

CARBON STORAGE POTENTIAL AND BIO-ECONOMIC APPRAISAL OF DIFFERENT LAND USE SYSTEMS IN DRY TEMPERATE NORTH WESTERN HIMALAYAS

Thesis

by

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CERTIFICATE

This is to certify that the thesis entitled, “**Carbon storage potential and bio-economic appraisal of different land use systems in dry temperate north western Himalayas**” submitted in partial fulfillment of the requirements for the award of degree of **MASTER OF SCIENCE (FORESTRY) AGROFORESTRY** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) is a record of bonafide research work carried out by **Mr. Kafula Chisanga (F-10-06-M)** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of investigations has been fully acknowledged.

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ABBREVIATIONS USED

a.m.s.l.	Above mean sea level
ANB	Annualized Net Benefits
ANOVA	Analysis of Variance
B/C	Benefits Cost Ratio
C	Carbon
CD	Critical Difference
C ha ⁻¹	Carbon per hectare
C ha ⁻¹ yr ⁻¹	Carbon per hectare per year
CH ₄	Methane
C/N	Carbon Nitrogen ratio
CSP	Carbon sequestration potential
cm	Centimeter
CO ₂	Carbon dioxide
°C	Degree Celsius
CT	Conventional Tillage
D	Depth
DBH	Diameter at Breast Height
DOE	Department of Energy
<i>et al.</i>	Co- workers
FCCC	Framework Convention on Climate Change
FYM	Farm Yard Manure
ft	Feet
g	gram
GHG	Green House Gas
GHGs	Green House Gases
Gt	Giga tonne
gcm ⁻³	Gram per centimeter cube
ha	Hectare (10,000 m ²)
H.P	Himachal Pradesh
IPCC	Intergovernmental Panel on Climate Change
i. e.	That is
IRRI	International Rice Research Institute
Kg	Kilogram
KVK	Krishi-Vigyan Kendra
m	Meter
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 year

mm	Milimeter
Mt	Mount
MT	Metric tone
N	North
Na	Sodium
NEP	Net Ecosystem Productivity
NFT	Nitrogen Fixing Tree
NOC	Net Organic Carbon
NPK	Nitrogen Phosphorous Potassium
NPP	Net Primary Productivity
NPV	Net Present Value
NT	No Tillage
NRCS	Natural Resource Conservation Services
N ₂ O	Nitrous Oxide
OC	Organic carbon
Pg	Petagram
Pg C	Petagram Carbon
pH	pouviour of Hydrogen
ppm	Parts per million
q	Quintal
Rs	Rupees
RT	Reduced Tillage
SOC	Soil Organic Carbon
SOC _D	Soil Organic Carbon Density
SOM	Soil Organic Matter
T	Tonne
t c ha ⁻¹	Tonne Carbon per hectare
t c ha ⁻¹ yr ⁻¹	Tonne Carbon per hectare per year
Tg	Tera gram
UNCED	United Nations Conference on Environment and Development
UNFCCC	United Nations Framework Convention of Climate Change
US	United States
USD	United States Dollar
USDA	United State Department of Agriculture
UP	Uttah Pradesh
WANA	West Asia and North Africa
WAS	West African Sahel
Yr	Year
%	Percent
µm	Micro meter

Chapter-1

INTRODUCTION

The concentration of carbon dioxide and other green house gases (GHGs) in the atmosphere has considerably increased over the last century and is set to rise further. Carbon is accumulating in the atmosphere at a rate of 3.5 Pg (Pg = 10^{15} g or billion tons) per annum, the largest of which resulting from the burning of fossil fuels and the over conversion of tropical forests to agricultural production (Paustian *et al.*, 2000). Scientific evidence suggests that negative changes in the global climate (rising temperatures, higher frequency of droughts and floods) are often the most consequential processes associated with an increased concentration of CO₂ in the atmosphere (USDA NRCS, 2000).

The debate on the atmospheric build up of GHGs and their role in global warming culminated in the third session of the Conference of the Parties to the United Nations Framework Convention of Climate Change (UNFCCC) in 1997, in Kyoto, Japan. One of the major achievements of this conference was the signature of a protocol urging participating countries to find ways of reducing GHGs concentration in the atmosphere. In case of C, reduction targets could be achieved through two major processes: (1) reducing anthropogenic emissions of CO₂ and (2) creating and/or enhancing C sinks in the biosphere. Current terrestrial (plant and soil) C is estimated at 2000 (+/-) 500Pg, which represents 25% of global C stocks (DOE, 1999). The sink option for CO₂ mitigation is based on the assumption that this figure can be significantly increased if various biomes are judiciously managed and/or manipulated. In this connection, agricultural lands have the potential to remove and store between 42 and 90 Pg of C from the atmosphere over the next 50-100 years (Albrecht and Kandji, 2003).

Promoting agroforestry is one option many perceive as a major opportunity to deal with problems related to land use and CO₂ – induced global warming. Bio-economic appraisal of agroforestry systems is applied in assessment of the economic significance of interesting plant combinations,

interactions and cultural manipulations among potential agroforestry land use systems. In this thesis, agroforestry is defined as any land use system that involves the deliberate retention, introduction or mixture of trees or other woody perennials with agricultural crops, pastures and/ or livestock to exploit the ecological and economic interactions of the different components (Lundgren, 1982, Nair, 1993, Young, 1997). Historical evidence shows that agroforestry has been widely practised through the ages as a means of achieving agricultural sustainability and slowing the negative effects of agriculture such as soil degradation and desertification.

The significance of agroforestry with regards to C sequestration and other CO₂ mitigating effects is being widely recognized, but there is still paucity of quantitative data on specific systems and ecosystems. According to recent projections, the area of the world under agroforestry will increase substantially in the near future. Undoubtedly, this will have a great impact on the flux and long-term storage of C in the terrestrial biosphere. Agro-ecosystems play a central role in the global C cycle and contain approximately 12% of the world terrestrial C (Smith *et al.*, 1993, Dixon *et al.*, 1994, Dixon, 1995). Soil degradation as a result of land-use change has been one of the major causes of C loss and CO₂ accumulation in the atmosphere. Agroforestry may involve practices that favour the emission of GHGs including shifting cultivation, pasture maintenance by burning, paddy cultivation, N fertilisation and animal production (Le Mer and Roger, 2001).

However, several studies have shown that the inclusion of trees in the agricultural landscapes often improves the productivity of systems while providing opportunities to create C sinks (Winjum *et al.*, 1992, Krankina and Dixon, 1994). The amount of C sequestered largely depends on the agroforestry system put in place, the structure and function of which are, to a great extent, determined by environmental and socio-economic factors. Other factors influencing carbon storage in agroforestry systems include tree species and system management.

Kinnaur district of Himachal Pradesh, India is known for its unique climatic conditions, lofty mountain ranges, neoza pine tree, dry fruits, high quality apple and pulse crop production etc. In recent times, however, the farmers of the district which falls in the dry temperate Himalaya have developed their own agroforestry systems integrating fruits, vegetables and field crops. These newly developed agroforestry systems need to be tested for their biological productivity, environmental suitability and economic sustainability vis-à-vis other land use systems of the region. Therefore, the present study entitled “*Carbon storage potential and bio-economic appraisal of different land use systems in dry temperate north western Himalayas*” was undertaken to test these land uses on these grounds. The specific objectives of the study were as follows:

- To find out the biological yield and economic returns from the different land use systems;
- To ascertain carbon stock under different land use systems along an altitudinal gradient;
- To identify suitable land use systems with high monetary return and carbon storage potential in dry temperate north-western Himalayas.

Chapter-2

REVIEW OF LITERATURE

Removing atmospheric carbon (C) and storing it in the terrestrial biosphere is one of the options, which have been proposed to compensate greenhouse gas (GHG) emissions. Agricultural lands are believed to be a major potential sink and could absorb large quantities of C if trees are reintroduced to these systems and judiciously managed together with crops and or/animals. Thus, the importance of agroforestry as a land use system is receiving wider recognition not only in terms of agricultural sustainability but also in issues related to climate change. The available literature sources relevant to the present study have been reviewed under the following heads:

- 2.1 Biological yield under different land use systems
- 2.2 Carbon stock in plant biomass under different land use systems
- 2.3 Carbon stock in soil under different land use systems
- 2.4 Economic returns from different land use systems

2.1 BIOLOGICAL YIELD UNDER DIFFERENT LAND USE SYSTEMS

Biomass is one of the very important parameters affecting biosphere-atmosphere interactions. Estimation of woody biomass is a prerequisite for determining the state of flux for biological materials in an ecosystem and for understanding the dynamics of ecosystem (Anderson 1971; Chaturvedi & Singh 1987; Rawat & Singh 1988). Information on biomass is not only important from the standpoint of fundamental ecology, but also relevant to planning for ecologically sustainable development of a region (Singh & Singh 1997). Over the last two decade many research workers have tried to quantify the biomass production potential of different land management systems, some of them are discussed hereunder.

Tokey *et al.*, (1989) analysed the species composition, biomass and productivity patterns of three types of traditional agroforestry systems, namely: agri-silviculture, agri-horticulture and agri-horti-silviculture in western Himalayas and reported that species composition in the systems varied depending upon the size of land holding and the basic requirements of the farmers. Agri-horti-silviculture system was highly diverse in vegetation, with 13 trees and 5 agriculture crops mixed together and gave the highest productivity of up to 25.5 t ha⁻¹yr⁻¹ with only 27 per cent contribution by the trees. Total above ground biomass in agri-horti-silvicultural system was around two times higher than the agri-silvicultural system.

Khybri *et al.* (1992) studied tree crop interactions under rain fed conditions in Dehradun valley for 13 years (1977 to 1990) and reported that *Grewia optiva* could produce 1.00 t ha⁻¹yr⁻¹ of branch biomass and 0.26 t ha⁻¹yr⁻¹ of leaf fodder. In Rajasthan, Bhimaya *et al.*, (1964) obtained an output of 69 kg of fresh leaves from a full grown tree of *Prosopis cineraria* on complete lopping when only the central leading shoot was left. Similarly, 25-30 kg of fresh leaf biomass was obtained from moderately sized tree of *P. cineraria* (Bohra and Ghosh, 1980).

While studying the biomass production pattern in traditional agroforestry systems in western Himalayas, Majumdar (1991) reported that Horti-silvi-pastural system gave the highest standing biomass (355.5 q ha⁻¹) compared to horti-agricultural system (301.5 q ha⁻¹) and grassland (63.2 q ha⁻¹). Fruit trees in horti-agricultural system produced the maximum biomass of 55.8 q ha⁻¹yr⁻¹. They also put the major portion of the annual biomass by 53.5 per cent in horti-silvi-pastural system followed by fodder trees (26.0 %) and timber/fuel wood trees (20.7%). In grassland system, timber/fuel wood species contributed the maximum share of 51.1 per cent to system productivity.

Dinssa (1993) reported that the growth and yield of soybean, black gram, horsegram and cowpea was higher under monoculture as compared to intercropping with *Morus alba*. Sharma *et al.*, (1993) studied the influence of *Acacia tortilis* and *Zizyphus rotundifolia* trees on the productivity of under storey

grasses viz. *Cenchrus ciliaris* and *Lasiurus sendicus* grown in association with trees. They found that reduction in yield under *Acacia tortilis* was higher than under *Zizyphus rotundifolia*. *Lasiurus sendicus* suffered greater reduction as compared to *Cenchrus ciliaris*.

Korwar and Radder (1997) evaluated the potential of alley cropping post rainy season sorghum between *Leucaena* hedge rows. They found that *Leucaena* produced on an average 2.47 t/ha of pruning biomass and 1.57 t/ha of wood annually. Hocking *et al.* 1997 while studying the effect of traditionally managed mature trees on adjacent crop yield and reported that there was a variable decrease in rice and wheat yield levels under all tree species which ranged from 18 per cent for light canopied *Acacia catechu* to a little over 40 per cent for the dense canopied *Artocarpus heterophyllus* and *Mangifera indica*.

Yadav (1997) evaluated the biomass productivity and nutrient contents of *Morus alba* and *Leucaena leucocephala* based silvi-pastoral systems. He observed that in *M. alba* based silvi-pastoral system the biomass productivity was 5.03 q ha⁻¹ of leaf biomass and 14.03 q ha⁻¹ of branch wood biomass at 2.0 m of pollarding height. Whereas, in *Leucaena* based silvi-pastoral system maximum tree leaf biomass was found to be 12.73q ha⁻¹ and branch wood biomass 58.58 q ha⁻¹ at 2.0 m pollarding height.

Chamshma *et al.*, (1998) carried out a study to see the growth and yield of maize alley cropping with *Leucaena leucocephala* and *Faidherbia albida* in Morogoro, Tanzania and observed that maize grain yield was little affected by the tree crop interaction as competition for resources was reduced through periodic pruning and clean weeding. There was no gain in maize grain yield due to the presence of *Leucaena leucocephala* and *Faidherbia albida*. These results suggested that alley cropping was justified for wood production but not for increasing maize grain yield. Whereas, Mugendi *et al.*, (1999) reported that inclusion of *Calliandra* hedges on crop land adversely affected maize yield on the other hand alley cropping with *Leucaena* was advantageous. Kushwaha *et al.*, (2000) conducted an experiment in which they pollarded the eight years old

multipurpose tree species i.e. *leucaena*, *eucalyptus*, *moringa* and after that black gram and sorghum were intercropped. They reported that the yield of arable intercrops after pollarding were 268.3, 254.2, 225.2 and 241.9 kg ha⁻¹ of black gram and 93.43, 29.72, 89.57 and 88.80 q ha⁻¹ of sorghum fodder under no tree, *Leucaena*, *Eucalyptus* and *Moringa*, respectively.

Meng Ping *et al.* (2002) tested the characteristics of wheat roots difference between apple wheat inter cropping system and wheat monoculture in hilly region of Taihang mountains China and showed that during the wheat double ridge maturity stage, the amount of wheat fine roots in the intercropping was approximately 4.74 % more than that in the wheat monoculture. Bao-Weikai *et al.*, (1999) achieved to show that maize cultivars characterized by early or middle maturity and short stature were suitable for intercropping under apple tree. Kumar (1999) pointed, tree crop interactions in association of Mulberry, Plum and Pomegranate with soybean influenced negatively to the soybean growth and yield attributes as compared with sole crop and the negative influence was significant. Soybean growth and yield response in general among the tree-crop combinations was in the order of pomegranate soybean > plum soybean > mulberry – soybean > pomegranate-mulberry – soybean > plum mulberry – soybean > plum – mulberry – pomegranate - soybean.

Verma *et al.* (2002) in another study on tree crop interaction in agri-horticulture system found that the fruit tree crop combinations suppressed growth and yield attributes of wheat. The reduction in wheat yield over sole cropping was 17.9, 21.3, 25.2 and 28.2 per cent with tree crop combinations Grewia + Almond + Wheat (17.85 q ha⁻¹), Morus + Almond + Wheat (17.10 q ha⁻¹), Grewia + Wheat (16.26 q ha⁻¹) and Morus + Wheat (15.61 q ha⁻¹), respectively. Increase in nitrogen level by 25% more than the recommended level enhanced the grain and straw yield below the tree crown in equal or even higher magnitude to that obtained outside the crown at recommended level of nitrogen.

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 horti-pastoral, 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 silvi-pastoral (59.72 t ha^{-1}) system produced the highest biomass, whereas minimum was (5.79 t ha^{-1}) in natural grassland. The agri-horti-silviculture system produced the second highest biomass among the different land use systems despite having lesser number of trees.

Tomar and Bhatt (2004) from fruit tree-rice intercropping recorded higher average grain yield and total yield of all rice cultivars in the control plots (without trees) than in under storey plots of the fruit trees. Verma *et al.*, (2004) studied the varietal response of wheat to different nitrogen levels in agri-horticulture system under rain fed hill farming system practiced in north western mid Himalayan region of H.P., India and concluded that with 3 levels of nitrogen viz. 60 kg ha^{-1} (25% less than the recommended doses 80 kg ha^{-1} (the recommended dose) and 100 kg ha^{-1} (25 % above the recommended dose) in 12 years old peach based agri-horticulture system, growth attributes of wheat cultivars, namely germination percentage, number of plant m^{-2} , number of tillers per plant were not influenced significantly. Plant height increased significantly with the 25% increase in nitrogen level. Varietal effects were also significant. The yield response such as a number of spikes per plant, 1000 grain weight, straw and grain yield as well as harvest index were influenced significantly by nitrogen levels. The direction of crop sowing also had significant effect on yield attributes. Grain yield was higher in south direction over north. Grain yield in agri-horticulture (AH) system, reduction in nitrogen level by 25% over the recommended level decreased the yield by 25.27% whereas, in sole crop just by 4.7%. These authors concluded that in fruit tree based agroforestry system the use of suitable wheat cultivar and application of additional quantity of nutrient N over the recommended level for mono crop system would be viable option to obtain higher yield and net returns.

Gill and Ajit (2006) conducted a study from 1990-91 to 1995-96 in U.P. India, to determine the effect of four cultivars of Mango (Langra, Deshari, Amrapalli and Mallika) on the yield of wheat sown in the interspaces of the mango cultivars. The grain yield of wheat was recorded from the first, third and fifth rows. On an average the highest grain and straw yield was recorded with 'Amarpalli' and lowest with 'Mallika'. Maximum wheat yield was registered from the fifth row followed by third row and minimum in the first row from the tree component. Macedo *et al.*, (2006) demonstrated that corn production in intercropped systems with *Eucalyptus* clone was lower than in monoculture. The highest corn yield in the agroforestry system with *Eucalyptus* was obtained in central planting rows.

Sanneh (2007) worked on status of carbon stock under different land use system in wet temperate north-western Himalayas at different altitudinal gradients viz., 1500 m -1800 m a.s.l, 1800 m -2100 m a.s.l and 2100 m – 2400 m a.s.l. Result of his finding indicated that maximum above ground biomass (308.96 t ha⁻¹), below ground biomass (62.09 t ha⁻¹) and total biomass (371.06 t ha⁻¹) was in the forest land use system. It was followed by silvi-pasture, agri-silvipasture, agri-horticulture, agriculture and grassland systems, respectively. The rate of biomass production (t ha⁻¹) increased with increasing altitudinal ranges. The rate of total biomass production at 1500 m-1800 m, 1800 m- 2100 m, 2100 m-2400 m a.s.l was 106.31 t ha⁻¹, 113.19 t ha⁻¹, and 141.41 t ha⁻¹, respectively.

Minj (2008) reported that maximum mean above ground biomass (188.60 t ha⁻¹), below ground biomass (49.04 t ha⁻¹) and total biomass (237.70 t ha⁻¹) was accumulated in pure popular plantation, followed by agri-silviculture, silvi-pastural, pure agriculture, and pure grassland systems, respectively. The rate of biomass production (t ha⁻¹) declined as we shifted from sub-tropical sub-montane and low hills to sub-temperate sub humid mid hills conditions. The mean total biomass production of all the systems in Zone I and Zone II was (98.14 t ha⁻¹) and (46.99 t ha⁻¹), respectively.

2.2 CARBON STOCK IN PLANT BIOMASS UNDER DIFFERENT LAND USE SYSTEMS

Agroforestry system can, however, be either sink or sources of carbon and other green house gases. Some agroforestry systems, especially, those that include trees and crops (agri-silviculture, agri-horticulture, agri-horti-silviculture) can be carbon sinks and store carbon (for medium to long term ranging from 10-40 years period) while others (e.g. ruminant based agri-silviculture system) are probably sources of carbon and other greenhouse gases. Especially in tropical region agroforestry system can be significant sources of GHGs: practices such as tillage, burning, manuring, chemical fertilization and frequent disturbance can lead to emissions of CO₂, CH₄ and N₂O from soils and vegetation to atmosphere. Silvi-pastoral system when practiced in unsustainable manner can result in soil compaction and erosion with losses of C & N from soils. Ruminant based agri-silvi-pastoral system and rice paddy agri-silviculture systems are well documented sources of CH₄ (Dixon, 1995).

Based on tree growth and wood production and assuming ratios of tree stem biomass to C content of 1:2 (i.e.50% of stem wood is assumed to be carbon), average carbon storage by agroforestry practices has been estimated to be 9,21,50 and 63 Mg C ha⁻¹ in semi arid, sub humid, humid and temperature regions (Schroeder, 1994), respectively. At a global scale it has been estimated that agroforestry systems could be implemented on 585 to 1275 x 10⁶ hectares of technically suitable land, these systems could store 12-228 Mg C/ha with a median value of 95 Mg C/ha under the prevalent climatic and edaphic conditions (Dixon, 1995 and Albercht and Kandji, 2003). Agroforestry system will also decrease pressure on natural forests, which are the largest sink of terrestrial carbon. Within tropical region, it has been estimated that one hectare of sustainable agroforestry could potentially offset 5 to 20 ha of deforestation (Dixon, 1995).

Planted forests are known to take up and store carbon at high rate compared to other world land covers. Storage rates commonly range from 1-8 Mg

C ha⁻¹ yr⁻¹ and typical mean carbon storage over a rotation period is from 50 to 80 Mg C ha⁻¹ (Winjum and Schroeder, 1995).

Beer *et al.* (1990) gave detailed break down of biomass production over 10 years in the tree combinations in Costa Rica: cacao (*Theobroma cacao*), laurel (*Cordia alliodora*) and Cacao-Pozo (*Erythrina poeppigiana*). Based on these data, whole system carbon stocks were calculated by averaging the annual biomass production in the two periods and multiplying the output by 0.5. Thus, 11 Mg C ha⁻¹ yr⁻¹ was stored over ten years in the system including 6 Mg C ha⁻¹ yr⁻¹ in the shade trees. Biomass estimation by Jensen (1993) in Java showed that 16 Mg C ha⁻¹yr⁻¹ could be stored if rice fields were transformed in home garden.

Lasco *et al.*, (2000) stated that one of the most alarming issues today is climate change brought by increasing concentration of the greenhouse gases (GHGs) in the atmosphere. This study was conducted in order to quantitatively assess the capacity of a multi-storey agroforestry system in Mount. Mailing to store and sequester CO₂. The methodology used to attain the objectives included the measurement of the total above ground biomass, ground biomass and belowground biomass of the stand. All the plant tissues were brought to the International Rice Research Institute (IRRI) (Los Banos, Laguna, Phillippines) laboratory to analyze the total carbon content. Annual litter fall production of the stand was also estimated including its carbon storage. Result of this study showed that total biomass accumulation of multi-storey agroforestry system was 236.22 tons/hectare. This was obtained from the biomass measured through woods and leaves of *Gmelina arborea* and *Theobroma cacao* under story vegetation, ground litter and roots of the stand. The total carbon storage of biomass was 105.24 t ha⁻¹ and the annual litter face production of this stand was 5.04 t ha⁻¹ which has a capacity of storing 2.2 carbon t ha⁻¹yr⁻¹. The result showed that *Gmelina arborea* and *cacao* multi-storey agroforestry system could be possible sink of CO₂ and has a good potentially of mitigating climate change.

Law *et. al.* (2003) studied a series of ponderosa pine (*Pinus ponderosa* var. Laws.) stands ranging from 9 to > 300 years in central Oregon, USA, and

used biological measurements to estimate carbon storage in vegetation and soil pools, net primary productivity (NPP) and net ecosystem productivity (NEP) to examine variation with stand age. Measurements were made on plots representing four age classes with three replications: initiation (*I*, 9–23 years), young (*Y*, 56–89 years), mature (*M*, 95–106 years), and old (*O*, 190–316 years) stands typical of the forest type in the region. Results revealed that Net ecosystem productivity was lowest in the *I* stands ($-124 \text{ g C m}^{-2} \text{ yr}^{-1}$), moderate in *Y* stands ($118 \text{ g C m}^{-2} \text{ yr}^{-1}$), highest in *M* stands ($170 \text{ g C m}^{-2} \text{ yr}^{-1}$), and low in the *O* stands ($35 \text{ g C m}^{-2} \text{ yr}^{-1}$). Net primary productivity followed similar trends, but did not decline as much in the *O* stands. The ratio of fine root to foliage carbon was highest in the *I* stands, which is likely necessary for establishment in the semiarid environment, where forests are subject to drought during the growing season (300–800 mm precipitation per year). Carbon storage in live mass was the highest in the *O* stands (mean 17.6 kg C m^{-2}). Total ecosystem carbon storage and the fraction of ecosystem carbon in aboveground wood mass increased rapidly until 150–200 years, and did not decline in older stands. Forest inventory data on 950 ponderosa pine plots in Oregon further showed that the greatest proportion of plots existed in stands ~ 100 years old, indicating that a majority of stands were approaching maximum carbon storage and net carbon uptake. The data suggested that NEP averages $\sim 70 \text{ g C m}^{-2} \text{ year}^{-1}$ for ponderosa pine forests in Oregon. About 85% of the total carbon storage in biomass on the survey plots existed in stands greater than 100 years, which has implications for managing forests for carbon sequestration. To investigate variation in carbon storage and fluxes with disturbance, simulation with process models requires a dynamic parameterization for biomass allocation that depends on stand age, and should include a representation of competition between multiple plant functional types for space, water, and nutrients.

Fang *et. al.* (2005) studied Biomass carbon accumulation by Japan's forests from 1947 to 1995. In their study, the results showed that the C accumulations have significantly increased during the last 50 years. The C density (C stock per hectare) and total C stock of aboveground biomass increased from 27.6 Mg C/ha and 611.7 Tg C in 1947 to 43.2 Mg C/ha and 1027.7 Tg C in

1995, respectively, and those of total living biomass increased from 33.9 Mg C/ha and 751.8 Tg C in 1947 to 53.6 Mg C/ha and 1274.8 Tg C in 1995. These increases were remarkable during 1976–1995, with a net increase of 5.6 Mg C/ha and 369 Tg C for the C density and total living biomass. These results suggest that Japan's forest vegetation is a significant C sink.

Ramachandran *et al.* (2007) studied carbon stock in a natural forest area of Kolli hills, part of the Eastern Ghats of Tamil Nadu, India which was estimated using geospatial technology. The total biomass, both above and below ground, was calculated and the total carbon stock estimated. Likewise, the sequestered soil organic carbon was also estimated. The results revealed that the biomass carbon estimated was 2.74 Tg and the soil carbon was 3.48 Tg. The scientists concluded that the lesser soil organic carbon indicated that the forest area was severely affected by degradation due to various need-based forestry practices and anthropogenic disturbances. A national-level carbon databank was envisaged for all types of forest in India to study the temporal change and carbon sequestration potential for better management of forests

Zhao and Zhou (2006) studied the carbon storage of forest vegetation in China and its relationship with climatic factors and found that total carbon storage and mean carbon density of forest vegetation in China were 3.8 Pg C (about 1.1 % of the global vegetation carbon stock) and 41.32 Mg/ha respectively. Also the result indicated that forest vegetation carbon storage was more sensitive to changes of mean annual temperature than other factors, suggesting that global warming would seriously affect the forest carbon storage.

Evrendik *et al.* (2006) studied the above ground biomass, above ground litter fall and leaf litter decomposition of five indigenous tree stands (pure stands of *Abies ciliata*, *P. nigra* and *C libani*) in eastern Mediterranean evergreen needle leaf forest of Turkey. Mean C stock of the conifer forests was estimated as 97.8 ± 79 Mg C ha⁻¹ consisting of 83.0 ± 67 Mg C ha⁻¹ in the above ground and 14.8 ± 12 Mg C ha⁻¹ in the below ground biomass.

Ramachandran *et al.* (2007) estimated 2.74 Tg biomass carbon in the natural forests in Eastern Ghats of Tamil Nadu using geospatial technology. In Himachal Pradesh state 48.90 Mt. biomass carbons was estimated by Jha and Gupta (2005), whereas, neighbouring states of Himachal Pradesh i.e. Haryana, Punjab, J & K and U.P. showed 162.49 Mt of carbon sink in forest biomass.

A study was conducted in mature coffee plantation in south- west Tago to determine carbon and nutrient stocks in shaded and open grown coffee systems. Biomass of *Albizia* trees was predicted by allometry, whereas biomass of coffee bushes was estimated through destructive sampling. Above and belowground biomass estimates were respectively, 140 mg ha⁻¹ and 32 Mg ha⁻¹ in the coffee + *Albizia* association and 29.7 Mg ha⁻¹ and 18.7 Mg ha⁻¹ in the open grown system, respectively. *Albizia* trees contributed 87% of total aboveground biomass and 55% of total root biomass in the shaded coffee system. Individual coffee bushes consistently had higher biomass in the open grown than in the shaded coffee system. Total C stock was 81 Mg ha⁻¹ in the shaded coffee system and only 22.9 Mg ha⁻¹ for coffee grown in the open (Dossa *et al.*, 2008).

Ravindranath *et al.*, (2008) reported that the afforested is increasing and currently 67.83 m ha of area is under forest cover. Assuming that the current trend continues, the area under forest cover is projected to reach 72 m ha by 2030. Estimates of carbon stock in Indian forests in both soil and vegetation range from 8.58 to 9.57 Gt C. The carbon stock in existing forests is projected to be nearly stable over the next 25 year period at 8.79 Gt C. However, if the current rate of afforestation and reforestation is assumed to continue, the carbon stock could increase from 8.79 Gt C in 2006 to 9.75 Gt C by 2030 an increase of 11%.

The study conducted by Minj (2008) in low and mid hills of western Himalaya during year 2004-2006 revealed that mean biomass carbon stock and CO₂ sequestration in zones I(sub montane low hills) was found to be 2.09 times higher than zone II (mid hills). Maximum mean total carbon stock (107.00 t ha⁻¹) was observed in pure plantation system of popular at an average density of 1066 trees/hectare. It was 2.68-4.86 times higher than other perennial plant based

system and about 12.40 – 22.57 times higher than annual crops or pure grassland systems.

2.3 CARBON STOCK IN SOIL UNDER DIFFERENT LAND USE SYSTEMS

2.3.1 Soil

In India, the amount of carbon stored in the soil is 23.4-27.1 Gt. which is 1.6 -1.8 per cent of the carbon stored in the world's soil (Rastogi *et al.*, 2002).

Globally carbon stocks in the soil exceed carbon stocks in vegetation by a factor of about 5. The ratio ranges from 1:1 in tropical forests to 5:1 in boreal forest and much larger factors in grasslands and wetlands (IPCC, 2000). Carbon stored in agriculture soil is 170 Gt, while entire vegetation contains 550 Gt C. The total carbon lost as a result of bringing land under crop cultivation the world over has been estimated at 54 Gt C, in which the contributions of temperate grasslands and tropical forest soils were substantial (Rastogi *et al.* 2002).

Conversion of natural forests to agriculture in humid tropics lead to a reduction in ecosystem carbon storage due to removal of above ground biomass and a subsequent -gradual reduction in soil organic carbon. Whereas, forest conversion to well managed grassland may lead to increased soil carbon storage, after an initial decline (Van *et al.*, 1997). Katagiri *et al.* (1992) reported that dry weight of dead organic matter including dead standing trees was 4.1 and 16.8 per cent of total above ground biomass in Sanbe forest, Shimane Japan. *Quercus semicarpifolia* and *Castanea cernato* comprised the principal broad leaved species. Forest show the best mitigation potential followed by agroforestry, plantations and agriculture. Agroforestry interventions in the farming sector appear to be the most suitable land use strategy. Degradation of soil has adverse effect on soil carbon. Causes of soil degradation, adopted from world resources in 1992 for the Asian region showed 40 per cent contribution from degradation, 27 per cent from industrialization and agriculture activities and 26 per cent from overgrazing and 6 per cent from over exploitation (Jha and Gupta, 2003)

SOC is sensitive to impact of anthropogenic activities sustaining or increasing soil productivity depends in part on soil and crop management practices that maintain or increase soil organic matter. Soil management strategies have great potential to contribute to carbon sequestration, since the carbon sink capacity of the world's agriculture and degraded soil is 50-60 % of the historic carbon loss of 42-72 Pg (1 Pg = 10^{15} g), although the actual carbon storage in cultivated soil may be smaller if climate changes lead to increasing mineralization. No tillage practices, cover crop management and manure application are recommended to enhance soil organic carbon storage and to contribute to sustainable food production, which also improves soil quality (Komatsuzaki and Ohta, 2007).

Ramachandran *et al.* (2007) estimated 3.48 Tg soil carbon in the natural forests in Eastern Ghats of Tamil Nadu, India. Forests show the best mitigation potential followed by agroforestry, plantation and agriculture. Total organic matter accumulate in soil constitute a major portion of the worlds 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% during 5 years period was studied by Singh (2005). However integration of trees allowed loss of SOC by 3.2 % in *Emblia officinalis*, 22%. *Hardwickia binnata* and 35.5% in *Colophospermum mopan* based agroforestry system in comparison of 56% from agricultural plot. A projection of carbon stocks for small holder agroforestry systems in the tropics indicated C sequestration rates ranging from 1.5 to 3.5 Mg C ha⁻¹ yr⁻¹ and a tripling of C stocks in a twenty year period to 70 Mg ha⁻¹ (Watson *et al.*, 2000).

Farm forestry plantations raised on farmer fields are mainly on marginal and sub marginal lands with low levels of soil carbon. However, the soil carbon in such area rises quite rapidly and can reach level of normal forest soils in a period of 15-25 years (Sampson and Sedja, 1997). Grass covered soil released more CO₂ than did forest vegetation (Dorr and Munnich, 1987). Similarly, newly cropped plots generated by slash and burn released more CO₂ than an uncut forest

plot (Tulaphitak *et al.*, 1983). It appears the conversion of native vegetation increase soil respiration conversion of natural forests to agriculture in the humid tropics leads to a reduction in ecosystem carbon storage due to removal of above ground biomass and a gradual subsequent reduction in soil carbon. Whereas, forest conversion to well managed grasslands may lead to increased soil carbon storage, after an initial decline (Van *et al.*, 1997).

Soil is the largest pool of terrestrial carbon, estimated as 2200 Pg; tropical top soils contain about 13% of world soil carbon (Young, 1997). Estimation of biomass and sequestered carbon on farm forest plantation in Northern New South Wales, Australia (Specht and West, 2003) revealed that analysis of organic carbon content of soil below plantations and adjacent pasture paddocks suggested there was a decline in soil carbon with time following establishment. Total soil organic carbon pool for the entire land area of the world excluding carbon held in the litter layer and charcoal, amount to 2175 to 2293 Pg of C in the upper 100 cm soil layer. Soil organic carbon estimated to be 684 to 724 Pg of C in the upper 30 cm, 1462 to 1548 Pg of C in the upper 100 cm and 2376 to 2456 Pg of C in the upper 200 cm. Although deforestation, changes in land use and predicted climate change can alter the amount of organic carbon held in the superficial soil layer rapidly (Batjes, 1996). The amount of carbon in Indian soil is 23.4-27.1 Gt, which is about 1.6 to 1.8 % of the carbon stored in world soil (Rastogi *et al.*, 2002). The total SOC pool in Indian forest soil is 4.13 Pg and 6.81 Pg C in top 50 cm to 100 cm depth, respectively (Chhabra *et al.*, 2003).

Agricultural practices can render soil either a sink or a source of the atmospheric CO₂ with direct influence on the greenhouse effect (Lal *et al.*, 1999). Total organic matter accumulated in the soils constitutes a major portion of the words fixed carbon reserve. This distribution of the organic matter among soil type is highly variable and generally not easily predictable from above ground vegetation types.

Indian soils are largely carbon depleted but can be brought back to their native carbon carrying capacity by reforestation. Wastelands in India cover more

than 100 million ha of which 70 per cent in carbon degraded. These soils have relatively high potential for accumulating organic carbon in vegetation and in soil, if suitable trees are grown along with proper soil conservation measures. Promoting agroforestry type of land use system in these lands is highly desirable (Rai and Sharma, 2003). Growing trees can improve soil quality, however at a slow rate and sequester carbon in soil and biomass. Kair (*Capparis decidua*) one such tree is adoptable to the dry lands of North West India (Gupta *et al.*, 1989).

Lal (2002a) studied the carbon sequestration in dry ecosystems of West Asia and North Africa (WANA) and reported that the region has a land area of 1.7 billion ha and population of 600 million. Deforestation and soil degradation are severe problems in this region. The problem of drought stress is exacerbated by low and erratic rainfall and soils of limited available water holding capacity and organic carbon content of < 0.5 per cent. The soil organic carbon pool of most soils has been depleted by soil degradation and widespread use of substances and exploitative farming system. The historic loss of a soil organic carbon sink capacity of the WANA region may be 3.7 Pg. This potential desertification, restore degraded soils and ecosystems and improve soil and crop management techniques that can enhance the soil organic carbon pool and improve soil quality. The strategies of soil carbon sequestration include integrated nutrient management and recycling, controlled grazing growing improved fodder species on rangeland. Through adapting of such measures, the potential of soil carbon sequestration in the WANA region is 0.2-0.4 Pg C yr⁻¹. Lal (2002 b) also advocated that the restoration of degraded soils and ecosystems is a important strategy for enhancing biomass production to improve soil quality and increase the carbon pool.

Lal (2002b) reported that most soils in mid Western USA have lost 30 to 50 per cent of their original pool or 25 to 40 MG C ha⁻¹ upon conversion from natural to agricultural ecosystems. About 60 to 70 per cent of the carbon thus depleted can be sequestered through adoption of recommended soil and crop management practices. The gross rate of soil organic carbon sequestration ranges from 500-800 kg ha⁻¹ yr⁻¹ in cold and humid regions and 100-300 kg ha⁻¹ yr⁻¹ in

dry and warm regions and there is also a large potential to sequester soil inorganic carbon in arid and semi arid regions.

Li *et al.* (2004) studied and estimated the current vegetation and soil carbon storage in China using a biogeochemical model driven with climate, soil and vegetation data at 0.5 latitude-longitude grid spatial resolution. The results indicated that the total carbon storage in China's vegetation and soils was 13.33 Gt C and 82.65 Gt C respectively, about 3% and 4% of the global total. The nationally mean vegetation and soil carbon densities were 1.47 kg C/m² and 9.17 kg C/m², respectively, differing greatly in various regions affected by climate, vegetation, and soil types. They were generally higher in the warm and wet Southeast China and Southwest China than in the arid Northwest China; whereas vegetation carbon density was the highest in the warm Southeast China and Southwest China, soil carbon density was the highest in the cold Northeast China and southeastern fringe of the Qinghai-Tibetan Plateau. These spatial patterns are clearly correlated with variations in the climate that regulates plant growth and soil organic matter decomposition, and show that vegetation and soil carbon densities are controlled by different climatic factors.

Wang *et al* (2004b) studied the characteristics of soil organic matter (SOM) and nitrogen (N) on the eastern slope of Gongga Mountain in china. The results of the study revealed that the content of SOM and N of horizon had an ascending trend with the increase of the elevation. The vegetation types distributed higher than the mixed broad – leaved and coniferous forest have the irregular trends. In the transitional zone vegetation such as mixed trees and treeline, the content of SOM and N is higher than other vegetation types. The distribution of SOM and N of A horizon is dependent on the synthetic effect of climate and vegetation types. The vertical distribution of SOM and N in soil profiles had the similar trends for all kinds of vegetation types i.e the content of A horizon was higher than that of B and C horizons, which is the same to the distribution of dead animal and plant in soil. The soil C:N was between 7 and 25, which is relatively low comparing to the appropriate C:N of 25 – 30. It was also found in this study that the ratio of soil carbon to nitrogen (C:N) increases with

the increase of the elevation, but its vertical distribution in soil horizons varies with different vegetation types. The N exists in SOM mainly in the form of organic nitrogen and the soil C:N correlates significantly with SOM.

Yang *et al* (2007) based on the data from China's second national soil survey and field observations in northwest of the country, estimated soil organic carbon (SOC) storage in China and investigated its spatial and vertical distribution. China's SOC storage in a depth of 1 meter was estimated as 69.1 Pg (1015 g), with an average density of 7.8 kg m⁻². About 48% of the storage was concentrated in the top 30 cm. The SOC density decreased from the southeast to the northwest, and increased from arid to semi-humid zone in northern China and from tropical to cold-temperate zone in the eastern part of the country. The vertical distribution of SOC differed in various climatic zones and biomes; SOC distributed deeper in arid climate and water-limited biomes than in humid climate. An analysis of general linear model suggested that climate, vegetation, and soil texture significantly influenced spatial pattern of SOC, explaining 78.2% of the total variance, and that climate and vegetation interpreted 78.9% of the total variance in the vertical SOC distribution.

Gupta *et al.* (2009) reported that popular based agroforestry system improves aggregation of soil through huge amounts of organic matter in the form of leaf biomass. The extent of improvement may be affected by the age of the popular trees and soil type. The surface and subsurface soil samples from agroforestry and adjoining non agroforestry sites with different years of popular plantation (1, 3 and 6 years) and varying soil textures (loamy and sandy clay) were analyzed for soil carbon increased from 0.36 in sole crop to 0.66 % in agroforestry soils. The increase was higher in loamy sand than sandy clay. The soil organic carbon increased with increased in tree age. The soil under agroforestry had 2.9-4.8 Mg ha⁻¹ higher soil organic carbon than in sole crop. The popular trees could sequester higher soil organic carbon in 0-30 cm profile during the first year of their plantation (6.07 Mg ha⁻¹ yr⁻¹) than subsequent year (1.95 – 2.65 Mg ha⁻¹ yr⁻¹). The sandy clay could sequester higher carbon (2.85 Mg ha⁻¹ yr⁻¹) than in loamy sand (2.32 Mg ha⁻¹ yr⁻¹).

Kaonga and Smith (2009) reported tree and soil C stocks and their response to different tree species and clay contents in improved fallow of eastern Zambia from 2002-2003. Soil and destructively harvested two years old tree, samples were analyzed for carbon. There were significant difference ($P < 0.05$) in above ground tree (Stocks and in net organic C (NOC) intake rates across coppicing tree species at *Msekera* and *Kalunga*. Above ground (stock ranged from 2.9 to 9.8 t ha⁻¹ equivalent to NOC intakes of 0.8-4.9 t ha⁻¹ yr⁻¹. SOC stock in non coppiced fallows at *Kalichero* and *Msekera* significantly differed ($P < 0.05$) across treatments. SOC stocks to 200 cm depth ranged from 64.7 t C ha⁻¹ under non coppicing fallow at *Kalunga* to 184.0 t ha⁻¹ in 10 year old coppicing fallow at *Msekera*. Therefore, tree and soil C stocks in improved fallow can be increased by planting selected tree species on soils with high clay content.

Lal (2010) studied Soil carbon sequestration impacts on global climate change and food security and noted that the carbon sink capacity of the world's agricultural and degraded soils is 50 to 66% of the historic carbon loss of 42 to 78 gigatons of carbon. He further indicated that the rate of soil organic carbon sequestration with adoption of recommended technologies depends on soil texture and structure, rainfall, temperature, farming system, and soil management. Strategies to increase the soil carbon pool include soil restoration and woodland regeneration, no-till farming, cover crops, nutrient management, manuring and sludge application, improved grazing, water conservation and harvesting, efficient irrigation, agroforestry practices, and growing energy crops on spare lands. An increase of 1 ton of soil carbon pool of degraded cropland soils may increase crop yield by 20 to 40 kilograms per hectare (kg/ha) for wheat, 10 to 20 kg/ha for maize, and 0.5 to 1 kg/ha for cowpeas. As well as enhancing food security, carbon sequestration has the potential to offset fossil fuel emissions by 0.4 to 1.2 gigatons of carbon per year, or 5 to 15% of the global fossil-fuel emissions.

2.3.2 Depth wise distribution of soil organic carbon pool

The soil organic carbon pool in the top one meter depth of the World soil range between 1462 and 1576 Pg. It is nearly three times than that in the above

ground biomass and approximately doubles than in the atmosphere 32% of this is contributed by soils in the tropics (Eswaran *et al.*, 1993). Kern and Johnson (1993) reviewed data from 17 fields comparing no tillage with conventional tillage plots in USA and observed that soil organic carbon gains were 27 per cent for the 0-8 cm layer, 16 per cent for the 8-15 cm layer and no gains for depth 715 cm. In tropical zones a significant impact on soil organic concentration has been observed for the 0-10 cm layer (Bayer *et al.*, 2000 and Lal 1976).

The difference between soil in organic carbon and nitrogen content with no tillage was related to soil texture. Similar results were reported from a long term tillage rotation study on two ohio soils (Dick, 1983) after 19 year of study soil organic carbon was higher in no till (0-75 cm depth) by 41 and 56 per cent compared with conventional tillage in a silt clay, loam and silt loam, respectively on a field with continuous corn crop (Havlin *et al.*, 1990).

Lal *et al.* (1998) studied the land use and soil management effect on soil organic matter dynamics on Alfisols in western Nigeria and found that the tillage and intensive cropping following, deforestation usually decrease soil organic carbon by 25-60 per cent for the top 0.5 cm depth. Cropping systems that maintained favourable soil organic carbon levels in the soil were characterized by high total and below ground root biomass and relatively narrow ratio of carbon to nitrogen and phosphorus and sulphur.

With increased cropping intensity, one would expect that more crop residue and carbon would be added to the soil than with a crop fallow system (Cambell *et al.*, 1995; 2000; Janzen *et al.*, 1998 and Peterson *et al.*, 1998). As the amount of crop residue returned to the soil is increased, soil organic carbon sequestration is expected to increase if the residue carbon is not lost as CO₂ to the atmosphere because of tillage induced decomposition (Larney *et al.*, 1997; Reicosky, 1997a). Campbell *et al.* (1998) reported increased soil organic carbon levels as fallow frequency and tillage intensity decreased within Canadian Prairie Province cropping system in the Northern Great Plains. The benefit of increasing soil organic carbon is due to not only improved soil structure and water nutrient

relationship, but includes the ability to store carbon in the soil to reduce atmospheric CO₂ (Lal *et al.*, 1998; 1999).

Batjes and Dijkshoorn (1999) reported that the mean carbon densities to a depth of 1 m range from 4.0 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 cm⁻²) was 9.8 kg m⁻². In total the top 1 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, the layer which was most prone to change upon land use conversion and deforestation.

Joao Carlos *et al.* (2001) studied the carbon sequestration rates for a tillage chronosequence and concluded that the carbon sequestration rates for no tillage was 80.6 g cm⁻² for the 0-20 cm depth. The no tillage carbon sequestration potential for south Brazil was estimated as 9.37 Tg C yr⁻¹. Roose (1996) found that the total and microbial carbon and nitrogen decline consistently with profile depth. Microbial carbon and nitrogen ratio differed little among soil profile depths and ecosystems. In 0-10 cm, depth mineral soil, CO₂-C production, metabolic quotients and net nitrogen mineralization were all highest in the pasture samples.

Lal (2002b) reported that most soils in mid Western USA have lost 30 to 50 percent of their original pool or 25 to 40 MG C ha⁻¹ upon conversion from natural to agricultural ecosystems. About 60 to 70 percent of the carbon thus depleted can be resequenced through adoption of recommended soil and crop management practices. The gross rate soil organic carbon sequestration ranges from 500-800 Kg ha⁻¹ yr⁻¹ in cold and humid regions and 100-300 Kg ha⁻¹ yr⁻¹ in dry and warm regions and there is also a large potential to sequester soil inorganic carbon in arid and semi arid regions.

Halvorson *et al.* (2002) evaluated long term (12 years) effect of tillage system and nitrogen fertilization on crop residue production and soil organic carbon sequestration suggested that continued use of crop fallow farming system, even with no tillage and estimated that 233 kg C ha⁻¹ was sequestered each year,

compared with 25 kg C ha⁻¹ with medium tillage and a loss of 141 kg C ha⁻¹ with conservation tillage.

Soil carbon sink under different forest types in Himachal Pradesh (India) was studied by Jha and Gupta (2005). Maximum SOC pool of 117.36 Mt was observed under mixed conifer forest in 1984, followed by chir (43.80 mt), upland hardwood (35.07 mt) and miscellaneous forest (15.04 Mt). During a span of 10 yrs (1984-1994) an increase of 21.60 % carbon sink was recorded in silver fir and spruce forest soil followed by 18.55% in Deodar, 17.19 % in Kail, 17.32 % in hardwood and conifers and 6.81% in upland hardwood. On the other hand during this period 39.21 % decrease in C sink was recorded under kail followed by 38.80 in bamboo and 22.60 % in miscellaneous forests. Overall 7.54 % increase in soil carbon sink was observed in Himachal Pradesh during 10 years period. SOC pools up to 30 cm depth of 16 old plantations were studied by Jha *et al.* (1997). SOC store was higher in *Eucalyptus* (99.6 t ha⁻¹) followed by *Shisham* (98.4 t/ha), *Khair* (79.6 t ha⁻¹), *Teak* (68.0 t ha⁻¹) and *Chir* (57.2 t ha⁻¹).

Land use changes and soil/crop management practices with potential for SOC sequestration of Norwegian agriculture ecosystem based on the data from long term agronomic and land use experiments include conservation tillage methods, judicious use of fertilizers and manures, use of crop residues, diverse crop rotations and erosion control measures. The potential for SOC sequestration is 0.146 MMTC yr⁻¹ for adopting conservation tillage, 0.011-0.035 MMTC yr⁻¹ for crop residue management, 0.026 MMTC yr⁻¹ for Judicious use of mineral fertilizers, 0.016-0.135 MMTC yr⁻¹ for manure application and 0.036 MMTC yr⁻¹ for adopting crop rotations. The overall potential of these practices for soil organic carbon sequestration ranges from 0.591 to 1.022 M MT C yr⁻¹ with an average value of 8.06 M MT C yr⁻¹. Of the total potential 59 per cent is due to adoption of erosion control measures, 5.8 % to restoration of peat lands, 21% to conservation tillage and residue management and 14 % to adoption of improved cropping systems (Singh and Lal, 2005).

In Geauga County, the SOC pool decreased by 34% in alfalfa (*Medicago sativa* L.) grown in a complex rotation with manuring and 51 % in unmanured

continuous corn (*Zea mays L.*). In Stark County, the soil organic carbon pool decreased by 32% in a field systematically amended with poultry manure and 40% in the field receiving only chemical fertilizers. In comparison with continuous corn, the rate of SOC sequestration in Geauga county was 379 kg C ha⁻¹ yr⁻¹ in no till corn (2 years) previously in hay (12 years), 760 kg C ha⁻¹ yr⁻¹ in a complex crop rotation receiving manure and chemical fertilizers and 355 kg C ha⁻¹ yr⁻¹ without manuring. The rate of SOC sequestration was 392 kg C ha⁻¹ yr⁻¹ on manure filled in stark county (Marek *et al.*, 2005).

Jha and Gupta (2005) compared carbon storage of top one foot of soil under 6 land uses. Forests showed the best mitigation potential (120.0 t ha⁻¹), followed by agroforestry (83.6 t ha⁻¹), plantations (80.5 t ha⁻¹), agriculture (66.0 t ha⁻¹), pasture (40.0 t ha⁻¹) and barren land (20 t ha⁻¹). Study suggested the permanency of tall vegetal cover be the reason to sequester more carbon. Kumar (2003) revealed that in western Himalaya SOC was influenced significantly to various agroforestry systems. SOC stock was higher under Silvi-pasture system (74.82 t ha⁻¹) followed by natural grassland (44.33 t ha⁻¹), Agri-horti-silviculture (43.97 t ha⁻¹), Horti-pastoral (42.97 t ha⁻¹), Agri-horticulture (27.81 t ha⁻¹) and minimum was under Agri-silviculture (27.33 t ha⁻¹). The SOC was maximum in surface soils (0-10 cm) whereas minimum was in soils at 30-40 cm profile depth among four profile depths i.e. 0-10 cm, 10-20 cm, 20-30 cm and 30-40 cm. SOC pool was also maximum in Silvi-pasture system followed by natural grassland and Agri-horti-silviculture, minimum was in Agri-horticulture system. Another study conducted in wet temperate north Western Himalaya revealed that forest land use system displayed the maximum value of SOC stock (108.99 t ha⁻¹), followed by Agri-horticulture (51.05 t ha⁻¹), horticulture (46.31 t ha⁻¹), Agri-silviculture (40.40 t ha⁻¹), grass land (36.37 t ha⁻¹) and Silvi-pasture (33.54 t ha⁻¹) in 0-40 cm layer. In the soil layer effect, SOC stock in 0-20 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 system studied in low and mid hills of western Himalaya.

After 10 years of conversion of pasture land to Australian pine (*Casuarina* species) forests in the reclaimed mine soils of southern Ohio showed

increased SOC pool in the top 50 cm by 6 Mg ha⁻¹ in 10 year. However, the nitrogen pool in the top 50 cm was not affected by land use conversion from pasture to Australian pine. Conversion to Black locust increased the SOC pool in the top 50 cm by 24 Mg ha⁻¹ (42%) while the N pool increased by 10 % under Black locust in 10 years. The increase in the SOC pool was accompanied by an increase in the 20 to 50 cm depth. Establishment of tree plantation has a greater potential for SOC sequestration than pastures in the reclaimed mine soils (Ussiri *et al.*, 2006).

Garten and Hanson (2006) measured and studied forest soil C stocks and estimated turnover times along a 1.3 km rise in elevation in the southern Appalachian Mountains. Turnover times were calculated based on estimated soil C inputs and near steady state soil C stocks in the O-horizon and the mineral soil to a 30-cm soil depth. Monte Carlo methods were used in the calculations to accommodate uncertainties in model parameterization. Measured mean stocks and calculated median turnover times of soil C ranged from 4.4 to 12.2 kg C m⁻² and 11 to 31 years, respectively. The predicted turnover times reflected a high proportion of labile soil C over the selected sampling depth. Both forest soil C stocks and the predicted turnover time of soil C increased with altitude. There were no consistent trends for stand basal area and forest soil C inputs along the elevation gradient suggesting that altitudinal changes in soil C stocks and turnover times could be attributed to different rates of soil organic matter decomposition. Soil respiration flux did not vary significantly with altitude, but soil respiration normalized for existing soil C stocks indicated decreasing rates of soil organic matter decomposition with increasing elevation. Measured soil N stocks and differences in O-horizon litter chemistry indicated increasing N availability from low-elevation to high-elevation forests. Soil C storage and turnover time increased from warmer, drier, less N-rich forests to colder, wetter, more N-rich forests. Considered together, these data supported assumptions of a declining rate of soil organic matter decomposition with increasing elevation in the southern Appalachian Mountains. Representative characterization of long-

term litter C inputs was found to be one of the most challenging aspects of the analysis.

Four long term experiments in Kansas were sampled for soil organic carbon. All sites evaluated (Tribune, Manhattan, Parson, Hays) include tillage as a variable: conventional tillage (CT), reduced tillage (RT) and no-tillage (NT). Crop rotation, studied at Manhattan, included combination of wheat sorghum and soybean. Soil samples were taken at the depths of 0-5, 5-15 and 15-30 cm for bulk density and soil organic carbon. Rates of carbon sequestration were calculated by two methods, references initiation of practice and references to the standard management practices. Soil organic carbon was significantly greater under NT at 0-5 cm and tended to be greater under NT at 0-30 cm, bare fallow negatively affected carbon sequestration even under NT. Nitrogen fertilization increased carbon sequestration. Rotations that contained wheat or sorghum had the highest carbon sequestration rates, while continuous soybean had the lowest rates. They found a factor of 1.14 for change from CT to NT and 1.08 from CT to RT (Fabrizzi *et al.*, 2007).

It is widely believed that soil disturbance by tillage was a primary cause of the historical loss of soil organic carbon (SOC) in North America and that substantial SOC sequestration can be accomplished by changing from conventional ploughing to less intensive methods known as conservation tillage. This is based on experiments where changes in carbon storage have been estimated through soil sampling of tillage trails. Essentially in all cases where conservation tillage was found to sequester carbon, soils were only sampled to a depth of 30 cm or less, even though crop root often extended much deeper. In the other experiment, where sampling extended deeper than 30 cm, conservation tillage has shown no consistent accrual of SOC, instead showing a difference in distribution of SOC, with higher concentration near the surface in conservation tillage and higher concentration in deeper layers under conventional tillage (Baker *et al.*, 2007).

Another long term experiment, initiated in 1973 on a soil under rain fed conditions to determine the influence of different combination of NPK fertilizer

and fertilizer + FYM at 10 Mg ha⁻¹ on SOC content and its changes in the 0-45 cm soil depth. Concentration of SOC increased 40% and 70% in the NPK + FYM treated plots as compared to NPK (43.1 Mg C ha⁻¹) and unfertilized control plots (35.5 Mg C ha⁻¹), respectively. Average annual contribution of C input from soybean (*Glycine max* (L.) Merr.) was 29% and that from wheat was 24 % of the harvestable above ground biomass yield. Annual gross carbon input and annual rate of total SOC environment were 4852 and 900 kg C ha⁻¹, respectively for the plots under NPK + FYM. It was estimated that 19% of the gross C input contributed towards the increase in SOC content. Carbon loss from nature soil organic matter during 30 years averaged 61 kg C ha⁻¹ yr⁻¹. The estimated quantity of biomass carbon required to maintain equilibrium soil organic matter content was 321 mg ha⁻¹ yr⁻¹. The total annual carbon input by the soybean wheat cropping was due to the fact that annual carbon input by the system was higher than the required amount to maintain equilibrium soil organic matter (Kundu *et al.*, 2007).

Takimoto *et al.* (2009) reported that consequent upon recent recognition of agriculture soils as carbon (C) sinks; agroforestry practices in the West African Sahel (WAS) region have received attention for their C sequestration potential. Five land use systems were selected in farmer's field two traditional parkland systems, two improved agroforestry systems (live fence and fodder bank) and a so called abandoned land. Soil samples taken from three depths (0-50 cm, 10-40 cm and 40-100 cm) were fractionated into three size classes (2,000-2500 µm, 250-53 µm, and >53 µm) and their C content determined whole soil C contents g kg⁻¹ soil, across three depths ranged from 1.33-4.69 in the parkland, 1.11-4.42 in live fence, 1.87-2.30 in fodder bank, and 3.69-5.30 in abandoned land.

Bai *et al.* (2011) studied soil organic carbon contents and their vertical distributions in two natural saline-alkalined wetlands (Erbaifangzi and Fulaowenpao) with different hydrological conditions in Xianghai National Nature Reserve of Northeast China in 2001. Soil properties such as total nitrogen, soil pH, C/N, soil particle size, and bulk densities were also analyzed in order to identify their relationships to soil organic carbon density (SOCD). Results showed

that mean SOCD of EBFZ from 30 soil profiles was $8.23 \pm 1.40 \text{ kg C m}^{-2}$, but both of them were much lower by 43% to 92% than those in other wetlands in China. Soil organic carbon generally decreased with depth in soil profiles and was mainly stored in the upper 30 cm (11.82 in), accounting for more than 50% of the total. Soil organic carbon density was positively significantly correlated with soil organic matter, total nitrogen, total phosphorus, and clay contents ($p < 0.001$) and was negatively significantly correlated with sand contents ($p < 0.001$). There was also a significant correlation between SOCD and soil pH or silt contents at the level of $p < 0.01$. Hydrological regime could impact carbon storage in wetland soils, and water deficit would lead to carbon loss. Ecological water supplement might be necessary to mitigate water shortage and increase carbon storage of wetlands in semi-arid and arid regions.

Mbah and Idike (2011) examined the carbon storage at two soil depths (0-5cm and 5-20cm) in four agricultural practices namely: natural undisturbed forest, *Gmelina arborea* forest, alley crop farming and sewage sludge dumpsite in southeastern Nigeria. At both depths the soil pH, bulk density, total porosity, water holding capacity and sand fraction showed low variation while silt + clay fraction was observed to vary moderately. Total carbon stored in soil was highest in natural uncultivated forest with 37%, 62% and 27% increase relative to alley cropping, sewage sludge dump and *Gmelina arborea* forest, respectively. Results also showed that forests and alley cropping can store large quantities of C in soils while sewage sludge is not effective in storing large quantities of C.

Singh *et al.* (2011) studied on two forest types *Quercus leucotrichophora* (oak) and *Pinus roxburghii* (pine) in Garhwal Himalaya, for vegetation analysis and soil carbon stock along altitudinal gradient and soil depth. The soil carbon was assessed in each forest type by collecting soil samples from three different altitudes and depths. In both the forest types, soil carbon has positive relation with leaf litter production, density and basal cover of the forests which decreases significantly with increasing altitude and soil depth. The results indicate that a change in vegetation type and a shift of vegetation belts as expected in most climate change scenario might have a profound impact on SOC in the Himalayas.

Between the forests; oak forest soil has more capacity to sequester carbon compared to pine forest, therefore, to enhance carbon sequestration potential the existed forest should be maintained and promote more regeneration for high density and basal cover within oak forest and where oak is invading in pine forest to mitigate future carbon level.

2.4 ECONOMIC RETURNS FROM DIFFERENT LAND USE SYSTEMS

Majumdar (1991) while studying the agroforestry systems in the mid-hills of Himachal Pradesh reported that horticultural system displayed the higher gross returns annually than horti-silvi-pastoral and grassland system.

Dyal *et al.* (1996) evaluated agri-silvi-horticulture system, whose components were *Leucaena leucocephala*, *Citrus aurantifolia*; *Carrica papaya* and *curcuma longa*. They found that mean annual returns were Rs. 17,746 and Rs. 15, 092 under agri-silvi-horticulture as against Rs. 7,752 and Rs. 3,342/ha from agricultural cropping system (maize + black gram/wheat + mustard/maize + wheat) under irrigated and rain fed conditions, respectively. Das *et al.* (1993) found that the agri-horticultural system required more cash input but gave a benefit-cost ratio of 2.16 compare to 1.95 with annual cropping and 1.52 with agri-silviculture system.

Kumar (1996) conducted a study on bio economic appraisal of agroforestry systems in Himachal Pradesh and found that agri-horticulture system yielded the highest net returns followed by agri-horti-silviculture, agri-silviculture and minimum in sole cropping.

Singh *et al.* (1998) evaluated the productivity and economics of eight intercrops in four crop sequences and indicated that the vegetable intercropping did not cause any adverse effect on the yield and income in eucalyptus. However, yield of all intercrops reduced with increase in the age of the trees. Among the crops sequences faba bean – colocasia (Rs 51, 037) was the best followed by french bean-turmeric (Rs 39,121), potato-onion (Rs, 37,861) and tomato- cowpea (Rs 32,797), cropping system.

Sood (1999) conducted an experiment to study tree crop interaction in agri-horticulture system in which he reported that the total cost incurred as well as net return were higher in agri-horticulture system as compared to sole crop.

Kumar (1999) reported that total costs, gross return and net return were higher from combinations with soyabean while least from pomegranate – soybean combination.

Under apple tree and ginger intercropping system, Fan-wei *et al* (2000) recorded 3 times more income from the system as compared with that of the apple orchard without intercropping. Lal *et al* (2005) carried out field experiments during 1998-2003 to determine the economic viability of an agroforestry based system in Allahabad district Uttar Pradesh, India. The rabi (*Cicer arietinum* and *Vigna*) and kharif (Green gram v. radiate) crops were intercropped for utilization of inter space of papaya. The authors observed that the cultivation of papaya + crop was comparatively more profitable than the traditional cultivation (sole papaya and sole pulse crop). The cost component of papaya + crop was higher than the sole crop of papaya and the cost of initial stage of plantation were higher than the recurring cost. The cost – benefit ratio showed that the papaya + crop at discounted prices were highest (3.79) in the agroforestry system under irrigated conditions followed by sole papaya crop (2.65).

In a tree crop association of agri-horti-silviculture system (Verma *et al.*, 2002) evaluated economic return of the system and reported that total cost incurred for Grewia + Almond + Wheat and Morus + Almond + Wheat associations was high at 80 kg ha⁻¹ nitrogen (recommended dose) and 100 kg ha⁻¹ nitrogen (25% higher than the recommended dose). Gross return were more in Grewia + Almond + Wheat than Morus + Almond + Wheat and net returns followed similar trends. Income from Almond fruit accounted for highest net returns. The net returns increase was 2.69 times more in Grewia + Almond + Wheat association with nitrogen level (25% higher than the recommended dose) over the sole wheat crop with similar nitrogen level. Cost benefit ratio values at

this nitrogen level for Grewia + Almond + Wheat and sole wheat was 2.34 and 1.99 respectively.

Plantinga and Wu (2003) studied, Co-benefits from carbon sequestration in forests: evaluating reductions in agricultural externalities from an afforestation policy in Wisconsin, USA. Besides they estimated the reductions in agricultural externalities (soil erosion, nitrogen, and atrazine pollution) from an afforestation programme. Existing benefits estimates were used to quantify the value of reduced soil erosion and some benefits from enhanced wildlife habitat. These values were found to be the same order of magnitude as the costs of the carbon sequestration policy, indicating that the co-benefits of forest carbon sinks are an important factor for countries to consider in designing a portfolio of climate mitigation strategies.

Verma *et al.* (2004) reported that net returns from agri-horticultural system were higher (Rs. 43, 424.14) compared to sole crop (Rs. 26, 876.73) at 100 kg/ha nitrogen level and the use of productive wheat cultivar HD-2380.

Tomar and Bhatt (2004) conducted a field experiment in a six year old plantation of guava (*Psidium guajava* cv. Allahabad safeda), Assam lemon (*Citrus lemon* [*Citrus limon*] and peach (*Prunus persica* cv. TA 170) during 2002 and 2003, on acid alfisol under rain fed condition in Umiam, Meghalaya, India to study the performance of upland rice cultivars as intercrops in the existing fruit plantation and to study the overall productivity of agri-horticulture systems. The report showed that on an average, the maximum net monetary benefit per hectare was recorded from peach intercropped with rice (Rs. 48,044), followed by guava (RS. 27,887) and Assam lemon (Rs. 20,991), irrespective of rice cultivars. Peach, guava and Assam lemon exhibited 5.09, 2.95 and 2.22 fold higher net return, respectively, compared to the control. Peach based AFS was found promising for rain fed agricultural conditions in the north-eastern region of India in general and Meghalaya in particular.

Ockwell and Lovett (2005) studied a combination of field sampling of woody vegetation with cost-benefit analysis and compared the social optimality

of fire-assisted pastoralism with sustainable forestry. Carbon sequestration was estimated to be significantly higher in the absence of fire. Results revealed that integration of carbon sequestration benefits for mitigating future costs of climate change into cost-benefit analysis demonstrated that sustainable forestry is a more socially optimal land use than fire-assisted pastoralism. Missing markets for carbon, however, implied that fire-assisted pastoralism would continue to be pursued in the absence of policy intervention. Creation of markets for carbon represents a policy solution that has the potential to drive land use away from fire-assisted pastoralism towards sustainable forestry and environmental conservation.

Shogaa (2009) studied and evaluated the sustainability of agroforestry in comparison to monocropping systems in terms of soil properties and farmers' perception. The results showed that soil N, P, K and soil organic carbon were significantly higher under agroforestry practices mixed trees with coffee (S_1), and Muringa (*Cordia africana* L.) with coffee (S_2) at two experimental sites as compared to the Arabian jujube (*Ziziphus spina-christi* L.) with maize (S_3) and the monocropping systems ($P < 0.01$). It was lowest under monocropping maize (S_5) in both sites. Other physical soil properties were better under agroforestry practices (S_1 and S_2) than the monocropping maize (S_5). The results of the SCUAF modeling illustrated that soil depth decline was negligible under agroforestry practices (S_1 and S_2) with soil loss less than 1000 kg/ha/yr even without using chemical fertilizers. The predicted decline of soil depth was highest under S_5 followed by S_3 which lost 43.1 % and 18 % of the top soil, respectively. Soil organic N and organic P were significantly higher under S_1 and S_2 systems even without using chemical fertilizers. It declined continuously under other systems at different rates during the simulation period. However adding 55 kg/ha/yr super phosphate (46 % P) and 271 kg/ha/yr urea (46 % N) to the systems (S_1 , S_2 , S_4 , and S_6) resulted in maintaining soil fertility and led to sustaining the yield over 20 years of the simulation period.

Shogaa (2009) results of cost benefit analysis further revealed that by using chemical fertilizers all systems were profitable at this level of the capital

cost. The results also showed that Muringa coffee system (S₂) and monocropping coffee (S₄) obtained the highest net present value (NPV) (US\$ 6163.6/ha) and (US\$ 5884/ha), respectively. The lowest NPV (USD 290.1/ha) was obtained under monocropping maize (S₅). Consequently, the agroforestry system (S₂) using fertilizers predicted the highest annualized net benefits (ANB) (US\$ 825.2/ha/year), to the farmers and the lowest ANB (38.8/ha/yr) was from monocropping maize (S₅). The results of soil conservation model showed that educational level, number of terraces and channels maintained during the last ten years, geographical location, water efficiency, farmers' experience, and agroforestry index significantly influenced soil conservation.

Chapter-3

MATERIALS AND METHODS

Investigations entitled “**Carbon storage potential and bio-economic appraisal of different land use systems in dry temperate north western Himalayas**” in Kinnaur district of Himachal Pradesh were carried out during the year of 2011-2012 with the following materials and methods as described in the following segments.

3.1 SITE DESCRIPTION

3.1.1 Location

The experimental area was located in Kinnaur district, Himachal Pradesh, India which lies in the north western part of Himachal Pradesh having an elevation, ranging from 1000 metres to over 6000 metres above mean sea level. It lies on Latitude 31⁰ 34' 59"N and Longitude 78⁰ 25' 00"E respectively. The locality factors and other details are tabulated in Table 1.

3.1.2 Climate

Kinnaur is one of the smallest districts in India by population (83, 950). The total Geographical area of the district is 6401 km². The economy of the district is predominantly agrarian and about 64% of the population is dependent on agriculture and its allied activities for earning their livelihood. Kinnaur experiences a dry temperate climate due to its high elevation, with long winters from October to May and short summers from June to September

3.1.3 Vegetation

Portions of Kinnaur are situated high in the Himalaya, where vegetation is sparse and consists primarily of hardy grasses. Alpine species such as juniper, pine, fir, cypress and *Rhododendron* can be found at elevations between 3,500 and 5,000 metres, primarily in middle Kinnaur. At lower altitudes, temperate-

climate trees are found, including oak, chestnut, maple, birch, alder, magnolia, apple, and apricot.

Table 1: Locality factors of the study area

Latitude	Between 31° 05' 50" and 32° 05' 15" North Latitude
Longitude	Between 77° 45' and 79° 00' 35" East Longitude
Altitude	Between 1600m to 2710m a.s.l
Climate type	High hill dry temperate zone
Texture	Sandy to loamy sand
Soil pH	6.0 – 6.8
Parental Material	Granite-gneiss and Mica schist
Soil type	Entisols and Inceptisols

3.2 EXPERIMENTAL METHODOLOGY

Experiment I: To study biomass carbon storage of different land use systems of dry temperate zone IV of Himachal Pradesh

A) Land use systems

- T₁ Agriculture
- T₂ Horticulture
- T₃ Agri-horticulture
- T₄ Agri-horti-silvicultural system
- T₅ Silvi-pastoral system
- T₆ Barren land

B) Altitudinal ranges

- A₁ 1900-2170m asl
- A₂ 2170-2440m asl
- A₃ 2440-2710m asl

Design : RBD (factorial)

No. of treatment combination : 18 {6 (land use systems) x 3 (altitudinal ranges)}

Replications : 3



Fig. 1 Map indicating study area (Kinnaur)

Experiment II: To study soil carbon density under different land use systems of dry temperate zone IV of Himachal Pradesh

A) Land use systems

T ₁	Agriculture
T ₂	Horticulture
T ₃	Agri-horticulture
T ₄	Agri-horti-silvicultural system
T ₅	Silvi-pastoral system
T ₆	Barren land

B) Altitudinal ranges

A ₁	1900-2170m asl
A ₂	2170-2440m asl
A ₃	2440-2710m asl

C) Soil layers

L ₁	0-20cm
L ₂	20-40cm
L ₃	40-100cm

Design	:	RBD (factorial)
No. of treatment combination	:	54 {6 (land use systems) x 3 (altitudinal ranges) x 3 (soil layers)}
Replications	:	3

Experiment III: To quantify the economic returns from different land use systems of dry temperate zone III of Himachal Pradesh. The treatment detail of experiment III was the same as that in experiment I.

Table 2: Land use systems used

Land use systems	System units/altitudinal gradients		
	1900 - 2170 m	2170 – 2440 m	2440 – 2710 m
Agriculture (A)	Pea- Maize Wheat – Rajmash Barley - Rajmash	Peas – cabbage Wheat – Rajmash Barley - Rajmash	Wheat – Rajmash Wheat – Rajmash Barley - Rajmash
Horticulture (H)	Apple	Apple	Apple
Agri – horticulture (AH)	Apple + Peas - Maize Apple + Wheat - Rajmash Apple + Barley – Rajmash	Apple – Peas – Cabbage Apple + Wheat – Rajmash Apple + Barley - Rajmash	Apple + Wheat – Rajmash Apple + Wheat – Rajmash Apple + Barley - Rajmash
Agri - hort – silviculture (AHS)	Robinia + Apple – Pea + Maize <i>Ailanthus altissima</i> + Apple – Pea + Maize <i>Salix tetraeperma</i> + Apple + Pea - Maize	<i>Robinia</i> + Apple + Pea – Cabbage <i>Populus ciliata</i> + Apple + Wheat – Rajmash <i>Cedrus deodara</i> + Apple + Barley – Rajmash	<i>Cedrus deodara</i> + Apple + Wheat – Rajmash <i>Pinus gerardiana</i> + Apple + Wheat – Rajmash <i>Cedrus deodara</i> + Apple + Barley - Rajmash
Silvi-pastoral (SP)	<i>Pinus gerardiana</i> + Grasses + <i>Artemisia inbia</i> + <i>A. brevifolia</i>	<i>Pinus gerardiana</i> + <i>A. brevifolia</i> + Grasses	<i>Cedrus deodara</i> + <i>A. brevifolia</i> + <i>Lespedeza</i> + Grasses
Barren land (BL)	<i>Artemisia inbia</i> + Grasses <i>A. inbia</i> + Grasses <i>Myrsine</i> species + Grasses	<i>Artemisia inbia</i> + Grasses <i>Artemisia inbia</i> <i>A. brevifolia</i> + Grasses	Grasses + <i>Lespedeza gerardiana</i> Grasses + <i>Lespedeza gerardiana</i> Grasses + <i>Lespedeza gerardiana</i>



1. Agriculture



2. Pure horticulture



3. Agri-horticulture



4. Agri-horti-silviculture



5. Silvi-pasture



6. Barren land

Plate 1: Different land use systems in dry temperate Himalayan ecosystem of Kinnaur district (H.P)

Table 3: Experimental details indicating specific tree crop combination and their distribution in the study area

Land use system/Elevation range	Code	Tree-Crop combination	Plot size M ²	Net cropped area (ha)	Area under Trees (ha)	Area under grasses ha	No. of trees ha ⁻¹	Average age of the tree component
Agriculture 1900 – 2170m 2170 – 2440m 2440 – 2710m	A	Pea- Maize, Wheat – Rajmash Barley – Rajmash, Peas – cabbage	50x20	1.00 1.00 1.00	- - -	- - -	- - -	Annual Annual Annual
Horticulture 1900 – 2170m 2170 – 2440m 2440 – 2710m	H	Apple Apple Apple	50x20	- - -	1.00 1.00 1.00	- - -	185 212 400	25 yr (A) 20 yr (A) 18 yr (A)
Agri-horticulture 1900 – 2170m 2170 – 2440m 2440 – 2710m	AH	Apple + Peas – Maize, Apple + Wheat – Rajmash, Apple + Barley – Rajmash Apple – Peas – Cabbage, Apple + Wheat – Rajmash, Apple + Barley – Rajmash Apple + Wheat – Rajmash , Apple + Barley – Rajmash,	50x20	0.9 0.9 0.9	1.0 1.0 1.0	- - -	185 212 400	25 yr (A) 20 yr (A) 18 yr (A)
Agri-horti-silviculture 1900 – 2170m 2170 – 2440m 24410– 2710m	AHS	<i>Robinia</i> + Apple – Pea + Maize, <i>Ailanthus altissima</i> + Apple – Pea + Maize, <i>Salix tetraeperma</i> + Apple + Pea – Maize <i>Robinia</i> + Apple + Pea – Cabbage, <i>Populus ciliata</i> + Apple +Wheat – Rajmash <i>Cedrus deodara</i> + Apple + Barley – Rajmash <i>Cedrus deodara</i> + Apple + Wheat – Rajmash, <i>P. gerardiana</i> + Apple +Wheat-Rajmash, <i>Cedrus deodara</i> + Apple + Barley– Rajmash	50x20	0.3 0.4 0.5	0.4 0.3 0.2	- - - -	55 63 120 100 100	40~ yr (R) 40~ yr (B-S) 50~ yr (A-I) 60~ yr (F-S) 60 cm dia (C)
Silvipasture 1900 – 2170m 2170– 2440m 2440 – 2710m	SP	<i>Pinus gerardiana</i> + Grasses + <i>Artemisia inbia</i> +A. <i>brevifolia</i> <i>Pinus gerardiana</i> +A. <i>brevifolia</i> + Grasses <i>Cedrus deodara</i> + <i>A.brevifolia</i> + <i>Lepedeiza gerardiana</i> +Grasses	50x20	- - -	0.4 0.5 0.7	0.6 0.5 0.3	160 171 159	26.4cm dia (P) 70~ yr (A-I) 70~ yr (Ab) 60cm dia (C)
Barren land 1900 – 2170m 2170– 2440m 2440 – 2710m	BL	<i>Artemisia inbia</i> + Grasses, <i>Artemisia inbia</i> + Grasses, <i>Myrsine</i> species + Grasses <i>A. inbia</i> + Grasses, <i>A. inbia</i> + Grasses, <i>A.brevifolia</i> + Grasses Grasses + <i>Lepedeiza gerardiana</i> , Grasses + <i>Lepedeiza gerardiana</i> , Grasses + <i>Lepedeiza gerardiana</i>	50x20	- - -	0.4 0.3 0.4	0.6 0.7 0.6	50 60 50	70~ yr (A-I) 60~ yr (L) 60~ yr (Ab)

A-Apple, P-*Pinus gerardiana*, C-*Cedrus deodara*, B-S, *Ailanthus altissima*, F-S, *Populus ciliata*, S-*Salix tetraeperma*, A-I, *Artemisia inbia*, Ab, *A. brevifolia*, L, *Lepedezia gerardiana*, R, *Robinia*

3.4 OBSERVATIONS RECORDED

3.3.1 Above ground biomass

A. Tree components

- i) Stem biomass
- ii) Branch biomass
- iii) Leaf biomass

B. Crop components

- i) Crop biomass
- ii) Crop yield

C. Detritus biomass

3.3.2 Below ground biomass

- i) Below ground biomass of tree was determined using Crains *et al* (1997) equation and Schulze (1983) ratio and as per Intergovernmental Panel on Climate Change (IPCC) guidelines
- ii) Below ground biomass of the agriculture crops and grasses was measured by uprooting the same

3.3.3 Economic yield

(A) Biological productivity

Biological productivity was calculated considering the utilizable biomass of each functional unit of the system type

(B) Economic productivity

The present utilizable yield from each functional unit in a system was taken for estimating the total returns from the system where as the total investment incurred on production and cultural management was taken into account to estimate the net returns

(C) Net returns

Net returns was based on prevailing marketing and production costs
(Variable costs)

3.3.4 Soils

Soil samples were collected from the sampling points, starting from 0-20cm, 20-40cm and 40-100cm layers for estimating the following parameters:

- i) Soil organic carbon (%)
- ii) Bulk density (gm/cm^3)
- iii) Available Nitrogen

Soil organic carbon was estimated by standard Walkley and Black (1934) method while bulk density of every site was estimated using standard core method (Wilde *et al.*, 1964) Available nitrogen was estimated by employing the Kjeldhal (1883) method.

Sample plot size = 0.1 ha

3.3.1.1 Stem biomass

To estimate biomass all the trees falling in the (50m x 20m) plot were enumerated. The diameter at breast height (dbh) was measured with calliper and height with Ravi's multimeter. Local volume equation developed for specific tree species and region were used for calculating the volume of the forest trees of the sample plot. Where volume equations were not available for the concerned species, form factor was calculated using Spiegel relascope to find out the tree volume using the formula given by Pressler's (1865) and Bitterlich (1984).

$$F = 2h_1/3h$$

Where, f = form factor

h_1 = height at which diameter is half of dbh

h = total height

Volume was calculated by Pressler's formula (1865)

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

Where,

V	=	volume
f	=	form factor
h	=	total height
g	=	Basal area
g	=	πr^2 or $\pi (dbh/2)^2$

Where,

r	=	radius
dbh	=	diameter at breast height

Specific gravity

Specific gravity was determined from the available literature. Where, the specific gravity values were not available in those cases the stem cores were taken to find out specific gravity which was used further to determine the biomass of the stem using maximum moisture method (Smith, 1954). The wood in the form of disc (5-8cm) was removed from two places (base and breast height) for the determination of specific gravity of wood. The weight of samples was taken at maximum moisture content. Then these samples were kept in oven at $102\pm 1^\circ\text{C}$ until a constant weight was obtained, dried samples were weighed and specific gravity of these samples was determined separately by applying the following formula:

$$G_f = \left[\frac{(M_m - M_o)}{M_o} + \frac{1}{GS_o} \right]$$

Where,

G_f	-	Specific gravity of wood
M_m	-	Constant weight of sample having maximum moisture content
M_o	-	Oven dried constant weight of sample
GS_o	-	Average density of wood, a constant having value of 1.53

The final value was determined by taking out the average of these samples (base and breast height). The final value was determined by taking out the average of these samples (Lower and upper). Thus the weight of wood was estimated using the formula i.e. mass per unit volume

Mass = Average specific gravity of stem wood x volume

3.3.1.2 Branch biomass of forest trees

Total number of branches irrespective of size were counted on each of the sample tree, then these were categorized on the basis of basal diameter into three groups, viz., <6 cm, 6-10 cm and >10 cm. Fresh weight of two sampled branches from each group was recorded separately. The formula which was used to determine the dry weight of branches was adopted from (Chidumayo, 1990) as shown below;

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

Where,

B_{dwi} - oven dry weight of branch

B_{twi} - Fresh/green weight of branches

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

Total branch biomass (Fresh/dry) per sample tree was determined as given by:

$$Bbt = n_1bw_1 + n_2bw_2 + n_3bw_3 - \sum nibwi$$

Where,

Bbt - Branch biomass (fresh/dry) per tree

n_i – number of branches in the i^{th} branch group

bw – average weight of branch of i^{th} group

i – 1,2, 3, -----

3.3.1.3 Leaf biomass of forest trees

Leaves from the branches were removed, weighed and oven dried separately to a constant weight at $80 \pm 5^\circ \text{C}$ (Chidumayo, 1990). Leaf biomass of the forest tree species was estimated using the table given by Jenkins *et al.* (2003)

3.3.1.4 Tree biomass

The total tree biomass was the sum of stem biomass, branch biomass and leaf biomass. The tree biomass was converted into carbon fraction by factor of 0.5 (IPCC default value).

3.3.1.4.1 Fruit tree biomass

For estimation of fruit tree biomass developed diameter-dry biomass based equations were employed. For each fruit tree crop we selected 4 trees per sample plot. Each selected tree was then sectioned into secondary branches and main stem. The lower and upper diameter (with tree caliper) of the stem was determined in the field including the height of the main stem.

Using the following equation, the dry biomass of each branch was determined i.e; $Y = 1.052 \times X^{1.076}$

Where;

$$\begin{aligned} Y &= \text{Dry branch biomass (kg)} \\ X &= \text{Diameter (cm) of the branch} \end{aligned}$$

$$\text{Dry weight of the sample tree} = \text{Biomass of the main stem log} + \text{Cumulative weight of all the secondary branches}$$

Biomass of the main stem log was determined as below:
The volume of the main stem is calculated by the formula

$$\text{Volume of the main stem} = \frac{S_1 + S_2}{2} \times l \quad (\text{Huber's Formula})$$

Where

$$\begin{aligned} S_1 &= \text{Basal area of the lower portion} \\ S_2 &= \text{Basal area of the upper portion} \\ l &= \text{Length of the main stem} \end{aligned}$$

$$\text{Biomass of the main stem of the sample tree} = \text{Volume of the main stem} \times \text{Specific gravity}$$

$$\text{Biomass of the sample tree} = \text{Biomass of the main stem} + \text{Sum of the biomass of all the secondary branches}$$

3.3.1.5 Shrub biomass

Shrub biomass was estimated using 1m x 1m quadrates. All the shrubs occurring within the borders of the quadrate were enumerated. The diameter of all tillers was measured at base with the help of calliper according to the method given by Chaturvedi and Khanna (1982). The length of tiller is measured with the help of measuring tape. Local volume equations developed for specific shrub species and region were used for calculating the volume of the forest shrubs of the sample plots.

3.3.1.6 Grass biomass

Grass biomass was estimated using 1m x 1m quadrates. The total grass biomass occurring within the borders of the quadrate were cut at ground level and collected samples were weighted, sub sampled and 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 0.5 (IPCC default value).

3.3.2 Below ground biomass

Below ground biomass of trees and shrubs was calculated by using Cairns (1997) equation and as per the IPCC guidelines. Below ground biomass of the grasses & herbs was measured by using root: shoot ratio given by Mokany *et al.* (2006).

Below ground biomass = Above ground biomass x Root: shoot ratio.

3.3.3 C estimation

3.3.3.1 Carbon stock

$$\text{Carbon} = \text{Biomass} \times 0.5 \text{ (IPCC default value)}$$

3.3.3.2 Carbon Density

Carbon density = Carbon in tonnes per hectare

3.4 Soil analysis

The observations were also recorded on soil physico-chemical properties status in order to access the effect of different land use systems on soil.

3.4.1 Collection and preparation of Samples

The composite soil samples were collected from different layers viz; 0-20cm, 20-40 and 40-100cm for studying the soil physical analysis and depth-wise distribution of nutrient elements from each site. The composite soil samples were dried, ground with mortar and pestles and sieved with 2mm mesh sieve before analysis. The weight of the pebble was measured and its proportion was calculated to know the percentage of pebble in each sample.

Methods Employed for Soil Chemical Analysis

The details of methods employed for estimating different soil chemical parameters are as follows:

Particular	Method employed
Bulk density (g cm^{-3})	Specific gravity method (Singh, 1980)
Organic carbon (%)	Walkley and Black method (1934).
Available nitrogen	Alkaline potassium permanganate method of Subbiah and Asija (1956).
Soil carbon (t ha^{-1})	$[\text{Soil bulk density (g m}^{-3}\text{)} \times \text{Soil depth (cm)} \times \text{Carbon (\%)}] \times 100$ (Nelson and Sommers, 1996)

Actual mass of the soil was taken into consideration while calculating the carbon density.

3.5 STATISTICAL ANALYSIS

The data obtained were subjected to statistical analysis as per procedure suggested by Gomez and Gomez (1984). Wherever, the effects exhibited significance at 5 percent level of probability, the critical difference (CD) was calculated.

Chapter-4

EXPERIMENTAL RESULTS

The results emerging out of the present investigation entitled “Carbon storage potential and bioeconomic appraisal of different land use systems in dry temperate North Western Himalayas” conducted in Kinnaur district of Himachal Pradesh has been described in this chapter. Land use systems because of their structure, function, tree species, altitudinal ranges, physiography and management practices to which each system is subjected to reflect a wide variability and economic benefit accrued from them. Biomass production and carbon storage potential and economic benefit derived from these land use system in Kinnaur district along a selected altitudinal gradient have been described in this chapter.

For conducting this study six land use system viz; agriculture, horticulture, agri-horticulture, agri- horti- silviculture, silvi-pasture, and barren land use system, which are common in the three altitudinal ranges viz; 1900-2170m a.s.l., 2170-2440m a.s.l. and 2440-2710m a.s.l. were selected based on lapse rate (1° C fall in temperature as we rise by 270 metre in the Himalayan hills). The carbon storage potential and bio-economic appraisal of different land use systems in Kinnaur district which falls under the dry temperate North Western Himalayas ecosystem is described under the following heads and sub heads:

- 4.1 Biomass production levels
- 4.2 Biomass carbon density
- 4.3 Soil physico-chemical properties
- 4.4 Carbon inventory
- 4.5 Economic analysis

4.1 BIOMASS PRODUCTION LEVELS

The above, below and total biomass production levels have been tabulated in this section under Tables 4-6.

4.1.1 Above ground biomass (t ha^{-1})

The data presented in the Table 4 demonstrates that land use system, altitudinal ranges and interaction between land use system and altitudinal ranges significantly influence the above ground biomass density.

Table 4: Effect of land use system, altitudinal gradient and their interaction effect on above ground biomass production (t ha^{-1}) in the dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Land use systems (T)	Altitudinal ranges (A)			
	A ₁ (1900 – 2170m)	A ₂ (2170 – 2440m)	A ₃ (2440 – 2710m)	Mean
T ₁ (Agriculture)	6.66	4.98	4.98	5.54
T ₂ (Horticulture)	18.78	23.58	18.93	20.43
T ₃ (Agri – horticulture)	26.05	18.73	21.67	22.15
T ₄ (Agri – horti – silviculture)	85.49	59.79	36.18	60.49
T ₅ (Silvi-pasture)	31.27	59.93	162.80	84.65
T ₆ (Barren land)	5.38	8.94	1.87	5.40
Mean	28.94	29.33	41.06	

	SE(d)	CD _{0.05}
T	5.86	11.91
A	4.15	8.42
T x A	7.18	10.15

A perusal of the data presented in Table 4 reveals that maximum above ground biomass (84.65 t ha^{-1}) is recorded in the silvipasture system, which is found to be significantly higher than all other land use systems. Whereas minimum above ground biomass (5.4 t ha^{-1}) is recorded in barren land use system, which is found to be significantly lower than all other land use systems.

The different land use system recorded the above ground biomass in the order: barren land, agriculture, horticulture, agri-horticulture, agri-horti-silviculture and silvi-pasture in the ascending order. In the altitudinal ranges the above ground biomass increased with increase in altitudinal ranges. Maximum above ground biomass (41.06 t ha^{-1}) is recorded at A₃ altitudinal range, which is found to be significantly higher than A₁ and A₂.

In the interaction between land use system and altitudinal ranges no consistent trend is noticed at the land use level with the increase in altitudinal ranges. Maximum above ground biomass is noticed in the silvi-pasture system at A₃ (2440-2710m a.s.l.) altitudinal range, which is found to be significantly higher than all other treatment combinations. Whereas, minimum is found in barren land use system at A₃ altitudinal range, which is found to be significantly lower than all other land use systems.

4.1.2 Below ground biomass (t ha⁻¹)

Below ground biomass is significantly influenced by the effect of land use systems, altitudinal ranges and their interaction effect (Table 5).

Table 5: Effect of land use system, altitudinal gradient and their interaction effect on below ground biomass production (t ha⁻¹) in the dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Land use systems (T)	Altitudinal ranges (A)			
	A ₁ (1900 – 2170m)	A ₂ (2170 – 2440m)	A ₃ (2440 – 2710m)	Mean
T ₁ (Agriculture)	1.33	1.75	1.00	1.36
T ₂ (Horticulture)	6.22	7.78	6.25	6.75
T ₃ (Agri – horticulture)	8.59	6.29	7.15	7.34
T ₄ (Agri – horti – silviculture)	23.08	15.68	10.04	16.27
T ₅ (Silvi-pasture)	6.87	16.16	35.47	19.50
T ₆ (Barren land)	2.70	4.47	0.95	2.71
Mean	8.13	8.69	10.14	

	SE(d)	CD _{0.05}
T	1.46	2.96
A	1.03	2.10
T x A	1.79	2.53

Data presented in the Table 5 shows that irrespective of altitudinal gradients, maximum below ground biomass (19.50 t ha⁻¹) is recorded in silvi-pasture system, which is found to be significantly higher than all other land use systems. Whereas, minimum below ground biomass (1.36 t ha⁻¹) is recorded in the treatment involving agriculture. In altitudinal ranges the below ground

biomass production (10.14 t ha^{-1}) is recorded at A_3 altitudinal range, which is found to be significantly at par with A_1 and A_2 .

In the interaction between land use system and altitudinal ranges no consistent trend is noticed at the land use level with the increasing altitudinal ranges. Maximum below ground biomass is noticed in silvi-pasture system at A_3 (2440-2710 m a.s.l.) altitudinal range, which is found to be significantly higher than all other treatment combination. Whereas minimum below ground biomass is recorded in barren land use system at A_3 altitudinal range, which is found to be lower than all other land use systems.

4.1.3 Total biomass (t ha^{-1})

A perusal of the data presented in Table 6 reveals that total biomass (above + below) is significantly influenced by land use systems, altitudinal gradient and interaction effect between land use system and altitudinal gradient.

Table 6: Effect of land use system, altitudinal gradient and their interaction effect on total biomass production (t ha^{-1}) in the dry temperate Himalayan ecosystem of Kinnaur district (H.P.), INDIA

Land use systems (T)	Altitudinal ranges (A)			
	A_1 (1900 – 2170m)	A_2 (2170 – 2440m)	A_3 (2440 – 2710m)	Mean
T_1 (Agriculture)	7.99	6.73	5.99	6.79
T_2 (Horticulture)	25.00	31.36	25.17	27.18
T_3 (Agri – horticulture)	34.64	25.02	27.89	29.18
T_4 (Agri – horti – silviculture)	108.60	75.48	46.21	76.75
T_5 (Silvi-pasture)	38.13	75.95	198.20	104.10
T_6 (Barren land)	8.08	13.41	2.82	8.10
Mean	37.01	37.99	51.05	

	SE(d)	CD _{0.05}
T	7.30	14.85
A	5.17	10.50
T x A	8.95	12.65

Data presented in the Table 6 shows that maximum mean total biomass (104.10 t ha^{-1}) is accumulated in the treatment T_5 (silvi-pasture), which is found

to be significantly higher than all other landuse systems. Whereas, minimum total biomass (6.79 t ha^{-1}) is recorded under T_1 (agriculture) landuse system, which is found to be significantly at par with T_6 (barren land), only.

Irrespective of the land use systems, in the altitudinal ranges maximum mean total above ground biomass is recorded in the altitudinal ranges 2440-2710m a.s.l., which is found to be significantly higher than A_1 (1900-2170m) and A_2 (2170-2440m). Whereas, minimum total biomass (37.01 t ha^{-1}) is recorded in the lowest altitudinal range i.e. A_1 , which is found to be significantly at par with A_2 .

In the interaction between land use system and altitudinal ranges no consistent trend is noticed at the land use system with the increase in altitudinal ranges. The value of total biomass decreases with increase in altitudinal ranges in T_1 and T_4 , whereas it is completely different in T_5 , in which the values increases with the increase in altitudinal range. Maximum total biomass (198.20 t ha^{-1}) is noticed in A_3T_5 treatment combination, which is found to be significantly higher than all other treatment combinations. Whereas, minimum is found in barren land use system at A_3 altitudinal range, which is found to be lower than all other land use system and altitudinal treatment combinations.

4.2 BIOMASS CARBON DENSITY

4.2.1 Total biomass carbon density

Data presented in Table 7 evinced that the total biomass carbon density (t ha^{-1}) is significantly influenced due to land use system, altitudinal ranges and their interaction effect. In the land use system, total biomass carbon density is found to be higher (52.88 t ha^{-1}) in T_5 (silvi-pasture) land use system, which is found to be significantly higher than all other treatment combinations. Whereas, minimum biomass carbon density (3.34 t ha^{-1}) is displayed by agriculture land, which is found to be significantly at par with T_6 (barren land) treatment, only. In the altitudinal range, the maximum biomass carbon density (25.52 t ha^{-1}) is recorded at A_3 (2440-2710m), which is found to be significantly higher than the biomass carbon density of other altitudinal ranges. Whereas, minimum value of

mean biomass carbon density is recorded in A₁ (1900-2170m a.s.l.), which, however remained statistically at par with A₂.

Table 7: Effect of land use system, altitudinal gradient and their interaction effect on total biomass carbon density (t ha⁻¹) in the dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Land use systems (T)	Altitudinal ranges (A)			
	A ₁ (1900 – 2170m)	A ₂ (2170 – 2440m)	A ₃ (2440 – 2710m)	Mean
T ₁ (Agriculture)	3.82	3.36	2.82	3.34
T ₂ (Horticulture)	12.49	15.68	12.75	13.64
T ₃ (Agri – horticulture)	17.32	12.51	13.94	14.59
T ₄ (Agri – horti – silviculture)	54.28	37.73	23.11	38.37
T ₅ (Silvi-pasture)	19.07	40.48	99.10	52.88
T ₆ (Barren land)	4.04	6.70	1.41	4.05
Mean	18.50	19.41	25.52	

	SE(d)	CD_{0.05}
T	3.64	7.39
A	2.57	5.23
T x A	4.45	6.30

In the interaction effect between land use system and altitudinal range, maximum total biomass carbon stock (99.10 t ha⁻¹) is displayed by silvi-pasture land use system at the elevation range of A₃ (2440-2710 m), which is found to be significantly higher than other land use systems. Whereas, minimum value of total biomass carbon density (1.41 t ha⁻¹) is recorded in barren land use system at an elevation range of 2440-2710m a.s.l.

4.3 SOIL PHYSICO-CHEMICAL PROPERTIES

4.3.1 Soil organic carbon (%)

It is evidently clear from the data presented in Table 8 that organic carbon (%) is significantly influenced by the average effect of land use system, altitudinal ranges, soil layer; and due to interaction between land use and altitudinal gradient, altitudinal gradient and soil depth, land use and soil layer, and three way interaction effect among land use, altitudinal gradient and soil layer (Table 8-12).

Table 8: Soil organic carbon, bulk density and available nitrogen as influenced by average effect of land use system, altitudinal ranges and soil layer in the dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Treatment	Soil Organic Carbon (%)	Bulk Density (gcm ⁻³)	Available nitrogen (kg ha ⁻¹)
(A) Land use systems			
T ₁ (Agriculture)	1.33 ^b	1.02 ^{ab}	514.40 ^d
T ₂ (Horticulture)	1.39 ^a	0.99 ^b	542.50 ^a
T ₃ (Agri – horticulture)	1.36 ^b	1.04 ^a	529.50 ^b
T ₄ (Agri – horti – silviculture)	1.38 ^a	0.90 ^c	522.20 ^c
T ₅ (Silvi-pasture)	1.41 ^a	1.02 ^{ab}	538.10 ^a
T ₆ (Barren land)	1.38 ^a	1.06 ^a	462.20 ^e
SE (d)	0.015	0.01	2.67
CD _{0.05}	0.030	0.05	5.29
(B) Altitudinal range (A)			
A ₁ (1900 – 2170m)	1.36 ^b	1.11 ^a	505.60 ^c
A ₂ (2170 – 2440m)	1.38 ^a	0.94 ^b	532.80 ^a
A ₃ (2440 – 2710m)	1.39 ^a	0.97 ^b	516.00 ^b
SE (d)	0.01	0.02	1.89
CD _{0.05}	0.02	0.03	3.74
(C) Soil Layer (L)			
L ₁ (0-20cm)	1.41 ^a	0.95 ^c	545.40 ^a
L ₂ (20-40cm)	1.37 ^b	1.00 ^b	527.10 ^b
L ₃ (40-100cm)	1.34 ^c	1.04 ^a	481.90 ^c
SE (d)	0.01	0.02	1.89
CD _{0.05}	0.02	0.03	3.74

*similar alphabets denotes at par values

Table 8 reveals that mean maximum organic carbon (1.41%) is recorded in silvi-pasture land use system, which, however, remained statistically at par with horticulture, agri-horti-silviculture and barren land use systems. Mean minimum organic carbon content (1.33%) is found in agriculture land use system, which, however, remained statistically at par with the land use system of T₃ (Agri-horticulture) only.

In the altitudinal range, maximum carbon percent (1.39%) is displayed by 2440-2710 m a.s.l. altitudinal range, which however, remained statistically at par with the value of percent carbon recorded in 2170-2440 m a.s.l. Whereas, minimum value of percent carbon (1.36%) is recorded in 1900-2170 m altitudinal

range. In the soil layers, L₁ (0-20 cm) soil layer depicted significantly higher values of organic carbon than other two layers under investigation.

Table 9: Effect of interaction between land use system, altitudinal gradient and their interaction effect on soil organic carbon (%) in the dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Land use systems (T)	Altitudinal ranges (A)		
	A ₁ (1900 – 2170m)	A ₂ (2170 – 2440m)	A ₃ (2440 – 2710m)
T ₁ (Agriculture)	1.31	1.33	1.34
T ₂ (Horticulture)	1.36	1.39	1.42
T ₃ (Agri – horticulture)	1.31	1.36	1.41
T ₄ (Agri – horti – silviculture)	1.38	1.39	1.36
T ₅ (Silvi-pasture)	1.42	1.41	1.40
T ₆ (Barren land)	1.36	1.40	1.35
TXA	SE (d) 0.020	CD _{0.05} 0.030	

In the interaction effect between land use system and altitudinal ranges resulted in significant influence on the soil organic carbon (%) (Table 9). A₃ (2440-2710m a.s.l.) altitudinal range under horticulture land use system displayed higher organic carbon percent. Whereas, minimum value of organic carbon percent (1.31%) is recorded in agri-horticulture and agriculture land use system at 1900-2170 m elevation range, displaying identical values.

Table 10: Effect of altitudinal gradient and soil depth on soil organic carbon (%) in the dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Altitudinal ranges (A)	Soil layer (L)		
	L ₁ (0-20cm)	L ₂ (20-40cm)	L ₃ (40-100cm)
A ₁ (1900 – 2170m)	1.40	1.39	1.34
A ₂ (2170 – 2440m)	1.40	1.39	1.31
A ₃ (2440 – 2710m)	1.40	1.37	1.35
SE (d)	0.01		
CD_{0.05}	0.02		

It is clear from the data presented in the Table 10 that soil organic carbon is significantly influenced by the interaction of altitudinal gradient and soil depth. All the altitudinal ranges displayed identical values (1.40 %) of organic carbon

(%) at 0-20 cm soil layer. At each altitudinal range, the value of organic carbon declined with increasing soil depth. But the rate of decrease in the organic carbon content is more pronounced at A₂ (2170-2440 m) altitudinal range than at A₁ and A₃.

Table 11: Effect of interaction between land use system and soil depth on soil organic carbon (%) in the dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Land use systems (T)	Soil Layer (L)		
	(0-20cm)	(20-40cm)	(40-100cm)
T ₁ (Agriculture)	1.35	1.34	1.31
T ₂ (Horticulture)	1.40	1.39	1.38
T ₃ (Agri – horticulture)	1.38	1.36	1.34
T ₄ (Agri – horti – silviculture)	1.40	1.39	1.34
T ₅ (Silvi-pasture)	1.48	1.43	1.31
T ₆ (Barren land)	1.42	1.38	1.33
T x D	SE (d) 0.020	CD _{0.05} 0.027	

Table 11 demonstrate that soil organic carbon (%) is significantly influenced by the interaction effect of land use system and soil depth. Maximum soil organic carbon percent (1.48%) is recorded in 0-20 cm soil layer under silvi-pasture land use system. Whereas, minimum value of carbon percent (1.31%) is recorded in 40-100 cm soil layer of T₁ (agriculture) and T₅ (silvi-pasture) land use systems, each system displaying identical values. Under each land use system, soil organic carbon declined with increasing soil depth. But this decline is more marked under silvi-pasture system than any other land use system under investigation.

Data presented in Table 12 gives the soil organic carbon status in different soil layers i.e. 0-20, 20-40 and 40-100 cm of 1900-2170m, 2170-2440m and 2440-2710m altitudinal ranges in different land use systems. Maximum soil carbon percent (1.46%) is recorded at 0-20 cm soil layer of silvi-pasture system at 1900-2170m altitudinal range. Whereas, minimum value of soil organic carbon (1.25%) is recorded at 40-100cm soil layer in agri-horticulture land use system in 1900-2170 m altitudinal range. In general, in all the land use systems the soil organic carbon (%) declined at each altitudinal gradient with increasing soil depth.

Table 12: Interaction effect of land use system, soil depth and altitudinal gradient on soil organic carbon (%) in the dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Land use Systems (T)	Altitudinal gradient								
	A ₁ (1900-2170m)			A ₂ (2170-2440m)			A ₃ (2440-2710m)		
	L ₁ (0-20cm)	L ₂ (20-40cm)	L ₃ (40-100cm)	L ₁ (0-20cm)	L ₂ (20-40cm)	L ₃ (40-100cm)	L ₁ (0-20cm)	L ₂ (20-40cm)	L ₃ (40-100cm)
T ₁ (Agriculture)	1.34	1.28	1.27	1.38	1.29	1.26	1.41	1.40	1.29
T ₂ (Horticulture)	1.39	1.39	1.29	1.42	1.38	1.37	1.43	1.42	1.42
T ₃ (Agri – horticulture)	1.43	1.26	1.25	1.43	1.36	1.29	1.43	1.41	1.40
T ₄ (Agri – horti – silviculture)	1.40	1.39	1.37	1.41	1.40	1.37	1.42	1.34	1.30
T ₅ (Silvi-pasture)	1.46	1.44	1.38	1.43	1.40	1.37	1.43	1.40	1.40
T ₆ (Barren land)	1.41	1.30	1.40	1.41	1.41	1.39	1.41	1.39	1.37
SE (d)	0.03								
CD _{0.05}	0.05								

4.3.2 Bulk density (g cm⁻³)

Bulk density is significantly influenced due to average effect of land use system, altitudinal range, soil depth and interaction effect between land use system and altitudinal range, altitudinal range and soil depth, land use system and soil depth ; and three way interaction between land use system, altitudinal range and soil depth (Table 13-16).

A perusal of data presented in the Table 8 indicates that maximum mean bulk density (1.06 g cm⁻³) is recorded in barren land, which however, remained statistically at par with T₃ (agri-horticulture), T₁ (agriculture) and T₅ (silvi-pasture). Whereas, minimum value of bulk density (0.90 g cm⁻³) is recorded in agri-horti-silviculture land use system, which shows significantly lower value than all other land use systems.

In the altitudinal ranges, maximum bulk density (1.11 g cm⁻³) is recorded in 1900-2170m altitudinal range, which is found to be significantly higher than other altitudinal ranges. Significantly minimum value of bulk density (0.94 g cm⁻³) is recorded in A₁ (2170-2440m) elevation range.

In the soil layer, soil depth 40-100 cm displayed highest value (1.04 g cm^{-3}) of bulk density, which, however remained significantly at par with the value displayed by 20-40 cm soil layer. Significantly lower value of bulk density (0.95 g cm^{-3}) is recorded in 0-20 cm soil layer.

Table 13: Effect of interaction between land use system and altitudinal gradient on bulk density (gcm^{-3}) in the dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Land use systems (T)	Altitudinal ranges (A)		
	A ₁ (1900 – 2170m)	A ₂ (2170 – 2440m)	A ₃ (2440 – 2710m)
T ₁ (Agriculture)	1.22	0.80	1.01
T ₂ (Horticulture)	1.06	1.04	0.87
T ₃ (Agri – horticulture)	1.08	0.90	1.15
T ₄ (Agri – horti – silviculture)	0.90	0.90	0.92
T ₅ (Silvi-pasture)	1.22	0.89	0.97
T ₆ (Barren land)	1.15	1.06	0.96
SE (d)	0.03		
CD _{0.05}	0.04		

It is clear from the data presented in the Table 13 that soil bulk density is significantly influenced by the interaction effect between land use system and altitudinal gradient. Maximum soil bulk density (1.22 g cm^{-3}) is recorded at 1900-2170m altitudinal range under T₁ (agriculture) and T₅ (silvi-pasture) land use systems, each displaying identical values. Whereas, minimum value of soil bulk density (0.8 g cm^{-3}) is recorded at A₁ (2170-2440m) elevation range of agriculture land use system.

Table 14 indicates that bulk density is significantly influenced by interaction effect between altitudinal gradient and soil depth effect. However, no consistent trend could be observed between altitudinal gradient and soil depth. In A₁ (1900-2170m) the values of bulk density enhanced significantly with increasing soil depth. Whereas, at A₂ (2170-2440m) altitudinal range significant difference could be observed between L₃ (40-100 cm) with L₁ (0-20 cm), L₂ (20-40 cm), only.

Table 14: Effect of interaction between altitudinal gradient and soil depth on bulk density in the dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Altitudinal ranges (A)	Soil layer (L)		
	L ₁ (0-20cm)	L ₂ (20-40cm)	L ₃ (40-100cm)
A ₁ (1900 – 2170m)	1.02	1.09	1.18
A ₂ (2170 – 2440m)	0.90	0.92	0.99
A ₃ (2440 – 2710m)	0.96	1.01	0.97
SE (d)	0.02		
CD _{0.05}	0.03		

Maximum soil bulk density (1.18 g cm⁻³) is recorded in 40-100 cm soil layer of A₁ (1900-2170 m) altitudinal range. Which is found to be significantly higher than other soil layers and altitudinal range treatment combinations. Whereas, minimum value of bulk density (0.90 g cm⁻³) is recorded in 0-20 cm soil layer of A₂ (2170-2440 m), which, however, remained statistically at par with L₂T₂ treatment combination.

It is clear from the data presented in the Table 15 that soil bulk density is significantly influenced by the interaction effect between land use system and soil depth. Maximum value of bulk density (1.15 g cm⁻³) is displayed in 40-100cm soil layer under barren land use system. Which, however, remained statistically at par with the value of bulk density displayed in 40-100cm soil layer of silvi-pasture land use system. Minimum value of bulk density (0.89 g cm⁻³) is recorded in 0-20 cm soil layer of agri-horti-silviculture land use system, which, however, remained statistically at par with the value displayed by agri-horti-silviculture land use system in 20-40 cm soil layer.

Table 15: Effect of interaction between land use system and soil depth on bulk density (gcm⁻³) in the dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Land use systems (T)	Soil Layer (L)		
	L ₁ (0-20cm)	L ₂ (20-40cm)	L ₃ (40-100cm)
T ₁ (Agriculture)	0.99	1.04	1.02
T ₂ (Horticulture)	0.97	0.99	1.01
T ₃ (Agri – horticulture)	1.01	1.08	1.04
T ₄ (Agri – horti – silviculture)	0.89	0.90	0.94
T ₅ (Silvi-pasture)	0.94	0.99	1.13
T ₆ (Barren land)	1.01	1.02	1.15
SE (d)	0.02		
CD _{0.05}	0.03		

Data presented in Table 16 depicts that the bulk density status of different soil layers i.e. 0-20, 20-40 and 40-100 cm at three altitudinal ranges viz; A₁ (1900-2440m), A₂ (2170-2440m) and A₃ (2440-2710m) under different land use systems. In the interaction effect between land use, altitudinal gradient and soil depth, maximum value of soil bulk density (1.39 g cm⁻³) is recorded in 40-100 cm soil layer of silvi-pasture land use system at A₁ (1900-2170 m) altitudinal range. Whereas, minimum value of bulk density (0.73 g cm⁻³) is recorded in 0-20 cm soil layer of agriculture land use system at A₂ (2170-2440 m) altitudinal range. In general, at all the altitudinal ranges, the values of soil bulk density increases with increasing soil depth i.e. the value of bulk density is maximum at 40-100 cm soil layer and is minimum in upper most layer i.e. 0-20 cm soil layer.

Table 16: Effect of land use system, altitudinal gradient and soil depth on bulk density (gcm⁻³) in the dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Land use Systems (T)	Altitudinal gradient								
	A ₁ (1900-2170m)			A ₂ (2170-2440m)			A ₃ (2440-2710m)		
	L ₁ (0-20cm)	L ₂ (20-40cm)	L ₃ (40-100cm)	L ₁ (0-20cm)	L ₂ (20-40cm)	L ₃ (40-100cm)	L ₁ (0-20cm)	L ₂ (20-40cm)	L ₃ (40-100cm)
T ₁ (Agriculture)	1.18	1.22	1.27	0.73	0.89	0.83	1.02	1.02	0.97
T ₂ (Horticulture)	0.99	1.11	1.06	1.04	1.01	1.08	0.87	0.85	0.89
T ₃ (Agri – horticulture)	0.96	1.06	1.23	0.87	0.89	0.96	1.19	1.30	0.96
T ₄ (Agri – horti – silviculture)	0.96	0.87	0.87	0.87	0.90	0.96	0.83	0.92	0.99
T ₅ (Silvi-pasture)	1.09	1.15	1.39	0.80	0.89	0.96	0.92	0.92	1.06
T ₆ (Barren land)	1.01	1.19	1.23	1.09	0.90	1.19	0.89	0.97	1.02
SE (d)	0.05								
CD _{0.05}	0.07								

4.3.3 Available Nitrogen (Kg ha⁻¹)

Data displayed in the Table 8 shows that available N (Kg ha⁻¹) in the dry temperate ecosystem of Kinnaur district of Himachal Pradesh is significantly influenced due to land use system, altitudinal gradient and soil layer. In the interaction effect N content is significantly influenced due to two way interaction between land use system and altitudinal gradient, land use system and soil layer and by the three way interaction of land use system, altitudinal gradient and soil layer.

Data presented in the Table 8 shows that maximum available N (542.50 t ha⁻¹) is in the horticulture based land use system, which is found to be statistically at par with silvi-pasture (538.10 kg ha⁻¹) system, only. The trend in respect of N status under different land use system is in the order of horticulture > silvi-pasture > agrihorticulture > agri-horticulture > agriculture > barren land use system. In the altitudinal ranges maximum available N (532.80 kg ha⁻¹) is displayed in 2170-2440 m a.s.l. and followed by A₃ (516 kg ha⁻¹) and A₁ (505.6 kg ha⁻¹), respectively in the significant declining order. Similarly in the soil layer effect, irrespective of the land use system and altitudinal gradient the N status declined significantly with the increasing soil depth.

In the interaction effect between land use system and altitudinal range (Table 17), no consistent trend is noticed at the land use level with the increasing altitudinal ranges. Maximum value of available N (554.60 kg ha⁻¹) is recorded under T₂ (Horticulture) land use system at A₃ (2440-2710m) elevation range, which, however, remained statistically at par with T₄A₃ and T₄A₂ treatment combinations. Whereas, minimum value of available N (431.40 kg ha⁻¹) is recorded under barren land at A₃ (2440-2710 m) elevation range, which is found to be significantly lower than the value in other land use systems of other altitudinal ranges.

Table 17: Effect of interaction between land use systems and altitudinal gradient on availability of nitrogen (kg ha⁻¹) in the dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Land use systems (T)	Altitudinal ranges (A)		
	A ₁ (1900 – 2170m)	A ₂ (2170 – 2440m)	A ₃ (2440 – 2710m)
T ₁ (Agriculture)	550.90	482.90	509.40
T ₂ (Horticulture)	547.80	525.10	554.60
T ₃ (Agri – horticulture)	531.00	551.90	505.70
T ₄ (Agri – horti – silviculture)	466.90	547.10	552.60
T ₅ (Silvi-pasture)	529.30	542.50	542.50
T ₆ (Barren land)	407.70	547.40	431.40
TXA	SE (d) 3.27	CD _{0.05} 4.62	

In the interaction effect between land use system and soil layer (Table 18) reveals that maximum amount of available N ($566.60 \text{ kg ha}^{-1}$) is recorded in 0-20 cm soil layer of T₅ (silvi-pastoral) land use system, which is found to be significantly higher than all other treatment combinations under consideration. Significantly minimum value of available N ($387.10 \text{ kg ha}^{-1}$) is recorded in 40-100 cm soil layer of barren land use system. Perennial tree based land use system viz; horticulture, agri-horticulture and silvi-pasture system displayed significantly higher values than agriculture based land use system.

Table 18: Effect of interaction between land use system and soil depth on available nitrogen (kg ha^{-1}) in the dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Land use systems (T)	Soil Layer (L)		
	(0-20cm)	(20-40cm)	(40-100cm)
T ₁ (Agriculture)	539.40	524.80	479.10
T ₂ (Horticulture)	560.60	538.30	528.50
T ₃ (Agri – horticulture)	557.20	549.10	482.30
T ₄ (Agri – horti – silviculture)	540.80	525.80	500.00
T ₅ (Silvi-pasture)	566.60	533.10	514.70
T ₆ (Barren land)	508.00	491.30	387.10
TXD	SE (d) 3.27	CD _{0.05} 4.62	

Table 19 depicts the N status with respect to land use system, altitudinal gradient and soil depth. It shows that there is marked variation in the N status under different treatment combinations. Maximum available N ($579.10 \text{ kg ha}^{-1}$) is

Table 19: Interaction effect of land use system, soil depth and altitudinal gradient on available nitrogen (kg ha^{-1}) in the dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Land use Systems (T)	Altitudinal gradient								
	A ₁ (1900-2170m)			A ₂ (2170-2440m)			A ₃ (2440-2710m)		
	L ₁ (0-20cm)	L ₂ (20-40cm)	L ₃ (40-100cm)	L ₁ (0-20cm)	L ₂ (20-40cm)	L ₃ (40-100cm)	L ₁ (0-20cm)	L ₂ (20-40cm)	L ₃ (40-100cm)
T ₁ (Agriculture)	560.30	550.90	541.50	514.30	504.90	429.60	543.60	518.50	466.20
T ₂ (Horticulture)	557.20	547.80	538.30	559.30	510.10	505.90	565.50	557.20	541.10
T ₃ (Agri – horticulture)	572.80	562.40	457.90	559.30	550.90	545.70	539.40	534.20	443.50
T ₄ (Agri – horti – silviculture)	499.70	470.40	430.70	561.30	549.80	530.00	561.30	557.20	539.40
T ₅ (Silvi-pasture)	567.60	492.30	527.90	553.00	545.70	528.90	579.10	561.30	487.10
T ₆ (Barren land)	441.10	420.20	361.70	554.00	546.70	541.50	528.90	507.00	258.20
SE (d)	5.66								
CD_{0.05}	8.01								

recorded under silvi-pasture system, which is found to be significantly at par with the N status under agri-horticulture land use system in 0-20 cm layer at A₁ (1900-2170 m a.s.l.), only. In general, N status is low under barren land situated at A₁ (1900-2170 m a.s.l.) altitudinal range at different soil depth.

Data presented in the Table 20 demonstrates that carbon density is significantly influenced by land use system, altitudinal gradient and interaction effect between land use system and altitudinal gradient.

Table 20: Effect of land use system, altitudinal gradient and their effect interaction on total Soil carbon density (0-100 cm layer) (t ha⁻¹) in the dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Land use systems (T)	Altitudinal ranges (A)			Mean
	A ₁ (1900 – 2170m)	A ₂ (2170 – 2440m)	A ₃ (2440 – 2710m)	
T ₁ (Agriculture)	159.39	105.99	132.86	132.74
T ₂ (Horticulture)	151.17	145.91	124.47	140.51
T ₃ (Agri – horticulture)	146.45	122.88	185.99	151.77
T ₄ (Agri – horti – silviculture)	122.23	128.31	125.57	125.37
T ₅ (Silvi-pasture)	127.34	95.34	106.60	109.76
T ₆ (Barren land)	82.84	99.89	69.86	84.19
Mean	131.57	116.38	124.22	
TXA	SE (d) 11.35	CD _{0.05} 16.04		

A perusal of the data in the Table 20 reveals that maximum carbon density (151.77t ha⁻¹) in (0-100cm) layer is in agri-horticulture land use system, which is found to be significantly higher than all other land use systems, except horticulture ones. Whereas, minimum carbon density is in the barren land use, which is also found to be significantly lower than all other land use systems under investigation. Irrespective of the land use, in altitudinal gradient maximum carbon density (131.57 t ha⁻¹) is recorded at A₁ (1900-2170m a.s.l) altitudinal range, which is found to be significantly higher than A₂ (2170-2440m a.s.l), only.

In the interaction effect between land use system and altitudinal gradient no definite trend could be ascertained between land use system and altitudinal gradient. Significantly highest values of soil carbon density (185.99 t ha^{-1}) is recorded in agri-horticulture land use system situated at an altitudinal range of 2440-2710m a.s.l. Whereas, minimum values are displayed by barren land use system at an altitude of 2440-2710m a.s.l

Data presented in the Table 21 depicts the interaction between altitudinal gradient and soil layer. At L_1 (0-20cm) as well as L_2 (20-40cm) soil layer the carbon density does not vary significantly at different altitude. However, at 40-100cm soil layer, maximum carbon density is recorded at A_1 altitudinal range which is found to be significantly higher than treatment combinations of L_3A_2 and L_3A_3 , only.

Table 21: Effect of interaction between altitudinal gradient and soil depth on soil carbon density (t ha^{-1}) in the dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Altitudinal ranges (A)	Soil layer (L)		
	L_1 (0-20cm)	L_2 (20-40cm)	L_3 (40-100cm)
A_1 (1900 – 2170m)	26.18	24.01	79.65
A_2 (2170 – 2440m)	26.19	23.60	66.56
A_3 (2440 – 2710m)	26.87	25.63	72.69
SE (d)	2.01		
CD_{0.05}	2.85		

Table 22 demonstrates that the three way interaction effect between land use system, altitudinal gradient and soil layer on soil carbon density. The data shows that carbon density at L_1 (0-20cm) and L_2 (20-40cm) layer did not vary appreciably among different land use systems at all altitudinal gradients, except for barren land, where in general quiet low values are recorded than other systems. However, wide variation exist at L_3 (40-100cm) layer at the three altitudinal ranges. Soil carbon density do not vary significantly between L_1 and L_2 layer at different altitude under different land use systems.

Table 22: Interaction effect of land use system, soil depth and altitudinal gradient on soil carbon density (t ha^{-1}) in the dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Land use Systems (T)	Altitudinal gradient								
	A ₁ (1900-2170m)			A ₂ (2170-2440m)			A ₃ (2440-2710m)		
	L ₁ (0-20cm)	L ₂ (20-40cm)	L ₃ (40-100cm)	L ₁ (0-20cm)	L ₂ (20-40cm)	L ₃ (40-100cm)	L ₁ (0-20cm)	L ₂ (20-40cm)	L ₃ (40-100cm)
T ₁ (Agriculture)	31.65	31.13	96.61	20.13	22.84	63.02	28.89	28.70	75.28
T ₂ (Horticulture)	27.50	30.03	93.62	29.60	27.79	88.52	24.84	24.16	75.47
T ₃ (Agri – horticulture)	27.32	26.70	92.50	24.84	24.09	73.86	34.27	36.74	114.99
T ₄ (Agri – horti – silviculture)	26.69	24.14	71.39	24.49	25.29	78.53	23.68	24.67	77.23
T ₅ (Silvi-pasture)	25.06	26.40	75.87	20.55	19.84	54.96	23.68	20.62	62.31
T ₆ (Barren land)	22.72	18.69	41.43	24.67	15.27	59.96	19.98	16.73	33.68
SE (d)	4.93								
CD _{0.05}	6.97								

4.4. CARBON INVENTORY

4.4.1 Total ecosystem carbon density (soil + plant) (t ha^{-1})

Total ecosystem carbon density (soil + plant) is significantly influenced due to land use system, altitudinal gradient and interaction effect between land use system and altitudinal gradient (Table 23). Data presented in the Table 23 reveals that maximum total ecosystem carbon density (166.36 t ha^{-1}) is in the agri-horticulture land use system, which however, remained statistically at par with all other land use systems except agriculture and barren land use system. The order of carbon density under different land use systems is agri-horticulture > agri-horti-silviculture > silvi-pasture > horticulture > agriculture > barren land.

Irrespective of the land use system, the carbon density at different altitudinal gradient followed the trend $A_1 > A_3 > A_2$. However, A_1 and A_2 remained statistically at par with one another but both displayed significantly higher values than A_3 . In the interaction effect between land use system and altitudinal gradient no consistent trend is seen in land use system with increasing altitudinal gradient. Maximum total carbon density (205.70 t ha^{-1}) is recorded in the treatment combination of T_5A_3 , which however, remained statistically at par with T_3A_3 , only. In general, barren land use system displayed quite low values of the total carbon density than other treatment combinations.

Table 23: Effect of land use system, altitudinal gradient and their interaction effect on Total ecosystem carbon density (t ha^{-1}) in the dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Land use systems (T)	Altitudinal ranges (A)			
	A ₁ (1900 – 2170m)	A ₂ (2170 – 2440m)	A ₃ (2440 – 2710m)	Mean
T ₁ (Agriculture)	163.21	109.35	135.68	136.08
T ₂ (Horticulture)	163.66	161.59	137.22	154.16
T ₃ (Agri – horticulture)	163.77	135.39	199.93	166.36
T ₄ (Agri – horti – silviculture)	176.51	166.04	148.68	163.74
T ₅ (Silvi-pasture)	146.41	133.44	205.70	161.85
T ₆ (Barren land)	86.88	106.59	71.27	88.25
Mean	150.07	135.40	149.75	
SE (d)				
T	9.43	19.18		
A	6.67	13.55		
TXA	11.55	16.35		

4.4.2 Soil plant carbon density ratio

The soil plant carbon density in the dry temperate Himalayas ecosystem under different land use lying at different altitudinal gradient is presented in the Table 24. It shows that land use system, altitudinal gradient and their interaction significantly influenced the carbon density. Irrespective of altitudinal gradient, maximum soil:plant carbon density ratio (23.10 t ha^{-1}) is recorded in agriculture land use system which is found to be significantly higher than all other land use systems under investigation.

Soil:plant carbon density ratio under the land use system viz; horticulture, agri-horticulture, agri-silvi-horticulture and silvi-pasture remained statistically at par with one another. In the altitudinal ranges, irrespective of the land use system, A₃ displayed maximum soil:plant carbon density ratio which is found to be significantly higher than A₁ and A₂ and followed the trend $A_3 > A_1 > A_2$.

In the interaction effect between land use system and altitudinal gradient no definite trend could be established in different land use system with altitudinal gradient. In agriculture, horticulture and barren land lower values were recorded at A₂ altitudinal range. Whereas, in agri-horticulture and agri-horti-silviculture

the soil:plant carbon density ratio enhanced with increasing altitudinal ranges. Whereas, in the silvi-pasture the trend is just reverse. Maximum and minimum values of soil:plant carbon density ratios are recorded in the treatment combinations of T₆A₃ and T₄A₁, respectively.

Table 24: Effect of land use system, altitudinal gradient and their interaction effect on soil: plant carbon density (t ha⁻¹) in the dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Land use systems (T)	Altitudinal ranges (A)			Mean
	A ₁ (1900 – 2170m)	A ₂ (2170 – 2440m)	A ₃ (2440 – 2710m)	
T ₁ (Agriculture)	41.73	31.54	47.11	23.10
T ₂ (Horticulture)	12.10	9.31	9.76	5.97
T ₃ (Agri – horticulture)	8.46	9.82	13.34	6.06
T ₄ (Agri – horti – silviculture)	2.25	3.40	5.43	2.12
T ₅ (Silvi-pasture)	6.68	2.50	1.08	1.93
T ₆ (Barren land)	20.50	14.91	49.55	12.94
Mean	15.29	11.91	21.05	

	SE(d)	CD _{0.05}
T	2.99	6.08
A	2.12	4.29
T x A	3.67	5.18

4.5 ECONOMIC ANALYSIS

Economic analysis of different land use systems along the altitudinal gradient of dry temperate Himalayan ecosystem of Kinnaur district of Himachal Pradesh is dealt with in this section under the following sub heads:

4.5.1 Gross return (Rs ha⁻¹ yr⁻¹)

The Table 25 exhibits that gross returns (Rs ha⁻¹ yr⁻¹) under dry temperate Himalayan ecosystem is significantly influenced due to land use system, altitudinal gradient and interaction effect between land use system and altitudinal gradient.

Table 25: Effect of interaction between land use system, altitudinal gradient and their interaction on gross returns (Rs ha⁻¹ yr⁻¹) in the dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Land use systems (T)	Altitudinal ranges (A)			Mean
	A ₁ (1900-2170 m)	A ₂ (2170-2440 m)	A ₃ (2440-2710 m)	
T ₁ (Agriculture)	246100	332100	259300	279200
T ₂ (Horticulture)	999000	1270000	2400000	1556000
T ₃ (Agri-horticulture)	1220000	1616000	2633000	1823000
T ₄ (Agri-horti-silviculture)	501700	631600	1396000	843000
T ₅ (Silvi-pasture)	647000	471000	523400	547100
T ₆ (Barren land)	7500	10000	13000	10170
Mean	603500	721000	1204000	

	SE(d)	CD_{0.05}
T	37338	75880
A	26402	53656
T x A	45730	64670

Irrespective of the land use system the gross returns (Rs ha⁻¹ yr⁻¹) enhanced significantly with increasing altitudinal range. A₃ (2170-2440m a.s.l.) altitudinal range displayed markedly higher gross returns than A₁ and A₂ altitudinal range. The Table also evinced that irrespective of altitudinal range, rate of gross return is maximum (Rs 1823000) in agri-horticulture system, which is followed by the land use system of horticulture, agri-horti-silviculture, silvi-pasture, agriculture and barren land system, respectively in the descending order.

It is evident from the interaction between the land use system and altitudinal gradient that agri-horticulture and horticulture based land use system yields very high gross return at all the altitudinal ranges. Maximum gross return (Rs 2633000) are recorded in agri-horticulture land use system at 2440-2710 m elevation range. Whereas, minimum return (Rs 7500) is recorded in barren land use system of 1900-2170 m altitudinal range. The Table also evinced that at A₃ (2440-2710 m a.s.l.) horticulture, agri-horticulture and agri-horti-silviculture land use system has about two or more than two times gross returns than at A₁ or A₂ altitudinal gradient.

4.5.2 Total expenses (Rs ha⁻¹ yr⁻¹)

A perusal of the data presented in the Table 26 reveals that total expenses are significantly influenced by the land use system, altitudinal gradient and interaction effect between them. Irrespective of the altitudinal ranges maximum expenses are involved (Rs 512900) in agri-horticulture land use system, closely followed by horticulture and agri-horticulture land use systems, only. Whereas, minimum expenses (Rs 2278) is recorded in barren land use system. In altitudinal ranges, maximum expenses (Rs 357416) are recorded in 2440-2710 m altitudinal range, which is followed by A₂ and A₁ altitudinal range, respectively.

Table 26: Effect of interaction between land use system, altitudinal gradient and their interaction on total expenses (Rs ha⁻¹ yr⁻¹) in the dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Land use systems (T)	Altitudinal ranges (A)			Mean
	A ₁ (1900-2170 m)	A ₂ (2170-2440 m)	A ₃ (2440-2710 m)	
T ₁ (Agriculture)	194400	209300	180000	194600
T ₂ (Horticulture)	272600	312400	589400	391400
T ₃ (Agri-horticulture)	393900	447100	697800	512900
T ₄ (Agri-horti-silviculture)	145900	345500	575700	355700
T ₅ (Silvi-pasture)	97200	95530	99100	97280
T ₆ (Barren land)	1833	2500	2500	2278
Mean	184300	235400	357416	

	SE(d)	CD_{0.05}
T	57794	117450
A	40866	83051
T x A	70780	100100

In the interaction effect between the land use system and altitudinal gradient, expenses are quite higher (Rs 697800) in agri-horticulture land use system situated at 2440-2710 m altitudinal range. Whereas, minimum value of total expenses (Rs 1833) is recorded in barren land use system in 1900-2170m altitudinal range.

4.5.3 Net profit (Rs ha⁻¹ yr⁻¹)

Data presented in the Table 27 demonstrates that net profit in the dry temperate Himalayan ecosystem of Kinnaur District of Himachal Pradesh, India is significantly influenced due to land use systems, altitudinal gradient and interaction between land use system and altitudinal gradient.

Table 27: Effect of land use system, altitudinal gradient and their interaction on net profit (Rs ha⁻¹ yr⁻¹) in the dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Land use systems (T)	Altitudinal ranges (A)			Mean
	A ₁ (1900-2170 m)	A ₂ (2170-2440 m)	A ₃ (2440-2710 m)	
T ₁ (Agriculture)	51660	122800	79290	84580
T ₂ (Horticulture)	726400	957600	1811000	1165000
T ₃ (Agri-horticulture)	826500	1169000	1936000	1310000
T ₄ (Agri-horti-silviculture)	355800	286000	820300	487400
T ₅ (Silvi-pasture)	549800	375500	424300	449900
T ₆ (Barren land)	5667	7500	10500	7889
Mean	419300	486400	846800	

	SE(d)	CD_{0.05}
T	33281	67635
A	23533	47825
T x A	40760	57640

Irrespective of the altitudinal gradient, maximum net profit is accrued from agri-horticulture land use system, which is found to be significantly higher than other land use systems and followed the trend: agri-horticulture > horticulture > agri-horti-silviculture > silvi-pastoral > agriculture > barren land. In the altitudinal range, irrespective of the land use system A₃ (2440-2710 m a.s.l.) demonstrated significantly higher net profit than either A₁ or A₂ altitudinal range. A₃ altitudinal range displayed 1.74 – 2.0 times more profit than A₁ and A₂.

In the interaction effect between land use system and altitudinal gradient agri-horticulture land use system situated at 2440-2710 m a.s.l. displayed significantly higher net profit than any other treatment combinations under consideration. In addition to it, agri-horticulture land use system displayed higher net profit than other land use system at each altitudinal range. However, agri-

horticulture land use system is closely followed by the horticulture land use system.

4.5.4 Benefit: cost ratio

The estimates of benefits: cost ratio in relation to land use system, altitudinal ranges and their combination is depicted in the Table 28.

Table 28: Effect of land use system, altitudinal gradient and their interaction on benefit cost ratio in the dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Land use systems (T)	Altitudinal ranges (A)			
	A ₁ (1900-2170 m)	A ₂ (2170-2440 m)	A ₃ (2440-2710 m)	Mean
T ₁ (Agriculture)	1.27	1.53	1.44	1.41
T ₂ (Horticulture)	3.67	4.06	4.07	3.93
T ₃ (Agri-horticulture)	3.10	3.61	3.78	3.50
T ₄ (Agri-horti-silviculture)	3.25	1.80	2.44	2.50
T ₅ (Silvi-pasture)	6.66	4.94	5.28	6.63
T ₆ (Barren land)	4.83	4.07	5.29	4.73
Mean	3.80	3.33	3.72	

	SE(d)	CD_{0.05}
T	33281	67635
A	23533	47825
T x A	40760	57640

Data presented in the Table 28 evinced that benefit: cost ratio is maximum (6.63) in silvi-pasture land use system, which is closely followed by the land use systems of barren land (4.73), horticulture (3.93), agri-horticulture (3.50), agri-horti-silviculture (2.50) and agriculture (1.41), respectively in descending order. In the altitudinal ranges the benefit: cost ratio is recorded maximum (3.80) in 1900-2170 m altitudinal range, whereas, minimum value of benefit: cost ratio is recorded in 2170-2440 m altitudinal range.

In the interaction effect between land use system and altitudinal range, the maximum value of benefit: cost ratio (6.66) is recorded in silvi-pasture land use system at 1900-2170 m altitudinal range. Whereas, minimum value of benefit: cost ratio (1.27) is recorded in agriculture land use system situated at 1900-2170m altitudinal range.

Chapter-5

DISCUSSION

The investigations on “Carbon storage potential and bio-economic appraisal of different land use systems in dry temperate north western Himalayas” were carried out in Kinnaur district of Himachal Pradesh during the year of 2011 - 2012. Kinnaur district of Himachal Pradesh which lies in the inner of the greater Himalayas is well known for its uniqueness of vegetation, quality apple production, dry fruits, majestic mountains, perennial river system, hydroelectric potential and is fast emerging as a centre of tourism.

Over the past 30 years, the cropping pattern of this district has seen a change because of integration of apple orchard in a big way and now almost all the fields are allotted with apple orchard. The present study is a maiden attempt to know the effect on integration of apple trees into the pre-existing land use system on biomass carbon storage potential and economic benefits as derived from different land use system. This chapter has been devoted to examine the results of 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 between them to derive out the fruitful conclusions under the following heads and subheads:

5.1 EFFECT OF LAND USE SYSTEMS

5.1.1 Biomass production levels of different land use systems

The biomass production as categorized into, above ground, below ground and total biomass has been presented in the Tables 4-6. The tables revealed that all the components of biomass viz; above, below and total biomass were significantly influenced due to the land use system effect in the dry temperate Himalayas ecosystem of temperate north western Himalayas.

Maximum above ground biomass (84.65 t ha⁻¹) was recorded in silvi-pasture system, which was followed by agri-horti-silviculture, agri-horticulture,

horticulture, agriculture and barren land in the descending order respectively (Table 4). Above ground biomass in the land use system of horticulture and agri-horticulture remained statistically at par with one another. Similarly, agriculture and barren land displayed identical values of above ground biomass.

The data presented in the Table 5 revealed that below ground biomass, in general, followed the same trend as that of above ground. Maximum below ground biomass (19.50 t ha^{-1}) was in the silvi-pasture which was found to be significantly higher than all other land use system but was closely followed by agri-horti-silviculture. Below ground biomass in horticulture and agri-horticulture remained statistically at par with one another. Table 6 demonstrates that total biomass production was maximum (104.10 t ha^{-1}) which followed more or less same trend as recorded in respect of above and below ground biomass (Tables 4 & 5).

The above results have indicated that biomass component viz; above ground biomass, below ground biomass and total biomass produced by particular land use system is influenced by the age of the components-annual or perennial, type of crop, structure of the system, nature and number of woody components etc. Nayak (1996) also found that above ground biomass was influenced due to species and density. Deshmukh (1998) reported that management practices also affect the biomass production of tree grown under different agroforestry systems. The differences in the productivity of agroforestry systems may also be due to differences in soil conditions, phenology of dominant species (Gupta and Singh, 1981), better root net working as well as efficient and economical use of limited resources for maintaining higher photosynthetic activities, leaf area index, better light interceptions and water use efficiency (Sehgal, 1999).

5.1.2 Biomass carbon density of different land use systems

The biomass carbon density in a particular land use system to a great extent depends upon its age, structure, functional component and its number and intensity of management. The total biomass carbon density is depicted in the Table 7. Data presented in the Table 7 revealed that maximum biomass carbon density is in the silvi-pasture system (52.88 t ha^{-1}), which differed significantly

from other land use systems and followed the trend: silvi-pasture > agri-horti-silviculture > agri-horticulture > horticulture > agriculture. It can again be inferred from the above discussion that variability in the carbon density of different land use system depends primarily on its age, structure, functional components and their number and intensity of management. The variability in the productivity of agroforestry systems as recorded in our case is in consonance with the observations of Alberect and Kandji (2003). They opined that carbon variability in plant biomass can be high within complex agroforestry system and productivity depends on several factors including age, the structure and the way the system is managed. The biomass carbon storage capacity as calculated in our fruit based land use system was quiet low than reported by Sanneh (2007) and Singh (2010) for fruit based agroforestry systems of the wet temperate and temperate Himalayas ecosystems of the north western Himalayas. This variation can be attributed to the prevailing climatic conditions – temperature and rainfall pattern, which affects the biomass carbon accumulation in fruit based land use system. In dry temperate Himalaya ecosystem average temperature and rainfall remain quite low than wet temperate and temperate Himalaya ecosystem which can be the main reason for their lower biomass carbon density.

5.1.3 Soil physico-chemical properties

5.1.3.1 Soil organic carbon

It is clear from the data presented in the Table 8 that organic carbon (%) varied significantly under different soil layers of different land use systems, under different altitudinal ranges and their interaction effect. Maximum organic carbon percent was in the silvi-pasture system, which however remained statistically at par with all other land use systems except agriculture and agri-horticulture. Significantly increased organic carbon contents in soils under these land based use systems may be ascribed to more leaf litter deposition followed by decomposition and root turn over from trees (Zegeye, 1999), Kater *et al* (1992), Rhodes (1995) and Sood (1999). Whereas, in agriculture and agri-horticulture high amount of organic carbon gets exhausted due to the intensive cultivation in these land use system and removal of high amount of harvest annually in the form of agriculture produce and fruits.

The carbon fixed by the plants is the primary source of organic matter input into the soil, which provides substrate for microbial process accumulation of soil organic matter. The below ground allocation of photosynthates is also an important factor for improving soil organic carbon content (Kaur, *et al.*, 2002). The result from the present studies also demonstrated that maximum accumulation of soil organic carbon is in the surface layer which decreased with soil depth (Table 8). The greater accumulation of soil organic carbon on the surface is due to the greater incorporation of leaf litter on it. Similar findings i.e increase in soil depth has also been reported by Minhas *et al* (1997), Sanneh (2007), Singh (2010) and Devi (2011).

5.1.3.2 Bulk density (g cm^{-3})

The data presented in the Table 8 showed that the bulk density (g cm^{-3}) varied significantly under the influence of land use system, altitudinal gradient and soil layer. The bulk density in the dry temperate Himalaya ecosystem followed the trend; barren land > agri-horticulture > agriculture > silvi-pasture > horticulture > agri-horti-silviculture. The higher bulk density in the barren land use system can be owed to the fact that the general texture of the soil in the season is sandy to sandy loam (Table 1) and the bulk density of the sandy textured and sandy loam soil is usually higher than other soils. Only those soils are left unused/barren which are more sandy in nature. The higher bulk density in the agri-horticulture and agriculture can be owed to the fact that these soils are intensively managed and now it is a well known fact that bulk density is very high in these type of soils. These findings are in agreement with the findings of Karan *et al* (1998), Cihacek and Ulmer (1998). It is also seen in the table 8 that bulk density enhanced with the increasing soil depth. This can be owed to the fact that organic carbon declines (Table 8) with increasing soil depth.

5.1.3.3 Available Nitrogen (Kg ha^{-1})

Data presented in the Table 8 indicated that available N content varied significantly under the influence of land use systems and they followed the trend: Horticulture > silvi-pasture > agri-horticulture > agri-horti-silviculture >

agriculture > barren land. Significantly higher N status in the agroforestry based system can be explained on two basis. First, tree shed their leaves, which continuously keep on adding to the N status of the land. Secondly, the fruit crops are highly remunerative in nature, therefore farmer tries to maintain the nutrients status of these land use systems by externally adding the fertilizers in both organic and inorganic forms on yearly basis. Whereas comparatively lower status of the N in the field crops based land use systems can be owed to the intensity of management and addition through external sources. The intensity of the cultivation is very high in the field crops as a result of which N is lost through removal of biomass, soil erosion and volatilization. In addition to it, the farmers in the district do not bother much about agriculture crops because they are least paying in terms of monetary returns (Table 27)

5.1.4 Carbon Inventory

The carbon pool inventory of land use system was prepared by adding both soil layer and ecosystem carbon density. Data presented in the Table 20 demonstrated that irrespective of altitudinal gradient the maximum carbon density (151.77 t ha^{-1}) in the 0-100cm layer is in the agri-horticulture land use system and followed the trend: agri-horticulture > horticulture > agriculture > agri-horti-silviculture > silvi-pasture > barren land. Higher soil organic carbon pool in the agri-horticulture and horticulture land use systems can be ascribed to greater incorporation of leaf litter and addition of decayed roots to the soil layers than in other land use systems. Similar findings have also been observed by Singh (2010) in the temperate Himalayan ecosystem of the Himachal Pradesh.

Total carbon stock of the ecosystem is presented in the Table 23. It showed that total ecosystem carbon density (plant and soil) was in the agri-horticulture and closely followed by agri-horti-silviculture, silvi-pasture > horticulture > agriculture > barren land. The carbon density in the tree based agroforestry systems is appreciably higher than agriculture and barren land use system. Higher amount of carbon stock in the tree based land use systems can be ascribed to continuous locking up of carbon in trees and regular addition of leaf

litter to the soil which helps in build up of carbon in the soil layers which inturn helps in greater productivity of the systems.

The soil and plant carbon ratio of different land use system was depicted in the Table 24. It was clear from the data that minimum soil plant carbon density ratio is in the silvi-pasture followed by agri-horti-silviculture, horticulture, agri-horticulture, barren land and agriculture. Lower soil-plant carbon density means that these systems have more carbon in the plant components which need to be protected in order to avoid these systems becoming source of CO₂ in future.

5.2 EFFECT OF ALTITUDINAL GRADIENT

5.2.1 Biomass carbon density production levels

The biomass production pattern as categorized into above ground biomass, below ground biomass and total biomass have been tabulated in the Table 4-7. A perusal of these tables revealed that all types of biomass density (t ha⁻¹), irrespective of land use system increased from 1900 – 2170m a.s.l to 2440 - 2710m a.s.l and thereafter showed a declining trend with increased in the altitudinal level. The above variation in the biomass level at different altitudinal level can be explained on the basis of density of woody species, variation in soil organic percentage and change in the pattern of temperature and rainfall with the change in the altitudinal ranges. Altitudinal ranges of A₁ and A₂ remained statistically at par with one another and differed significantly from A₃.

The above variation in the biomass level at different altitude can be explained on the basis of combined effect of age of woody species, soil organic carbon (%) and human population density. It is evidently clear from the Table 3 that the major contributor of biomass at different altitudinal ranges are woody perennial and the average age of tree species increases with increasing altitudinal level. This may be one of the major reasons for biomass variation at different altitudinal ranges. Secondly, the organic matter (% C) also increased significantly as we moved from lower to upper altitudinal levels.

Higher level of organic carbon at upper altitudinal range may have favoured more biomass production. Similar views were also expressed by

Lehmann *et al* (1998), Rao *et al* (1998), Kumar (2003), Sanneh (2007) and Singh (2010). Thirdly, the level of human interference with nature declines as we move from lower to higher altitude because of decreasing population density and inhospitability of the site. Usually at higher altitude, the population density in the region happens to be lesser than lower altitude. Fourthly, the frequency of rainfall and snowfall and their intensity keeps on increasing as we move upward in the higher hills of Kinnaur district and lower elevation ranges falls under almost complete shadow zone.

5.2.2 Soil physico-chemical properties

5.2.2.1 Soil organic carbon

It was found that organic carbon declined with increasing altitudinal range (Table 8), which can be owed to continuous accumulation of leaf litter and slower decomposition of rate of higher altitude than at lower ones. Slower decomposition means less mineralization and hence losses of organic carbon through erosion will be lower at higher altitude and hence more carbon content concentration.

5.2.2.2 Bulk density

Bulk density showed a decreasing trend with increasing altitudinal ranges (Table 8). This can again be owed to increasing trend of soil organic matter with increasing altitude. As we know, soil organic matter increased with the increasing altitude because of slower decomposition rate with increasing altitude. Table 8 also revealed that bulk density also increased with increasing depth of soil layer. The lower bulk density values in upper layer of soil profile may have resulted from the dilution of soil matrix (mineral matter) with lesser denser material (organic matter) and improvement in soil aggregation. Improvement in aggregation encouraged fluffy and porous condition in soil resulted in lower bulk density of soil due to increase in soil organic carbon has been amply reported in literature (Soane 1975, Coote and Ramsay 1983, Sharma and Aggarwal 1984, Sharma *et al.*, 1995, Lav Bhushan 1998, Sanneh 2007 and Singh, 2010)

5.2.2.3 Available Nitrogen (Kg ha^{-1})

The data demonstrated in the Table 8 showed that the available N increased from A_1 to A_2 and then declined at A_3 . Higher available N status at A_2 (2170-2440m a.s.l) can be due to combined effect of higher biomass production and optimum mineralization at this altitude. At lower altitude, the rate of mineralization is higher which may have caused loss of available through various processes. Whereas, on the upper most altitude level the rate of mineralization may be too low. Data in the Table 8 also showed that available N significantly declined with increasing soil depth. This can again be owed to continued deposition of leaf litter on the surface layer.

5.2.4 Carbon Inventory

5.2.4.1 Soil organic carbon pool

5.2.4.1.1 Soil organic carbon density

Results presented in the Table 20 showed that highest soil carbon density (129.82 t ha^{-1}) was displayed at 1900-2170m a.s.l, which was found to be higher than A_2 (2170-2440m a.s.l), only. Higher soil carbon density at lower most altitude can be owed to significant higher bulk density of soils at lower most altitude.

5.2.4.2 Total ecosystem (soil + plant) carbon pool

Data presented in the Table 23 exhibited that ecosystem carbon density at both A_1 (1900-2170m) and A_3 (2440-2710m) displayed significantly higher values than A_2 (2170-2440m a.s.l). This may be due to cumulative effect of nature of the land use system, influence of age, structure, functional component and their density, soil types as well as climatic conditions.

5.2.4.3 Soil: plant carbon density ratio

It is crystal clear from soil: plant carbon ratio that data did not showed a consistent trend with increase in altitudinal range. However, it was found to be significantly higher at A_3 (2440-2710m a.s.l) than at A_1 and A_2 . Higher soil: plant

carbon density ratio reflects toward greater stability of the system. If in future temperature increases and vegetation shift takes place then there will be net emission of CO₂ from these land use systems because of greater mineralization from the soil and more respiration through the vegetation. This shift between one altitudinal range to another signifies the difference of approximately one degree centigrade.

5.3 INTERACTION EFFECTS

5.3.1 Effect of interaction between land use system and altitudinal gradient on biomass production and biomass carbon density

Silvi-pasture systems situated at 2440-2710m a.s.l exhibited significantly highest value of above mentioned traits in comparison to all other land use systems. The registering of higher values of these traits in this treatment combination may be ascribed to higher average age diameter of the tree component at this altitudinal range, nature of the functional component in question and intensity of management involved. As we know the average age of the timber trees is quiet higher than fodder and fruit based land use systems. In addition to it, the biomass production and its removal is quiet high in field crops based systems.

5.3.2 Effect of interaction between land use systems, altitudinal ranges and soil layer

5.3.2.1 Effect on soil organic carbon (%)

Tables 9, 10, 11 displayed that maximum organic carbon (%) was observed in various combination of silvi-pasture. Higher organic carbon (%) in the various combinations of silvi-pasture land use system can be ascribed to continous addition of leaf litter and dead organic carbon (%) of the different layers. Minimum organic carbon content in the various combination of agriculture can be owed to depletion of organic carbon due to continous cropping, which depletes the soil of its organic carbon content.

In the interaction effect between the altitudinal ranges and soil layer (Table 10), the organic carbon (%) declines continuously from L₁ to L₂ and L₂ to

L₃, but this decline is quiet pronounced between in latter ones at A₁ (1900-2170m a.s.l) altitudinal range. This variation in the decline can be ascribed to temperature differences. At lower most altitudinal range, the temperature is more than higher altitudinal range. Because of higher temperature the rate of mineralization and loss from the systems may be quiet high.

5.3.2.2 Effect on Bulk density (gcm⁻³)

Data depicted in the Table 13 showed that the bulk density was significantly influenced by the interaction between land use system and altitudinal gradient. Higher values of bulk density were seen in various combinations of the land use systems viz; agriculture, horticulture, agri-horticulture, silvi-pasture and barren land at A₁ (1900-2170m a.s.l) altitudinal range. Higher values at this treatment combination can be ascribed to combined effect of cropping intensity and higher temperature.

It is clear from the data presented in the Table 14 showed that in the interaction effect between altitudinal gradient and soil layer, bulk density enhanced with increasing soil depth at all the altitudinal ranges, but this decline is more pronounced at A₁ (1900-2170m a.s.l) than at A₂ and A₃. This may be due to the greater proportion of sand content (lower altitude lies very close to satluj river) and faster rate of mineralization of organic carbon at lower altitude than at upper ones because the bulk density and soil organic carbon are inversely related. Data revealed that bulk density enhanced in the studied land use systems but this enhancement is more pronounced in silvi-pasture than others. This can be owed to the fact that in silvi-pasture, the size of trees and their proportion is more in the silvi-pasture which may have mineralized the organic matter at deeper layer at a faster rate than others followed by deposition on the surface layer.

5.3.3.3 Effect on available nitrogen (Kg ha⁻¹)

A perusal of the data presented in the Table 17 & 19 revealed that available nitrogen was significantly influenced by the interaction effect of land use system and altitudinal gradient ; and land use system, altitudinal gradient and soil layer. The data evinced that there was no discernible trends in the amount of

available nitrogen in different land uses with respect to increasing level of altitude. This may be due to the fact that N status is greatly influenced by human interference, cattle population, migratory animals and fertilizer application.

5.3.3.4 Effect on carbon density

Data presented in the Tables 20, 22 and 23 showed that carbon density in the barren land is quite lower at different altitude and soil layer. This may be owed to the fact that under barren land most of the soil is occupied by the stones, which do not store any carbon content in them hence low carbon density. Whereas, higher values of ecosystem carbon density in agri-horticulture and silvi-pasture (Table 23) at A₃ (2440-2710m a.s.l) altitude range can be owed to more proportion of tree component (Table 3) and increased carbon content (Table 9 & 12) at this altitude.

5.4.1 Economic returns

The data for gross returns, total expenses, net profit and cost-benefit ratio had been presented in Table 25-28. The gross returns, total expenses, net profit which can be obtained from agroforestry land use systems as well as pure orchard at their respective altitudinal ranges were markedly higher than pure agriculture. Maximum gross returns (Rs 18,23,000 ha⁻¹yr⁻¹) as well as net profit (Rs 13,10,00 ha⁻¹yr⁻¹) were in the agri-horticulture land use systems. Whereas, benefit-cost ratio was maximum (6.63) in silvi-pasture and least in agriculture. This is because of the fact that these systems hardly require any input but gives good returns because of valuable produce i.e. neoza which fetches high market price.

From the above results it is clear that the benefits were higher in the land use systems involving apple fruit trees in association with the agriculture and vegetable crops viz; peas, rajmash, cabbage, wheat, barley etc. The higher per unit market price of apple and vegetable crops, particularly peas and rajmash is because of favourable climatic condition which makes them highly beneficial to the region. Higher profitability of the fruit based agroforestry systems have also been reported in the literature, elsewhere. Sood (1999) conducted an experiment

studying tree crop interaction in which he reported that total cost incurred as well as net returns were higher agri-horticulture systems as compared to sole crops. Kumar (1999) reported that total costs, gross returns and net profit were higher from combination of pomegranate with soya bean, while least from soyabeans.

Tomar and Bhatt (2004), recorded maximum net monetary benefit per hectare when peach was intercropped with rice (Rs 40,4004), followed by guava (Rs 27, 087) Assam lemon (Rs 20, 991), respectively as compared to sole cropping. Under apple trees in ginger intercropping systems (Fan-wie *et al.*, 2000) recorded 3 times more income from the system as compared with that of the apple orchard without intercropping. Singh (2010) also found apple with agri-horticulture system in temperate ecosystem of Himachal's Himalayas highly paying in comparison to monoculture.

Tables 25-27 also showed that the gross returns, total expenses as well as net profit increases with increasing altitudinal ranges. Highest altitudinal range i.e 2440-2710m a.s.l displayed almost 2 times more net profit than A₁ & A₂ altitudinal range. These altitudinal ranges viz; 1900-2170m, 2170-2440m and 2440-2710m a.s.l were framed in such a way that they represent 1⁰ shift in the temperature. Therefore in future if the temperature of the region increases then it is bound to have an impact on the socio-economy of the people. Therefore, we need to plan and adopt suitable measures in order to avoid any financial losses to the people.

Chapter-6

SUMMARY AND CONCLUSION

The present investigations entitled “**Carbon storage potential and bio-economic appraisal of different land use systems in dry temperate north western Himalayas**” were carried out through experiments at different altitudinal gradients in Kinnaur district of Himachal Pradesh located at an elevation ranging from 1000 meters to over 6000 meters above mean sea level and lies on Latitude $31^{\circ} 34' 59''$ N and Longitude $78^{\circ} 25' 00''$ E respectively. These experiments were laid out in Randomized Block Design (Factorial). The present investigations were conducted to assess the biological yield and economic returns from the different land use systems; ascertain carbon stock under different land use systems along an altitudinal gradient and to identify suitable land use systems with high monetary return and carbon storage potential in dry temperate north-western Himalayas. Three altitudinal gradients were considered for the study viz; 1900-2170m, 2170-2440m and 2440-2710m a.s.l. In each altitudinal gradient six land use systems i.e, agriculture, horticulture, agri-horticulture, agri-hort-silviculture, silvipastural and barren land which were common to all the three altitudinal levels were selected as land use systems.

The data was recorded on above ground biomass of all land use systems at three altitudinal ranges. The total tree biomass was the sum of stem biomass, branch biomass and leaf biomass. The plot size for trees was 50 m x 20 m. The tree biomass was converted into carbon fraction by factor of 0.5 (IPCC default value). Crop, shrubs and grass biomass was estimated with the help of a 1 square metre plot size. Crop and fruit yield of trees was determined by either on a unit area basis or on the basis of qualitative interviews with the farmers of the respective land use system. Litter biomass was also measured in 1m x 1m plot size. Soil attributes viz; bulk density, organic carbon and available nitrogen were also analyzed. The tabulated values for soil attributes were used to prepare the

carbon pool inventory and soil organic carbon density. Soil samples were collected from 0-20cm, 20-40cm and 40-100cm respectively.

Data concerning economics of the land use systems was collected through interviews with the farmers in the existing research sites of the study area. Other data concerning weather and agriculture production situation in the study area was obtained from the Krishi-Vigyan Kendra (KVK) office in Kinnaur district, through the Programme Coordinator. The results of the experiments have revealed that different land use systems have significant influence on the production of above, below and total biomass, carbon stock, financial returns, expenses, net-profit and benefits-cost ratio. The salient findings of the experiments in this study are summarized as under:

The results of the experiment have revealed that different land use systems has significant influence on the production of above, below as well as on total biomass, carbon density. In the land use systems maximum mean above ground biomass (84.65 t ha^{-1}), below ground biomass (19.50 t ha^{-1}) and total biomass (104.10 t ha^{-1}) was recorded in the silvi-pasture (T_5) land use system. Total biomass production of different land use systems followed the order: silvipasture > agri-horti-silviculture > agrihorticulture > horticulture > agriculture > barren land, respectively. This trend is same for carbon density of different land use systems. In the effect of altitudinal ranges, the above ground biomass, below ground biomass, total biomass and carbon stock irrespective of land use systems increased with the increase in altitudinal level.

Soil physico-chemical analysis revealed that there is significant variation due to bulk density, organic carbon and available nitrogen in different soil layers of different land use systems.

Maximum soil organic carbon (1.41 %) was recorded in silvi-pasture land use systems, which, however remained statistically at par with the organic carbon contents as observed in the T_2 (horticulture), T_4 (agri-hort-silviculture) and T_6 (barren land) and differed significantly from all other land use systems. Mean minimum organic carbon content (1.33 %) was found in the agriculture land use

system, which however, remained statistically at par with the land use system of T₃ (agri-horticulture). Soil organic carbon, irrespective of land use systems increases with increase in altitudinal range and decreases with increase in depth of soil.

Maximum mean bulk density (1.06 g cm^{-3}) was recorded in barren land treatment, which was found to be significantly higher than horticulture and agri-horti-silviculture land use systems. Whereas, in the altitudinal ranges bulk density first decreased from A₁ to A₂ thereafter there was a slight increase at elevation range of A₃. In soil depth, L₂ (40-100 cm) layer displayed significantly higher bulk density than L₁ layer but was statistically at par with L₂.

Maximum mean available N ($542.50 \text{ kg ha}^{-1}$) was recorded in the horticulture, which, however, remained statistically identical to the N status of T₅, only. Nitrogen status in the different land use systems followed the trend: T₂ > T₅ > T₃ > T₄ > T₁ > T₆, respectively. In the altitudinal ranges, maximum available nitrogen was found at the altitudinal range of A₂ ($532.80 \text{ kg ha}^{-1}$), which differed significantly from all other treatment combinations. In the soil depth nitrogen status decrease with the increase in soil depth.

Maximum carbon density (155.77 t ha^{-1}) in (0-100cm) layer was in agri-horticulture land use system, which was found to be significantly higher than all other land use systems excepting horticulture, ones. Irrespective of the land use system, in altitudinal gradient maximum carbon density (129.82 t ha^{-1}) was recorded at A₁ (1900-2170m a.s.l) altitude range, which was found to be significantly higher than A₂ (2170-2440m a.s.l) only.

Maximum total ecosystem carbon density (166.36 t ha^{-1}) was recorded in the agri-horticulture land use system. The order of carbon density under different land use systems was agri-horticulture > agri-horti-silviculture > silvi-pasture > horticulture > agriculture > barren land. Irrespective of the land use system, the carbon density at different altitudinal gradient followed the trend A₁>A₃>A₂. In

general, barren land use system displayed quite low values of the total carbon density than other treatment combinations.

The maximum soil:plant carbon density ratio (23.10 t ha^{-1}) was recorded in agriculture land use system which was found to be significantly higher than all other land use systems under investigation. In the altitudinal ranges, irrespective of the land use system, A_3 displayed maximum soil:plant carbon density ratio which was found to be significantly higher than A_1 and A_2 and followed the trend $A_3 > A_1 > A_2$

Rate of gross return was maximum (Rs 18,23,000) in agri-horticulture system, which was closely followed by the land use systems of horticulture, agri-horti-silviculture, silvi-pasture system, agriculture and barren land system respectively in the descending order. Irrespective of land use systems rate of gross return increases with the increase in altitudinal levels.

Maximum expenses were recorded in the agri-horticulture, (Rs. 5,12,900) based land use system, which was closely followed by horticulture (Rs 3,91,400), agri-horti-silviculture, (Rs 3,55,700), agriculture (Rs 1,94,600) silvi-pasture systems (Rs 97,280) and barren land (Rs 2,278), respectively. In the altitudinal ranges, expenses showed a consistent increasing trend in respect of total expenses incurred with the increase in altitudinal levels.

Maximum net profit was attained in agri-horticulture system (Rs, 13,10,000), which was closely followed by horticulture (Rs 11,65,852), only. Net returns as achieved in other land use systems viz., agriculture, agri-horti-silviculture, silvi-pasture and barren land were quite low in comparison to fruit based land use systems. In altitudinal ranges, the net profit obtained increased appreciably from A_1 to A_3 . A_3 altitudinal range had the highest net profit.

Benefit-cost ratio was maximum (6.63) in the silvi-pasture based land use system, which was closely followed by the land use systems of barren land (4.73), horticulture (3.93), agri-horticulture (3.50) and agriculture (1.41), respectively, in the descending order. In the altitudinal ranges the benefit: cost

ratio showed a decreasing trend initially from A₁ to A₂ and then increased appreciably.

CONCLUSIONS:

- Maximum biomass density (104 t ha⁻¹) potential was displayed by silvi-pasture system, which was closely followed by agri-horti-silviculture system, only. Fruit based systems viz, horticulture and agri-horticulture displayed about 4 times more carbon storage potential than agriculture land use system
- In the altitudinal ranges maximum biomass density (51.05 t ha⁻¹) was at the elevation range of 2440-2710m, which was found to be significantly higher in both A₁ (1900-2170m) and A₂ (2170-2440m)
- Carbon storage density (0-100cm) (t ha⁻¹) of different land use system followed the trend; agri-horticulture (151.77 t ha⁻¹) > horticulture (140.52 t ha⁻¹) > agriculture (132.75 t ha⁻¹) > agri-horti-silviculture (125.37 t ha⁻¹) > silvi-pasture (109.76 t ha⁻¹) > barren land (84.19 t ha⁻¹). In the altitudinal ranges 2440-2710m a.s.l displayed significantly higher carbon storage potential (t ha⁻¹) than A₂ (2170-2440m) and A₁ (1900-2170m)
- Total ecosystem carbon density (soil + plant) of different land use systems followed the trend: agri-horticulture > agri-horti-silviculture > silvi-pasture > horticulture > agriculture > barren land, respectively. In the altitudinal ranges 1900 – 2170m a.s.l displayed higher carbon storage potential than A₃ and A₂.
- Maximum net profit (13,10,000 Rs ha⁻¹ yr⁻¹) was calculated to be in agri-horticulture system which was followed by horticulture, agri-horti-silviculture, silvi-pasture, agriculture and barren land, respectively in the descending order. In the altitudinal ranges the net-profit enhanced with increasing altitudinal ranges

In a nutshell we can say that agri-horticulture systems are best because not only do they provide very high returns but also increases the carbon storage potential as well as fertility status (% C and N) in comparison to the agriculture based land use system.

Chapter-7

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ABSTRACT

The present investigations entitled **“Carbon storage potential and bio-economic appraisal of different land use systems in dry temperate north western Himalayas”** were carried out through experiments at different altitudinal gradients in Kinnaur district of Himachal Pradesh. These experiments were laid out in Randomized Block Design (Factorial). The present investigations were conducted to assess the biological yield, carbon stock and economic returns from the different land use systems along an altitudinal gradient and to identify suitable land use systems with high monetary return and carbon storage potential in dry temperate north-western Himalayas. Three altitudinal gradients were considered for the study viz; 1900-2170m, 2170-2440m and 2440-2710m a.s.l. In each altitudinal gradient six land use systems i.e, agriculture, horticulture, agri-horticulture, agri-horti-silviculture, silvipasture and barren land which were common to all the three altitudinal levels were selected. The total tree biomass was the sum of stem biomass, branch biomass and leaf biomass. The plot size for trees was 50 m x 20 m. The tree biomass was converted into carbon fraction by factor of 0.5 (IPCC default value). Crop, shrubs, grass biomass and litter biomass were estimated with the help of a 1 square metre plot. Soil attributes viz; bulk density, organic carbon and available nitrogen were also analyzed. Data concerning economics of the land use systems was collected through interviews with the farmers, published literature and Krishvigyan Kendra resource person of the study area. The results have revealed that different land use systems have significant influence on the production of above, below and total biomass, carbon density ($t\ ha^{-1}$), financial returns, expenses, net-profit and benefits-cost ratio. Maximum above ground biomass ($84.65\ t\ ha^{-1}$), below ground biomass ($19.50\ t\ ha^{-1}$) and total biomass ($104.10\ t\ ha^{-1}$) was recorded in the silvi-pasture (T_5) land use system. Total biomass production of different land use systems followed the order: silvipasture > agri-horti-silviculture > agrihorticulture > horticulture > agriculture > barren land, respectively. This trend is same for carbon density ($t\ ha^{-1}$), of different land use systems. In the effect of altitudinal ranges, the above ground biomass, below ground biomass, total biomass and carbon stock, irrespective of land use systems increased with the increase in altitudinal level. Soil physico-chemical analysis revealed that there is significant variation due to bulk density, organic carbon and available nitrogen in different soil layers of different land use systems. The value of SOC and available N decreases with increase in depth, but it increases with increase in altitudinal level. Maximum soil carbon density ($155.77\ t\ ha^{-1}$) in (0-100cm) layer was in agri-horticulture land use system. Maximum total (soil+plant) ecosystem carbon density followed the trend agri-horticulture > agri-horti-silviculture > silvi-pasture > horticulture > agriculture > barren land, respectively in descending order. The maximum soil:plant carbon density ratio ($23.10\ t\ ha^{-1}$) was recorded in agriculture land use system which was found to be significantly higher than all other land use systems under investigation. Rate of gross return was maximum (Rs 18,23,000) in agri-horticulture system, which was closely followed by the land use systems of horticulture, agri-horti-silviculture, silvi-pasture system, agriculture and barren land, respectively in the descending order. Irrespective of land use systems rate of gross return increases with the increase in altitudinal levels. Maximum expenses followed the order: agri-horticulture > horticulture > agri-horti-silviculture > agriculture > silvi-pasture > barren land, respectively. Maximum net profit was attained by agri-horticulture system (Rs, 13,10,000), which was closely followed by horticulture (Rs 11,65,852), only. Net returns as achieved in other land use systems viz., agriculture, silvi-pasture and barren land were quite low in comparison to fruit based land use systems. In altitudinal ranges, the net profit obtained increased appreciably from A_1 to A_3 . A_3 altitudinal range had the highest net profit. Benefit-cost ratio was maximum (6.63) in the silvi-pasture based land use system, which was closely followed by the land use systems of barren land (4.73), horticulture (3.93), agri-horticulture (3.50) and agriculture (1.41), respectively, in the descending order. From this finding we can conclude that agri-horticulture systems are better land use option because not only do they provide very high returns but also increases the carbon storage potential as well as fertility status (% C and N) in comparison to other land use systems in general and agriculture in particular.

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APPENDIX-I

Metrological data for the month of April, 2011 to March 2012

Month	Rainfall (mm)	Temperature		Relative Humidity (%)	
		Maximum	Minimum	Maximum	Minimum
April 2011	44.90	20.69	6.87	82.14	21.71
May 2011	22.30	27.72	10.40	83.20	18.15
June 2011	29.30	27.68	14.21	86.82	30.39
July 2011	09.60	27.46	17.18	89.58	41.48
August 2011	01.90	26.57	16.87	92.39	42.00
September 2011	00.80	26.96	13.96	90.35	29.74
October 2011	00.07	23.86	8.34	76.81	15.94
November 2011	00.00	20.77	4.94	55.27	11.38
December 2011	02.20	15.21	0.40	47.85	10.55
January 2012	40.60	7.68	- 2.01	86.10	31.33
February 2012	73.20	9.23	- 0.36	85.21	35.85
March 2012	86.18	17.43	4.09	72.11	15.95
Total/Average	311.05	20.94	7.96	78.99	25.37

Source: Metrological observatory, Department of Agronomy, Agricultural Research and Extension Centre, Kinnaur district (H.P.)

APPENDIX-II

Proportion of biomass (%) in tree vegetation components (Jenkins *et al.*, 2003)

Dbh (cm)										
	10	20	30	40	50	60	70	80	90	
Hardwood										
Stem	54	68	74	77	79	79	80	81	82	83
Branches	43	29	24	21	19	18	17	16	16	15
Foliage	3	2	2	2	2	2	2	2	2	2
Softwood										
Stem	68	74	77	78	78	79	79	79	78	78
Branches	23	19	17	16	16	16	15	15	15	15
Foliage	8	6	6	6	6	6	5	5	5	5

APPENDIX- III

Volume equations for biomass estimation of some forest and fruit tree species

Forest Species name	Volume equation (Anonymous, 1996)
<i>Cedrus deodara</i>	$V = 0.167174 - 1.735312 \times D + 12.039017 \times D^2$ ($R^2 = 0.2664$)
<i>Populus ciliata</i>	$V = 0.193297 - 2.267002 D + 10.679492 D^2$
Fruit tree species	
<i>Malus domestica</i>	$Y = 1.052 \times X^{1.076}$ ($R^2 = 0.823$)
Y = Dry biomass of secondary branches	
X = Diameter in meter(cm)	

APPENDIX-IV

Specific gravity of different forest trees

S. No.	Species Name	Specific gravity
1	<i>Pinus gerardiana</i>	0.47
2	<i>Cedrus deodara</i>	0.46
3	<i>Quercus leucotrichophora</i>	0.75
4	<i>Populus ciliata</i>	0.40

APPENDIX-V

ANOVA table for biomass production potential in dry temperate Himalayan ecosystem of Kinnaur district (H.P.), INDIA

Source of variation	df	Mean sum of square			Total biomass carbon density (t ha ⁻¹)
		Above ground biomass (t ha ⁻¹)	Below ground biomass (t ha ⁻¹)	Total biomass (t ha ⁻¹)	
Land use system (T)	5	4.6937E+04	2419	7.0529E+04	1.8116E+04
Altitudinal range (A)	2	1709.9	38.88	2210.3	524.68
Replication (R)	2	130.61	5.5460	194.49	31.313
TxA	10	3.0833E+04	1527.8	4.6027E+04	1.1335E+04
TxAxR	34	5258.3	325.20	8164.3	2022.7

APPENDIX -VI

ANOVA table for different parameters of soil in dry temperate Himalayan ecosystem of Kinnaur district (H.P.), INDIA

Source of variation	df	Mean sum of square			
		Soil organic carbon (%)	Bulk density (g cm ⁻³)	Soil organic carbon density (t ha ⁻¹)	Available Nitrogen (kg ha ⁻¹)
Land use system (T)	5	5.9474E-02	1.3621E-01	197.84	1.1574E+05
Soil depth (D)	2	7.1481E-04	6.6794E-02	13503	1.1526E+05
Altitudinal range (A)	2	8.3248E-02	2.6856E-01	280.66	2.0391E+04
Replication (R)	2	2.8337E-02	3.9269E-03	0.31	1974.2
TxD	10	3.1678E-02	5.4997E-02	78.94	3.5188E+04
TxA	10	1.0877E-01	3.6932E-01	51.38	1.5776E+05
AxD	4	5.9259E-02	3.1290E-02	85.44	2.5288E+04
TxAxD	20	1.1330E-01	1.6103E-01	35.51	7.5096E+04
TxAxDxR	106	3.3846E-01	2.6982E-01	24.13	1.0199E+04

APPENDIX-VII

Local cost of agricultural inputs and outputs in dry temperate Himalayan ecosystem of Kinnaur district of (H. P.), INDIA

Sr. No.	Particulars	Rate (Rs)
Input		
1.	Labour cost	
	a) Labour charges per day in year 2011-2012	158
	b) Bullock hire (per day)	455
	c) Ploughing by tractor (per hour)	325
2.	Seed cost (per kg)	
	a) cabbage	32500
	b) Maize	22.50
	c) pea	78
	d) Wheat	39
	e) Barley	15
	f) Rajmash	120
3.	Manure and fertilizers (per quintal)	
	a) FYM	80
	b) Urea	910
	c) NPK 12:32:16	936
	d) Cain	1040
4.	Fungicides & Pesticides	
	a) Formalin (5 litre)	325
	b) Dithane M-45 (500 g)	208
	c) Bavestin (100 g)	71.50
	d) Blytox- 50 (500 g)	195
	e) Metasystox (1 litre)	552.50
	f) Nuvon (100 ml)	84.50
5.	Land rent for agriculture (Rs ha ⁻¹ yr ⁻¹)	48750
Output		
1.	Agriculture (per quintal)	
	a) Wheat grain	1300
	b) Wheat straw	1500
	c) Maize corn	1040
	d) Maize stover	260
	e) Pea (pods)	5850
	f) Cabbage	780
	g) Rajmash	10000
	h) Barley grain	10000
	i) Barley straw	1040
2.	Fruits (per quintal)	
	a) Apple	3250
3.	Pastures (per quintal)	
	a) Grass	390
	b) Leaf fodder	195
4.	I. Wood (per cubic ft)	1885
	<i>Cedrus deodara</i>	
	II. Fuel wood (per quintal)	585
	III. Neozapine seed (kg)	300

1. Cost of cultivation for annual crops:

APPENDIX-VIII

1.1 Ploughing and land preparation -

Crops	Cost for using bullocks (Rs/ 800m ²)	Cost for labour (Manday)	Cost Rs/ 800m ²	Cost Rs/ha
Wheat	217	2x52	962	4008
Maize	217	2x52	962	4008
Cabbage	433	4x52	1924	8016
Pea	433	4x52	1924	8016
Barley	217	2x52	962	4008
Rajmash	217	4x52	1923	8016

*Local wage rates prevailing in the area (2011-12 market prices)

APPENDIX-IX

1.2 Seeds for sowing

Cost item	Seed rate/ha	Price Rs/kg	Rs/ha
Wheat	100 kg	39	3900
Maize	60 Kg	36.4	2184
Cabbage	750 g	2860	1950
Pea	100 kg	78	61800
Barley	100kg	15	1500
Rajmash	100kg	120	12000

*Values calculated at 2011-2012 market prices

APPENDIX-X

1.3 Irrigation

Crop	No of irrigation	Labour (Man day)	Cost Rs/800m ²	Rs/ha
Wheat	0	0	0	0
Maize	0	0	0	0
Cabbage	6	3	936	11700
Pea	2	3	468	5850
Barley	0	0	0	0
Rajmash	0	0	0	0

* Local wage rates prevailing in the area (2011-12 market price)

APPENDIX-XI

1.4 Pesticides

Crop	Cost Rs/ 800m ²	Rs/ha
Wheat	-	-
Maize	-	-
Cabbage	1560	9100
Pea	1560	19500
Barley	780	9750
Rajmash	0	0

*Values calculated at 2011-12 market prices

APPENDIX-XII

1.5 Fertilizer supplied to annual crops

Fertilizer type	Unit	Price (Rs)	Per ha required	Total price (Rs/ha)
FYM	kg	0.65	750q	48750

*Values calculated at 2011-2012 market prices

APPENDIX XIII

Fertilizer supplied to annuals classified by crop, type of fertilizer, quantity and price

Crop	Fertilizer	Quantity/ha	Price Rs
Wheat	FYM	250 q	16250
Maize	FYM	250 q	16250
	FYM	250 q	16250
	CAN	400 Kg	5525
Cabbage	SSP	600 Kg	3120
	MOP	90 Kg	585
	12:32:16	150 Kg	16250
Pea	CAN	375 kg	4875
	SSP	500 kg	3250
	MoP	375 kg	2925
	FYM	250 q	16250
Barley	NPK-complex	625kg	4387
	FYM	250q	16250
Rajmash	CAN	375kg	4875

*Values calculated at 2011-12 market prices

APPENDIX-XIV

Fertilizer supplied to apple trees

Fertilizer type	Per tree	For 278 trees/ha	Total price Rupees
FYM	30 kg	8340 kg	5421
CAN	3 kg	834 kg	10842
SSP	2 kg	556 kg	3614
MoP	2 kg	556 kg	4336.8
Tracel	0.5 kg/biga	6.25 kg	345.80

*Values calculated at 2011-12 market prices

APPENDIX-XV

1.6 Weeding/Agronomic practices

Crop	Number of weeding	Man days	Cost Rs/800m ²	Rs/ha
Wheat	1	0	468	0
Maize	1	3	78	975
Cabbage	3	6	936	11700
Pea	2	1	156	11700
Barley	1	0	468	0
Rajmash	1	0	468	0

* Local wage rates prevailing in the area (2011-12 market prices)

APPENDIX-XVI

1.7 Harvesting

Crop	Man days	Cost Rs/800m ²	Rs/ha
Wheat	2	312	3900
Maize	2	312	3900
Cabbage	2	312	3900
Pea	5	780	9750
Barley	2	312	3900
Rajmash	2	312	3900

* Local wage rates prevailing in the area (2011-12 market prices)

APPENDIX-XVII

1.8 Grading and packing

Crop	Man days	Cost Rs/800m ²	Rs/ha
Wheat	1	156	1950
Maize	1	156	1950
Cabbage	3	468	5850
Pea	3	468	5850
Barley	1	156	1950
Rajmash	1	156	1950

* Local wage rates prevailing in the area (2011-12 market prices)

APPENDIX-XVIII

1.9 Transportation to nearest market

Crop	Three-wheeler carrying capacity	Cost (Rs) for three-wheeler	Average produce q/ha	Transport cost (Rs/ha) produce
Wheat	3 q	130	12	250
Maize	5 q	130	14	500
Cabbage	5 q	325	29	750
Pea	7.5 q	325	25	1000
Barley	3q	130	8.7	200
Rajmash	3q	130	3.12	250

*Values calculated at 2011-12 market prices

APPENDIX-XIX

Cost of cultivation of Apple orchard

Orchard	Apple (185 trees)	Apple (212 trees)	Apple (400 trees)
Cost items	Expenses in Rs/ha		
Basin Preparation	5728	6564	12384
Fertilization and Its Application	36060	41322	79967
Plant protection measures	20050	22976	45351
Irrigation	2060	2361	4454
Pruning	6181	7083	13364
Picking, Grading, Packing	61600	75590	135189
Miscellaneous	5000	5729	10810
Transportation charges	70818	80153	173303
Sub Total	207497	241778	474822
Land Rent	38600	38600	48750
Management (5%)	10375	12089	23741
Interest (5%)	10375	12089	23741
Risk	5753	7844	18346
Total	272600	312400	589400

APPENDIX-XX

Economics of different land use systems at 1900-2170m a.s.l. in dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Treatment/Crop name	Av. Yield (t/ha)	Gross returns (Rs ha ⁻¹ yr ⁻¹)	Selling price (Rs/kg)	Total expenses (Rs ha ⁻¹ yr ⁻¹)	Benefit-cost ratio	Net profit (Rs ha ⁻¹ yr ⁻¹)
T₁ Agriculture						
Wheat	0.91 (2.12)	39390	13	41708	0.94	-2318
Maize	1.31 (0.87)	17440	8	19516	0.89	-2076
Pea	2.48	99530	40	43027	2.32	56503
Rajmash	0.6256	62560	100	44056	1.42	18504
Barley	0.72 (1.09)	27180	15	46133	0.59	-18953
Total		246100		194400	1.27	51660
T₂ Horticulture						
Apple	2.2	999000	50	272600	3.67	726400
Total	2.2	999000	50	272600	3.67	726400
T₃ Agri-horticulture						
Wheat	1.09 (1.64)	35451	13	37537	0.94	-2086
Maize	1.962	15696	8	17546	0.89	-1868
Pea	2.23	89577	40	38724	2.32	51114
Barley	0.66 (0.97)	24462	15	41519	0.59	-17057
Rajmash	0.5630	56304	100	39650	1.42	16654
Apple	1.98	998510	50	218906	4.12	779604
Total		1220000		393900	3.10	826361
T₄ Agri-horti-silviculture						
Maize	1.18 (0.78)	15696	8	17564	0.89	-1868
Pea	2.23	89577	40	38724	2.31	50853
Apple	1.1	384199	50	89612	4.29	294587
<i>Robinia</i>	-	3228	-	-	-	3228
<i>Ailanthus altissima</i>	-	4000	-	-	-	4000
<i>Salix tetra perma</i>	-	5000	-	-	-	5000
Total	-	501700	-	145900	3.40	355800
T₅ Silvi-pasture						
Trees/m ³	-	630230	-	-	-	-
Grasses	4.2	16770	-	-	-	-
Total		647000	-	97200	6.66	549800
T₆ Barren land						
Total	-	7500	-	1833	4.09	5667

APPENDIX-XXI

Economics of different land use systems at 2170-2440m a.s.l. in dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Treatment/Crop name	Av. Yield (t/ha)	Gross returns (Rs ha ⁻¹ yr ⁻¹)	Selling price (Rs/kg)	Total expenses (Rs ha ⁻¹ yr ⁻¹)	Benefit-cost ratio	Net profit (Rs ha ⁻¹ yr ⁻¹)
T₁ Agriculture						
Wheat	0.91 (2.12)	39390	13	41708	0.94	-2318
Pea	0.436	17440	8	43027	0.41	-25587
Rajmash	0.6256	62560	100	17211	3.63	45349
Barley	0.72 (1.09)	27180	15	46133	0.59	-18953
Cabbage	9.276	185530	20	61221	3.03	124309
Total		332100		209300	1.58	122800
T₂ Horticulture						
Apple	2.54	1270000	50	312400	4.06	957600
Total	2.54	1270000	50	312400	4.06	957600
T₃ Agri-horticulture						
Wheat	0.82 (1.91)	34451	13	37537	0.94	-2086
Pea	1.41	56304	8	38724	1.45	17580
Barley	0.65 (0.98)	24462	15	15489	1.58	8973
Rajmash	0.5630	56304	100	41519	1.36	14785
Cabbage	8.3484	166977	20	55098	3.03	111879
Apple	2.28	292102	50	156731	1.86	135371
Total		631600		345500	1.82	286502
T₄ Agri-horti-silviculture						
Wheat	0.27 (0.639)	11817	13	12512	0.94	-695
Pea	0.131	5232	8	12908	0.41	-7676
Barley	0.326 (0.218)	8154	15	13839	0.59	-5685
Cabbage	2.7828	55659	20	18366	3.03	37293
Rajmash	0.1876	18768	100	5163	3.64	13605
Apple	1.01	504970	50	282712	1.79	222258
<i>Robinia</i>	-	3000	-	-	-	3000
<i>Populus ciliata</i>	-	4000	-	-	-	4000
<i>Cedrus deodara</i>		20000	-	-	-	20000
Total		631600		345500	1.82	286000
T₅ Silvi-pasture						
Trees/m ³	-	458222	-	-	-	-
Grasses	3.2	12778	-	-	-	-
Total		471000		95530	4.93	375470
T₆ Barren land						
Total	-	10000	-	2500	4.00	7500

APPENDIX-XXII

Economics of different land use systems at 2440-2710m a.s.l. in dry temperate Himalayan ecosystem of Kinnaur district (H.P), INDIA

Treatment/Crop name	Av. Yield (t/ha)	Gross returns (Rs ha ⁻¹ yr ⁻¹)	Selling price (Rs/kg)	Total expenses (Rs ha ⁻¹ yr ⁻¹)	Benefit-cost ratio	Net profit (Rs ha ⁻¹ yr ⁻¹)
T₁ Agriculture						
Wheat	11.23 (4.00)	138280	13	83416	1.66	54864
Rajmash	0.9384	93840	100	50451	1.86	43389
Barley	0.72 (1.09)	27180	15	46133	0.59	-18953
Total		259300		180000		79300
T₂ Horticulture						
Apple	4.8	2400000	50	589400	4.07	1810600
Total	4.8	2400000	50	589400	4.07	1810600
T₃ Agri-horticulture						
Wheat	1.40 (3.28)	124452	13	75074	1.66	49378
Barley	0.66 (0.97)	24462	15	41519	0.59	-17057
Rajmash	0.8445	84456	100	45405	1.86	39051
Apple	4.30	2399630	50	535802	4.48	1863828
Total		2633000		697800	3.77	1935200
T₄ Agri-horti-silviculture						
Wheat	1.28 (1.91)	41484	13	25024	1.66	16460
Barley	0.326 (0.218)	8154	15	13839	0.59	-5685
Rajmash	0.2815	28152	100	15135	1.86	13017
Apple	2.40	1188210	50	521702	2.28	666508
<i>Cedrus deodara</i>	-	10000	-	-	-	10000
<i>Pinus gerardiana</i>	-	120000	-	-	-	120000
Total		1396000		575700	2.42	820300
T₅ Silvi-pasture						
Trees/m ³	-	513417	-	-	-	-
Grasses	2.5	9983	-	-	-	-
Total		523400	-	99100	5.28	424300
T₆ Barren land						
Total	-	13000	-	2500	5.20	10500

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