. p. 333-348.
10. Gupta, M.K. and Sharma, S.D., (2013). Status of sequestered organic carbon in the soils under different orchards in Uttarakhand State. *Indian Horticulture Journal*, *3*(1&2), pp.6-9.
11. Houghton, R. A. 2003. "Revised Estimates of the Annual Net Flux of Carbon to the Atmosphere from Changes in Land Use and Land Management 1850–2000." Tellus B: Chemical and Physical Meteorology 55(2): 378.
12. Jackson, Robert B., and Justin S. Baker. 2010. "Opportunities and Constraints for Forest Climate Mitigation." BioScience 60(9): 698–707.
13. Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. Science, 304, 1623-1627.
14. National Horticultural Board. National horticulture board. Department of agriculture and cooperation; c2022.
15. Naik, S. K., Sarkar, P. K., Das, B., Singh, A. K., & Bhatt, B. P. (2021). Biomass production and carbon stock in Psidium guajava orchards under hot and sub-humid climate. *CURRENT SCIENCE*, *120*(10), 1627.
16. Nimbalkar SD, Patil DS, Sharma JP, Daniel JN. Quantitative estimation of carbon stock and carbon sequestration in smallholder agroforestry farms of mango and Indian gooseberry in Rajasthan, India. Environment Conservation Journal. 2017;18(1&2):103-107.
17. Paladinić E, Vuletić D, Martinić I, Marjanović H, Indir K, Benko M, Novotny V. Forest biomass and sequestered carbon estimation according to main tree components on the forest stand scale. Periodicum Biologorum, 2009;111(4):459-466.
18. Post, W. M., Peng, T. H., Emanuel, W. R., King, A. W., Dale, V. H., & DeAngelis, D. L. (1990). The global carbon cycle. American scientist, 78(4), 310-326.
19. Rathore, A. C., Mehta, H., Islam, S., Saroj, P. L., Sharma, N. K., Jayaprakash, J., & Raizada, A. (2021). Biomass, carbon stocks estimation and predictive modeling in mango based land uses on degrade d lands in Indian Sub-Himalayas. Agroforestry Systems, 95(8), 1563-1575.
20. Ravindranath, N. AU - Ostwald, Madelene PY - 2008/01/01 SP - SN - 978-1-4020-6546-0 T1 - Carbon Inventory Methods Handbook for Greenhouse Gas Inventory, Carbon Mitigation and Roundwood Production Projects VL - DO - 10.1007/978-1-4020-6547-7
21. ER - Salunkhe, S. S. et al. 2021. "Assessment of Biomass and Carbon Stocks in Mango (Mangifera Indica L.) Orchards of Ratnagiri District of Maharashtra State, India." International Journal of Environment and Climate Change (March 2022): 487–94.
22. Selvaraj, A., Jayachandran, S., Thirunavukkarasu, D. P., Jayaraman, A., & Karuppan, P. (2016). Carbon sequestration potential, physicochemical and microbiological properties of selected trees Mangifera indica L., Manilkara zapota L., Cocos nucifera L. and Tectona grandis L. *Cocosnucifera L*, 131-139.
23. Statistics, Agriculture. 2018. "Educational Statistics at a Glance 2018." Educational Statistics at a Glance: 1–127. https://www.mhrd.gov.in/sites/upload_files/mhrd/files/statistics-new/ESAG-2018.pdf.
24. Sundarapandian, Sm et al. 2015. "Soil Organic Carbon Stocks in Different Land Uses at Puthupet , Tamil Nadu , India." Journal of Ecology 4(3): 2278–2230.
25. UNFCCC, 2007. Status of ratification of the Kyoto Protocol. Available online www.unfccc.int/kyoto protocol/background/status of ratification/items/2613.php