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Quantitative estimation of carbon stock and carbon sequestration in smallholder agroforestry farms of mango and Indian gooseberry in Rajasthan, India

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Abstract

Tree-based farming systems have the potential to sequester large quantities of carbon. An agroforestry system, promoted among small farmers in rural development projects in India, combines fruit and forestry trees with annual crops. As the carbon sequestration potential of this system has not been quantitatively estimated, a study was conducted on 25 orchards each of amla (*Emblica officinalis*) and mango (*Mangifera indica*) in two districts of Rajasthan, India. The orchards, aged between 7-14 years, were selected randomly and biomass accumulation of the trees was estimated using non-destructive allometric methods with quadrate sampling. The mean accumulated carbon in above-ground woody biomass of an amla tree was 0.05 t and that of mango was 0.04 t at an average age of 10 years. Similarly, the estimated carbon sequestered by multipurpose forestry trees growing along the border of the orchard was 0.012 t m^2. Besides the above-ground biomass, the orchards also accumulated 8.1 t carbon ha^{-1} in the upper 15 cm of the soil. The study estimated that the total above and below-ground biomass in a 10 year old agroforestry farm having amla or mango with forestry trees contained 23 t ha^{-1} of carbon which was equivalent to 84.67 t CO_2 ha^{-1}.

Key Words: agroforestry, amla, carbon, mango, sequestration

Introduction

The influence of carbon on earth and the atmosphere can be positive or negative depending upon where it is present. Carbon is essential to sustain biological activity, biodiversity and ecosystem productivity. Excessive release of carbon into the atmosphere, primarily the result of human activity, has led to adverse consequences in recent decades. In order to reverse this situation, there have been concerted global efforts to sequester carbon. Foremost among them is the process of fixing carbon in plant biomass through photosynthesis. Forests, both vegetation and soil, are the primary sinks in this regard. Although agricultural systems do not ensure the level of permanency for sequestered carbon, they cannot be ignored as the land area under crop production is vast. In particular, farming systems having perennial species can hold substantial quantities of carbon. The BAIF Development Research Foundation in India has been promoting an agroforestry system on degraded farmlands of small holders as a rural livelihood generation activity. Popularly known as *wadi* (meaning orchard), this system consists of horticultural trees, annual intercrops and a live fencing with multipurpose trees (Hegde, 1998). The area under this system has now grown to nearly 70,000 ha in India. Besides providing livelihood on degraded smallholdings, this orchard development programme brings in long term environmental benefits, mainly through carbon sequestration. Although the socio-economic benefits of this programme have been comprehensively documented, its contribution to environment has not yet been quantitatively assessed. Many studies have been conducted on carbon stock estimations of natural ecosystems such as forests and grasslands (Ullah, 2012). In comparison, studies on intensively managed agricultural systems are limited. Prone to frequent human interventions, accurate estimates of agricultural systems are difficult. The present study was undertaken in orchards of mango (*Mangifera indica*) and Indian Gooseberry (*Emblica officinalis*,

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locally known as amla), in Udaipur and Banswara districts of Rajasthan. The overall objective of the study was to estimate carbon stock and sequestration rate of agroforestry farms of different age groups.

Material and Methods

Location

The study was conducted in Jhadol (26°N 75°E) in Udaipur district and Garhi (23°N and 74°E) in Banswara district of Rajasthan state. The average annual rainfall of Jhadol is 598 mm, (Singh *et al.* 2013) and the temperature extremes are 38.3 and 11.6°C (SWRPD 2014). The corresponding figures for Garhi are 831 mm and 46-10°C (Kundu *et al.* 2015). The soil of the area ranges from very shallow 25 cm to moderately deep 100 cm (Jain *et al.* 2006).

Experimental material

The farms selected for the study were established through sponsored development projects implemented by BAIF on land belonging to economically disadvantaged farmers. Grafted mango of variety Keshar was planted at 10 x 10 m while the spacing for grafted amla variety NB-7 was 8.0 x 8.0 m. At the time of the study, the age of the trees on these farms ranged from seven to 14 years. In each location, 25 mango farms and an equal number of amla farms were selected for the study. A 15 x 15 m quadrate was demarcated in each farm with a measuring tape which enclosed an average of eight amla or five mango trees.

Measurements

Height and girth at breast height (GBH) of each tree in the quadrate was measured. Non-destructive methods were adopted for the estimation of above and below ground tree biomass of horticulture and forestry species. Established allometric relationships were made use of for the estimation of biomass by measuring of individual tree trunk and crown. The below ground root biomass was estimated using the equation derived by MacDicken, 1997. Soil organic carbon stock was estimated by the analysis of soil in the upper 15 cm layer.

a. Tree height

Tree height was measured using the method described by Kuhns, 1997. The method involved walking toward or away from the tree while holding a stick vertically until the tip of the stick is visually lined up with the top of the tree and bottom of the stick is lined up with the bottom of the tree. At this point, the distance from the eye to the base of the tree is equal to the height of the tree.

b. Tree circumference

It is common in grafted mango and amla to have more than one trunk or main branch. The circumference of such trees was calculated by measuring the circumference of each branch separately and obtaining an integrated value as follows: Circumference of the tree = $\sqrt{(a)^2 + (b)^2 + (c)^2 + (d)^2}$ where a, b, c and d are the circumferences of individual branches.

c. Volume over the bark

As no equation is available to indirectly estimate the volume over the bark (VOB), the following equation derived by Bohre *et al.,* 2013 for *Gmelina arborea*, based on maximum correlation coefficient and minimum standard error, was used for mango and amla:

$VOB = -0.017+0.003D+0.0014H+1.899 \times 10^{-5} D^2H$

where VOB = volume over the bark in CMT; D = diameter at breast height in cm and H = height of the tree in meter.

d. Tree biomass

The wood biomass in kilogram was calculated by multiplying volume with wood density of amla (0.8 g cm^{-3}) and mango (0.55 g cm^{-3}). As wood density is unavailable for forestry species, the standard average density of 0.6 g cm^{-3} as reported by Zanne *et al.*, 2009 and Pandya, 2012 was applied as follows: AGB = V x WD x BEF x 1000 where AGB = Above Ground Biomass; V = Volume of the tree; WD = Wood density; BEF = stem wood biomass expansion factor (BEF =1.5) which includes leaves, twigs, branch and bark.

The below-ground biomass was estimated as 20% of the above-ground biomass as reported by Santantonio *et al.,* 1997 and Mac Dicken, 1997 BGB = AGB x 0.2. The total standing tree biomass was calculated as Total biomass =AGB + BGB.

e. Soil organic carbon, carbon stock and carbon sequestration rate

The equation derived by Yeoman was used to calculate soil organic carbon (SOC) as follows: SOC ha^{-1} = Total volume of soil ha^{-1} x % SOC / 100where volume of soil is 3048 metric tons at a soil density of 1.2. Carbon stock (C) was calculated by multiplying the total biomass by the widely used coefficient of 0.55 as described by MacDicken, 1997. C = 0.55 x total biomass. Carbon dioxide sequestered by different tree species was calculated by multiplying total calculated carbon stock in tree woody biomass by atomic weight of the carbon 3.6663 (USDE, 1998). Sequestration of CO_2 or Equivalent CO_2 = Carbon stock x 3.6663.

Results and Discussion

a. Total biomass, carbon stock and CO_2 sequestration by fruit trees

There was a marked difference between mango and amla in their biomass accumulation and thereby carbon sequestration. In the present study, there were 723 amla trees growing on 7.4 ha of land, accumulating 70 t of biomass containing 38 t of C which was equivalent to 139 t of CO_2 (Table 1). Similarly, 544 mango trees growing on 5.7 ha of land accumulated 47 t of biomass that contained 26 t of carbon or 96 t of equivalent CO_2. The per tree average accumulated carbon stock in mango and amla, respectively, were 0.04 t C and 0.05t C. As the wood density value of 0.8 g cm^3, reported for amla by FAO, 1997 was higher than that of mango 0.59 g cm^3, its carbon sequestration was also higher.

b. The total biomass, carbon stock and sequestration by forestry trees

Besides fruit trees, the agroforestry model introduced by BAIF included 300-400 fast growing multipurpose trees planted on farm borders. The biomass of these trees was estimated by counting the trees on 25 m length of bund in each orchard. There were 51 forestry trees in amla orchards and 80 trees in mango orchards. The total cumulative carbon stock from standing woody biomass of 2050 forestry trees along the border of 13.1 ha land was 132 t (Table 2). The total length of bunds in the sample orchards was 10,480 m^2. Assuming the bund width to be 2.0 m, the estimated carbon sequestration of trees on 1.0 m^2 bund area was 0.012 t.

Total carbon stock sequestered by standing woody biomass in horti-forestry system

The carbon stock by fruit trees was 64 t C and by forestry trees 132 t C and the equivalent CO_2 was 235 and 484 t CO_2, respectively (Table 1 and 2). Thus, the total carbon stock and equivalent CO_2 from the perennial vegetation in the orchard was 196 t C and 719 t CO_2. The carbon stock in this study, 15t C ha^{-1}, was higher than the estimate of 7.0 t ha^{-1} reported by Murthy, 2013 in an agroforestry system.

Table 1 Carbon stock and sequestration by amla and mango.

Particulars	Amla	Mango	Total
Number of trees sampled	191	113	304
Trees in study orchards	723	544	1267
Area (ha)	7.4	5.7	13.1
Volume (m^3)	50	46	95
Above-ground biomass (tons)	56	38	94
Below-ground biomass (tons)	15	10	24
Total biomass (tons)	70	47	117
Carbon stock in biomass (tons)	38	26	64
Equivalent CO_2 in biomass	139	96	235
Carbon stock t ha^{-1}	5.1	4.5	9.6
Equivalent CO_2 t ha^{-1}	18.7	16.8	35.5

Table 2 Carbon stock and sequestration by forest trees in amla and mango orchards.

Type of orchards	Forestry trees		Total
	Amla orchards	Mango orchards	
Sample trees	51	80	131
Trees in study orchards	507	1543	2050
Area (ha)	7.4	5.7	13.1
Volume (m^3)	16	194	210
Above-ground biomass (tons)	14	176	191
Below-ground biomass (tons)	4	46	50
Total biomass (tons)	18	222	240
Carbon stock in biomass (tons)	10	122	132
Equivalent CO_2	36	448	484

c. Carbon stock in soil

Soil samples up to a depth of 15 cm were collected from all 50 orchards and analyzed for organic carbon using the method of Walkley and Black (1934). A total of 106 t C was found to be sequestered in the 13.1 ha of agri-horti-forestry orchards. In the nearby Manas wildlife sanctuary that had a forest cover of 64%, a soil carbon stock of 37.5 t C ha^{-1} was reported by Pandey, 2012. In the present study, however, the average carbon stock in the upper 15 cm soil depth was only 8.0 t C $ha^{1.}$ This is to be expected as the forest of the sanctuary is older and had denser vegetation. In addition, the orchards where the present study was carried out had relatively low soil organic carbon of 0.28% and other varied climatic factors like high temperature and low rainfall.

d. Total carbon stock above and below ground

Based on the estimated tree biomass, the total carbon stock in above and below ground were estimated. The partitioning of carbon stock among forestry, horticulture and soil is shown in 'Fig 1'. The highest quantity of carbon stock was found in the forestry trees growing on the bunds of orchards. They are all have survived and grown well on the bunds of the farmers field and forest trees produced the biomass of 240 t in both amla and mango wadi orchards (Table-2). The estimated total carbon stock from each of variables like, horticulture-forestry, and soil is 15 t C ha^{-1} and 8 t $ha^{-1}C$ respectively. The total carbon accumulated was 23 t ha^{-1} or 84.6 t ha^{-1} CO_2.

e. Carbon accumulation of trees of two different age groups

The orchards in the study were grouped into 7-10 years old (average of 8.5 years) and 11-14 years old (average of 12.5 years) trees. The calculated carbon stock at 8.5 and 12.5 years for amla were 11.3 t ha^{-1} and 13.9 t ha^{-1}, respectively. The respective values for mango were 12.2 t ha^{-1} and 14.2 t ha^{-1}. As would be expected, the carbon stock and sequestration of CO_2 increased with age.

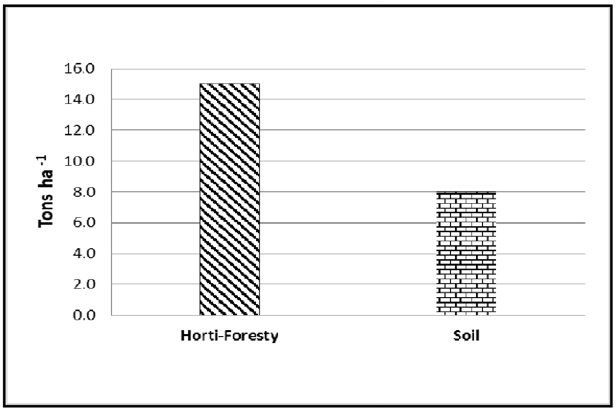

Fig 1- Total carbon stock from horti-forestry and soil

Conclusion

Tree-based farming systems are recommended for tropical smallholders because of their lower susceptibility to unpredictable seasonal weather conditions. Less recognized is their potential to sequester carbon. This is evident in the present study where the biomass accumulated by amla and mango trees of an average age of 10 years was 23 t ha^{-1} which was equal to 84.67 t ha^{-1} of CO_2. Thus, the establishment of orchards with forestry species as a live-fence on degraded land not only stores carbon, but also enhances the fertility of soils that have suffered a high degree of organic matter depletion. The estimated carbon sequestered by multipurpose forestry trees growing along the border of the orchard was 0.012 t $m^{2.}$. Promotion of tree-based farming with fruit and forestry trees as components will have the benefit of securing rural livelihoods as well as mitigating climate change.

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