# CARBON SEQUESTRATION IN TOONA BASED AGROFORESTRY SYSTEM OF KANGRA VALLEY OF HIMACHAL PRADESH

**THESIS**

*By*

**MANSHI MEHTA**

**(S-2017-30-007)**

***Submitted to***

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

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**Partial fulfilment of the requirements for the degree**

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**(DEPARTMENT OF BIOLOGY AND ENVIRONMENTAL SCIENCES)**
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**Dr. Rajesh Uppal**
Professor

Department of Biology and Environmental Sciences
CSK Himachal Pradesh Krishi Vishvavidyalaya
Palampur-176062 (H.P.) India

# CERTIFICATE – I

This is to certify that the thesis entitled **"Carbon Sequestration in Toona based Agroforestry System of Kangra Valley of Himachal Pradesh"** submitted in partial fulfillment of the requirement for the degree of **Master of Science (Basic Sciences)** in the discipline of **Environmental Sciences** of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur is a bonafide research work carried out by **Manshi Mehta (S-2017-30-007)** daughter of Smt. Sapna Devi and Sh. Ranvir Singh under my supervision and that no part of 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.

Place : Palampur
Dated : , 2019

**(Dr. Rajesh Uppal)**
**Major Advisor**

# CERTIFICATE- II

This is to certify that the thesis entitled **"Carbon Sequestration in Toona based Agroforestry System of Kangra Valley of Himachal Pradesh"** submitted by **Manshi Mehta (S-2017-30-007)** daughter of Smt. Sapna Devi and Sh. Ranvir Singh to CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur in partial fulfillment of the requirement for the degree of **Master of Science (Basic Sciences)** in the discipline of **Environmental Sciences** has been approved by advisory committee after an oral examination of student in collaboration with an External Examiner.

(Dr. Rajesh Uppal)
Chairperson
Advisory Committee

( )
External Examiner

(Dr. R.C Chauhan)
Member

(Dr. Nageswer Singh)
Member

(Dr. R.K. Mittal)
Dean's nominee

Head of the Department

Dean, Postgraduate Studies

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***Place: Palampur*** ***(Manshi Mehta)***
***Dated: , 2019***

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# LIST OF ABBREVIATIONS USED

| Abbreviations | Meaning |
|---|---|
| BD | Bulk Density |
| C $ha^{-1}$ | Carbon per hectare |
| C $ha^{-1}yr^{-1}$ | Carbon per hectare per year |
| $^{o}C$ | Degree celsius |
| CD | Critical difference |
| $CH_4$ | Methane |
| cm | Centimeter |
| $CO_2$ | Carbon dioxide |
| DBH | Diameter at breast height |
| EC | Electrical conductivity |
| g | Gram |
| g $cm^{-3}$ | Gram per centimeter cube |
| GHGs | Greenhouse gasses |
| Gt | Giga tonne |
| G $Kg^{-1}$ | Gram per kilogram |
| Ha | Hectare (10,000 $m^2$) |
| IPCC | Intergovernmental Panel on Climate Change |
| Km | Kilometer |
| Kg C $m^{-2}$ | Kilogram carbon per meter square |
| LULUC | Land-use and landuse changes |
| m | Meter |
| M sl | Meter sea level |
| M ha | Million hectare |
| Mg $ha^{-1}$ | Mega gram per hectare |
| Mg C $ha^{-1}$ | Mega gram carbon per hectare |
| Mg C $ha^{-1}$ $yr^{-1}$ | Mega gram carbon per hectare per year |
| NFTs | Nitrogen fixing trees |
| $N_2O$ | Nitrous oxide |
| NOC | Net organic carbon |
| NPP | Net primary productivity |
| OC | Organic carbon |
| Pg | Peta gram |
| Pg C | Peta gram carbon |
| Pg c $yr^{-1}$ | Peta gram carbon per year |
| SIC | Soil inorganic carbon |
| SOC | Soil organic carbon |
| SOCD | Soil organic carbon density |
| t $ha^{-1}$ | Tonne per hectare |
| t c $ha^{-1}yr^{-1}$ | Tonne carbon per hectare per year |
| Tg | Tera gram |
| % | Per cent |
| UNFCCC | United Nation Framework on Convention on climate change |

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**Department of Biology and Environmental Sciences**
**CSK Himachal Pradesh Krishi Vishvavidyalaya**
**Palampur-176 062 (H.P) India**

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## ABSTRACT

The present investigation entitled "Carbon Sequestration in Toona based Agroforestry System of Kangra Valley of Himachal Pradesh" was undertaken during the year 2018-19 at different locations of Palampur. Phytosociological exercises were undertaken for determining the Importance value Index (IVI) along with the species diversity in the selected quadrates. It was found that the most frequently occurring species were *Toona ciliata, Albizia chinensis* and *Melia azaderach* with maximum IVI value of 130.2, 97.3 and 46.7 in the unmanaged system and 170.6, 131.5 and 60.4 in the managed system. 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 (1.06 g $cm^{-2}$) and it was found that bulk density increased with the increase in the soil depth. Soil organic carbon was calculated higher under unmanaged system (2.43%) in comparison to managed system (1.89%). The total carbon stock i.e. (plant + soil) was higher in unmanaged system (100.02 t $ha^{-1}$). 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.

**(Manshi Mehta)**
**Student**
**Date: , 2019**

**(Dr. Rajesh Uppal)**
**Major Advisor**
**Date: , 2019**

**Head of the Department**

# 1. INTRODUCTION

Carbon sequestration is the process involved in carbon capture and the long-term storage of atmospheric carbon dioxide or other forms of carbon to mitigate or defer global warming. It has been proposed as a way to slow the atmospheric and marine accumulation of greenhouse gases, which are released by burning fossil fuels. Carbon dioxide ($CO_2$) is naturally captured from the atmosphere through biological, chemical, and physical processes.

Carbon on earth has primarily four major reservoirs: geological formations and fossils; the atmosphere; the oceans and the terrestrial ecosystems (Melillo *et al*., 1993, Prentice *et al*., 2001). Carbon dioxide ($CO_2$) is the primary greenhouse gas (GHG) mainly responsible for increasing the global average temperature where concentration in the atmosphere has increased from 280 ppm in 1750 to 441 ppm by 2014 (NOAA, 2014).

There are two general approaches to put the carbon cycle back into balance: changing activities which have resulted in imbalance and expanding sinks to draw carbon from the atmosphere. In the developing world, it is difficult to reduce emissions because it involves cost and slow down the developmental activities. However, we need to plan carbon storage in different pools (Sedjo and Sohngen, 2012).

Carbon in land-use systems consists of biomass and the soil carbon pools. The biomass pool includes living aboveground and belowground biomass, litter and deadwood. Biomass is also considered as most important carbon sinks of the terrestrial ecosystem which serve as an important means of sequestering atmospheric $CO_2$ (Ravindranath and Ostwald, 2008). About four times the amount of carbon present in our atmosphere is stored in terrestrial ecosystems, where-of, about one-third is stored aboveground and remaining two-third belowground (Watson *et al*., 1998; IPCC, 2006; Nair *et al.*, 2009).

Forests play a critical role in global carbon cycle as growing trees remove carbon dioxide from the atmosphere through photosynthesis and have potential to sequester carbon, thus, form an important climate change mitigation option (Kumar and Singh, 2003). The undisturbed forest ecosystems are generally highly productive, which accumulate more biomass and carbon per unit area compared to other land-use systems like agriculture and agroforestry.

Theoretically, trees are considered to be the major part of global carbon sink, which involves minimum cost due to natural process of photosynthesis. Consequently, the managed forests can conceptually sequester/store carbon both *in-situ* (soil and biomes) and *ex-situ* (end products as finished products). The rationale for carbon inventory methods is to estimate emissions or removal of $CO_2$ from biomass and soil or changes in carbon stocks from a given land-use system resulting from human interventions such as Land-use and landuse changes (LULUC), felling/ removal of biomass, afforestation, reforestation, forest conservation, burning of above and belowground biomass, soil disturbance leading to reduction in soil organic matter, deep ploughing / tillage and other management practices. Carbon inventory is not directly aimed at climate change mitigation, however, required for activities related to climate change in land-use sector.

Land-use systems (forests, agroforestry, horticulture and agriculture) are critical in stabilizing $CO_2$ concentration in the atmosphere as they offer large mitigation potential besides providing multiple sustainable benefits such as biodiversity conservation, watershed protection, increased crop and grass productivity for stakeholders (Rabindranath and Ostwald, 2008). Different land-use systems like agriculture, forestry, horticulture and agroforestry can sequester varying amount of atmospheric carbon that significantly influence organic carbon dynamics and carbon flux of the soil (Tian *et al.,* 2002). The agriculture land-use system contributes to the net out-flux of methane, nitrous oxide and carbon dioxide generated from the terrestrial biosphere. Such fluxes have substantially increased mainly due to catering of large human and cattle populations, increased incidents of stubble burning and rampant use of nitrogen fertilizer.

Agroforestry systems have potential to sequester carbon through enhanced growth of trees and shrubs. It has been found that the overall (biomass) productivity, soil fertility, soil conservation, nutrient cycling, microclimate improvement and carbon sequestration potential of an agroforestry system are usually better than that of an annual cropping system (Dhyani *et al.*, 2009).

Also, agriculture land-use system can sequester carbon when organic matter accumulated in soil or belowground woody biomass act as a permanent sink or used as an energy source that substitute fossil fuels (Ball and Pretty, 2002). The total biomass carbon on agricultural land is 11.08 Pg C and average biomass carbon is 5t C $ha^{-1}$ globally, excluding the contribution by trees to biomass carbon on agricultural land (Zomer *et al*., 2016).

Soils hold the largest pool of terrestrial carbon (Scharlemann *et al*., 2014) and play very crucial role in the global carbon balance. Soil organic carbon (SOC) stocks are estimated to be 1,500 ± 230 Gt C in the first meter of soil, which is nearly twice as much as atmospheric carbon i.e. 828 Gt C as CO2 (LeQuere *et al*., 2016). Globally, the carbon stocks in soil are nearly five times more than present in vegetation and their ratio varies from 1:1 in tropical forests to 5:1 in boreal forest with much larger factor in grasslands and wetlands (IPCC, 2006).

The SOC pool up to 1m depth ranges from 30 t $ha^{-1}$ in arid climate to 800 t $ha^{-1}$ in organic soils in cold regions, and a predominant range of 50 to 150 t $ha^{-1}$ (Lal, 2004). The depletion of SOC pool deteriorates soil quality, diminishes biomass productivity and such depletion is likely to be aggravated in future by the anticipated global warming.

In this background, present study of **Carbon Sequestration in Toona Based Agroforestry System of Kangra Valley of Himachal Pradesh** was carried out with the following objectives:

i. To assess the contribution of Agroforestry on Carbon stock.

ii. To quantify and compare soil physical and chemical parameters under existing land use system.

# 2. REVIEW OF LITERATURE

As a major carbon pool on earth, soil organic carbon may act either as a sink or a source of atmospheric $CO_2$. The soils of the world contain more carbon than the combined total amounts of carbon occurring in vegetation and the atmosphere (Eswaran *et al.* 2000). Globally, 1576 Pg of C is stored in soils, with approximately 506 Pg (32%) of this is in soils of the tropics. Shreshta *et al*. (2006) observed that the total carbon (TC) storage in uncultivated, < 10-year cultivated and > 50-year cultivated soil was 38, 25 and 19 Mg $ha^{-1}$ in subtropical climate, respectively. Different land uses have different potentials for carbon sequestration due to differential SOC and aggregation dynamics. The mass distribution of SOC within different sized aggregates varies with time and space in interaction with land use system as well as soil management (Six *et al.* 1999). Different SOC fraction viz. labile carbon, particulate organic carbon, hot water extractable carbon, aggregate associated carbon, rather than total SOC, respond very rapidly to land use change and thus could be used as an important indicator of critical soil functions.

The work pertaining to the objectives of the study have been discussed in this chapter under the following heads:

2.1. Species Diversity: Importance Value Index (IVI)

2.2. Soil physico-chemical properties

2.3. Biomass Estimation

2.4. Biomass Carbon Stock Determination

2.5. Soil Organic Carbon Stock

2.6. Soil Organic Carbon Pool

## 2.1. Species Diversity: Important Value Index (IVI):

Many authors have shown that traditional Agroforestry practices contribute to the conservation of biodiversity through *in situ* conservation of tree species on farms, reduction of pressure on remnant forests, and the provision of suitable habitat for a number of plant and animal species on farmland (Atta-Krah *et al*., 2004; Acharya, 2006; McNeely and Schroth, 2006).

Kumar and Bhatt (2006) conducted an experiment on floristic diversity, dominance and abundance to frequency ratio of tree, sapling, seedling, and shrub and herb species. They observed that the dominant species recorded on both the sites were *Lannea coromandelica* (IVI-39.80) and *Anogeissus latifolia* (IVI 29.50) respectively. The ranges of diversity for tree layers were 4.580 to 4.643. Most of the species on both the sites were contagiously distributed except few species which were distributed randomly.

Khan (2007) undertook a study to assess the status of vegetation in Shankaracharya Reserved Forest of Kashmir Valley and reported that among tree species, *Cedrus deodara* recorded maximum density (107.5), frequency (100), abundance (74) and IVI (164.5) in north-west aspect-I. In north-east aspect II, *Robinia pseudoacacia* registered maximum density (6.5), frequency (50), abundance (13) and in south-east aspect-III, *Cupressus torulosa* recorded maximum density of 36, frequency (100) and abundance (72). In both aspects i.e. II and III *Cedrus deodara* registered maximum IVI (96.99) and 120.87 respectively. Among shrubs, *Jasminum humile* was the dominant with IVI (166.65) and (149.57) in the north-west and south-east respectively. In the northeast, *Rosa webbiana* registered density (5.75), frequency (25), abundance (23) and IVI 300.

A comparative study was conducted at two different ecosystems that is, site I (pastureland) and site II (forest) in the lower Dachigam National Park of Kashmir, Himalaya, India (Shameem *et al*. 2010). The pasture site was located outside the National Park and is under grazing whereas forest site is located inside the National Park and is protected. The study was done on seasonal basis and the average results revealed comparatively more or equal values of diversity (H’) for both sites (site I = 2.435 and site II = 2.395) while dominance index showed higher value at site I (average = 0.147). The richness index (average = 3.842) and equability index (average = 0.90) both showed higher value at site II. Seasonal trend of Shannon diversity (site I = 3.03, site II = 2.87), richness index (site I = 3.70, site II = 5.83) and evenness or equability index (0.94, site I and II) depicted highest value during summer season whereas lowest variation in Shannon diversity and richness index was observed in winter season at both sites. However, dominance index was recorded lowest in summer season at both sites (site I = 0.06 and site II = 0.07) hence inversely related to diversity (H'). The frequently occurred dominant species during prominent seasons based on importance value (IVI) were *Cynodon dactylon*, *Salvia moorcroftiana* and *Thymus serphyllum* at site I and *Fragaria nubicola*, *Galinsoga parviflora*, *Stipa sibirica* and *Viola indica* at site II. The abundance to frequency ratio (A/F) indicated most of the species performed contagious pattern of distribution.

Shameem and Kangroo (2011) conducted a study to investigate the comparative assessment of edaphic factors and phytodiversity of herbaceous vegetation on seasonal basis spring (March to May), summer (June to August), autumn (September to November) and winter (December to February), at two different ecosystems in lower Dachigam National Park, Kashmir Himalaya, India. The results indicated edaphic factors were highest at site II (MC, 35.55%), (OC, 4.73%) and (TN, 0.36%). pH showed acidic to nearly alkaline kind of nature at both sites with site I at higher side (5.95 to 7.52). Phytodiversity revealed site II comparatively higher in Shannon diversity and species richness during summer season (3.66, 7.92). However, evenness index showed similar trend with equal value at both sites (0.94). Dominance showed an inverse relationship to diversity (H′). Species at both sites were contagiously distributed followed by random one whereas regular distribution was almost negligible. The study concluded that seasons had great influence on edaphic factors and species diversity. An increase in species diversity was observed during spring and summer season which declined thereafter as autumn and winter approached resulted in decrease in diversity due to multitude of factors.

The phytosociological attributes of western Himalayan moist temperate forests were investigated by Shaheen *et al*. (2012) in Bagh district, Kashmir. Species diversity and community structure patterns were significantly correlated to environmental variables including altitude and slope inclination as well as intensity of anthropogenic pressure. *Abies pindrow* and *Pinus wallichiana* showed exclusive dominance comprising 30 per cent of IVI weightage of all 122 recorded species. Forest ground flora was dominated by grasses of the Poaceae. Average tree density was 151 ha whereas basal area was estimated at 68.8 $m^2$ $ha^{-1}$. A stem/stump value of 1.62 indicated immense tree felling and logging pressure on local forests. A disturbed forest regeneration pattern was indicated by an average seedling count of 124 ha. A negative correlation was found between diversity and richness with altitudinal gradient as well as slope and aspect.

The study conducted by Hashemi *et al*. (2013) in home gardens of two eco-geographically different areas in Gachsaran, south-western Iran to evaluate crop species diversity. Shannon-Weiner diversity index for this group was up to 1.5 in all villages on the hilly-plain compared to an evaluation of less than 1 in all villages in the mountainous ecology.

Amjad *et al*. (2014) undertook a vegetation study in a traditionally managed mountain woody pasture in Nikyal valley, Rawalpindi, Pakistan to investigate the patterns of species diversity, and regenerating capacity in relation to environmental variables and underlying anthropogenic influence during July 2012 to June 2013. Density, frequency and basal cover were recorded. Then diversity, its components and regenerating capacity were also calculated. Shannon's diversity ranged from (2.75 to 3.31), Simpson's diversity (0.90 to 0.95), Menhinicks diversity (0.83 to 1.19), evenness (0.41 to 0.65), species richness (4.89 to 6.08) and species distribution pattern (30 to 44). *Pinus roxburghii* was the only regenerating species among four other species i.e. *Quercus dilatata*, *Prunus persica*, *Punica granatum* and *Olea ferruginea*, which were at extreme risk of elimination due to anthropogenic factors.

Sahoo and Rocky (2015) studied species composition and plant diversity in homegardens of Mizoram homegardens. Shannon and Simpson‘s diversity indices were used in the study. About 351 plant species belonging 101 families were found in 92 home gardens. Shannon index of diversity showed that higher diversity of shrubs found in the lower elevation while Simpson‘s index value found to be lowest.

Floristic structure, composition and functional characteristics of homegardens were studied by Rana *et al*. (2016) in the Garhwal region. They had selected two districts on the basis of maximum (Uttarkashi) and minimum (Rudraprayag) geographical area of the state. The result showed that floristic tree diversity was maximum contributed by agroforestry crops (64% 53.84%, 62.5%, 66.7%) and followed by horticulture crops (36%, 46.16%, 37%, and 33.3%) with respect to Malkhi, Khumera, Kurura and Panchan gaun village respectively. It is observed that 35 species of trees (forest trees+ fruit trees), 18 species of agriculture crops, 13 species of vegetable crops, 9 species of grasses and 13 species of shrub were identified by them from the study area.

Shukla *et al.* (2017) studied that plant diversity, structure and uses of plants in Homegardens of Jharkhand. A total of 116 species representing 50 families and 102 genera were documented in this study. Dominating family recorded in the gardens was Fabaceae with 20 species. They classified plant species in home garden as four strata in which the first strata consist of annuals and herbaceous plants (vegetables, medicinal and ornamental). Out of the total documented species, leaves of the 44 species were used followed by fruits (31 species), flowers (25 species) and at least one species each for bulb, culm, bark, pods and stem. Majority of the plant species were used as vegetables (51 species) followed by traditional medicines (30 species) and at least with two species each for house construction, furniture and agricultural implements. This study presented the baseline data about plant diversity in the home gardens, uses of plants and arrangement of the plants in the home gardens.

**2.2. Soil physico-chemical properties:**

Ghuman *et al.* (1997) reported that continuous green manuring of sunhemp significantly increased soil water retention and decreased the bulk density. In situ incorporation of sunhemp reduced the bulk density as compared with fertilizer application. Similarly, improvement in the infiltration rate, water stable aggregates, porosity, field capacity and maximum water holding capacity under dry lands was observed due to application of sunhemp incorporation with fertilizers (Bellaki and Badanur, 1997).

Mongia *et al.* (1998) studied the ameliorating effect of forest trees on highly sodic soils in Haryana. They found that by growing *Acacia nilotica* for more than three years the pH, electrical conductivity and $CaCO_3$ content of the soil were lowered while organic matter, Fe and Mn content increased. Phogat *et al.* (1999) studied soil properties under *Acacia tortilis* in arid region of Haryana. *Acacia sp.* plantation was found to considerably increase the organic matter but decreased soil pH in 10 to 15 cm soil depth.

Thakare *et al.* (2005) conducted long term change in soil properties and nutrient availability under sorghum-wheat cropping sequence at Dr. PDKV, Akola. The results revealed that the pH of the soil ranged between 7.6 to 8.1 and electrical conductivity varied from 0.27 to 0.32dSm$^{-1}$ and which was non-significant.

Dwivedi *et al.* (2007) observed that decrease in soil pH due to continuous application of inorganic fertilizers having residual acidity. It however remained almost unchanged if fertilizers were used along with organic manure (FYM) might be due to stabilizing effects of FYM.

Saroj Mahajan and Dilip Billore (2008) Carried out work on the study of physicochemical parameters like pH, specific conductivity, chloride, total alkalinity, calcium, magnesium nitrate, sulphate, phosphate sodium and potassium from July 2008 to June 2009. During the study year fluctuation was observed in several parameters. Investigation results showed that the soli was alkaline throughout the study year. The productivity of an ecosystem depends upon the quality of soil. Some parameters were above permissible limit and some below the permissible limit which affects the quality and productivity of pond soil.

Prasad *et al.* (2010) compared the effect of nutrient application through inorganic and organic sources in rice-wheat cropping sequence and found that soil pH was marginally higher in treatments where integration of inorganic and organic fertilizers and manures was done.

Parvathi *et al.* (2013) reported that soil pH was not affected significantly by different treatments of integrated nutrient application. Highest (7.6) value was recorded in 100% NPK + FYM where as the lowest (7.3) value was recorded in 50% NPK + FYM. A slight decrease in soil pH was observed in all the treatments as compared to the initial (7.7) value which was ascribed to the acidifying effect of acids during decomposition of organics.

Jadhao *et al*. (2014) found an increased in soil pH under all the treatments of inorganic fertilizers application except that integrated with FYM (100% NPK + FYM @ 10 t ha$^{-1}$) where it was decreased.

Agarwal *et al*. (2014) reported that continuous application of nitrogen alone as urea reduced the soil pH by 0.8 units in 38 years under soybean-wheat system. They further reported that addition of FYM (15 t $ha^{-1}$ $yr^{-1}$) stabilized the soil pH and maintained a higher soil organic carbon status.

Challa *et al*. (2015) assessed the impact of continuous application of chemical fertilizers and manures on soil pH in a long term experiment and stated that soil pH was not affected significantly by the application of 150% NPK or 100% NPK+FYM treatments.

**2.3. Biomass Estimation:**

Production of biomass (aboveground, belowground and total biomass) by different components of the system is mainly affected by age of the perennial woody component, nature and distribution of different components of the system and other abiotic factors. Nayak (1996) also reported that the system above-ground biomass production was influenced due to species composition and distribution. Different management practices for perennial woody species such as training, pruning and other cultural practices for annual crops also affect the biomass production in agroforestry systems (Deshmukh 1998). Whereas efficient use of limited resources for maintaining higher photosynthetic activities, leaf area index, better light interaction and water use efficiency were the biomass governing factors reported by Sehgal (1999) and Huxley (1983).

Silvi-pasture recorded highest above-ground carbon (59.40 t $ha^{-1}$), belowground carbon density (12.23 t $ha^{-1}$) and total vegetation carbon density (71.63 t $ha^{-1}$), whereas highest soil organic carbon (56.70 t $ha^{-1}$) from agri-silvi-horticulture. Soil organic carbon in grasslands and tree based systems not showed too much difference. An intensive root cycling system, which has great content of lignin, is responsible to store organic carbon in soil by grassland equivalent to the other tree based systems (Lugo *et al*., 1992; Tornquist *et al*., 1999; Martens, 2000).In the long-term, areas under grasslands have similar potential to store total organic carbon as areas under tree-based systems (Franzluebbers *et al*. 2000).

In an experiment, Kumar (2003) studied five agroforestry systems viz., horti-pastoral, silvi-pastoral, agri-horticulture, agri-silviculture, agri-horti-silviculture and natural grassland in mid hill conditions of Himachal Pradesh. Different land-use systems had significant variation in their total biomass production potential. Biomass production potential of hortipastoral, silvi-pastoral, agri-silviculture, agri-horticulture and agri-horti-silviculture was 3.15, 10.31, 3.55 and 3.97 times higher over natural grassland, respectively. The silvipastoral (59.72 t $ha^{-1}$) system produced the highest biomass followed by Agri-horti-silviculture system despite having lesser number of trees, whereas minimum was (5.79 t $ha^{-1}$) in natural grassland.

Sanneh (2007) reported that maximum aboveground biomass (308.96 t $ha^{-1}$), belowground biomass (62.09 t $ha^{-1}$) and total biomass (371.06 t $ha^{-1}$) was in the forest landuse system. It was followed by silvi-pasture, agri-silvipasture, agri horticulture, agriculture and grassland systems, respectively under different land-use systems in wet temperate north western Himalayas at different altitudinal gradients.

Minj (2008) studied the biomass production potential of different land-use systems in low and mid hills of Himachal Pradesh and reported maximum mean aboveground biomass (188.60 t $ha^{-1}$), belowground biomass (49.04 t $ha^{-1}$) and total biomass (237.70 t $ha^{-1}$) in pure poplar plantation, followed by agroforestry, agriculture and pure grassland systems, respectively.

Singh and Lodhiyal (2009) evaluated the biomass and carbon production potential in 8-years old agroforestry based *Populus deltoides* plantation in Tarai region of central Himalaya. They observed that the total biomass of plantation was 202.59 t $ha^{-1}$ and the aboveground components contributed 78.68 per cent and belowground biomass contribution was 21.32 per cent to the total biomass.

In an experiment, Kumar *et al.* (2011) estimated the biomass and net primary productivity of different age (5, 10 and 15 year old) grouped *Butea monosperma* forest ecosystems in western India. It was found that the tree biomass and net primary productivity increased with increasing age of the forest stand, whereas the herb biomass and net primary productivity decreased significantly with increase in the forest age. The all values of biomass and NPP of trees, shrubs and herbs were low in 5-year-old, moderate in 10-year-old and high in 15-year-old forest stands. The total forest biomass increased from 190.7 t $ha^{-1}$ in the 5-year-old to 306.3 t $ha^{-1}$ in 15-year-old forest. The tree biomass increased with age of forest stand from 183.7 to 298.3 t $ha^{-1}$.

The assessment of biomass production, carbon storage and carbon dioxide mitigation potential of plantations of *Populus deltoides, Eucalyptus tereticornis, Dalbergia sissoo, Mangifera indica, Litchi chinensis* and *Prunus salicina* were assessed in different tree based systems of central Himalayan Tarai region by Kanime *et al*., (2013).The maximum total biomass (94.8 Mg $ha^{-1}$) was observed in a 10-year-old *D. sissoo* monoculture plantation, followed by an 8-year-old *P. deltoides* block plantation (63.0 Mg $ha^{-1}$). Carbon stocks ranged from 4.51 Mg $ha^{-1}$ in an 8-year-old *P. deltoides* boundary plantation to 43.39 Mg $ha^{-1}$ in *D. sissoo* plantation. The carbon sequestration rate for *P. deltoides* block and boundary plantations was estimated 2.75 and 0.43 Mg $ha^{-1}$ $year^{-1}$, respectively. *Eucalyptus* boundary plantation sequestered 0.84 Mg $ha^{-1}$ year $^{-1}$ while *D. sissoo* plantation sequestered 2.73 Mg $ha^{-1}$ $year^{-1}$. Among fruit trees, the highest sequestration rate was recorded in *M. indica* plantation, with 1.43 Mg $ha^{-1}$ $year^{-1}$.

Sharma and Kant (2014) conducted a study in sub-tropical forest of districts Jammu and Samba of J&K with the objective of determining floristic composition, species diversity and structure of woody vegetation in drier *kandi* Shivaliks. The vegetation analysis revealed the dominance of *Mallotus philippensis* (SIV%, 6.4), *Acacia modesta* (10.44%) and *Pinus roxburghii* (24.27%) as over storey elements in northern dry mixed deciduous forests, himalayan subtropical scrub and himalayan subtropical pine forest, respectively.

**2.4. Biomass Carbon Stock Determination:**

Indian soils are largely carbon depleted but can be brought back to their native carbon carrying capacity by reforestation. Moreover, wastelands in India cover more than 100 million ha of which 70 per cent is low in carbon. These soils have been reported to have relatively high potential for accumulating organic carbon in vegetation and soil by growing suitable trees along with proper soil conservation measures Rai and Sharma (2003).

Forests show the best mitigation potential followed by agroforestry, plantation and agriculture. Degradation of soil has its adverse effect on soil carbon which in the Asian region is caused by deforestation, industrialization, agricultural activities, overgrazing and over exploitation Jha and Gupta (2003). Also forest soils are one of the major carbon sinks on earth, because of their higher organic matter content Dev (2005).

Total organic matter accumulated in the soil constitutes a major portion of the world's fix carbon reserves. The distribution of organic matter among soil type is highly variable and generally not easily predictable from above ground vegetation type. Decreased soil carbon content with time in agricultural plot in arid region with a loss of SOC by 56 per cent during 5 years period was studied by Singh *et al*. (2005). He further reported that integration of trees reduced SOC loss which was 3.2 per cent under *Emblica officinalis,* 22 per cent under *Hardwickia binnata* and 35.5 per cent under *Colophospermum mopen* based agroforestry system as compared to 56 per cent under agricultural plots. Ramchandran *et al*. (2007) estimated 3.48 Tg soil carbon in the natural forests in Eastern Ghats of Tamil Nadu, India. The Himalayan zones, with dense forest vegetation, cover nearly 19 per cent of India and contain 33 per cent of SOC reserves of the country Bhattacharyya *et al*. (2008).

Kumar (2010) while studying the distribution, growth and biological yield potential of bamboos in Himachal Pradesh found organic carbon in the range of 2.43-3.0 per cent which decreased with increasing soil depth.

Sheikh *et al.* (2011) estimated wood specific gravity of different tree species (34 tree species) in Garhwal Himalayas. The average wood specific gravity was 0.631 (ranging between 0.275±0.01 and 0.845±0.03) for the species at lower elevations and 0.727 (ranging between 0.628±0.02 and 0.865±0.02) for the upper elevations. *Aegle marmelos* among the lower elevation species and *Quercus leucotrichophora* among the upper elevation species had the highest wood specific gravity, which were 0.845 ± 0.03 and 0.865 ± 0.02, respectively.

Ullah (2012) estimated above and belowground carbon stock in natural forests of Bangladesh. They observed that *Dipterocarpus turbinatus* has the highest total (aboveground and belowground) biomass and total carbon (81.42 and 45.40 t $ha^{-1}$, respectively). Among shrub species, the highest total biomass and total carbon stock (134.42 and 69.47 kg $ha^{-1}$, respectively) were found in *Melastoma melabathricum* and among the herbs and grass species, *Cynodon dactylon* contains the highest total biomass and total carbon (34,911 and 76.05 kg $ha^{-1}$, respectively).

Sundarapandian *et al.* (2013) estimated biomass and carbon stock of woody plants in different landuse systems (four plantations and a natural forest) at Puthupet, Tamil Nadu. The aboveground biomass in the study sites were 32.7, 38.1, 121.1, 143.2 and 227.2 Mg ha$^{-1}$in *Anacardium occidentale, Casuarina equisetifolia, Mangifera indica, Cocos nucifera* and natural forest, respectively. The maximum carbon stock was reported from the natural forest site (131.8 Mg ha$^{-1}$) while the minimum was from *Anacardium occidentale* plantation (19.5 Mg ha$^{-1}$). A significant positive relationship was observed between basal area with biomass and total carbon. The low values of biomass and carbon stocks in plantations may be due to less stand age structure.

Guleria *et al.* (2014) studied the effect of nitrogen fixing trees (*Acacia nilotica, Acacia auriculiformis, Acacia albida, Leucaena leucocephala, Albizia lebbeck, Acacia catechu, Dalbergia sissoo* and *Bauhinia variegata*) on the growth biomass, site amelioration and carbon sequestration. They opined that carbon stocks in above and belowground parts of *Dalbergia sissoo* were 145.2 and 42.12 t ha$^{-1}$, respectively which was closely followed by *Acacia albida.* Carbon dioxide mitigation potential of *Dalbergia sissoo* was maximum among all the species to the tune of 28.42 t ha$^{-1}$ yr$^{-1}$. They concluded that *Dalbergia sissoo* is the highest carbon sequestering species with maximum survival and growth in subtropical climate.

Zhao *et al.* (2014) examined the biomass and carbon pools in *Pinus tabuliformis* secondary forest stands in Northern China. The results showed that the tree biomass of *P. tabulaeformis* stands was ranged from 123.8 Mg ha$^{–1}$ for the young stand to344.8 Mg ha$^{–1}$ for the mature stand. The underground biomass ranged from 1.8 Mg ha$^{–1}$ in the middle-aged stand to 3.5 Mg ha$^{–1}$ in the young stand. Forest floor biomass increased steady with stand age, ranging from 14.9 to 23.0 Mg ha$^{–1}$. The highest mean carbon concentration across the stand was found in tree branch while the lowest mean carbon concentration was found in forest floor.

Justine *et al.* (2015) investigated the biomass stock and carbon sequestration across stand ages in *Pinus massoniana* plantations. The results revealed that plantation biomass increased with increasing stand ages, ranging from 0.84 tonnes per hectare (t ha$^{–1}$) in the three year stand to 252.35 t ha$^{–1}$ in the 42 year stand. The aboveground biomass (AGB) contributed 86.51%. Carbon concentrations and storage in soil decreased with increasing soil depth. The total ecosystem carbon storage varies with stand age, ranging from 169.90 t ha$^{-1}$in the five-year plantation to 326.46 t ha$^{-1}$ in the 42-year plantation, of which 80.29% comes from soil carbon and 19.71% from the vegetation.

Gautam and Mandal (2016) quantified biomass, production and carbon dynamics in moist tropical forest of eastern Nepal. Results revealed that total stand biomass in undisturbed forest stand were 960.4 Mg ha$^{-1}$ while in disturbed forest stand it was 449.1 Mg ha$^{-1}$. The biomass of trees, shrubs and herbs in undisturbed was 948.0, 4.4 and 1.4 Mg ha$^{-1}$, respectively, while in disturbed they were 438.4, 6.1 and 1.2 Mg ha$^{-1}$, respectively. Total carbon input into soil through litter plus root turnover was 6.78 and 3.35 Mg ha$^{-1}$yr$^{-1}$in undisturbed and disturbed, respectively.

Naeem *et al.* (2017) studied the rate of litter fall and decomposition in *Acacia modesta* dominated forest of Pakistan. It was revealed that the total amount of litter fall (including leaves, twigs and pods) in *Acacia modesta* dominated subtropical forest was 31.95 t ha$^{-1}$yr$^{-1}$. Annually the highest litterfall was in April to September (72–96%) while it was lowest (4-28%) between October to March.

**2.5. Soil Organic Carbon Stock:**

Batjes and Dijkshoorn (1999) reported the mean carbon densities to a depth of l m range from 4 kg m$^{-2}$ for coarse textured Arenosols to 72.4 kg m$^{-2}$ for the poorly drained Histosols of the Latin America. Mean carbon density for the mineral soils excluding Arenosols and Andosols (30.5 kg m$^{-2}$) was 9.8 kg m$^{-2}$. In total the top one m holds 66.9 Pg C and 6.9 Pg N. Approximately 52 per cent of the carbon pool was held in the top 30 cm of the soil layer which was most prone to changes upon land use conversion and deforestation.

Kumar (2003) while studying the various agroforestry systems of western Himalaya found that the SOC was maximum in surface soils (0-10 cm) which 15 decreased with depth and minimum was at 30-40 cm profile depth. The SOC content in 0-20 cm layer was found to be significantly higher than 20-40 cm layer (Sanneh, 2007). Minj (2008) also reported maximum SOC at 0-10 cm depth under various land use systems studied in low and mid hills of western Himalaya.

Verma *et al.* (2008) while studying the effect of slope aspects and altitude on SOC content on Himalayan soils observed higher SOC contents on northern than southern aspects. They correlated this effect with better vegetation cover on northern aspects.

Sharma and Kumar (2011) studied the hydro physical and chemical characteristics of soil under different land uses in Shiwalik hills of Himachal Pradesh. Different land uses were found to differ appreciably for organic carbon content distribution and among land uses, both grass (18.6-23.4 g kg-1) and forest lands (8.4-25.2 g kg-1) had comparatively higher organic carbon contents. All the land uses exhibited a consistent decreasing trend in organic carbon distribution with soil depth. The SOC content in 0.0-15 cm, 15-30 cm and 30-45 cm soil layers of forest land uses were reported to be 17.3 g kg-1, 15.5 g kg-1, 13.2 g kg-1, respectively. Addition of sufficient amount of organic matter i.e. roots and other plant remains in the upper layers were found to be responsible for comparatively higher organic carbon contents than sub-surface layer.

Iqbal *et al.*, (2014) carried out a research in Mymensigh (Bangladesh) to investigate the effects of present landuse and soil management practices on SOC accumulation. Different cropped land (single, double and triple cropped), agroforestry, fallow land and grass land were taken for determining SOC. Soil organic carbon varied significantly in different land-use pattern and soil management practices. Among all land-use patterns the highest SOC was found under agroforestry and the lowest was found under fallow land. Organic carbon dynamics highly regulated by organic fertilizer application and tillage operation.

A study was conducted by Koppad and Tikhile (2014) in Uttar Kannada district of Karnataka to assess the carbon sequestration in soils of different landuse systems viz., dense forest, sparse forest, plantation, agriculture and open land. He observed that among the different land-use classes, higher SOC was sequestered in horticulture plantations (361.05 t ha$^{-1}$) followed by dense forest (335.25 t ha$^{-1}$). The SOC in sparse forest and barren land is 239.39 t ha$^{-1}$ and 168.74 t ha$^{-1}$ respectively. The lowest SOC was recorded in agriculture land (76.50 t ha$^{-1}$). The $CO_2$ mitigation potential of horticulture plantation is 4.72 times higher followed by dense forest (4.38 times), sparse forest (3.13 times) and open land (2.21 times) as compared to agriculture land.

Venkanna *et al.* (2014) conducted an experiment to study the soil organic and inorganic carbon stocks under different land-use systems in Warangal district, Andhra Pradesh. Among the different land-use systems, total C stock was highest in forest soils followed by fodder system, paddy, maize, cotton, redgram, intercrop, chilli, permanent fallow and lowest in castor system. Soil nitrogen also followed similar trend as SOC stock. The total C stock was estimated 0.088 Pg out of which SOC stock was 77% and SIC stock was 23% for the district.

Melenya *et al.* (2015) carried out an experiment to assess soil organic carbon storage (SOC) under different land-use systems in Ghana. The soils were taken from a depth of 0-20 from a cocoa plantation, oil palm plantation, uprooted oil palm plantation and an arable land under cultivation (cassava + plantain). The land-use systems that sequestered more organic carbon and less $CO_2$ emission was ranked as: uprooted oil palm plantation followed by maize> oil palm plantation> cocoa under deep litter> cocoa under shallow litter> arable land> cocoa under weed. The $CO_2$ emission ranged between 17.4 to 65.9 % depending on the type of land-use.

Iqbal and Tewari (2017) undertaken a study in Achanakmar, Chhattisgarh to estimate soil carbon sequestration potential of four land-uses (forestland, grassland, agricultural land and wasteland) and five land covers (sal, teak, bamboo, mixed, open and scrub). The highest soil carbon storage potential was found in forestland (118.14 t $ha^{-1}$) followed by grassland (95.54 t $ha^{-1}$), agricultural land (75.70 t $ha^{-1}$) and least was found in the wasteland (57.05 $tha^{-1}$). Among the different land covers, maximum soil carbon storage potential was found in the soils under mixed land cover (118.18 t $ha^{-1}$) followed by teak (76.64 t $ha^{-1}$), bamboo (67.21 t $ha^{-1}$), sal (64.28 t $ha^{-1}$) and least under soils of open and scrub (48.72 t $ha^{-1}$) land cover.

Nwite and Alu (2017) studied carbon sequestration for agronomic potentials under different land-use systems *viz.* cropping, forest, fallow and grazing land-uses, mixed cropping and continuously cultivated soil. The results of carbon sequestration in different land-uses ranged from 3.48±12.30-66.83±16.03t $ha^{-1}$ for the land-uses. The order of value of carbon sequestration for the different land-uses was alley cropping > forest land-use> fallow > grazing land-use>mixed cropping > continuously cultivated soil. Highest carbon sequestration obtained under alley cropping land-use compared to other land-uses could be linked to higher efficiency of legume trees in conversion of carbon dioxide to soil carbon pool.

Ajit *et al.* (2017a) also reported the soil organic carbon stocks of existing agroforestry systems (AFS) for simulation period of 30 years in twenty six districts from ten selected states of India that ranged from 4.28 to 24.13 Mg C $ha^{-1}$. Further, Ajit *et al.* reported the estimated rate of soil carbon sequestration.

Ajit *et al.* (2017b) reported that the soil carbon was estimated to be 22.28 Mg $ha^{-1}$ in Kupwara district of J&K. The estimated rate of soil carbon sequestration at district level was 0.1236 Mg C $ha^{-1}$ $yr^{-1}$. In Indo-Gangetic plains rate of soil carbon ranged from 0.003 to 0.51 Mg C $ha^{-1}$ $yr^{-1}$. In fact, soil carbon sequestration depends upon a number of factors, *viz.* existing tree $ha^{-1}$, rainfall, temperature, sunshine hours and other local climatic parameters as well as on management practices.

**2.6. Soil Organic Carbon Pool:**

Studies have shown that microbial biomass responded quickly to change in soil perturbation by tillage (Carter 1986) and soil moisture (Skopp *et al*. 1990). Ladd *et al.* (1994) added that microbial biomass C is a good measure of the state of edaphic environment and its inclusion in a soil quality index leads to reduction in the number of properties that need to be considered. Brookes (1995) agreed on the use of microbial biomass C as indicator of soil quality, owing to its high sensitivity to changes in land use and management practices. Microbial biomass C represent vital components of ecosystem cycling with a turnover time from days to years (Hu *et al.* 1997) and serve as a source (mineralization) or a sink (immobilization) of labile nutrients.

Neff and Asner (2001) synthesized information on geochemical and biological factor that control dissolved organic carbon (DOC) fluxes through soil. They focused on conceptional 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 contributes 25 percent of total soil profile carbon whereas roots provided remainder.

Ghani *et al.* (2003) stated that the water soluble fraction is a sensitive indicator of labile organic matter. WSOC are considered as almost mobile and reactive soil carbon source which modulates a number of physical, chemical and biological processes in both aquatic and terrestrial environments. In arid and semiarid regions that cover as much as one-third of the surface of the planet, SIC pool is approximately two to ten times larger than SOC storage (Batjes 2004) while the SIC rate of accumulation is generally higher than of SOC (Landi *et al* 2003).

Walker and Deshankar (2004) studied the impact of land use on soil carbon in Miombo woodlands of Malavi. In the study they reported that the surface soil organic carbon level in Miombo soil varied from 1.2 to 3.78 percent. Agriculture soil carbon was significantly lowered with the surface layer ranging 0.35 to 1.2 percent carbon

The microbial biomass carbon (MBC) constitutes living microorganisms help in aggregate formation by producing gums and mucilages (Watts et al 2005). A study carried in Hunchin of Jilin Province and Erenhot, Inner Mongolia, China by Shu-Ping *et al.* (2005) observed that the mean values of soil organic carbon and soil labile carbon in the topsoils (A Horizon) were 22.3±4.93 and 3.52±0.88 g kg-1 respectively, with soil labile carbon accounting for 13.1±0.8 percent of the soil organic carbon.

Shreshta *et al.* (2006) observed a large difference in $KMnO^{4-}$ oxidizable soil organic C (KOC) due to the effect of cultivation length and cropping system. During a 3 year study period, large changes in soil C were observed for $KMnO^{4-}$ oxidizable C but not for total carbon (TC), indicating the usefulness of the $KMnO^{4-}$ oxidized fraction for detecting a relatively short-term increase or decrease in soil C pool.

Ramachandran *et al.* (2007) in Tamil Nadu (Kolli Hills) noticed that total area under forest cover in kolli hills is about 27.01 ha and total biomass carbon estimation is 2.74 Tg. Total soil carbon in forest area is 3.18 Tg.

Naturally-occurring organic carbon forms are derived from the decomposition of plants and animals. In soils and sediments, a wide variety of organic carbon forms are present and range from freshly deposited litter (eg. leaves, twinges, branches etc.) to highly decomposed forms such as humus. According to the estimates by the European Soil Bureau, nearly 74 percent of the land in Southern Europe is covered by soils with less than 2.0 percent organic carbon in the first 0.3 m depth. Grimm *et al*. (2008) studied soils at 165 sites, stratified according to topography and lithology, on Barro Colorado Island (BCI), Panama. The estimates for SOC stocks in the upper 30 cm ranged between 38 and 116 Mg $ha^{-1}$, with lowest stocks on midslope and highest on toeslope positions.

Jiao *et al*. (2009) reported that the SOC contents for the soil of 0-10, 10-20 and 20-30 cm was 3.37, 2.89 and 2.1 percent 6 in the grassland and 2.55, 2.27 and 1.55 percent in the forest soils. Studies have shown that an increase in SOC levels is directly related to the amount of organic residues added to the soils and fertilizer as well as manure application.

The SOC in agricultural soils has a turnover time from decades to centuries, thus the gross contents of SOC change very slowly. It would, therefore, be useful if alternative C fractions could be identified that are more sensitive or indicative of changes in C contents than SOC (Banger *et al.* 2009).

Chivhane and Bhattacharyya (2010) studied the effect of land use and bio-climatic systems on organic carbon pools of swell-shrink soils of Vidarbha region, Maharashtra and reported that high atmospheric temperature in central India does not allow very labile form ($C_{VL}$) of organic carbon to persist in soils.

Ferreira (2012) studied that the adoption of no-tillage systems (NT) and the maintenance of crop residues on the soil surface result in the long-term increase of carbon (C) in the system, promoting carbon sequestration and reducing C-$CO_2$ emissions to the atmosphere.

Abril *et al.* (2013) studied the decomposition and carbon dynamics of crop residue mixtures in a semiarid long term no-till system: effects on soil organic carbon and reported that the decomposition and carbon dynamics of crop residues mixtures in long term no-till systems are strongly influenced by the interaction of the chemical quality of the residue. Plant residues decomposition transfers organic matter, nutrients to soil and plays a decisive role in carbon cycling in terrestrial ecosystems.

# 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 agroforestry farm in the university campus. The details of technical programme along with methodological detail are as under.

## 3.1. Site Description:

### 3.1.1 Location

Two sites were selected in and around Palampur for the present study.

Site I was selected in the CSK HPKV Palampur agroforestry farm at the university campus located at an elevation of 1272 m.

Site II was selected in Bandla which is located 5 kms from Palampur and is located at an elevation of 1320 m.

### 3.1.2 Climate

The climatic factors of the area which were studied for the study of "Carbon sequestration in Toona based agroforestry system of Kangra valley of Himachal Pradesh" are described as follows:

- **Locality factors of the Study area.**

| **Factor** | **Site 1** | **Site 2** |
|---|---|---|
| Latitude | 32°06' | 32°04' |
| Longitude | 76°33' | 76°03' |
| Altitude | 1272 | 1320 |
| Soil ph | 6.1 | 5.7 |

## 3.2 Experimental Methodology:

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

The entire area under tree experimental farm was traversed and demarcated into managed and unmanaged system which will further divided in quadrats of 25×25 m and out of these selected quadrats 2 were selected by random number table for further studies.

### 3.2.2 Estimation of Species Diversity

Phyto socio ecological exercise was undertaken for working out the Importance Value Index (IVI) species diversity in the said quadrats to know the relative frequency, density and dominance.

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

**i) Frequency:**

Frequency as introduced by Raunkiaer (1934) indicates the number of sampling units in which a given 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.

$$\textbf{Frequency Percentage} = \frac{\text{total no.of sampling unit in which species occurred}}{\text{total no.of sampling quadrats studied}} X\ 100$$

**ii) Density:**

The term density represents 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 individual 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.

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

**iii) Basal Area:**

It refers to the ground actually penetrated by the stem, 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 characteristic 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 method 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.

$$\textbf{Basal Area} = \pi(r)^2$$

Here ‘r’ is the radius.

**iv) 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 and dominance (Curtis and Mcltosh 1951; Mishra 1968 and Burns and Honkala 1990).

Dominance 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:

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

$$\textbf{RelativeDensity(RD)} = \frac{\text{Total no. of individuals of the species}}{\text{Total no. of individuals of all the species}} X\ 100$$

$$\textbf{Relative Dominance (RDo)} = \frac{\text{Total basal area of the species}}{\text{Total basal area of all the species}} X\ 100$$

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

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

**v) 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-** 0-10 cm

**D2-** 10-20 cm

**D3**- 20-30 cm

**D4**- 30-40 cm

### 3.3 Observation Recorded:

#### 3.3.1 Aboveground Biomass

Aboveground biomass was studied for different components:

-Stem biomass

-Branch biomass

-Shrub biomass

-Leaf biomass

-Grass biomass

#### 3.3.2 Carbon Stock in Agroforestry System:

Above ground biomass carbon stock.

| **Agroforestry System** | **Code** | **Studied tree-crop Combination** |
|---|---|---|
| Site 1- Managed<br>Site 1- Unmanaged | (S1M)<br>(S1U) | *Toona ciliata*+ *Albizia chinensis*<br>+ *Camellia sinensis* |
| Site 2- Managed<br>Site 2- Unmanaged | (S2M)<br>(S2U) | *Toona ciliata*+ *Albizia chinensis*<br>+ *Camellia sinensis* |

### 3.3.3 Soil physico-chemical properties

Soil organic carbon (SOC)

-Soil organic carbon stock

-Total carbon estimation

## 3.4 Procedure:

Aboveground biomass was estimated by non-destructive methods for different plants.

### 3.4.1 Stem Biomass:

To estimate the stem biomass all trees falling in plot (25×25 m) were enumerated and the DBH (Diameter at breast height) was measured with tree caliper and height with Ravi's multimeter. Form factor were calculated with Spiegel Relaskop to find out the volume of the tree using the formula given by (Pressler 1865 and Bitlerlich 1984).

$$\mathbf{f=2hi/3h}$$

where,

f - form factor.

hi - height at which diameter is half of dbh.

h - total height.

Volume was calculated by formula given by (Pressler 1865)

$$\mathbf{V=f \times h \times g}$$

where,

V = volume

f = form factor

h = total height

g = basal area = $\pi r^2$

Stem biomass was estimated by multiplying the stem volume of wood specific gravity (IPCC 2006).

$$\textbf{Stem}_{\textbf{biomass}} = \textbf{Stem}_{\textbf{volume}} \times \textbf{Wood specific gravity}$$

The value of wood specific gravity of different agroforestry species were used as reported value of (Sheikh *et al.* 2011) etc. was given

| **Tree** | **Wood Specific Gravity value** |
|---|---|
| *Grewia oppositifolia* | 0.606 |
| *Celtis australis* | 0.444 |
| *Bauhinia retusa* | 0.550 |
| *Mallotus philippenis* | 0.649 |
| *Toona ciliata* | 0.424 |
| *Leucaena leucocephala* | 0.747 |
| *Morus alba* | 0.603 |
| *Melia azedarach* | 0.491 |
| *Ficus glomerata* | 0.450 |
| *Acacia catechu* | 0.825 |
| *Ougeinia oojeinensis* | 0.606 |
| *Ficus auriculata* | 0.443 |
| *Syzygium cumini* | 0.669 |
| *Ficus carica* | 0.578 |
| *Cassia fistula* | 0.812 |
| *Terminalia ballerica* | 0.480 |
| *Pinus roxburghii* | 0.491 |
| *Ficus roxburghii* | 0.443 |
| *Bombax ceiba* | 0.330 |
| *Ficus religiosa* | 0.020 |
| *Malus domestica* | 0.670 |

### 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 < 5cm, 5-10 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.

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

where,

$B_{dwi}$ = 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).

$$\mathbf{B_{bt}=n_1bw_1+n_2bw_2+n_3bW_3= \sum n_ibw_i}$$

where,

$B_{bt}$ = branch biomass (fresh/dry) per tree

$n_i$ = no. of branches in the $i^{th}$ branch group

$bw_i$ = average weight of branch of $i^{th}$ group

i = 1- n, refers to branch group

### 3.4.3 Leaves Biomass:

Leaves from branches were removed, weighed and oven dried separately to a constant weight 60+5 °C to determine leaf biomass (Chidumaya 1990).

$$\mathbf{L_{dwi} = L_{fwi}/ 1+ M_{cbdi}}$$

where,

$L_{dwi}$ = oven dried weight of leaves

$L_{fwi}$ = fresh weight of leaves

$M_{cbdi}$ = moisture content of leaves on dry weight basis.

Also total leaves biomass per sample tree was determined as given by (Chidumaya 1990).

$$\mathbf{L_{bt} = n_1lw_1 + n_2lw_2 + n_3lw_3 = \sum n_ilw_i}$$

where,

$L_{bt}$ = Leaves biomass (fresh/dry) per tree

$n_i$ = Number of leaves in the ith branch group

$lw_i$ = Average weight of ith group

**3.4.4 Total aboveground biomass:**

The total above ground biomass was the sum of stem, branch and leaves biomass (Kanime *et al.* 2013).

$$\mathbf{AGB_t = Stem_{biomass} + Branch_{biomass} + Leaves_{biomass}}$$

$AGB_t$ is the total above ground biomass.

**3.4.5 Belowground biomass:**

Below ground biomass of the tree was calculated by multiplying the above ground biomass by a factor of 0.25.

**3.4.6 Tree Biomass:**

The total tree biomass was the sum of above ground biomass and below ground biomass of tree.

$\mathbf{C_t = AGB_t + BG_t}$

$C_t$ = total biomass of tree

$AGB_t$ = total above ground biomass of tree

$BG_t$ = total below ground biomass of tree

**3.4.7 Crop (Tea) Biomass:**

Crop biomass was estimated using 1m × 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+5 °C to a constant weight. The crop biomass was converted into Carbon by multiplying with a factor of 0.45 (Woomer 1999).

### 3.4.8 Surface Litter:

Surface litter was collected within a 1m × 1m frame centrally placed within each quadrate. Samples were weighed, sub sampled and oven dried at 65+5 °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 quadrate area into randomly selected two 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 2 mm sieve and stored in cloth bags for further laboratory analysis**.**

## 3.6 Carbon profile

The soil organic carbon profile expressed as t $ha^{-1}$ 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).

# 4. RESULTS AND DISCUSSION

The results emerged out of present investigation entitled **“Carbon Sequestration in Toona Based Agroforestry System of Kangra Valley of Himachal Pradesh”** has been presented in this chapter. The biomass production levels obtained and the carbon stored in the biomass through the different agroforestry systems has been described under following heads.

**4.1 Estimation of species diversity (IVI):**

In two study sites the majorly occurring species were *Toona ciliata*, *Albizia chinensis* and *Melia azedarach* out of which the most frequently occurring species was *Toona ciliata* having highest value of frequency viz. 75.0 and 83.8 per cent in the manage system and 72.8 and 75.0 per cent in the unmanaged system. This table 4.1 shows that the species having higher frequency represent high value of IVI i.e. 139.6, 170.6 in the managed system and 118.3 and 130.2 in unmanaged system under two sites respectively. Similar results were obtained by Gauchan *et al.* (2003) and Ghosh *et al*. (2005).

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

| | TREE SPECIES | Frequency (%) | | Density per 100 $m^2$ | | Basal area ($cm^2/m^2$) | | Relative frequency (%) | | Relative Density (%) | | Relative Dominance (%) | | Importance Value Index | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Site** | | **M** | **U** | **M** | **U** | **M** | **U** | **M** | **U** | **M** | **U** | **M** | **U** | **M** | **U** |
| 1 | *Albizia chinensis* | 66.6 | 70.8 | 0.78 | 0.96 | 1.13 | 0.98 | 23.9 | 15.7 | 80.8 | 65.3 | 26.8 | 16.3 | 131.5 | 97.3 |
| | *Toona ciliata* | 75.0 | 72.8 | 2.33 | 1.67 | 2.43 | 1.09 | 26.3 | 23.8 | 84.6 | 70.4 | 28.7 | 24.1 | 139.6 | 118.3 |
| | *Melia azedarach* | 33.3 | 25.0 | 0.21 | 0.13 | 0.28 | 0.15 | 14.3 | 10.5 | 30.8 | 26.5 | 15.3 | 9.72 | 60.4 | 46.7 |
| 2 | *Albizia chinensis* | 70.8 | 45.8 | 1.30 | 0.66 | 1.84 | 1.13 | 21.8 | 11.9 | 79.1 | 57.4 | 23.7 | 10.6 | 124.6 | 79.9 |
| | *Toona ciliata* | 83.8 | 75.0 | 2.34 | 1.67 | 3.19 | 1.94 | 34.8 | 25.4 | 96.5 | 78.3 | 39.3 | 26.5 | 170.6 | 130.2 |
| | *Melia azedarach* | 19.5 | 12.50 | 0.19 | 0.06 | 0.19 | 0.08 | 11.6 | 5.84 | 28.3 | 16.5 | 13.7 | 6.9 | 53.6 | 29.2 |

### 4.2 Biomass production levels of different Toona based agroforestry system

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 (91.17 t ha$^{-1}$) which could be due to canopy management and lower spacing.

The high biomass as shown in the managed system of site 2 (82.62 t ha$^{-1}$) depend upon number of factors such as 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 site 2 is higher density value of tree species. Similar studies were substantiated by Nayak (1996) and Ghosh *et al.* (2005) who reported high biomass in lower areas.

**Table 4.2: Biomass production level for managed and unmanaged systems and different Toona based agroforestry sites (t ha$^{-1}$)**

| Component/ Factors | | Stem | Branch | Leaf | Whole tree | Tea bush | Grass | Litter | Total |
|---|---|---|---|---|---|---|---|---|---|
| **System*** | ***M*** | 38.25 | 20.86 | 9.18 | 68.27 | 19.68 | 0.54 | 2.68 | 91.17 |
| | ***U*** | 31.83 | 17.05 | 7.86 | 56.74 | 16.38 | 1.32 | 2.08 | 76.52 |
| **CD (P=0.05)** | | **0.42** | **0.06** | **0.06** | **0.39** | **0.02** | **0.01** | **0.01** | **0.75** |
| **SITES**** | **S1** | 32.21 | 20.07 | 5.21 | 57.49 | 16.52 | 0.42 | 2.03 | 76.46 |
| | **S2** | 36.02 | 19.86 | 5.90 | 61.78 | 16.90 | 0.86 | 3.08 | 82.62 |
| **CD (P=0.05)** | | **0.57** | **0.04** | **0.03** | **0.48** | **0.02** | **0.02** | **0.05** | **0.61** |

*Average of two sites

**Average of managed and unmanaged sites (M+U)

The managed system of site 2 (S2M) shows significantly higher biomass in tree component as well as crop and litter (69.26 t $ha^{-1}$) as shown in (Table 4.3). It represent that the managed system of site 2 (S2M) have higher biomass production level (69.26 t $ha^{-1}$) because of the management, whereas unmanaged system of site 1 (S1U) shows significantly lower biomass (58.68 t $ha^{-1}$). The same results were reported by Nayak (1996).

**Table 4.3: Effect of managed and unmanaged systems of different Toona based agroforestry sites on Biomass (t $ha^{-1}$)**

| COMPONENTS | Systems | Stem | Branch | Leaf | Whole Tree | Tea Bush | Grass | Litter | Total |
|---|---|---|---|---|---|---|---|---|---|
| **SITES** | | | | | | | | | |
| **Site 1** | **M** | 24.54 | 19.60 | 5.02 | 49.16 | 15.08 | 0.41 | 2.34 | 66.99 |
| | **U** | 20.08 | 17.81 | 3.86 | 41.75 | 13.93 | 1.29 | 1.71 | 58.68 |
| **Site 2** | **M** | 26.01 | 20.21 | 4.80 | 51.02 | 15.05 | 0.81 | 2.38 | 69.26 |
| | **U** | 23.81 | 18.93 | 4.00 | 46.74 | 14.86 | 1.89 | 2.10 | 65.59 |
| **CD (P=0.05)** | | **0.47** | **0.03** | **0.50** | **0.95** | **0.02** | **0.01** | **0.04** | **0.63** |

## 4.3 Biomass Carbon stocks in different Toona based agroforestry systems

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 are shown below.

The highest carbon stock was found in managed system (35.37 t $ha^{-1}$). Among sites, site 2 shows best result in the production of maximum carbon stock (33.29 t $ha^{-1}$) and minimum carbon stock was found in site 1 (30.12 t $ha^{-1}$). Site 2 (S2) have maximum carbon stock, it can be inferred from studies that site 2 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 (Table 4.4).

**Table 4.4: Biomass Carbon stock level for managed and unmanaged systems and different tea based agroforestry sites (t ha$^{-1}$):**

| Component/ Factors | | Stem | Branch | Leaf | Whole tree | Tea bush | Grass | Litter | Total |
|---|---|---|---|---|---|---|---|---|---|
| **System*** | ***M*** | 12.86 | 9.06 | 2.69 | 24.61 | 9.32 | 0.13 | 1.31 | 35.37 |
| | ***U*** | 11.74 | 8.31 | 2.18 | 22.23 | 7.86 | 0.56 | 1.08 | 31.73 |
| **CD (P=0.05)** | | **0.17** | **0.03** | **NS** | **0.03** | **0.02** | **0.01** | **0.01** | **0.19** |
| **SITES**** | **S1** | 10.58 | 8.56 | 1.43 | 20.57 | 8.03 | 0.29 | 1.23 | 30.12 |
| | **S2** | 11.39 | 9.21 | 2.33 | 22.93 | 8.42 | 0.41 | 1.53 | 33.29 |
| **CD (P=0.05)** | | **0.39** | **0.04** | **NS** | **0.06** | **0.02** | **0.04** | **0.01** | **0.28** |

*Average of two sites
**Average of managed and unmanaged systems

## 4.4 Soil physico-chemical properties

### 4.4.1 Bulk Density

As shown in the Table 4.5 the bulk density ranged between (1.02 to 1.11 g/cm$^2$) at different soil depth (0-10, 10-20, 20-30 and 30-40 cm) in managed system with a mean value of(1.06 g cm$^{-2}$). However, it varies from (0.83 to 0.93 g cm$^{-2}$) in unmanaged system with a mean value of (0.89 g cm$^{-2}$). Similarly the site 1 (S1) had revealed maximum bulk density (1.01 g cm$^{-2}$) in the system.

**Table 4.5: Effect of managed and unmanaged systems in Toona based agroforestry sites on bulk density at different soil depth (g cm$^{-2}$)**

| SOIL DEPTH | | 0-10 cm | 10-20 cm | 20-30 cm | 30-40 cm | Mean |
|---|---|---|---|---|---|---|
| **FACTOR** | | | | | | |
| **System*** | **M** | 1.02 | 1.06 | 1.08 | 1.11 | 1.06 |
| | **U** | 0.83 | 0.90 | 0.92 | 0.93 | 0.89 |
| **CD (P=0.05)** | | **0.27** | **0.02** | **0.01** | **0.01** | |
| **Sites**** | **S1** | 0.91 | 0.98 | 1.02 | 1.06 | 1.01 |
| | **S2** | 0.92 | 0.93 | 1.03 | 1.05 | 0.98 |
| **CD (P=0.05)** | | **0.41** | **0.05** | **0.01** | **0.02** | |

*Average of two sites
**Average of managed and unmanaged systems

### 4.4.2 Soil organic carbon

Per cent organic carbon in managed and unmanaged system at different soil depth was 2.46, 1.98, 1.68, 1.45 and 2.89, 2.53, 2.36, 1.96 per cent respectively. Organic carbon content in unmanaged system was significantly higher (2.43%) in comparison to managed system (1.89%) due to continuous addition of organic matter through decomposition in that area (Table 4.6).

The organic matter accumulated was highest at the surface soil decreases with soil depth (Table 4.6). 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 4.6: Per cent organic carbon of managed and unmanaged systems at different soil depths in different agroforestry sites (t ha$^{-1}$)**

| SOIL DEPTH | | 0-10 cm | 10-20 cm | 20-30cm | 30-40 cm | Mean |
|---|---|---|---|---|---|---|
| **FACTOR** | | | | | | |
| **System*** | **M** | 2.46 | 1.98 | 1.68 | 1.45 | 1.89 |
| | **U** | 2.89 | 2.53 | 2.36 | 1.96 | 2.43 |
| **CD (P=0.05)** | | **0.01** | **0.02** | **0.04** | **0.02** | |
| **Sites**** | **S1** | 2.63 | 1.79 | 1.70 | 1.76 | 1.97 |
| | **S2** | 2.86 | 2.56 | 2.64 | 2.28 | 2.58 |
| **CD (P=0.05)** | | **0.11** | **0.07** | **0.04** | **0.02** | |

*Average of two sites
**Average of managed and unmanaged systems

### 4.4.3 Soil organic carbon stock inventory

Soil Organic carbon (SOC) values in soils of managed system were 25.41, 21.92, 21.26 and 20.40 t ha$^{-1}$ for managed and 30.89, 29.86, 26.03 and24.09 t/ha in unmanaged system at different soil depths (0-10, 10-20, 20-30 and 30-40) respectively. The mean value of soil organic carbon of managed system is 22.24 t ha$^{-1}$ whereas in case of unmanaged it is 27.71 t ha$^{-1}$, respectively (Table 4.7).

Similarly out of two sites S1 and S2, the mean value of site 2 (S2) is significantly higher (25.65 t $ha^{-1}$) than remaining site. The mean values of unmanaged system (U) and site 2 (S2) 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).

**Table 4.7: Soil organic carbon stocks for managed and unmanaged systems and different Toona based agroforestry sites (t $ha^{-1}$)**

| SOIL DEPTH | | 0-10 cm | 10-20 cm | 20-30 cm | 30-40 cm | Mean |
|---|---|---|---|---|---|---|
| **FACTOR** | | | | | | |
| **System*** | **M** | 25.41 | 21.92 | 21.26 | 20.40 | 22.24 |
| | **U** | 30.89 | 29.86 | 26.03 | 24.09 | 27.71 |
| **CD (P=0.05)** | | **0.02** | **0.19** | **0.02** | **0.01** | |
| **Site**** | **S1** | 23.93 | 19.54 | 18.84 | 17.66 | 19.92 |
| | **S2** | 26.88 | 26.31 | 25.19 | 24.25 | 25.65 |
| **CD (P=0.05)** | | **0.04** | **0.03** | **0.05** | **0.04** | |

*Average of two sites
**Average of managed and unmanaged systems

### 4.4.4 Soil organic carbon pool inventory

The mean of managed and unmanaged systems revealed that the soil organic carbon pooling in unmanaged system of site 1 (S1U) was significantly higher (249.35 t $ha^{-1}$) than managed system (241.10 t $ha^{-1}$) and in case of sites2 unmanaged system (S2U) have maximum value (259.60 t $ha^{-1}$) of carbon pool than managed system (249.25 t $ha^{-1}$) (Table 4.8).

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) and Minhas (1997).

**Table 4.8: Effect of Toona based agroforestry system on soil organic carbon pool (t ha$^{-1}$)**

| SITES | DEPTH | 0-10 cm | 10-20 cm | 20-30 cm | 30-40 cm | Mean |
|---|---|---|---|---|---|---|
| | ***System*** | | | | | |
| **Site 1** | **M** | 314.00 | 227.40 | 219.00 | 204.00 | 241.10 |
| | **U** | 320.00 | 235.00 | 226.40 | 216.00 | 249.35 |
| **Site 2** | **M** | 317.00 | 239.00 | 225.00 | 216.00 | 249.25 |
| | ***U*** | 321.00 | 252.40 | 238.00 | 227.00 | 259.60 |
| **CD (P=0.05)** | | **0.45** | **0.04** | **0.02** | **0.26** | |

## 4.5 Carbon stock

The carbon stock at (0-20 cm) depth was found to be significantly higher than at soil depth (0-40cm).The total carbon stock increases when soil depth was (0-20 cm) instead of (0-40 cm) as shown in the (table 4.9). Here managed system shows significantly high stock of carbon. These results are in conformity with the findings of Lai *et al.* (1998).

At (0-20) depth (plant + soil) carbon stock was highest in S2M system (100.02 t ha$^{-1}$) whereas inS1U it was lowest (89.10 t ha$^{-1}$). Whereas at (0-40 cm) depth (plant + soil) carbon stock was higher in S2U (94.62 t ha$^{-1}$) and lowest in S1U (80.42 t ha$^{-1}$). This table also shows that total carbon stock was maximum at depth (0-20 cm). It is also 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).

The plant- soil ratio (Table 4.9 and 4.10) 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 4.9: Carbon stocks under different Toona based agroforestry system up to 20 cm profile depth (t ha$^{-1}$)**

| SYSTEM | S1M | S1U | S2M | S2U |
|---|---|---|---|---|
| **Components** | | | | |
| **Plant carbon stock** | 31.98 | 28.02 | 35.82 | 30.64 |
| **Soil carbon stock** | 58.83 | 61.08 | 64.20 | 68.03 |
| **TOTAL** | 90.81 | 89.10 | 100.02 | 98.67 |
| **Soil: Plant** | **1.84** | **2.18** | **1.79** | **2.22** |

**Table 4.10: Carbon stocks under different Toona based agroforestry system up to 40 cm profile depth (t ha$^{-1}$)**

| SYSTEM | S1M | S1U | S2M | S2U |
|---|---|---|---|---|
| **COMPONENTS** | | | | |
| **Plant carbon stock** | 31.98 | 28.02 | 35.82 | 30.64 |
| **Soil carbon stock** | 49.79 | 52.40 | 57.34 | 63.98 |
| **TOTAL** | 81.77 | 80.42 | 93.16 | 94.62 |
| **Soil: Plant** | **1.56** | **1.87** | **1.60** | **2.08** |

Also aboveground and belowground carbon stocks in Toona based agroforestry was also calculated and following results are obtained:

**Table 4.11: Aboveground Carbon stocks in different Toona based agro forestry system (t ha$^{-1}$):**

| SYSTEM | S1M | S1U | S2M | S2U |
|---|---|---|---|---|
| **Component** | | | | |
| **Tree** | 28.20 | 21.06 | 29.62 | 24.91 |
| **Crop** | 9.60 | 7.04 | 8.45 | 8.68 |
| **Grass** | 0.03 | 0.81 | *0.09* | 0.93 |
| **Litter** | 1.41 | 0.39 | 1.85 | 0.63 |
| **A (Total)** | **39.24** | **29.30** | **40.01** | **35.15** |

Total carbon stock in the aboveground system was found highest in the managed system of site 2 (40.01 t ha$^{-1}$) which is followed by managed system of site 1 (39.24 t ha$^{-1}$) and it is found lowest in the unmanaged system of site 1 (29.30 t ha$^{-1}$) (Table 4.11).

It also represents that the carbon stocks assimilates well when the system was kept in the managed form than that of unmanaged form.

For belowground carbon stocks in Toona based agroforestry it was found from the above results that the carbon stocks were significantly higher in the unmanaged system of site 2 (121.87 t ha$^{-1}$) whereas it was found lowest in managed system of site 1 (94.57 t ha$^{-1}$) (Table 4.12).

It shows that in case of belowground carbon stock shows best results when the system is kept in the unmanaged form than that of the managed form.

**Table 4.12: Belowground Carbon stocks in different Toona based agro forestry system (t $ha^{-1}$):**

| SYSTEM | S1M | S1U | S2M | S2U |
|---|---|---|---|---|
| **Component** | | | | |
| **Soil (0-10 cm)** | 29.84 | 31.60 | 30.17 | 34.80 |
| **Soil (10-20 cm)** | 25.04 | 29.20 | 26.08 | 31.09 |
| **Soil (20-30cm)** | 21.89 | 28.02 | 24.20 | 28.90 |
| **Soil (30-40 cm)** | 17.80 | 26.78 | 20.98 | 27.08 |
| **B(Total)** | **94.57** | **115.6** | **101.94** | **121.87** |

**Table 4.13: Total carbon stocks (Aboveground + Belowground) in different Toona based agroforestry system (t $ha^{-1}$):**

| SYSTEM | S1M | S1U | S2M | S2U |
|---|---|---|---|---|
| **Component** | | | | |
| **(Aboveground)** | | | | |
| **A (Total)** | 39.24 | 29.30 | 40.01 | 35.15 |
| **(Belowground)** | | | | |
| **B (Total)** | 94.57 | 115.6 | 101.94 | 121.87 |
| **(A+B)** | **133.81** | **144.9** | **141.95** | **157.02** |

Table 4.13 shows that the total carbon stock (aboveground and belowground) is maximum in unmanaged system of site 2 (157.02 t $ha^{-1}$) whereas it is minimum in the managed system of site 1 (133.81 t $ha^{-1}$).

# 5. SUMMARY AND CONCLUSIONS

The present investigation entitled **"Carbon Sequestration in Toona based Agroforestry System of Kangra Valley of Himachal Pradesh"** was carried out during 2018-2019. This chapter has been devoted to examine the results of the current study based on logical arguments in the light of the scientific evidences available in the literature. The results have been proved by establishing the cause and effect relationship wherever necessary and feasible between them to derive out the fruitful conclusions under the following heads.

**5.1 Estimation of Species Diversity (IVI):**

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 *Toona ciliata*, *Albizia chinensis* and *Melia azaderach* and representing high value of IVI. *Toona ciliata* had the maximum frequency at all the two sites in both the systems as shown in the table (Table 4.1). On the basis of IVI index different components of Agroforestry were made for the biomass estimation.

**5.2 Biomass estimation of different components of Agroforestry system:**

For biomass estimation all the components of the tree, tea bushes, shrubs and grasses were taken and biomass was calculated by the non-destructive method. It was observed from the results that different agroforestry system i.e. (Managed (M) and unmanaged (U) and sites (S1 and S2) the maximum above-ground biomass was present in managed system of site 2 (69.26 t $ha^{-1}$). Thus the managed system (M) was better for biomass production in comparison to unmanaged (U) system as shown in the table (Table 4.2 & Table 4.3).

## 5.3 Soil physico-chemical properties:

### 5.3.1 Bulk Density-

Bulk density was calculated at different depths (0-10, 10-20, 20-30, 30-40 cm).Bulk density was higher in managed system (1.06 g $cm^{-2}$) and in Site 1 (1.01 g $cm^{-2}$) and it was found that bulk density increase with increase in soil depth (Table 4.5).

### 5.3.2 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 0-20 was maximum, where as it was minimum at 0-40 cm (Table 4.6). This showed that the soil organic carbon decrease with increase in soil depth. Site 2 (25.65 t $ha^{-1}$) contained maximum soil organic carbon pool.

### 5.3.3 Total carbon stock-

The total stock i.e. (plant + soil) was highest in managed system of Site 2 (100.02 t $ha^{-1}$) whereas lowest in unmanaged system of Site 1 (89.10 t $ha^{-1}$) at 0-20 cm soil depth. Also, the highest carbon stock (plant + soil) was maximum in the unmanaged system of site 2 (94.62 t $ha^{-1}$) and minimum in the unmanaged system of site 1 (80.42 t $ha^{-1}$) at 0-40 soil depth. It showed that total carbon stock was maximum at 0-20 cm soil depth and minimum at 0-40 cm soil depth profile carbon profile (Table 4.9 & Table4.10).

## CONCLUSION

- The carbon assimilation in the form of biomass is at its best when the agroforestry system was kept in managed form.
- The organic carbon in the soil assimilates well when the system is unmanaged form this can be attributed to the leaf and litter fall at the soil surface which decays and decomposes there. This decay and decomposes results in enhancement of the soil organic carbon.
- The bulk density also differs significantly with the soil depths. Bulk density at 0-20 cm soil depth was significantly higher than that of 0-40 cm soil depth.

- Also the organic carbon present in the soil reduces as we go on increasing the depth of the soil.

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# Brief Biodata of student

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|---|---|---|
| **Name** | : | Manshi Mehta |
| **Father's Name** | : | Sh. Ranvir Singh |
| **Mother's Name** | : | Smt. Sapna Devi |
| **Date of Birth** | : | 28-02-1997 |
| **Permanent Address** | : | Hariomniwas, Ghuggar (Aima) Post Office Palampur Teh Palampur, Kangra, H.P. (176061) |

**Academic Qualifications:**

| **Qualification** | **Month** | **Year** | **School/Board/University** | **Marks (%)** | **Division** |
|---|---|---|---|---|---|
| $10^{th}$ | March | 2012 | Chand Public School, Palampur | 76.85% | $1^{st}$ |
| 10+2 | March | 2014 | Chand Public School, Palampur | 76.2% | $1^{st}$ |
| B.Sc (Honours) | June | 2017 | GGDSD College, Rajpur | 70.96% | $1^{st}$ |
| M.Sc (Environmental Sciences) | July | 2019 | CSK HPKV, Palampur (HP) | 7.64 | $1^{st}$ |