

**CARBON PROFILE OF TEA BASED AGROFORESTRY SYSTEM
OF KANGRA VALLEY IN HIMACHAL PRADESH**

THESIS

By

NIRJA KAPOOR
(S-2007-30-37)

Submitted to



CHAUDHARY SARWAN KUMAR
HIMACHAL PRADESH KRISHI VISHVAVIDYALAYA
PALAMPUR – 176 062 (H.P.) INDIA

in

Partial fulfilment of the requirements for the degree

of

MASTER OF SCIENCE IN BASIC SCIENCES
(DEPARTMENT OF BIOLOGY AND ENVIRONMENTAL SCIENCES)
(ENVIRONMENTAL SCIENCES)

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*Is there anything I can say,
Anything I can give
Or do for you.....*

*Because all that I'm
All that I have
I owe to you.....*

*Affectionately Dedicated
to my
all family members*

*Who sacrificed
their present
to make my
future better*

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CERTIFICATE - I

This is to certify that the thesis entitled “**Carbon profile of Tea Based Agroforestry system of Kangra Valley in Himachal Pradesh**” submitted in partial fulfilment of the requirements for the award of the degree of **Master of Science (Basic Sciences)** in the discipline of **Biology and Environmental Sciences** of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, is a bonafide research carried out by **Ms. Nirja Kapoor (S-2007-30-37)** daughter of **Sh. Rahkar Kapoor** under my supervision and that no part of this thesis has been submitted for any other degree or diploma

The assistance and help received during the course of this investigation have been fully acknowledged.

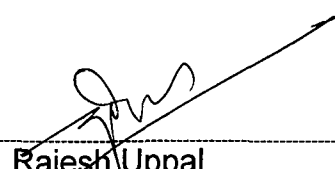
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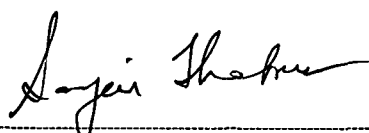

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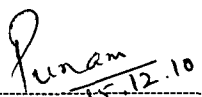
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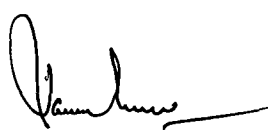
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Needless to say, all omissions and errors are mine.

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Dated: 14 July, 2010

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TABLE OF CONTENTS

<i>Chapter</i>	<i>Title</i>	<i>Page</i>
1	INTRODUCTION	1-3
2	REVIEW OF LITERATURE	4-8
3	MATERIALS AND METHODS	9-17
4	RESULTS AND DISCUSSION	18-29
5	SUMMARY AND CONCLUSIONS	30-31
	LITERATURE CITED	32-39
	BRIEF BIODATA OF THE STUDENT	

LIST OF TABLES

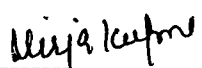
Table No.	Title	Page
4.1	Dominance and ecological success of tree species in different tea based agroforestry system	19
4.2	Biomass production level for managed and unmanaged systems and different tea based agroforestry sites	19
4.3	Interaction effect of managed and unmanaged systems and different tea based agroforestry sites on Biomass	20
4.4	Biomass Carbon stock level for managed and unmanaged systems and different tea based agroforestry sites	21
4.5	Interaction effect of managed and unmanaged systems and different tea based agroforestry sites on biomass carbon stock	21
4.6	Effect of managed and unmanaged systems in tea based agroforestry sites on bulk density at different soil depth	22
4.7	Interaction effect of managed and unmanaged systems and different tea based agroforestry sites on bulk density	23
4.8	Percent organic carbon of managed and unmanaged systems at different soil depths in different agroforestry sites	24
4.9	Interaction effect of managed and unmanaged systems in different tea based agroforestry sites on organic carbon	24
4.10	Soil organic carbon stocks for managed and unmanaged systems and different tea based agroforestry sites	25
4.11	Interaction effect of managed and unmanaged systems and different tea based agroforestry sites on soil organic carbon stock	26
4.12	Effect of tea based agroforestry system on soil organic carbon pool	27
4.13	Carbon stocks under different Tea based agroforestry system up to 20 cm profile depth	28
4.14	Carbon stocks under different Tea based agroforestry system up to 40 cm profile depth	28
4.15	Total Carbon stocks in different tea based agro forestry systems	29

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ABSTRACT

The present investigation entitled "Carbon profile of the tea based Agroforestry system of Kangra Valley in Himachal Pradesh" were undertaken during the year 2008-09 at different locations in and around Palampur. Phytosociological exercise were undertaken for determining the Importance value Index(IVI) and species diversity in the selected quadrates. It was found that the most frequently occurring species were *Albizia chinensis*, *Melia azaderach* and *Toona ciliata* with maximum IVI value of 59.8, 26.6 and 51.3. All the tree components, tea bushes, shrubs and grasses were taken for biomass estimation and biomass was calculated by the non-destructive method. Bulk density was higher in managed system and it was found that bulk density increased with increase in soil depth. Soil organic carbon was calculated higher under unmanaged system in comparison to managed system. The total carbon stock i.e. (plant + soil) was higher in unmanaged system. It was concluded from the studies that carbon assimilation in the form of biomass is at its best when the agroforestry systems are kept managed, on the other hand the organic carbon in the soil assimilates well when the system is unmanaged.



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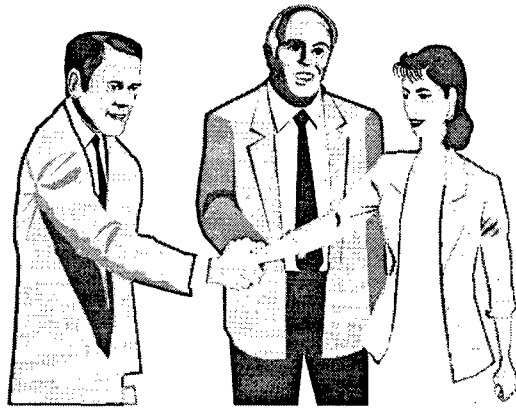


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INTRODUCTION

1. INTRODUCTION

Global climate change caused by increased emission of green house gases (GHGs) is likely to affect the agro ecosystems. The concentrations of major contributing gases *viz.* Carbon dioxide, nitrous oxide and methane (CO₂, N₂O and CH₄) have considerably increased over last century in the atmosphere and is set to rise further. Among these, continuous increase in CO₂ level of atmosphere has serious implications for agriculture, forests as well as the environment. It is accumulating at an alarming rate in the atmosphere. The largest proportion of which resulting from the burning of fossil fuels and conversion of tropical forests to agriculture land. (Paustian *et. al* 2000). Scientific evidences suggest that increased atmospheric CO₂ could have some positive effects on plant productivity (Idso and Kimball, 2001, Keutgen and Chen,2001) however, negative changes such as rising temperature, higher frequency of drought and floods are often the most consequential processes associated with an increased concentration of CO₂ in the atmosphere cause global warming (Anonymous 2000).

Carbon is one of the principle elemental components of ecosystem and intimately coupled with biogeochemical cycles of other major elements such as nitrogen, phosphorus, sulphur, oxygen and hydrogen. Primary productivity, herbivory, litter fall, plant and soil respiration, natural and human disturbances are the primary ecosystem processes that control the global carbon cycle. Current terrestrial (plant and soil) carbon is estimated at 2000± 500 Pg, which represents 25% of global carbon stocks (Anonymous 1999). The carbon sequestration potential of tropical agroforestry system is estimated between 12 and 228 Mg per hectare with a median value of 95 Mg ha⁻¹. (Albrecht and Kandji 2003).

Only green plants can assimilate carbon on earth, forests are the sites for the long term carbon storage on earth. But forest cover is decreasing at an alarming rate due to various types of disturbances. Out of various causes forest

fire is a major cause which is not only damaging the forest wealth but also releases huge amount of carbon from secured storage of carbon. Forests constitute to retain and increase their stored carbon and thus help to reduce the increase of CO₂ and stabilize atmospheric concentration (Singh *et al.* 2000).

According to recent projection, the area of the world under agroforestry will increase substantially in near future. Undoubtedly, this will have a great impact on the flux and long term storage of carbon in global carbon cycle and contain approximately 12% of world terrestrial carbon (Dixon *et al.* 1993).

Looking at contributions, agroforestry landuse systems can make in solving current climatic problems, it can be easily inferred that agroforestry is one among a range of strategies. It can be justified for many other reasons too; first, increasing soil carbon greatly benefits agricultural productivity and sustainability. secondly, giving the probability of obtaining any single mitigating method, adding modest contributions together, appears to be a more realistic way of achieving CO₂ reduction targets. Thirdly, the financial costs of carbon sequestration through agroforestry appear to be much lower than through other CO₂ mitigating options. These costs could be easily offset by the monetary benefits from agricultural products and trading in carbon credits (Albrecht and Kandji, 2003).

Historical evidences show that agroforestry has been widely practiced through the ages as a mean of achieving agriculture sustainability and slowing the negative effect of agriculture such as soil degradation and desertification.

In India, agroforestry is being promoted as an alternate landuse system to deal with the problems related to landuse sustainability and environmental amelioration yet, its real potential needs scientific evidences. Numerous agroforestry systems both natural as well as planted developed in different agroclimatic regions of the country have been found highly productive and environmentally suitable.

The significance of agroforestry with regard to carbon sequestration and other CO₂ mitigating effects is widely recognized, but still there is a paucity of quantitative data on specific system. Therefore, present study on “**Carbon Profile of Tea based Agroforestry System of Kangra valley of Himachal Pradesh**” was undertaken with the following objective.

- 1). To develop a Carbon profile of managed and unmanaged tea based agroforestry system.



REVIEW
OF
LITERATURE

2. REVIEW OF LITERATURE

Agroforestry system has been found to be more productive and sustainable than other existing land use system under medium and small holder conditions. It also holds good promise to enhance plant-soil carbon pools by sequestering carbon from the atmosphere. Forests contribute both sink and as a source of atmospheric CO₂. Managing forests in order to retain and increase their stored carbon will help to reduce the rate of increase of CO₂ and stabilize atmospheric concentrations. Carbon sequestration is the provision of long term storage of carbon in the terrestrial biosphere, underground or the ocean so that the built up of CO₂ concentration in the atmosphere will reduce in order to improve environmental conditions and check the processes of environmental degradation.

2.1 Species Diversity: importance Value Index (IVI)

Ilorkar and Khatri (2003), in a study conducted at Navegaon National Park (Maharashtra) observed that the density of shrubs varied from 79.55/ha (500-600 m) to 1185/ha (300-400m). The values for tree layer showed that *Tectona grandis* (IVI 75.21, 30.05, 16.45 at elevation 300-400, 400-500 and 500-600 m elevation range, respectively) was a dominant species.

Gauchan *et al.* (2003) conducted experiments on the distribution and dominance of *Citrullus colocynthis* and *Corchorus depressus*, as well as the vegetation associated with the crops in Rajasthan, India. Out of the 90 species associated the highest importance value index (IVI) was recorded by *Parthenium hysterophorus*, whereas the lowest IVI was recorded by *Euphorbia chamaesyce*

Ghosh *et al.* (2005), in IVI studies of plant species in Goalpara District, Assam, data showed that *Oplismenus* sp. has the greatest IVI value of 41.28, relative density (25.8), relative frequency (12.16), and relative dominance (4.04), whereas *Trifolium trilobatum* had the lowest IVI of 2.08, relative density (0.52), relative frequency (1.38) and relative dominance (0.18).

2.1.1 Biomass Estimation

Chidumaya (1990) studied above ground woody biomass structure and productivity in Zambebian woodland and obtained leaf biomass per stem by multiplying number of twigs per stem with mean dry weight of leaves per twig. Mishra *et.al.* (1992) have reported that total biomass per hectare increased proportionally with density and biomass partitioning revealed on an average 19.83 % leaf, 7.99 % twig and 49.85 % stem component.

Nayak (1996) found that above ground biomass was influenced due to density and type of species. Deshmukh (1998) reported that management practices also affect the biomass production of the trees grown under different agroforestry system. The differences in productivity of agroforestry system may be due to differences in soil condition, phenology of dominant species, better root networking (Gupta and Singh, 1981). In Haryana, Bhojvaid and Timmer (1996) reported that large increase in soil organic carbon content by reclamation of sodic soil through growing *Prosopis juliflora*.

Marked seasonal fluctuations in the atmospheric CO₂ concentration are attributed to forest growth during spring and summer seasons in the northern hemisphere. Katagiri *et al.* (1992) reported that dry weight of dead organic matter including standing trees was 4.1 to 16.8 % of the total above ground biomass in Samba forest, Shimane Japan. The association of trees within the grasses in the silvi-pastoral system revealed that an increased input of plant residues into the soil played a significant role in improving nutrient cycling and biological productivity in the tree based systems (Kaur *et al.* 2002).

Kumar (2003) concluded in his study that biomass production level both below and above ground was highest (59.72 tonnes ha⁻¹) in silvi pastoral system. Lal (2002) also advocated that reforestation of degraded soils and ecosystem is an important strategy for enhancing biomass production, improving soil quality and increasing the carbon pool.

Benchalli and Prajapati (2004) had worked in gund forests of haliyal forest division in Kanara districts of Western Ghat region of Karantaja. This study depicted the importance and contribution of various variables in predicting forest

biomass. Domasch (1980) in a study of 26 agricultural soils found that the microbial biomass contained between 0.27 and 4.8 % of the total carbon (with a mean of approximately 2.5%).

2.1.2 Biomass Carbon stock determination.

Singh and Singh (1997) reported that trees maintain soil organic matter and nutrient cycling through the addition of litter and root residues in the soil. There is a potential of sequestering carbon in soil and vegetation by adopting the amount of carbon sequestered. It largely depends on agroforestry system (Albrecht and Kandji 2003) and concluded that structure, function and some other factors influencing the carbon storage in agroforestry system includes tree species and system management.

Woomer (1999) investigated the impact of cultivation on carbon fluxes in woody Savannah of Southern Africa and found decline in the total soil carbon from 28 to 9 tonnes / hectare, by clearing the Miombo and establishment of maize based agriculture on sandy alfisols.

Martius *et al.* (2004) conducted study of agroforestry system in Amazonia concluded that the reduced decomposition rates indicate quantitative and/ or qualitative changes in the decomposer communities of these systems that lead to higher build up of litter stock on the forest floor. Due to low decomposition rates forest site showed large litter accumulation inspite of relatively low litter fall. Sanneh (2007) inferred from his discussion that variability in the carbon stocks of different land use system depends primarily on its age, structure, functional component and their number and intensity of management. Cihacek and Ulmer (1995) reported high value of bulk density in cultivated soil in comparison to grass land. They observed that intensively managed system have higher bulk density. The higher bulk density in soil can be attributed to lower soil organic carbon. Zegeye (1999) reported that the increased organic carbon content in soil under tree based system may be ascribed to more leaf litter decomposition and root turn over from trees.

2.1.3 Soil organic carbon stock

Minhas *et al.* (1997) revealed that maximum accumulation of Soil organic carbon is in surface layer which decreased with increase in soil depth. It is due to incorporation of leaf litter. Soane (1975), Coote and Ramsay (1983), Sharma and Aggarwal (1984), Sharma *et al.* (1989) and Lav Bhushan (1998) reported that lower bulk density value in upper layer of soil profile may have resulted from dilution of soil matrix (mineral matter) with lesser denser material (organic matter) and improvement in soil aggregation. Lal (2002) reported in USA that gross rate of soil organic carbon sequestration ranges from 500-800 kg/ ha / year in cold and humid region and 100-300 kg/ha/year in dry and warm region and there is also a large potential to sequester soil inorganic carbon in arid and semi arid region.

Hussain *et al.* (1987) studied the effect of *Leucaena* and *Sesbania* leaf manuring on crop growth and physicochemical properties of soil. Analysis of soil properties after crop harvest showed that all doses of green manure significantly reduced pH and increase soil organic matter compared with the control and NPK treatments. Montagnini and Sancho (1990) compared soil fertility under a 2.5 year old plantation, under grass and in 20 year old secondary forest. High level of organic matter were found under the plantation than undergrasses with value close to those in secondary forest .

Hazra and Tripathi(1986) examined the effect of Nitrogen on growth of Oat with and without *Leucaena* tree canopy. There was reduction in forage yield but the organic carbon, available Nitrogen and Phosphorus, field capacity and porosity of soil increased as well as bulk density decreased under *Leucaena* compared with lots without trees.

2.1.4 Soil organic carbon pool

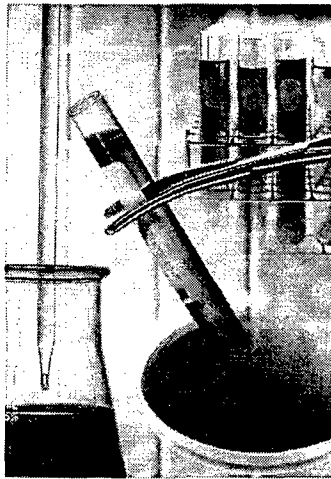
Walker and Deshankar (2004) studied the impact of land use on soil carbon in Miombo woodlands of Malawi. In this study they reported that the surface soil organic carbon level in Miombo soil varied from 1.2 to 3.78%. Agriculture soil carbon was significantly lowered with the surface layer ranging

0.35 to 1.2 % carbon. Neff and Asner (2001) synthesised information on geochemical and biological factor that control dissolved organic carbon (DOC) fluxes through soil. They focussed on conceptual issues and quantitative evaluation of key processes rates to present a numerical model of dissolved organic carbon (DOC) dynamics. It indicates that in temperate forest DOC contributed 25% of total soil profile carbon whereas roots provided remainder. Young *et al.* (2000) worked on a carbon balance assessment, in this study carbon balance estimate showed that growth of wood fibre and production which results in a net sequestration ratio of roughly 1.3 times as much carbon is emitted to atmosphere.

Ramachandran *et al.* (2007) in Tamil Nadu (Kolli hills) noticed that total area under forest cover in kolli hills is about 27.10 ha and total biomass carbon estimated is 2.74 Tg. Total soil organic carbon in forest area is 3.18 Tg.

Bharti (2007) had worked on carbon sequestration and nutrient dynamics in long term *Lantana* amended soil under rice wheat system. It was reported that addition of *Lantana* and application of fertilizer increased carbon stock with time. The minimum carbon stock build up was observed under no *Lantana* addition along with 33% of recommended dose of and maximum under 30 quintal per ha along with 100% of recommended dose. Kaonga and Bayliss (2009) in a study conducted at Zambia reported that above ground carbon stock ranged from 2.9 to 9.8 tonnes per ha.

Song *et al.* (2009) in a study conducted for estimation of soil organic carbon storage in forest vegetation in Jiangxi Province concluded that the organic carbon density of 20 cm of forest soil ranges from 0.89-10.92 kg/m² and the organic carbon density of 100cm of forest soil ranges from 2.71-35.61 kg/m².



MATERIALS AND METHODS

3. MATERIALS AND METHODS

In order to prepare a carbon profile of the system and to assess the complete carbon budgeting of the system, the work was carried out at Tea garden of CSK HPKV Palampur at Banuri, Lohna (Palampur) and Tashi jong (Taragarh) during 2008-09. The details about experimental site, material used and methodology adopted in undertaking these studies are given below:-

3.1 Site Description

3.1.1 Location

Three sites were selected in and around Palampur for the present investigation.

Site 1 was selected in the CSK HPKV Palampur tea gardens at Banuri which is located 6 kms from Palampur at an elevation of 1291m.

Site 2 was selected in the Lohna which is located 5 kms from Palampur which is located at an elevation of 1320m.

Site 3 was located at Taragarh (Baijnath) which is located 12 kms from Palampur and located at an elevation of 1050m.

3.1.2 Climate

The climatic factors of the area are described as follows

Table1: Locality factors of the Study area.

Factors	Site 1	Site 2	Site 3
Latitude	32 ⁰ 06'	32 ⁰ 07'	32 ⁰ 04'
Longitude	76 ⁰ 03'	76 ⁰ 32'	76 ⁰ 36'
Attitude	1291 m	1320 m	1050 m
Soil pH	6.0	5.9	5.6

3.2 Experimental Methodology

3.2.1 Mapping of the area and laying out of the quadrates.

The entire area under tea experimental farm was traversed and demarcated into managed and unmanaged systems which were further divided into different quadrates as described by Anonymous, 2002 for further studies by taking size of the quadrate and minimum number of the trees.

3.2.2 Estimation of species diversity(IVI)

Phytosociological exercises were undertaken for determining the Importance Value Index (IVI) and species diversity in the selected quadrates to know the following parameters of various species.

i) Frequency

Frequency as introduced by Raunkiaer (1934) indicates the number of sampling units in which a given species occurs; and thus expresses the distribution or dispersion of various species in community. The following formula used to get the frequency percentage.

$$\text{Frequency Percentage} = \frac{\text{Total No. of sampling unit in which species occurred}}{\text{Total No. of sampling units studied}} \times 100$$

3.2.3 Density and Abundance

The terms density and abundance represent the numerical strength of species in the community. The former if considered along with frequency, gives an idea of distribution pattern of the species while the latter represents the number of individuals per unit area. The density and frequency taken together are of prime importance in determining community structure and have a variety of uses far beyond those of other quantitative values (Oosting 1958). After counting the number of individuals of each species, following formulae were used to get density and abundance.

$$\text{Density} = \frac{\text{Number of individuals of the species}}{\text{Total no. of sampling units studied}}$$

$$\text{Abundance} = \frac{\text{Numbers of individuals of the species}}{\text{Total no. of sampling units of occurrence}}$$

3.2.4 Basal Area

It refers to the ground actually penetrated by the stems, and is readily seen when the leaves and stems are clipped at the ground surface (Hanson and Churchill, 1961). It is one of the chief characteristics determining the dominance and the nature of the community. This is measured either 2.5 cm. aboveground or actually on the ground level. Most common methods for determination of basal area is to measure the diameter of each tree and shrub using caliper and then radius is calculated and ultimately the basal area was determined through the following relation.

$$\text{Basal area} = \pi(r)^2$$

Here 'r' is the radius

3.2.5 Importance Value Index. (IVI)

To determine the agro-ecological importance value of trees and shrubs in the regions, number of species, number of individuals of each species, and the diameter at the base were used to calculate the parameters like frequency, density, abundance and basal area (Curtis and McIntosh 1951; Mishra 1968 and Burns and Honkala 1990).

Importance value index-dominance and ecological success of any species, is expressed with a single value, by using the concept of importance value index. This index utilizes three characteristics viz., relative frequency, relative density and relative dominance which can be determined by using the following formulas:

$$\text{Relative Dominance (RDo)} = \frac{\text{Total Basal area of the species}}{\text{Total Basal area of all the species}} \times 100$$

$$\text{Relative Density (RD)} = \frac{\text{Total No. of individuals of the species}}{\text{Total No. of individuals of all the species}} \times 100$$

$$\text{Relative Frequency (RF)} = \frac{\text{Total No. of occurrence of species}}{\text{Total No. of occurrence of all the species}} \times 100$$

$$\text{IVI} = \text{RDo} + \text{RD} + \text{RF}$$

On the basis of IVI index selection of trees, tea bushes, shrubs and grasses was made for biomass estimation and total carbon estimation.

3.2.6 Soil physico-chemical characteristics

For determination of different soil physico-chemical properties like bulk density, soil organic carbon, soil organic carbon stock and total carbon stock following soil depths (D1, D2, D3, and D4) were taken:

D1 - 0-10cm

D2 - 10-20cm

D3 - 20-30cm

D4 - 30-40cm

3.3 Observation Recorded:-

3.3.1 Aboveground Biomass

Above ground biomass was studied for the following component

- Trees
- Tea Bush (Crop)
- Shrubs
- Grasses
- Surface Litter

3.3.2 Carbon stocks in agroforestry system

Above ground biomass carbon stock.

Table 3.2 Experimental details showing the different combinations

	Agroforestry System	Code	Studied tree- crop Combination
Site 1 (S1)	Managed (M)	S1M	<i>Albizia chinensis</i> + <i>Toona ciliata</i> + <i>Melia azedarach</i> + <i>Camellia sinensis</i>
	Unmanaged (U)	S1U	
Site 2 (S2)	Managed (M)	S2M	<i>Albizia chinensis</i> + <i>Toona ciliata</i> + <i>Melia azedarach</i> + <i>Camellia sinensis</i>
	Unmanaged (U)	S2U	
Site 3 (S3)	Managed (M)	S3M	<i>Albizia chinensis</i> + <i>Toona ciliata</i> + <i>Melia azedarach</i> + <i>Camellia sinensis</i>
	Unmanaged (U)	S3U	

3.3.3 Soil physico-chemical properties

- Bulk density
- Soil Organic Carbon
- Soil organic carbon stock
- Total carbon estimation

3.4 Procedure Adopted

Above ground biomass was estimated by non destructive method for different plant parts viz., stem, branch and leaf.

3.4.1 Stem Biomass

To estimate stem biomass all the trees falling in the plot (35 x 30m) were enumerated. The diameter at breast height was measured with caliper and height with Scurto clinometer. Form factor was calculated with Spiegel relaskope to find out tree volume using the formula given by Pressler (1865) and Bitterlieh (1984).

$$f = 2h_1/3h$$

Where f is form factor.

h_1 - height at which diameter is half of dbh.

h - total height

Volume was calculated by Pressler formula (1865)

$$V = f \times h \times g$$

Where

V = volume

f = form factor

h = total height

g = basal area

$$g = \pi r^2 \text{ or } \pi(\text{dbh}/2)^2$$

r = radius,

dbh = diameter at breast height.

Specific Gravity:-

The stem cores were taken to find out specific gravity which was used further to determine the biomass of stem using moisture method (Smith 1954).

$$G_f = \frac{1}{\frac{M_n - M_o}{M_o} + \frac{1}{GS_o}}$$

Where

G_f = Specific gravity based on gross volume.

M_n = Weight of saturated volume sample.

M_o = Weight of oven dried sample.

GS_o = Average density of wood substances equal to 1.53

Thus the weight of wood was estimated using formula *i.e.* mass per unit volume

Mass = Average specific gravity of wood X volume

3.4.2 Branch Biomass:-

Total number of branches irrespective of size were counted on each of the sample tree, then these branches were categorized on the basis of basal diameter into 3 groups *viz* < 3cm, 3-5 cm, >10 cm. Fresh weight of 2 sampled branches from each group was recorded separately. The following formula (Chidumaya, 1990) was used to determine the dry weight of branches.

$$B_{dwi} = B_{fwi} / 1 + M_{cbdi}$$

Where

B_{dw} = oven dry weight of branches

B_{fwi} = fresh/green weight of branch

M_{cbdi} = Moisture content of branch on dry weight basis

Total branches biomass (fresh/ dry) per sample tree was calculated by as given by (Chidumaya, 1990)

$$B_{bt} = n_1bw_1 + n_2bw_2 + n_3bw_3 = \sum_{i=1}^n n_i b_{wi}$$

Where

- B_{bt} = branch biomass (fresh/dry) per tree
- n_i = no. of branches in the i^{th} branch group
- b_{wi} = average weight of branch of i^{th} group
- i = 1,2,3.....n, refers to branch group

3.4.3 Leaf Biomass:-

Leaves from branches were removed, weighed and oven dried separately to a constant weight $60 \pm 5^{\circ}\text{C}$ (Chidumaya 1990)

3.4.4 Tree Biomass:-

The total tree biomass was the sum of stem biomass, branch biomass and leaf biomass. The tree biomass was converted into carbon by a factor 0.45 (Woomer 1999)

3.4.5 Crop (Tea) Biomass:-

Crop biomass was estimated using 1m X 1m quadrates. All the crop plants occurring within the border of the quadrate were cut at ground level and collected samples were weighed, sub sampled, oven dried at $65 \pm 5^{\circ}\text{C}$ to a constant weight, The crop biomass was converted into Carbon by multiplying with a factor of 0.45 (Woomer 1999)

3.4.6 Grass Biomass:-

Grass biomass was estimated using 1m X 1m quadrates. The total grass biomass occurring with in the borders of the quadrate were cut at ground level and collected samples were weighed, sub sampled and oven dried at $65 \pm 5^{\circ}\text{C}$ to a constant weight. The grass biomass was converted into Carbon by multiplying with a factor of 0.45 (Woomer 1999).

3.4.7 Surface Litter:-

Surface litter was collected within a 1m X 1m frame centrally placed within each quadrat. Samples were weighed, sub sampled and oven dried at $65\pm 5^{\circ}\text{C}$ to a constant weight, weighed, ground and ashed, Ash corrected dry weight was assumed to contain 45 per cent of carbon.

3.5 Soil Analysis

3.5.1 Collection and preparation of soil samples :-

Soil samples were collected by dividing each main quadrat area into randomly selected three sub areas. Soil samples for each sub areas were obtained by digging sub surface area at different depth (0-10cm, 10-20cm, 20-30cm,30-40 cm). Composite samples from all sub areas were obtained for each depth. Samples were air dried in shade, ground with wooden pestle, passed through 2mm sieve and stored in cloth bags for further laboratory analysis.

3.6 Carbon profile

The soil organic carbon profile expressed as t /ha. for a specific depth was calculated by multiplying soil organic carbon with the bulk density and depth (Carlos *et.al.* 2001)

3.7 Statistical analysis

Data collected under different experiments were subjected to statistical analysis for drawing inferences using standard statistical methods (Gomez and Gomez, 1984)



RESULTS AND DISCUSSION

4. RESULTS AND DISCUSSION

Agroforestry systems due to their structure, function and tree species included and the management to which the system is put reflects variability both in productivity and the carbon stored in a agro climatic region. The biomass production levels obtained and the carbon stored in the biomass through the different agroforestry systems have been described in this chapter under following heads

4.1 Estimation of species diversity (IVI)

In three study sites the majorly occurring species were *Albizia chinensis*, *Toona ciliata* and *Melia azedarach* out of which the most frequently occurring species was *Albizia chinensis*, having highest value of frequency viz. 70.8, 83.3 and 75.0 per cent in the manage system and 33.3, 45.8 and 37.5 per cent in the unmanaged system. This table 4.1 shows that the species having higher frequency represent high value of IVI i.e. 58.1, 193.1, 137.2 in the managed system and 40.9, 59.8 and 50.4 in unmanaged system under three sites respectively. Similar results were obtained by Illorkar and Khatri (2003), Gauchan *et al.* (2003) and Ghosh *et al.* (2005)

4.2 Biomass production levels of different tea based agroforestry systems

The variation in biomass levels of stem, branch, leaf and whole tree for woody perennial components as well as for crop grass and litter for different systems and sites is shown in Table 4.2. In case of stem branch, leaf, whole tree, tea bush and litter components, maximum biomass was recorded for managed systems which could be due to canopy management, weeding and lower spacing. This study was similar to the findings of Ghosh *et al.* (2005) who reported high biomass in lower spacing. The high biomass in managed system (S2) depend upon number of factors viz. Growth, habit of species, soil on which it grows, age of tree species, its management and also its compatibility with associated crop plant. Another reason of maximum biomass in S2 is higher density value of tree species. Similar studies were substantiated by Nayak (1996).

Table 4.1: Dominance and ecological success of tree species in different tea based agroforestry system

Tree species	Frequency percentage		Density per 100 m ²		Basal area cm ² /m ²		Relative frequency (%)		Relative Density (%)		Relative dominance (%)		Importance value Index	
	M	U	M	U	M	U	M	U	M	U	M	U	M	U
Site1 <i>Albizia chinensis</i> ,	70.8	33.3	1.08	0.42	3.73	1.07	26.4	9.2	84.8	21.2	27.0	10.5	38.2	40.9
<i>Toona ciliata</i>	25.0	25.0	0.33	0.33	0.96	0.96	6.8	6.8	18.7	17.8	18.3	17.3	45.8	41.9
<i>Melia azedarach</i>	4.2	8.3	0.04	0.08	0.04	0.40	2.1	2.3	6.2	4.3	3.5	3.5	11.8	8.1
Site2 <i>Albizia chinensis</i>	83.3	45.8	4.34	0.79	8.32	1.66	28.5	12.6	93.1	28.8	71.5	18.4	193.1	59.8
<i>Toona ciliata</i>	45.8	33.3	0.75	0.42	2.40	1.95	12.6	6.44	28.5	25.4	11.2	19.5	52.3	51.3
<i>Melia azedarach</i>	12.5	16.7	0.13	0.17	0.48	0.36	2.7	6.4	10.4	6.4	1.8	13.8	14.9	26.6
Site3 <i>Albizia chinensis</i>	75.0	37.5	3.66	0.46	8.28	0.36	20.4	11.3	85.6	25.8	31.2	13.3	137.2	50.4
<i>Toona ciliata</i>	37.5	29.2	0.92	0.37	1.41	0.64	11.3	7.9	15.9	19.2	9.7	5.7	36.9	32.8
<i>Melia azedarach</i>	8.3	12.5	0.04	0.13	0.20	0.28	2.4	3.4	6.4	5.8	1.5	2.9	10.3	12.1

Table 4.2: Biomass production level for managed and unmanaged systems and different tea based agroforestry sites (t / ha)

Components/Factors		Stem	Branch	Leaf	Whole tree	Tea bush	Grass	Litter
System*	M	25.68	20.35	5.18	51.86	18.21	0.00	3.0
	U	23.81	18.1	4.70	46.75	16.31	1.84	2.28
CD (P =0.05)		0.36	0.02	0.01	0.22	0.01	0.01	0.01
Sites **	S1	23.21	18.08	4.07	45.21	16.49	0.82	2.27
	S2	25.53	19.69	5.78	51.83	18.57	1.02	2.59
	S3	25.5	19.89	4.98	50.87	17.6	0.92	3.06
CD (P =0.05)		0.99	0.01	0.03	0.61	0.02	0.02	0.03

*Average of three sites

** Average of Managed(M) + Unmanaged system(U)

The managed system of site 2 (S2M) shows significantly higher biomass in tree component as well as crop and litter (Table 4.3) whereas unmanaged system of site 3 (S3U) shows significantly lower biomass. The managed system of site 2 (S2M) have higher production of biomass. This is due to management of tea gardens, high frequency, density of tree species and manuring as reported by Nayak (1996).

Table 4.3: Interaction effect of managed and unmanaged systems and different tea based agroforestry sites on Biomass. (t / ha)

Components Sites	Systems	Stem	Branch	Leaf	Whole tree	Tea bush	Grass	Litter	Grand total
Site 1	M	24.05	18.54	4.21	46.80	17.23	0.00	2.69	66.72
	U	22.40	17.60	3.90	43.60	15.80	1.60	1.90	62.90
Site 2	M	26.00	21.80	6.20	55.00	20.00	0.00	3.30	78.30
	U	25.00	17.60	5.30	48.70	17.20	2.00	1.90	69.80
Site 3	M	26.90	20.70	5.00	53.80	19.30	0.00	3.10	34.28
	U	24.00	19.00	4.80	48.00	16.00	1.80	3.10	31.00
CD (P=0.05)		1.39	0.01	0.30	0.86	0.02	0.02	0.03	0.95

4.3 Biomass Carbon stocks in different tea based agroforestry systems

The data in table 4.4 shows the variation in carbon stock level of stem, branch, leaf and whole tree as well as for crop, grass and litter for different systems and sites. The highest carbon stock was found in managed system. Among sites, site 2 shows best result in the production of maximum carbon stock and minimum carbon stock was found in S1.

Site 2 (S2) have maximum carbon stock, it can be inferred from studies that site 2 (S2) had maximum frequency of trees which attribute to maximum biomass in the site and this can be correlated with the presence of maximum carbon stock in site 2 (S2). (Table 4.4).

Table 4.4: Biomass Carbon stock level for managed and unmanaged systems and different tea based agroforestry sites. (t / ha)

Components Factors		Stem	Branch	Leaf	Whole tree	Tea bush	Grass	Litter
System*	M	11.55	9.15	2.33	23.33	8.46	0	1.35
	U	10.71	8.14	2.11	21.03	7.33	0.82	1.02
CD (P =0.05)		0.15	0.01	NS	0.01	0.01	0.01	0.01
Sites **	S1	10.44	8.13	1.83	20.34	7.42	0.36	1.02
	S2	11.48	8.86	2.6	23.32	8.35	0.45	1.16
	S3	11.47	8.95	2.24	22.89	7.92	0.41	1.37
CD (P =0.05)		0.43	0.02	NS	0.04	0.03	0.05	0.02

*Average of three sites

** Average of Managed (M) + Unmanaged system(U)

Similar trend was found in biomass and carbon production because the carbon stock depends upon biomass content. From the Table 4.5 it is observed that S2M have highest biomass potential than other sites. The result discussed above can be supported by Nayak (1996) who found that above ground biomass is influenced by high frequency and density.

Table 4.5: Interaction effect of managed and unmanaged systems and different tea based agroforestry sites on biomass carbon stock. (t / ha)

	Factors System	Stem	Branch	Leaf	Whole tree	Tea bush	Grass	Litter	Grand total
Site 1	M	10.82	8.43	1.89	21.06	7.75	0.00	1.21	30.02
	U	10.08	7.92	1.75	19.62	6.32	0.72	0.85	27.51
Site 2	M	11.70	9.81	2.79	24.75	9.00	0.00	1.48	35.23
	U	11.25	7.92	2.38	21.91	7.74	0.92	0.85	31.42
Site 3	M	12.10	9.31	2.25	24.21	8.68	0.00	1.39	34.28
	U	10.80	8.55	2.16	21.60	7.20	0.81	1.39	31.00
CD (P=0.05)		0.61	0.02	NS	0.06	0.04	0.8	NS	

Deshmukh (1998) similarly further ascertained that management practice also affect the biomass production under all agroforestry systems, thus carbon stock can also be affected.

4.4 Soil physico-chemical properties

4.4.1 Bulk Density

As depicted in Table 4.6 the bulk density ranged between 1.06 to 1.17 g/cm³ at different soil depth (0-10 to 30-40) in managed system with a mean value of 1.12 g/cm³. However, it vary from 0.90-0.95 g /cm³ in unmanaged system with a mean value of 0.93 g/cm³ in managed and unmanaged system. Similarly the site 2 (S2) had revealed maximum bulk density in managed system.

Table 4.6: Effect of managed and unmanaged systems in tea based agroforestry sites on bulk density at different soil depth. (g / cm³)

	Soil depth	0 -10cm	10-20cm	20-30cm	30-40cm	Mean
Factors						
System*	M	1.06	1.12	1.15	1.17	1.12
	U	0.90	0.93	0.95	0.94	0.93
CD (P =0.05)		0.24	0.02	0.01	0.01	
Sites **	S1	0.94	1.02	1.06	1.06	1.02
	S2	1.00	1.05	1.04	1.06	1.03
	S3	0.92	1.07	1.03	1.03	1.01
CD (P =0.05)		0.67	0.08	0.02	0.03	

*Average of three sites

** Average of Managed (M)+ Unmanaged systems(U).

The site 2 (S2) had significantly higher bulk density both under managed and unmanaged system (Table 4.7) when compared with other two sites. The results confined to findings of Sharma *et al.* (1996), Sheeba and Kumaraswamy (2001), Selvi *et al.* (2005) and Bajpai *et al.* (2006)

Table 4.7: Interaction effect of managed and unmanaged systems and different tea based agroforestry sites on bulk density (g / cm^3)

	Soil depth System	0-10cm	10-20cm	20-30cm	30-40cm	Mean
Site 1	M	1.06	1.13	1.16	1.16	1.12
	U	0.08	0.90	1.00	1.00	0.74
Site 2	M	1.10	1.20	1.20	1.10	1.15
	U	0.90	0.90	1.00	1.00	0.95
Site 3	M	1.00	1.10	1.10	1.20	1.10
	U	1.20	1.00	1.20	0.90	1.07
CD (P=0.05)		0.95	0.10	0.03	0.04	0.28

4.4.2 Soil organic carbon

Per cent organic carbon in managed and unmanaged system at different soil depth was 2.58, 1.61, 1.56, 1.44 and 3.88, 3.68, 2.62, 2.57 per cent respectively. Organic carbon content in unmanaged system was significantly higher (3.19%) in comparison to managed system (1.80%) due to continuous addition of organic matter through decomposition in that area (Table 4.8).

The organic matter accumulated was highest at the surface soil decreases with soil depth (Table 4.8). The accumulation of organic carbon in the surface is larger due to incorporation of leaf litter and addition of decayed roots to the upper layers. Similar observations were reported by Domasch (1980) in 26 agriculture soils.

Table 4.8: Per cent organic carbon of managed and unmanaged systems at different soil depths in different agroforestry sites (t/ ha)

	Soil depth	0 -10cm	10-20cm	20-30cm	30-40cm	Mean
Factors						
System*	M	2.58	1.61	1.56	1.44	1.80
	U	3.88	3.68	2.62	2.57	3.19
CD (P =0.05)		0.01	0.04	0.01	NS	
Sites **	S 1	3.56	2.85	2.38	2.22	2.69
	S 2	3.65	2.72	2.02	1.86	2.73
	S 3	2.49	2.37	1.49	1.94	2.07
CD (P =0.05)		0.13	0.12	0.03	NS	

*Average of three sites

**Average of Managed (M) + Unmanaged system (U)

The organic carbon of soil also vary with soil depth. The highest value was recorded in 0-10 cm where it was minimum at 30-40 cm of soil depth. The maximum soil organic carbon was found in S2U and minimum in S3M because of increased biomass, maximum density and higher frequency of tree species.

This study is supported by Kaur *et al.* (2002) who revealed that the increased biological production will lead to greater carbon storage in the vegetation and soil.

Table 4.9: Interaction effect of managed and unmanaged systems in different tea based agroforestry sites on organic carbon (t/ha)

System	Soil depth	0-10cm	10-20cm	20-30cm	30-40cm	Mean
Site 1	M	2.64	2.27	2.17	1.95	2.26
	U	4.50	3.40	2.61	2.50	3.25
Site 2	M	2.70	1.30	1.30	1.10	1.60
	U	4.60	4.10	3.70	2.40	3.70
Site 3	M	2.40	1.40	1.20	1.20	1.55
	U	2.60	3.50	2.70	2.60	2.85
CD (P=0.05)		0.06	0.16	0.04	NS	

4.4.3 Soil organic carbon stock inventory

Soil Organic carbon (SOC) values in soils of managed system were 28.42, 24.41, 22.12 and 17.38 tonnes / ha for managed and 40.89, 34.99, 25.96 and 26.71 in unmanaged system at different soil depths 0-10, 10-20, 20-30 and 30-40 cm respectively. The mean value of soil organic carbon of managed system is 23.08 whereas in case of unmanaged it is 32.14 tonnes/ ha, respectively (Table 4.10).

Table 4.10: Soil organic carbon stocks for managed and unmanaged systems and different tea based agroforestry sites (t / ha).

Factors	Soil depth	0 -10cm	10-20cm	20-30cm	30-40cm	Mean
System*	M	28.42	24.41	22.12	17.38	23.08
	U	40.89	34.99	25.96	26.71	32.14
CD (P =0.05)		0.01	0.16	0.01	0.01	
Sites **	S1	34.42	27.94	23.81	22.85	27.26
	S2	35.48	28.44	24.6	21.33	27.46
	S3	34.48	32.71	23.71	15.95	26.71
CD (P =0.05)		0.02	0.05	0.04	0.04	

*Average of three sites

**Average of Managed(M) + Unmanaged system (U)

Similarly out of three sites S1, S2 and S3 the mean value of site S2 is significantly higher (27.46) than remaining two sites. The mean values of unmanaged system and site 2 shows high potential for soil organic carbon production and also it was observed that the soil organic carbon production decreases with increase in soil depth or the surface soil had significantly higher organic carbon than the sub surface soil, this is due to the fact that more and more litter got accumulated near the tree trunk with advancement of growth. The continuous addition of higher amount of litter in the soil resulted in higher organic carbon content than sub surface. These results are well supported by the findings of Saralch (1994), Banerjee and Badola (1980), Gupta *et.al.* (1991) and Kaushal (1992)

The interaction studies (Table 4.11) of systems and sites showed significant variation with respect to soil organic carbon. The unmanaged system of site 2 (S2U) having significantly higher value in comparison to other two sites.

Table 4.11: Interaction effect of managed and unmanaged systems and different tea based agroforestry sites on soil organic carbon stock (t /ha).

System	Soil depth	0-10cm	10-20cm	20-30cm	30-40cm	Mean
Site 1	M	28.17	24.07	21.94	19.98	23.54
	U	29.00	26.90	23.70	21.00	25.15
Site 2	M	28.80	24.70	22.50	20.40	24.10
	U	29.50	27.01	26.80	22.20	26.37
Site 3	M	28.30	24.40	22.00	11.70	21.60
	U	29.80	27.50	25.40	20.20	25.72
CD (P=0.05)		0.02	0.05	0.06	0.06	

Similar vertical distribution pattern of organic carbon with depth has been reported by Nair and Chamuah (1988), Minhas *et al.* (1997), Krishnan *et al.* (2004) and Sharma *et al.* (1996).

4.4.4 Soil organic carbon pool inventory

Soil organic carbon pool inventory for a particular system was determined by multiplying bulk density, organic carbon and depth. The mean of managed and unmanaged systems revealed that the soil organic carbon pooling in unmanaged system was significantly higher (251.5 t/ha) than managed system (235.60 t/ha) and in case of sites S2U have maximum value (258.27 tonnes/ ha) of carbon pool then S1 and S2 (Table 4.12).

Table 4.12: Effect of tea based agroforestry system on soil organic carbon pool (t / ha)

Depth		0-10cm	10-20cm	20-30cm	30-40cm	Mean
System						
Site 1	M	282.00	241.00	219.40	200.00	235.60
	U	290.00	269.00	237.00	210.00	251.50
Site 2	M	288.00	247.00	225.00	204.00	241.00
	U	295.00	250.10	268.00	220.00	258.27
Site 3	M	283.00	244.00	220.00	117.00	216.00
	U	298.00	275.00	254.00	202.00	257.25
CD(P=0.05)		0.34	0.03	0.02	0.19	

Soil organic carbon pool varies with the depth of soil profile and was determined by taking into account bulk density and soil organic carbon. The increase or decrease in soil organic pool is associated with bulk density and organic carbon content of soil. The soil organic carbon pool decreases with increase in soil depth, the higher accumulation of soil organic carbon is due to incorporation of leaf, litter, and addition of decomposed root to upper layer. The similar result is in line with the findings of Carlos ^{et al.} (2001), Nair and Chamuah (1988) and Minhas (1997).

4.5 Carbon stock

Carbon stock at 0-20 cm profile depth was found to be significantly higher than at soil depth 0-40cm. Table 4.13 indicates that total carbon stock increases when profile depth was 0-20 cm instead of 0-40 cm. Here managed system shows significantly high stock of carbon. These results are in conformity with the findings of Lal *et al.* (1998)

Total carbon stock (plant + soil) was highest in S3U system whereas in S1M it was lowest at 0-20 cm soil profile depth. Whereas at 0-40 cm depth highest plant + soil carbon stock was in S2U and lowest in S1M. This table also

Table 4.13: Carbon stocks under different Tea based agroforestry system up to 20 cm profile depth (t / ha)

System/ component	S1M	S1U	S2M	S2U	S3M	S3U
Plant carbon stock	30.02	27.51	35.23	31.42	34.28	31.00
Soil carbon stock	52.24	72.5	53.50	73.40	52.70	81.70
TOTAL	82.26	100.01	88.73	104.80	86.98	112.70
Soil : Plant	1.74	2.63	1.51	2.33	1.53	2.63

shows that total carbon stock was maximum at 0-20 cm profile depth. It is clear from the table that the carbon stock present in the soil was due to regular addition of biomass in the surface soil which favoured high production of soil carbon. These results are further support the findings of Rao *et al.* (1998) and Kumar *et al.* (2003).

The plant- soil ratio table 4.13 and 4.14 shows that plant biomass contained less amount of Carbon than that of soil and soil-plant ratio was greater than 1. These results are supported by Kumar (2003).

Table 4.14. Carbon stocks under different Tea based agroforestry system up to 40 cm profile depth (t / ha)

System/ Component	S1M	S1U	S2M	S2U	S3M	S3U
Plant carbon stock	30.02	27.51	35.23	31.4	34.28	31.0
Soil carbon stock	41.92	55.4	42.9	57.0	33.7	45.64
TOTAL	71.94	82.9	78.13	88.4	67.98	76.64
Soil : Plant	1.39	2.01	1.21	1.81	0.98	1.47

It is observed in the Table 4.15 that the above ground carbon stock was significantly higher in S2M followed by S3M and S1M whereas S3U and S2U having almost equally distributed carbon. S1U shows significantly lower carbon. In case of below ground the maximum carbon present in S2U followed by S3U and S1U which shows almost same carbon. Lowest carbon was found in S3M.

Table 4.15 Total Carbon stocks in different tea based agro forestry systems (t / ha)

System/ component	S1M	S1U	S2M	S2U	S3M	S3U
Above ground						
Tree	21.06	19.62	24.75	21.91	24.21	21.6
Crop	7.75	6.32	9.00	7.74	8.68	7.20
Grass	0.00	0.72	0.00	0.92	0.00	0.81
Litter	1.21	0.85	1.48	0.85	1.39	1.39
TOTAL(A)	30.02	27.51	35.23	31.42	34.28	31.0
Below ground						
Soil(0-10cm)	28.17	40.73	28.80	41.30	28.30	40.70
Soil(10-20cm)	24.07	31.80	24.70	32.21	24.44	41.00
Soil(20-30cm)	21.94	25.75	22.53	26.83	22.02	25.40
Soil (30-40cm)	19.98	29.71	20.41	30.25	11.73	20.20
TOTAL(B)	94.16	127.99	96.44	130.69	86.49	127.30
Total (A+B)	124.18	155.41	131.63	161.82	120.69	158.30



SUMMARY
AND
CONCLUSIONS

5. SUMMARY AND CONCLUSIONS

The present investigation entitled “Carbon profile of the tea based Agroforestry system of Kangra Valley in Himachal Pradesh” were undertaken during the year 2008-09 at different locations in and around Palampur. The brief detail of the same is as under

Estimation of Species diversity

Phytosociological exercise were undertaken for determining the Importance value Index(IVI) and species diversity in the selected quadrates for calculating Relative Density (RD), Relative Frequency (RF) and Relative Dominance(RDo) of various species and it was found that the most frequently occurring species were *Albizia chinensis*, *Melia azaderach* and *Toona ciliata* representing high value of IVI. *Albizia* sp. had the maximum frequency at all the three sites in both the systems (Table 4.1). On the basis of IVI index different components of Agroforestry were made for the biomass estimation.

6.2 Biomass estimation of different components of Agroforestry system

All the tree components , tea bushes, shrubs and grasses were taken for biomass estimation and biomass was calculated by the non-destructive method. It was observed from the results that different agroforestry system i.e. (Managed(U) and unmanaged (U)) and sites (S1, S2 and S3) the maximum above ground biomass was present in managed system and Site 2 (S2). Thus in interaction S2M was better for biomass production in comparison to unmanaged(U) system and remaining other sites (Table 4.2 & Table 4.3)

6.3 Soil physico-chemical properties

Bulk Density

Bulk density was higher in managed system and Site 2 (S2) and it was found that bulk density increase with increase in soil depth (Table 4.6). The value of bulk density was lowest at 0-20 cm soil depth and highest at 30-40 cm soil depth (Table 4.7).

Soil organic carbon

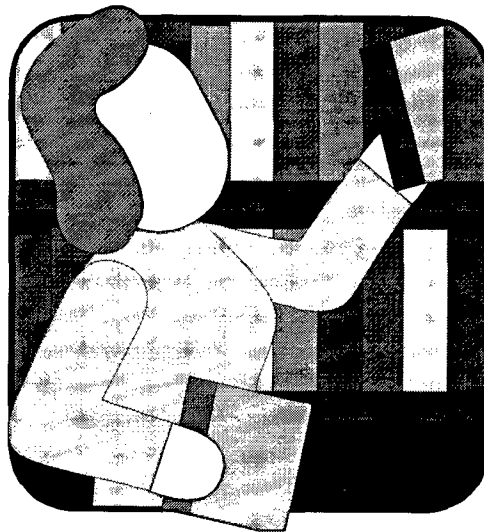
Soil organic carbon was calculated higher under unmanaged system as comparison to managed system. It was found that the soil organic carbon in surface soil was maximum where as at 30-40 cm depth it was minimum (Table 4.8). It showed that the soil organic carbon decrease with increase in soil depth and unmanaged system of site 2 (S2U) contained maximum soil organic carbon pool (Table 4.9).

Total carbon stock

The total stock i.e. (plant + soil) was highest in unmanaged system of Site 3 (S3U) whereas lowest in managed system of Site 1 (S1M) at 0-20 cm soil depth. The highest carbon stock (plant + soil) was maximum in unmanaged system of site 2 (S2U) and minimum in managed system of site 2(S2M) which showed that total carbon stock was maximum at 0-20 cm soil depth and minimum at (30-40 cm) soil depth profile carbon profile (Table 4.13 & Table 4.14).

Conclusion

It can be concluded from the studies that carbon assimilation in the form of biomass is at its best when the agroforestry systems are kept managed, on the other hand the organic carbon in the soil assimilates well when the system is unmanaged this can be attributed to the leaf and litter fall at the soil surface which decay and decomposes there thus results in enhancement of the soil organic carbon. It is revealed in the data that as we go deeper in the soil the soil organic carbon goes on reducing.



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