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

Thesis

by

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DOCTOR OF PHILOSOPHY

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

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ABBREVIATIONS USED

AF	Agroforestry
AFS	Agroforestry systems
AFTA	Association for Temperate Agroforestry
AH	Agri-horticulture
AHS	Agri-horti-silviculture
approx	Approximately
AS	Agri-silviculture
BD	Bulk density
C ha^{-1}	Carbon per hectare
C $ha^{-1}yr^{-1}$	Carbon per hectare per year
^oC	Degree Celsius
CSP	Carbon sequestration potential
CD	Critical difference
CH_4	Methane
cm	Centimeter
CO_2	Carbon dioxide
DOE	Department of Energy
FCCC	Framework Convention on Climate Change
g	gram
gcm^{-3}	Gram per centimeter cube
GHG	Green House gas
GHGs	Green house gasses
Gt	Giga tonne
g Kg^{-1}	Gram per kilogram
ha	Hectare (10,000 m^2)
HP	Horti-pastoral
IPCC	Intergovernmental Panel on Climate Change
Kg ha^{-1} Yr^{-1}	Kilogram per hectare per year
Kg ha^{-1} day^{-1}	Kilogram per hectare per day
Kg m^{-2}	Kilogram per square meter
Kg CO_2 ha^{-1} day^{-1}	Kilogram carbon dioxide per hectare per day
Kg cm^{-2}	Kilogram per square centimeter
Km	Kilometer
m	Meter
m.a.m.s.l	meter above mean sea level
MAP	Mean Annual precipitation
MAT	Mean Annual Temperature
M ha	Million hectare
Mg ha^{-1}	Mega gram per hectare
Mg c ha^{-1}	Mega gram carbon per hectare
Mg c ha^{-1} yr^{-1}	Mega gram carbon per hectare per year
Mg km^{-1} yr^{-1}	Mega gram per kilometer per year

$MMTCY^{-1}$	Million metric tonne carbon per year
N	Nitrogen
Na_2O	Nitrous oxide
NE	North East
NRCS	National Resource Conservation Services
OC	Organic carbon
P	Phosphorus
PA	Pure agriculture
Pg	Petagram
PG	Pure grassland
PP	Pure plantation
Pg C	Peta gram carbon
Pg c yr^{-1}	Peta gram carbon per year
Rs. ha^{-1} yr^{-1}	Rupees per hectare per year
SOC	Soil Organic carbon
SOM	Soil organic matter
SP	Silvi-pastoral
t c ha^{-1}	Tonne Carbon per hectare
t c $ha^{-1}yr^{-1}$	Tonne Carbon per hectare per year
Tg	Tera gram
Tg C yr^{-1}	Teragram Carbon per year
UNCED	United Nations Conference on Environment and Development
USA	United States of America
USDA	United State Department of Agriculture,
US$	United State's dollar
WANA	West Asia and North Africa
$	Dollar
%	Per cent

Chapter-1

INTRODUCTION

Agroforestry is a collective name for land use systems and technologies where woody perennials (Tree, shrubs, palms, bamboos etc) are deliberatively used on the same land management units as agricultural crops and/ or animals, in some form of spacial arrangement or temporal sequence. In agroforestry systems there are both ecological and economical interactions between the different components (Lundgren and Raintree, 1982). There are almost unlimited numbers of agroforestry systems in use all over the world. Common to all these systems, practices and technologies is the deliberate use of trees and shrubs in order to achieve higher productivity, sustainability and diversity of output from land use systems.

In agroforestry system, there are both ecological and economical interactions between the different components. Ecological interactions between trees crops are beneficial for three major reasons. First, leguminous trees have a beneficial effect on soil fertility through nitrogen fixation, greater organic matter production and recycling of nutrients (Young, 1986). Second, a combination of annual crops and trees raises biomass production because differences in rooting depth enable uptake of more water and nutrients (Huxley, 1983). Third, the presence of trees act as a protective barrier against soil erosion or as wind breaks (Wiersum, 1984).

The challenge in the design of agroforestry systems lies in managing interactions between components into the most advantageous forms i.e. maximize positive interactions and minimize negative ones. For scientists to accomplish this, first of all the existing land management systems should be diagnosed to determine these problems, potentials and constraints. Secondly, information is required on trees/crop interactions in a biological as well as an economic sense (ICRAF, 1983).

Manipulation of biological and economic interactions between components can be achieved through the proper choice of components and management practices. The choice of management practices can take various forms including spatial arrangement, plant densities, cultivation practices, timing of activities, etc, (Cannell, 1983). Especially when availability of labour and capital resources fluctuates significantly between time periods and hence these resources command a different price in an economic sense, it is worthwhile to examine the biological consequences of scheduling operations of the time of highest availability so as to reduce overall resource cost.

Bio-economic appraisal of agroforestry systems assesses the economic significance of interesting plant combinations, interactions, and cultural manipulations. In order to evaluate competitive, complementary, and supplementary relationship among potential agroforestry land use systems, particularly as they effect assessment of optimum productivity under realistic field conditions (Raintree, 1983).

Global climate change, considered to be one of the most serious threats to the environment, has been at the centre of scientific and political debate in recent years. Climate change, more precisely global warming, is a reality (IPCC, 2001 & GISS, 2004) but there are considerable uncertainties existing about the event of warming (Malhman, 1997). Atmospheric concentration of green house gases (GHGs) is very important for survival on this planet. Their presence in atmosphere at the right levels ensures that the planet is maintained at a temperature of $+14^0$ C, warm enough for life to exist. The problem of GHG-forced climate change occurs when GHG concentration in the atmosphere increased to high level that the warming they cause is too severe to interfere with the planets sensitive climate system (IPCC, 2001). The dominant gas of concern in this category is CO_2. The other important GHGs include CH_4, N_2O, CO, NO_x (oxides of nitrogen) (IPCC, 1996).

The atmospheric CO_2 concentration is around 390 ppm, which was around 280 ppm prior to industrial revolution (IPCC, 2007). Out of approximate

100 ppm rise in CO_2 concentration in the atmosphere almost 60 ppm rise has occurred in the second half of the 20th century alone (Jacob, 2005). During the decade i.e. 1995-2005 average annual carbon dioxide growth rate was 1.9 ppm/year, then it has been since the beginning of continuous direct atmospheric measurement (1960-2005 average: 1.4 ppm/year) (IPCC, 2007). According to future emission scenario (Shukla *et al.,* 2003) CO_2 emission shall continue to dominate national GHG emission with its share reaching 74 per cent in 2030. The doubling of atmospheric concentration of CO_2 could raise the mean temperature of the earth's surface by 1.5 to 4.5^0C (Malhman, 1997).

The accumulation of greenhouse gases in the upper atmosphere is a global concern, and finding low cost methods to sequester carbon is emerging as a major international policy goal. At current greens house gas emission rates average global surface temperature is expected to rise by approximately 0.3-2.5^0C in the next fifty years and 1.4-5.8^0C in the next century (Houghton 1996; Houghton *et al*., 1992; Watson *et al*., 2000). Although the economic and ecological consequences of global warming continue to be debated (Reddy and Price 1999), many scientists believe that costs will likely out weight benefits (Bruce *et al*., 1996). To date, most interest has focused on carbon dioxide, which is the most important greenhouse gas. (Heath L S. 1996, and Manne and Richels, 1991).

The United Nations Framework Convention on Climate Change (the Kyoto Protocol) provides a mechanism by which a country that emits carbon in excess of agreed-upon limits can purchase carbon offsets from a country or region that manage carbon sinks. Some observers suggest that through this clean development mechanism (CDM), a ratified Kyoto Protocol could reduce rural poverty by extending payments to low income farmers who provide carbon storage (Smith and Scherr 2002). Carbon sequestration involves the removal and storage of carbon from the atmosphere in carbon sinks (such as oceans, vegetation and soils) through physical or biological process. The incorporation of trees or shrubs in agroforestry systems can increase the amount of carbon sequestered compared to a monoculture field of crop plants or pasture (Sharrow and Ismail 2004; Kirby and Potvin 2007). In addition to the significant amount of

carbon stored in above ground biomass, agroforestry systems can also store below ground biomass. Carbon sequestration in agroforestry systems could be sold in carbon credit markets where such opportunities exist. The largest amount and most permanent form of carbon may be sequestered by increasing the rotation age of trees and/or shrubs and by manufacturing durable products from them upon harvesting.

An average temperature rise of 3^0C would translate into severe weather changes viz., change in pattern of precipitation and the frequency and intensity of extreme climate events. This may cause setbacks to economic and social progress of developing countries. The economical, ecological and social consequences of climatic variability will vary by region, but in mountain ecosystem, it will likely to threaten production of vegetable and fruit crops, species extinction, and flow of water in river system.

Agricultural activities greatly contribute to global net flux of CH_4, N_2O and CO_2 from the terrestrial biosphere into the atmosphere. The increased flux from the change and intensification of land use in order to feed needs of the rapidly growing human population. Increased biomass burning and soil cultivation, increased number of livestock, increased acreage of paddy fields and increased use of nitrogen fertilizer have been considered as most important factor for the increased flux. Following the agreement of Kyoto-protocol in 1997 policy makers or the Ministers of Agriculture of many countries have involved in discussion about policy measures to decrease greenhouse gases emission from agriculture. Various possible measures have been identified to decrease emission of CO_2, CH_4, and N_2O from agricultural sources. However, few of these measures have been tested at field scale. Vegetation in terrestrial ecosystem has been recognized as an effective and low cost method of offsetting carbon emission. Carbon sequestration problem varies with the kind of land use. Forest has been recognized as most effective land use system because of their abilities to lock carbon for long term in addition to other environmental benefits they bestow upon us. But, since India being most populous and developing country, it cannot spare huge chunk of land for this purpose because it has to feed teeming

Panoramic view of valley ecosystem

Panoramic view of mountain ecosystem

Integration of fruit trees in large scale in valley ecosystem

Integration of fruit trees in large scale in mountain ecosystem

Extension of apple belt into the high altitude range in the valley ecosystem

Extension of apple belt very near to tree line in mountain ecosystem

Plate 1. Integration of apple in the valley and mountain ecosystems in temperate north-western Himalayas

population, first. Therefore, the need is to assess the potential of different land management options, which can fulfils both environmental and economic goals. Carbon sequestration depends upon the biological productivity which in turn depends upon interaction between species, climate, topography and management practices. Thus, the CO_2 sequestration potential varies from place to place, which need to be worked out on region to region basis.

In India, agroforestry is being promoted as an alternate land use system to deal with the problems related to land use sustainability and environmental amelioration yet its real potential needs scientific evidences. Numerous agroforestry systems both natural as well as planted have been developed in different agro-climatic regions of the country, which have been found highly productive and environmentally suitable. Kullu district of Himachal Pradesh, which falls in the transition zone between lesser to greater Himalayas, has got two conspicuous types of land features i.e. valley areas and mountainous region. This district is well known for its rich biodiversity, magnificent forest, apple orchards, off-season vegetables and traditional field crops (Plate 1). Over the years (particularly 1960s onward), the farmers have developed their own agroforestry systems integrating fruits, vegetables and field crops. These newly developed agroforestry systems needs to be tested for their biological productivity, environmental suitability and economic sustainability. Hitherto, no attempts have been made till date to test these newly developed land management systems on these grounds. Therefore, the present study was conducted with the below mentioned objectives:

Objectives:

i) To find out the biological yield and economic returns from the different land use systems;

ii) To study carbon stock under different land use systems along with altitudinal gradient;

iii) To identify the suitable land use systems having high monetary return and carbon sequestrations potential in both valley and mountainous regions of north-western temperate 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. Agriculture 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 for 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.

Carbon sequestration which is the provision of long term storage of carbon in the terrestrial biosphere, belowground or the ocean so that the build up of CO_2 concentration in the atmosphere will reduce or slow down in order to improve environmental conditions and check the process of environmental degradation especially through agriculture, horticulture and forestry land management operations both on arable as well as non-arable lands, using agro-forestry as a sustainable land use system to address these concerns. This land management system termed as agroforestry has been found to be more productive and sustainable than other existing land use systems, particularly for medium and small land holders. It also holds good promise to enhance plant- soil-carbon pools by sequestering carbon from the atmospheric CO_2. However, to elucidate the potential of agroforestry practices or other land use systems for enhanced biomass productivity and carbon sequestration for long term either in biomass or soil needs scientific evidences. The scientific work on the subjects is of very recent origin. The pertinent literature from the sources available has been reviewed under the following heads:

2.1 Biological yield under different land use systems

2.2 Carbon sequestration and its mitigations through plant biomass

2.3 Carbon sequestration thorough soils

2.4 Economic returns from different land use systems

2.1 Biological yield under different land use systems

Biomass is the 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 $ha^{-1}yr^{-1}$ 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 $ha^{-1}yr^{-1}$ of branch biomass and 0.26 t $ha^{-1}yr^{-1}$ 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, Mazumdar (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 $ha^{-1}yr^{-1}$. 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 *Lasiuras 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.*

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 Morogora, 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*, *eucalyptu*s, *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.

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.

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.

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-horiticulture 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 recommend 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.

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 statures 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.

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 sequestration and its mitigation through plant biomass

Carbon sequestration is naturally occurring taking up of atmospheric carbon dioxide by forests, agro-ecosystems, oceans and grasslands during photosynthesis. Most terrestrial carbon storage is in tree trunks, branches, foliage and roots which is often biomass. Carbon is also deposited directly into soil.

Carbon sequestration is simply the intake and storage of the element carbon. The most common example in nature is during the photosynthesis process of trees and plants, which store carbon as they absorb carbon dioxide (CO_2) during growth. Because they soak up the carbon that would otherwise give up and trap heat in the atmosphere, trees and plants are important layers in efforts to stave off global warming.

Many natural and artificial processes can act as atmospheric sponges that absorb carbon dioxide. Ocean, forests, most plants and algae collect carbon through the photosynthesis process. This capturing of atmospheric carbon by a healthy ecosystem is called a “Carbon Sink”. While all living plant matter absorbs CO_2 as part of photosynthesis, trees process significantly more than smaller plants due to their large size and extensive root structures. In essence, trees, as kings of the plants world, have much more “woody biomass” to store CO_2 than smaller plants, and as a result are considered nature’s most efficient “Carbon Sinks”.

Carbon sequestration through biomass seems to be a cheap and viable option. There are several land use options which can sequester carbon. Their

potential of locking carbon differs not only with the type of species, but also with the agro-climatic zones. In the tarai zone of West Bengal, fallow land and agricultural field sequestered 5.86% and 4.73 % carbon respectively, compared to the natural forest of *Shorea roubsta*. However, agroforestry systems viz. tea garden and agri-horticulture contributed 24.24% and 9.09% carbon, respectively. The agri-horticulture system while sequestering carbon also provides agricultural crops and other economic gain, including carbon credits and hence seems to be the best option. The potential of carbon storage of tree + crop based system can be further increased using improved planting materials of perennial components (Koul and Panwar, 2008).

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 + *Albezia* association and 29.7 Mg ha^{-1} and 18.7 Mg ha^{-1} in the open grown system, respectively. *Albezia* 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

CO_2 sequestration in zones 1(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.

Ramchandran *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.

Gera *et al.* (2006) studied carbon sequestration potential and cost effectiveness of tree growing operations on farm lands of Rupnagar District of Punjab (India). Project based comprehensive mitigation analysis process was used to estimate the sequestration potential between 2005- 2030 under three models: popular block planting, popular bund planting and Eucalyptus bund planting. The popular block plantation gave maximum sequestration potential of 115 t/ha which was higher by 79.69 per cent and 105.34 per cent with respect to popular bund plantation and Eucalyptus bund plantation, respectively.

The study on role of farm forestry and agroforestry in carbon sequestration in India was carried out on a part of Bajpur block, Uttarakhand (India). Five plantation models were selected to be studied: Popular block planting (5x4 m spacing), Eucalyptus bund planting (2 m spacing), Teak block planting (2x2 m followed by 2 thinning and final harvest), Mango orchard plantation (10x10 m spacing) and Litchi orchard plantation (10x10 m specing). The maximum sequestration potential of 93.14 t C ha^{-1} for project period of 2005 – 2030 is forecasted for popular block plantation followed by 79.00 t C ha^{-1}, 51.17 t C ha^{-1}, 38.06 t C ha^{-1} and 38.06 t C ha^{-1} for teak, Eucalyptus, mango and litchi plantations, respectively when products are also accounted (Gera, 2006).

Agroforestry has been recognized to be special importance as a carbon sequestration strategy because of its applicapability in agriculture lands as well as

in reforestation programs (Carins and Meganck 1994; Rurak *et al*., 2003). The tree component in agroforestry systems can be significant sink of atmospheric carbon due to their fast growth and high productivity. By including trees in agricultural production systems, agroforestry can arguably, increase the amount of carbon stored in lands devoted to agriculture, while still allowing for the growing of food crops (Kursten, 2000). In most agroforestry systems, the tree component is managed, often intensively for its products such as pruning of hedge row in tropical alley cropping and harvest of commercial mostly non-timber products. Such harvested products often are returned to the soil (as in alley cropping and improved fallow system for soil fertility improvement). In addition, the amount of biomass and therefore, carbon that is harvested and exported (labile carbon) from the system is relatively low in relation to the total productivity of the trees. Therefore, unlike in plantation and other monoculture systems, agroforestry seems to have a distinct advantage in terms of carbon sequestration (Verma, 2005).

Swamy and Puri (2005) studied the biomass production and carbon sequestration of *Gmelina arborea* in sole plantation and agri-silviculture system on abandoned agriculture land. Over the 5 years trees had 3.5 Mg ha^{-1} more carbon in plantation than agri-silviculture system. So carbon increased by 51.2 and 15.5% in plantation and agri-silviculture system, respectively. Total carbon storage in abandoned agriculture lands before planting was 26.3 Mg ha^{-1}, which increased to 33.7 and 45.8 Mg ha^{-1} after 5 year of plantation and agri-silviculture system, respectively. Net C storage (soil + tree) was 7.4 Mg ha^{-1} in AS system compared to 19.5 Mg ha^{-1} in *Gmelina arborea* plantation. The study suggested that plantations were more efficient in accreting carbon than agri-silviculture system on abandoned agriculture lands.

Studies from Costa Rica have shown that a ten year old alley cropping with *E. poeppigiana* sequestered carbon at the rate of 0.4 Mg $ha^{-1}yr^{-1}$ in coarse roots and 0.3 Mg C $ha^{-1}yr^{-1}$ in tree trunks. Tree branches and leaves are added to the soil as mulch contributing 1.4 mg C $ha^{-1}yr^{-1}$ in addition to 3.0 mg C $ha^{-1}yr^{-1}$ from crop residues (Oelbermann *et al*., 2004).

The clonal plantations promoted by pulp and paper industry have high rate of survival and productivity (average 25 tonne ha^{-1} $annum^{-1}$) with fairly uniform growth. Under farm forestry, the industry in India is promoting plantation activity at an average rate of 40,000 ha per annum. The carbon sequestration potential of these plantation work out to 20 million tonne, resulting in carbon dioxide mitigation of 7.2 million tonne, with an approximate carbon credit value of US $ 6.0 million (30 crore). These plantations apart from serving as effective carbon sinks, also provide several other environmental benefits such as conservation of natural forests and biodiversity, prevention of soil and water erosion, increasing green cover and improving the socio-economic condition of the rural poor (Kulkarni, 2003). Singh *et al*., (2000) found that farm forestry plantation have sequestered nearly 20 million tonne of carbon. Therefore, farm forestry is the major instrument for increasing carbon sequestration while supplying wood and non wood products to meet both domestic and market requirement.

The amount of carbon sequestered largely depends on the agroforestry system put in place. The structure and function of which to a great extent are determined by environmental and socio-economic factors. Other factors influence carbon storage in agroforestry system includes tree species and system management. The association of trees with grasses in the silvi-pastoral system revealed that an increased input of plant residues into the soil played a significant role to improve nutrient cycling and biological productivity in the tree based system. Increased biological production will lead to greater carbon storage in the vegetation and soil along with an enhanced nitrogen uptake by plants. A study conducted by Kaur *et al.,* (2002) in natural vegetation and silvi-pastoral system on sodic soil at Bichian, Saraswati Reserved Forest, Kurukshetra in NW India revealed that the total carbon storage in silvipastaral system comprised of six year old tree species of *A. nilotica*, *D. sissoo* and *P. juliflora* with two grass species *Desmostachya bipinnata* and *Sporobolus marginatus* was 1.18 to 18.55 Mg C ha^{-1}. Compared to grass only system soil organic matter, biomass productivity and carbon storage were greater in silvi-pastoral system.

Biomass serves as a carbon sink, absorbing carbon from the atmosphere and storing it in the form of living plants matter and decomposed plant matter in the soils. Vast amount to carbon are continually being exchanged between this biospheric sink and the atmosphere. Approximately 120 billion tonnes of carbon (Gt C) is absorbed annually through photosynthesis and comparable amount is released through respiration and decomposition (Kartha, 2001).

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 CO_2. 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 $ha^{-1}yr^{-1}$. The result showed that *Gmelina arborea* and *cacao* multi-storey agroforestry system could be possible sink of CO_2 and has a good potentially of mitigating climate change.

A comprehensive study on the production and carbon sequestration potential of *Leucaena leucocephala* during the fallow phase of the Naalad system was carried out by Lasco and Suson (1999) using a 6 year old model fallow. Above ground biomass of *Leucaena leucocephela* increased from 4 Mg C $ha^{-1}yr^{-1}$ in the first year to 64 Mg C ha^{-1} yr^{-1} in the sixth year (end of the fallow). Carbon in the understory soils and woody debris was estimated at 25 per cent of the

above ground carbon. Overall, average carbon storage calculated was 16 Mg C $ha^{-1}yr^{-1}$ over six years period.

Malhi *et al*. (1999) studied the climatic influence on the carbon dynamics of boreal, temperate and tropical forests by presenting a new synthesis of micro metrological, eco physiological and forestry data. They concluded that there have been significant advances in determining the carbon balance of forest, but there are still critical uncertainties remaining particularly in the behaviour of soil carbon stock. Houghton *et al*. (1987) reported that deforestation in the tropics is responsible for an annual net release of carbon to the atmosphere, estimated for 1980 at 0.5-4.2 x 10^{15}g. Comparative carbon release from fossil fuel combustion in 1980 was 5.2 x 10^{15} g. The wide range of estimates for the tropical biota and soils has been primarily caused by different estimates of the rate of deforestation.

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 10^6 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).

Baggio and Heuveldop (1984) studied the potential of *Calliandra calothyrsus* as a live fences species in Costa Rica. At 10 months the total biomass produced was 3-4 Mg dry matter KM^{-1} offence (2 mg carbon sequestration/km). Biomass production in boundary planting can be highly variable dependent on environmental and soil characteristics. Live fence of *Gliricidia sepium* monitored on a four year cycle produced a total biomass of 7 Mg/km/yr (35 mg C/ha/yr)

when pruned every 4 months and 9.5 Mg/km/yr (50 Mg C/ha/yr) when pruned every 6 months (Romero *et al.*, 1991). In a carbon sequestration trial in Mexico, live fences trees were reported to store 24-36 Mg c/ha during a cycle of 25-30 year (De Jong *et al*., 1995).

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 CO_2, CH_4 and N_2O 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-pastural system and rice paddy agri-silviculture systems are well documented sources of CH_4 (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 alliadara*) 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 $ha^{-1}yr^{-1}$ could be stored if rice fields were transformed in home garden.

2.3 Carbon sequestration thorough soils

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).

Tiessen *et al*. (1992) studied the carbon sequestration and turn over in semi arid savannas and dry forests. Study was conducted at North –East Brazil and West Africa. In NE Brazil approximately 40 per cent of the land have near climax native vegetation < 10 per cent of the area was affected by shifting cultivation which had an average cycle of 5 years arable use, followed by 20 years or more recovery. Standing biomass of native cuttings showed nearly the full global range with 2-50 Mg C ha^{-1}. Litter fall around 1-2 Mg C ha^{-1} yr^{-1} was partially decomposed and partially consumed by animals resting in low average soil C levels near 8o g kg^{-1} or 20 Mg C ha^{-1} under cultivation. Carbon sequestration was decreased and soils loose approximately half their carbon stock, before being abandoned. In West Africa between 50-70 per cent of the land was under a management regime with minimal carbon returns to the soils. Overgrazing and over exploitation for fuel wood has resulted in land degradation. Short fallow periods on cultivated land have caused serious decline in soil carbon stocks. Both carbon sequestration and stock area, therefore, are lower in West Africa than in NE Brazil. Concern about rising carbon dioxide trends has prompted considerable interest in these years regarding the sink potential of soil organic carbon. The worlds soils are estimated to contain 1500 Gt of SOC in top 1 m soil, roughly double the amount of carbon in atmosphere (Schlesinger, 2000) and while that is very low in comparison to the 38000 Gt of C contained in worlds ocean, it attract attention because it is potentially responsive to modification. Indeed, though fossil fuel combustion has been the major cause of increasing CO_2 in atmosphere, land modification has been a significant contributor (Kucharik *et al*., 2001).

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 recommenced to enhance soil organic carbon storage and to contribute to sustainable food production, which also improves soil quality (Komatsuzaki and Ohta, 2007).

Ramchandran *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 *Emblica officinalis*, 22%. *Hardwickia binnata* and 35.5% in *Colophospermum mopen* 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 CO_2 than did forest vegetation (Dorr and Munnich, 1987). Similarly, newly cropped plots generated by slash and burn released more CO_2 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 fallowing 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 CO_2 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).

Carbon sequestration rates for a tillage chronosequence were studied by (Joao Carlos *et al*., 2001). They concluded that the carbon sequestration rate for no tillage was 80.6 g cm^{-2} yr^{-1} for 0-20 depth. The no tillage carbon sequestration potential for South Brazil was estimated as 9.37 Tg C yr^{-1}. According to Ball *et al*. (1999), low or Zero CO_2 fluxes under no tillage are associated with reduced

gas diffusivity and air filled porosity, while increased CO_2 emission with plough is due to degassing of soil carbon dioxide.

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.

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.

2.3.2 Depth wise distribution of soil organic carbon pool

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 fallowing, 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.

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).

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.

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 CO_2 to the atmosphere because of tillage induced decomposition (Larney *et al*., 1997; Reicosky, 1997a,b). 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 CO_2 (Lal *et al*., 1998; 1999).

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).

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 fallowed 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 fallowed 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}) fallowed 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 in 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).

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 (74.82t 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.

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 though soil sampling of tillage trails. However, sampling protocol may have based the results. In essentially 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 another 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).

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).

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).

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).

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 topics (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).

Joao Carlos *et al*. (2001) studied the carbon sequestration rates for a tillage chronosequence and conducted 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 *et al*. (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, CO_2-C production,

metabolic quotients and net nitrogen mineralization were all highest in the pasture samples.

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.

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.

2.4 Economic returns from different land use systems

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 experiment during 1998-2003 to determine the economic viability of an agroforestry based system in Allahabad district Uttar Pradesh, India. The rabi (*Cicer arietihum* and *Vigna mungo*) 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).

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.

In 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.

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 soybean while least from pomegranate- soybean combination.

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.

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.

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.

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-silivi-pastoral and grass land system.

Chapter-3

MATERIALS AND METHODS

The present investigations entitled **"Bio-economic appraisal and carbon sequestration potential of different land use systems in temperate north-western Himalayas"** were conducted in Kullu district of Himachal Pradesh, during 2008-2009. The details about experimental site, material used and methodology adopted in undertaking these studies are given as below:

3.1 SITE DESCRIPTION

3.1.1 Location

The study was carried out in Kullu district of Himachal Pradesh (Fig. 1.), which is located between $31^0$58'00" North latitude and $77^0$06'4" East longitude. It is bounded by Lahaul -Spiti and Kangra districts, on the East and South East by Kinnaur and Shimla districts.

3.1.2 Climate

The climate of the study areas varies a lot depending upon the altitude and aspect. The district receives moderate rainfall and bulk of it is received during the months of July, August, December and January. The wettest month is August. The district Kullu forms a transitional zone between the lesser and the greater Himalayas and presents a typical rugged mountainous terrain with moderate to high relief. The average rainfall also varied in the valley as well as on the high altitude. Average mean monthly climate - temperature (maximum and minimum), relative humidity and rainfall is appended in Appendix I.

3.1.3 Forest types

The forests of study area are having vegetation of temperate nature mainly comprising of the following forest types (Champion and Seth. 1968).

$12/C_1$	Low Himalayan temperate forest
$12/C_{16}$	Mohru Oak forest

$12/C_2$ Upper west Himalayan temperate forest

$12/2S_1$ Low level blue pine forest

$12/C_4$ West Himalayan high level dry blue pine forest

The Locality factors of the study site are also depicted in the Table 1 as below.

Table 1: Locality factors of the Kullu district (HP).

Latitude	$31^0$58'00"
Longitude	$77^0$06'4"
Altitude	1000 to over 6000 m a.s.l.
Climate type	Cool and dry
Texture	Sandy loam and clay loam
Soil pH	6.3 to 6.6
Parent material	Shale, Schist, Micacious schist
Soil type	Entisols, Inceptisols, mollisol

3.2 EXPERIMENTAL METHODOLOGY

Experiment 1: Bio-economic appraisal and carbon sequestration potential of different land use systems in valley ecosystem of Kullu districts of Himachal Pradesh.

(A) Land use systems (Plate 2)

T_1 Cereal - cereal

T_2 Cereal - vegetable

T_3 Vegetable - vegetable

T_4 Orchard + Cereal – cereal

T_5 Orchard + Cereal – Vegetable

T_6 Orchard + Vegetable – Vegetable

T_7 Pure Orchard

(B) Altitudinal ranges

A_1 1000-1300 m a.s.l.

A_2 1300-1600 m a.s.l

A_3 1600-1900 m a.s.l

A_4 1900-2200 m a.s.l

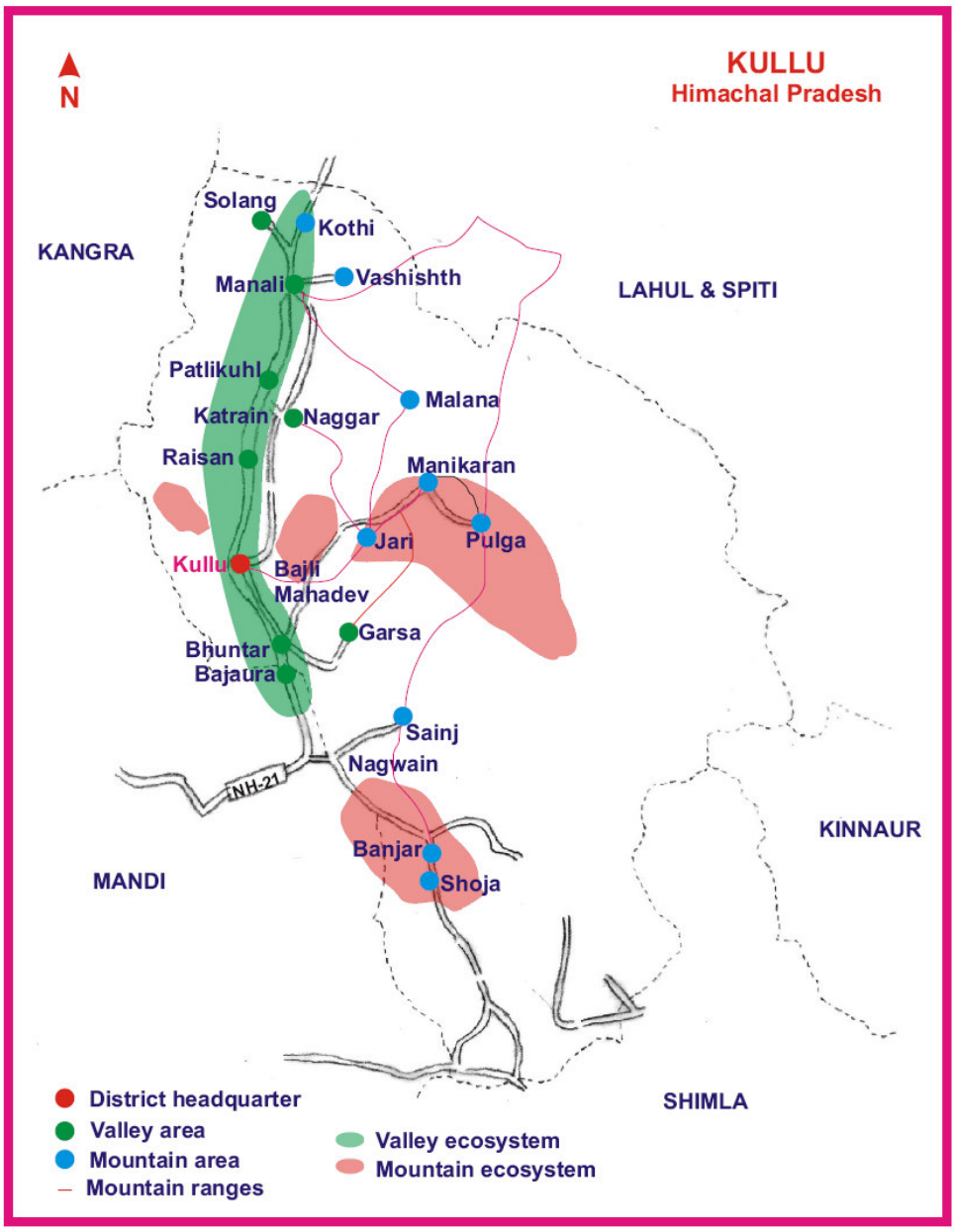

Fig. 1. Map of Kullu district depicting the area selected for conducting the present study

Maize field

Cabbage field

Maize and Cabbage field

Apple + Maize crop

Apple + Wheat crop

Plum + Maize crop

Apple + Vegetable crop

Apple orchards

Plate 2. Different types of land use systems in the valley ecosystem of the temperate north-western Himalayas

(C) Soil layers

L_1 0-20 cm layer

L_2 20-40 cm layer

Replications = 3

Design = RBD (Factorial)

No. of treatments combinations for biomass related studies = 28 [7 (land use systems) x 4 (altitudinal ranges)]

No. of treatments combinations for soil related studies = 56 [7 (land use systems) x 4 (altitudinal ranges) x 2 (Soil layer)]

3.3 EXPERIMENTAL METHODOLOGY

Experiment 2: Bio-economic appraisal and carbon sequestration potential of different land use systems in mountainous ecosystem of Kullu districts of Himachal Pradesh.

(A) Land use systems (Plate 3 a & b)

T_1 Agriculture

T_2 Agri-horticulture

T_3 Horticulture

T_4 Silvi -pastural system

T_5 Forest

(B) Altitudinal ranges

A_1 1100-1400 m a.s.l

A_2 1400-1700 m a.s.l

A_3 1700-2000 m a.s.l

A_4 2000-2300 m a.s.l

(C) Soil layers

L_1 0-20 cm

L_2 20-40 cm

Replications : 3

Design : RBD (Factorial)

No. of treatments combinations for biomass related studies = 20 [5 (land use systems) x 4 (altitudinal ranges)]

No. of treatments combinations for soil related studies = 40 [5 (land use systems) x 4 (altitudinal ranges) x 2 (Soil layer)]

Table 2: Experimental details indicating specific tree-crop combinations and their distribution in valley ecosystem of Kullu district (HP).

Land use systems/ elevation range	Code	Tree-crop combinations	Plot size m^2	Net cropped ha^{-1}	Area under tree ha^{-1}	Area under/ grass ha^{-1}	No of trees ha^{-1}	Average age of tree component
Cereal- cereal	A							
1000-1300 m		Wheat+ maize	50x10	1.00	-	-	-	Annuals
1300-1600 m		Wheat +maize						Annuals
1600-1900 m		Wheat+ Maize						Annuals
1900-2200 m		Wheat +maize						Annuals
Cereal -vegetable	A							
1000-1300 m		Wheat +cabbage	50x10	1.00	-	-	-	Annuals
1300-1600 m		Wheat +cabbage						Annuals
1600-1900 m		Wheat+ tomato						Annuals
1900-2200 m		Garlic+ maize						Annuals
Vegetable-vegetable	A							
1000-1300 m		Cauliflower+ cabbage	50x10	1.00	-	-	-	Annuals
1300-1600 m		Pea + tomato						Annuals
1600-1900 m		Pea+ tomato						Annuals
1900-2200 m		Garlic						Annuals
Orchard +cereal -cereal	AH							
1000-1300 m		Plum+ wheat- maize	50x10	0.45	0.55	-	278	~18 yr
1300-1600 m		Apple + wheat-maize					278	~20 yr
1600-1900 m		Apple + wheat-maize					278	~20 yr
1900-2200 m		Apple + Wheat-maize					278	~20yr
Orchard+ cereal -vegetable	AH							
1000-1300 m		Plum + wheat – cabbage	50x10	0.45	0.55	-	278	~18 yr
1300-1600 m		Apple + wheat-cabbage					278	~20 yr
1600-1900 m		Apple+ wheat-tomato					278	~20 yr
1900-2200 m		Apple+ garlic-maize						~20yr
Orchard+ vegetable – vegetable	AH							
1000-1300 m		Plum+ cauliflower cabbage	50x10	0.40	0.60	-	278	~18 yr
1300-1600 m		Apple+ pea- tomato					278	~20 yr
1600-1900 m		Apple+ pea -tomato					278	~20 yr
1900-2200 m		Apple+ garlic					278	~20yr
Pure orchard	H							
1000-1300 m		Plum, apple	50x10	-	1.00	-	278	~18 yr
1300-1600 m		Apple					278	~20 yr
1600-1900 m		Apple					278	~20 yr
1900-2200 m		Apple					278	~20yr

Vegetable based agriculture land use system at 1700-2000 m a.s.l.

Agriculture land use system at 1400-1700 m a.s.l.

Vegetable based agriculture land use system at 2000-2300 m a.s.l.

Apple based horticulture land use system

Intercropping of plum with wheat at 1100-1400 m a.s.l.

Intercropping of apple with wheat at 1400-1700 m a.s.l.

Intercropping of apple with maize at 1700-2000 m a.s.l.

Intercropping of apple with rajmah at 1700-2000 m a.s.l.

Plate 3a. **Different types of land use systems in the mountain ecosystem of the temperate north-western Himalayas**

Landscape showing apple, wheat and forest

Silvi-pasture system

Pure Deodar forest at 1700-2000 m a.s.l.

Apple, Silvi-pasture and forest land use system at 1700-2000 m a.s.l.

Conflict between two dominating land use system of temperature north-western Himalayas

Apple orchard, agriculture and forest land use system at 2000-2300 m a.s.l. in the mountain ecosystem

Landscape showing orchard + cereal in the valley ecosystem at 1700-2000 m a.s.l.

Plate 3b. Different types of land use systems in the mountain ecosystem of the temperate north-western Himalayas

Table 3: Experimental details indicating specific tree-crop combinations and their distribution in mountainous ecosystem of Kullu district (HP).

Land use systems/ elevation range	Code	Tree-crop combinations	Plot size m^2	Net cropped area ha^{-1}	Area under tree ha^{-1}	Area under crop/ grass ha^{-1}	No of trees ha^{-1}	Average age of tree component
Agriculture	A							
1100-1400 m		Wheat+ maize	50x10	1.00	-	-	-	Annuals
1400-1700 m		Wheat +maize		1.00	-	-	-	Annuals
1700-2000 m		Pea +Maize		1.00	-	-	-	Annuals
2000-2300 m		Garlic+ maize		1.00	-	-	-	Annuals
Agri horticulture	AH							
1100-1400 m		Plum+ wheat- maize	50x10	0.40	0.60	-	278	~20 yr
1400-1700 m		Apple + wheat-maize		0.40	0.60	-	278	~20 yr
1700-2000 m		Apple + pea -maize		0.40	0.60	-	278	~20 yr
2000-2300 m		Apple + Garlic – maize		0.30	0.70	-	333	~18 yr
Horticulture	H							
1100-1400 m		Plum ,apple	50x10	-	1.00	-	278	~20 yr
1400-1700 m		Apple		-	1.00	-	278	~20 yr
1700-2000 m		Apple		-	1.00	-	278	~20 yr
2000-2300 m		Apple		-	1.00	-	278	~18 yr
Silvi- pasture	SP							
1100-1400 m		*Pinus roxburghii* + *grasses*	50x10	-	0.70	0.3	250 (Pr)	~60 yr(Pr)
1400-1700 m		*P wallichiana* + *grasses*		-	0.70	0.3	217 (Pr)	~60 yr(Pw)
1700-2000 m		*Cedrus deodara* + *grasses*		-	0.70	0.3	212 (Pw)	~70 yr (Cd)
2000-2300 m		*Cedrus deodara* + *grasses*		-	0.70	0.3	218 (Cd)	~90 yr (Cd)
Forest	F							
1100-1400 m		*Pinus roxburghii*	50x10	-	1.00	-	650	~70 yr(Pr)
1400-1700 m		*P. wallichiana, C. deodara*		-	1.00	-	580 (Pw), 400 (Cd)	~90 yr(Pw) ~90 yr(Cd)
1700-2000 m		*P. Wallichiana, C. .deodara*		-	1.00	-	370(Cd), 450 (Pw)	120 yr(Pw), 140 yr (Cd)
2000-2300 m		*C. deodara, Abies pindrow, Picea smithiana*		-	1.00	-	192 (Ap), 202 (Cd), 190 (Ps)	~140 yr (Cd) ~180yr(Ap) ~180yr(Ps)

* Pr- *Pinus roxburghii*, Pw- *Pinus wallichiana*, Cd- *Cedrus deodara*, Ap- *Abies pindrow*, Ps- *Picea smithiana*

3.4 OBSERVATIONS RECORDED

3.4.1 Plants above ground biomass:

- Trees
- Crops

- Grasses
- Surface litter
- Grain yield
- Straw/Stover yield
- Fruit yield
- Pruned wood yield

3.4.2 Below ground biomass

- Trees
- Grasses
- Crops
- Vegetables

3.4.3 Soil parameters

- Soil organic carbon (%)
- Bulk density (g cm^{-3})
- Carbon inventory (t ha^{-1})
- Available Nitrogen (kg ha^{-1})

3.5 ECONOMIC YIELD

- Biological yield
- Economic productivity
- Net returns

3.4.1.1 Stem biomass

To estimate biomass all the tree falling in the plot (50 x 10 m^2) were enumerated. The diameter at breast height (dbh) was measured with caliper and height with Ravi's multimeter. Local volume equation developed for specific tree species (Appendix XXVI) and region were used for calculating the volume of the forest trees of the sample plot. Where volume equation were not available for the concerned species, form factor was calculated using Spiegel relaskope to find out the tree volume using the formula given by Pressler's (1865) and Bitlerlich (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

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

Where,

r = radius, dbh – diameter at breast height

Specific gravity

Specific gravity was determined from the available literature (Appendix-X). Where, the specific gravity values were not available in that case 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).

$$G_f = \frac{1}{\frac{Mn-Mo+1}{Mo \quad GSo}}$$

Where,

G_f	=	Specific gravity based on gross volume
M_n	=	Weight of saturated volume sample
M_o	=	Weight of oven- dried sample
GS_o	=	Average density of wood substances equal to 1.53

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

Mass = Average specific gravity of stem wood x volume

3.4.1.2 Branch Biomass of forest trees

Total numbers 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., < 6cm, 6-10cm, and >10 cm. Fresh weight of two sampled branches from each group was recorded separately. The formula (Chidumaya 1990) was used to determine the dry weight of branches.

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

Where,

B_{dwi} - oven dry weight of branch

B_{dwi} - 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:

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

Where,

B_{bt} - Branch biomass (fresh/dry) per tree

N_i - Number of branches in the i^{th} branch group

B_{wi} - average weight of branch of i^{th} group

I - 1, 2, 3,---------- refers to branch group

3.4.1.3 Leaf biomass

Leaves from the branches where ever were removed, weighed and oven dried separately to a constant weight at $80\pm5^{o}C$ (Chidumaya, 1990). Leaf biomass of the forest tree species was estimated using the table given by Jenkins *et al.,* (2003) (Appendix XXXVI). Whereas, the leaf biomass of each fruit tree was calculated during the leaf fall (Dec.-Jan.). The fallen leaves under each tree were collected and then dried to constant weight in oven. Leaf carbon was converted into carbon by multiplying with a factor of 0.5.

3.4.1.4 Pruned wood yield

Pruned wood of each sample tree with in 50 x 10 square meter plot was weighed during the pruning operations (Appendix XXXVIII). Then the represented sample was

oven dried to a constant weight. Dry biomass of the each sample tree was calculated from the formulae:

$$\text{Dry biomass of pruned branches/ tree} = \frac{\text{Oven dry weight of pruned branches sub-sample}}{\text{Fresh weight of the pruned branches sub-sample}} \times \text{Fresh weight of whole sample}$$

3.4.1.5 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 a factor of 0.5 (IPCC default value).

3.4.1.6 Fruit tree biomass

For estimation of fruit tree biomass we developed diameter-dry biomass based equations. For this purpose, we visited orchardist field from time to time, when they were uprooting their orchards during winter. For each fruit tree crop we selected around 20 trees. Each selected tree was then sectioned into secondary branches and main stem. The diameter of basal portion (with tree caliper) and fresh weight of each branch was determined in the field with the help of balance. Dry weight of branches was estimated using the following equation

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

Where,

B_{dwi} - Oven dry weight of branch
B_{dwi} - Fresh/green weight of branches
M_{cbdi} - Moisture content of branch on dry weight basis

After estimating the dry biomass of the each secondary branch, we developed non-linear regression equation between diameter and dry biomass of the branches. This regression equation was then used to estimate the dry weight of secondary branches of the sample trees of the sample plot (Appendix XXVI).

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

Biomass of the main stem log is determined as below:

The volume of the main stem is calculated by the formula

$$\text{Volume of the main stem} = \frac{S_1 + S_2}{2} \times l$$

(Huber's Formula)

Where

S_1 = Basal area of the lower portion
S_2 = Basal area of the upper portion
l = Length of the main stem

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

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

3.4.1.7 Fruit tree root biomass

In fruit trees, the trees uprooted by the farmers during their orchard replacement time were used to develop the diameter- biomass equations on dry biomass and the same trees were used for the estimation of the fruit tree root biomass on the basis of root and shoot biomass we developed shoot-root ratio (Appendix IX).

3.4.1.8 Crop and herbage biomass

Five plots of 1 x 1 m^2 were used for estimation of crop biomass. All the crops biomass occurring within the borders of the quadrates were cut at ground level and collected samples were weighed, sub sampled and oven dried at 65 $\pm$ 5^oC to a constant weight. The grass biomass was converted into carbon by multiplying with a factor of 0.5 (1PCC default value).

3.4.1.9 Grass biomass

Grass biomass was estimated using 1 m x 1 m quadrates. The total grass biomass occurring within the borders of the quadrate were cut at ground level and collected samples were weighed, sub sampled and oven dried at 65 $\pm$ 5^oC to a constant weight.

The grass biomass converted into carbon by multiplying with a factor of 0.5 (1PCC default value).

3.4.1.10 Surface litter

Surface litter was collected in five quadrates of 1 x 1 m^2. Samples were weighed, sub-sampled and oven dried at 65 $\pm$ 5^{o}C to a constant weight ground and ashes. Ash corrected dry was assumed to contain 45 per cent of carbon.

3.4.2 Below ground biomass

Below ground biomass of trees was calculated by using the guidelines of IPCC (1996) and Cairns *et al.* (1997). Below ground biomass of crops and grasses was calculated by multiplying above ground biomass of crops/grasses with a factor of root: shoot ratio of particular crop/grass. The data pertaining to root: shoot ratio of agriculture crops and grasses are shown in Appendix IX.

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

3.4.3 C and CO_2 estimation

3.4.3.1 Carbon stock

Carbon stock = Biomass x 0.5 (IPCC default value)

3.4.3.2 CO_2 estimation

CO_2 sequestered = Biomass carbon stock x 3.67

3.4.3.3 CO_2 mitigated

CO_2 mitigated = CO_2 sequestrated - CO_2 loss from the system through biomass, fruit yield or through pruned wood

3.4.4 Soil analysis

3.4.4.1 Collection and preparation of samples

Soil samples were collected by dividing each main plot area into five areas each having 10 m x 10 m. Soil samples for each sub area were obtained by digging five profiles up to 40 cm deep. Composite samples from all sub area were obtained for each depth. Samples were air dried in shade, grinded with wooden pestle, passed through 2

mm sieve and stored in cloth bags for further laboratory analysis. The following physico-chemical attributes of soils were determined.

Sr. No.	Parameters	Method employed
1.	Bulk density (g cm^{-3})	Specific gravity method (Singh, 1980)
2.	Organic carbon (%)	Walkley and Black (1934)
3.	Available nitrogen (Kg/ha)	Kjeldahl distillation method (Subbijah and Asija, 1956)

3.4.5 Carbon inventory

The soil organic carbon pool inventory expressed as t ha^{-1} for a specific depth was computed by using the formulae of Nelson and Sommers (1996). The bulk density and carbon concentration data are used to compute amounts of carbon per unit area of land use as follows:

C (t ha^{-1}) = [(soil bulk density (g cm^{-3}) x soil depth (cm) x C (%)] x 100

In this equation, the C must be expressed as a decimal fraction.

3.6 ECONOMIC YIELD

3.6.1 Biological yield

Biological productivity was calculated considering the utilizable biomass of each functional unit of the system type and the same is given in Appendix XXVIII - XXXV.

3.6.2 Economic productivity

The present utilizable biomass from each functional unit in a system were taken for estimating the total returns from the system whereas, the total investment incurred on production, land value of the system and cultural management practices were taken into account to estimate the net returns (Appendix XXVIII - XXXV).

3.6.3 Net returns

Net returns were taken on marketing, land value and production costs (variable cost) are given Appendix XXVIII - XXXV

3.7 CARBON CREDITS

One ton of net sequestered or mitigated carbon dioxide in the form of plant biomass is equal to one carbon credit. Therefore, total carbon credit in a land use system was calculated from CO_2-eq values of retained biomass in respective system. The eligible carbon credits were calculated from the net sequestered or mitigated carbon dioxide in the form of tree or crop biomass only.

3.8 STATISTICAL ANALYSIS

The data obtained were subjected to statistical analysis as per the procedure suggested by Gomez and Gomez (1984). Wherever, the effects exhibited significance at 5 per cent level of probability, the critical difference (CD) was calculated. Analysis was carried out on computer using the package “STATISTICS”.

Chapter-4

EXPERIMENTAL RESULTS

The results emerging out of the present investigations entitled **"Bio-economic appraisal and carbon sequestration potential of different land use systems in temperate north-western Himalayas"** conducted in the valley and mountainous ecosystem of Kullu district of Himachal Pradesh has been described in this chapter. Different land use systems due to their structure, function, tree species, altitudinal ranges, topography and management to which each system is subjected to reflect a wide variability in term of biomass production potential, carbon storage ability and economic returns derived from them. Biomass production and carbon storage potential and economic benefits/return derived from different land use systems along an altitudinal gradient in both valley and mountains ecosystems of temperate north western Himalaya have been described in this chapter under the following major heads and sub heads:

4.1 BIO-ECONOMIC APPRAISAL AND CARBON SEQUESTRATION POTENTIAL OF DIFFERENT LAND USE SYSTEMS OF KULLU VALLEY OF HIMACHAL PRADESH

Exploratories expeditions were carried out in the Kullu valley before planning and execution of the present study. The Kullu valley, which is around seventy kilometer in length is divided into four altitudinal gradients based on the lapse rates (1^0C fall in temperature as we rise by 270 meter in the Himalayan hills). Survey revealed that many cropping systems are emerging in the valley system because of the incorporation of fruit and vegetable component into the land use systems in large scale over the last forty-fifty years. For the sake of convenience and drawing conclusions the cropping systems which are common in all the four altitudinal gradients of the valley ecosystem are designated as a land use systems. The bio-economic appraisal and carbon sequestration potential of these land use systems as prevalent in the Kullu valley of Himachal Pradesh is discussed under the following heads and subheads:

4.1.1 Biomass production levels

4.1.2 Biomass carbon density

4.1.3 Rates of C and CO_2 sequestration, removal and retention

4.1.4 Soil physico- chemical properties

4.1.5 Carbon inventory

4.1.6 Relative CO_2 mitigation potential

4.1.7 Carbon credits

4.1.8 Economic analysis

4.1.1 Biomass production levels

The above, below and total biomass production level as well as rate of biomass accumulation, removal and retention have been tabulated in this section under table 4-9

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

A perusal of the data presented in the Table 4 reveals that above ground biomass production in the valley area of the Kullu district is significantly influenced by the land use system, attitudinal gradient and their interaction effects between land use system and altitudinal gradient.

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

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	20.02	20.07	18.10	6.99	16.30
T_2 (Cereal – Vegetable)	12.22	12.45	11.45	3.43	9.89
T_3 (Vegetable – Vegetable)	6.62	8.82	9.72	3.13	6.36
T_4 (Orchard+Cereal-Cereal)	75.22	79.84	74.88	69.63	75.64
T_5 (Orchard+Cereal - vegetable)	72.74	75.93	74.25	68.84	72.94
T_6 (Orchard+Vegetable- Vegetable)	70.50	70.07	73.53	65.67	69.94
T_7 (Pure Orchard)	68.93	67.31	68.92	68.85	68.50
Mean	47.04	47.79	47.26	40.93	

	SE±	$CD_{0.05}$
T	3.72	7.54
A	3.33	6.74
TxA	7.54	15.26

In the land use systems maximum mean above ground biomass (75.64 t ha^{-1}) is recorded in the land use system of orchard + cereal-cereal (T_4). Although, T_4 recorded significantly higher biomass production over T_5 (orchard + cereal - vegetable), T_6 (orchard + vegetable – vegetable) and T_7 (pure orchard) but there is only a slight variation in the quantum of biomass recorded by them. The amount of biomass recorded in annual land use systems viz., vegetable-vegetable (T_3) is significantly lower than the treatments of T_2 (cereal – vegetable), T_1 (cereal - vegetable) and other fruits based land use systems.

Above ground biomass irrespective of the land use system increased from 1000-1300 m to 1300-1600m and thereafter showed a declining trend with increase in the altitude level. This decrease is quite sharp from A_3 to A_4.

Interaction between land use systems and altitudinal gradient demonstrated significant influence on the above ground biomass accumulation under different treatment combinations. All land use systems at the elevation ranges of 1000-1300 m, 1300-1600 m and 1600-1900 m displayed significantly higher above ground biomass production potential then their respective land use systems at the elevation range of 1900-2200 m a.s.l.

4.1.1.2 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).

Data presented in the table 5 shows that fruit based land use treatments of T_4 (orchard + cereal – cereal), T_5 (orchard + cereal – vegetable) T_6 (orchard + vegetable – vegetable) and T_7 (pure orchard) exhibited more than 3 times below ground potential than the annual based land use treatments i.e. T_1 (cereal – cereal) T_2 (cereal - vegetable) and T_3 (vegetable – vegetable). Minimum mean below ground (2.79 t ha^{-1}) accumulation is recorded in the treatment involving cereal - vegetable combination. In the effect of altitudinal ranges, the below ground biomass production increased from 1000-1300 m to 1300 - 1600 m and declined thereafter. Altitudinal range of 1900-2200 m (A_4) displayed minimum below

ground biomass (12.86 t ha^{-1}), which was found to be significantly higher than all other treatments A_1, A_2 & A_3.

Maximum below ground biomass (25.29 t ha^{-1}) is recorded in the land use system of orchard + cereal-cereal at an altitudinal range of 1300-1600 m a.s.l., which is found to be significantly higher than all other treatment combinations. Whereas, minimum (1.03 t ha^{-1}) is in the treatment combination of T_2A_4.

Table 5: Effect of land use system, altitudinal gradient and their interaction effect on below ground biomass production (t ha^{-1}) in the valley ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	7.00	8.43	7.38	2.80	6.40
T_2 (Cereal – Vegetable)	2.58	3.92	3.65	1.03	2.79
T_3 (Vegetable – Vegetable)	1.59	4.10	4.61	2.57	3.22
T_4 (Orchard+Cereal-Cereal)	24.79	25.29	23.10	21.23	23.60
T_5 (Orchard+Cereal - vegetable)	21.67	22.86	22.35	20.65	21.88
T_6 (Orchard+Vegetable- Vegetable)	20.77	21.01	23.08	21.11	21.49
T_7 (Pure Orchard)	20.70	20.19	20.67	20.65	20.55
Mean	14.16	15.11	14.98	12.86	

	SE±	$CD_{0.05}$
T	0.21	0.43
A	0.16	0.32
TxA	0.43	0.87

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

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

Data presented in the Table 6 shows that maximum mean total above ground biomass (99.23 t ha^{-1}) is accumulated in the treatment T_4 (orchard + cereal – cereal), which was found to be significantly higher than all other treatments. Although T_4, recorded significantly higher total above ground biomass but its difference from other fruit based land use systems viz., orchard + cereal – vegetable, orchard + vegetable – vegetable and pure orchard is found to

be 4-10 times more only. Whereas, total biomass accumulation in the annual land use systems viz., T_1 (cereal – cereal), T_2 (cereal – vegetable) and T_3 (vegetable – vegetable) was found 5-10 times lesser than the fruit based cropping systems.

Table 6: Effect of land use system, altitudinal gradient and their interaction effect on total biomass production (t ha^{-1}) in the valley ecosystem of Kullu District (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	27.03	28.30	25.51	9.80	22.66
T_2 (Cereal – Vegetable)	14.81	16.39	15.20	4.46	12.71
T_3 (Vegetable – Vegetable)	8.20	12.92	14.33	5.70	10.28
T_4 (Orchard+Cereal-Cereal)	103.0	105.0	98.00	90.87	99.23
T_5 (Orchard+Cereal - vegetable)	94.41	100.1	96.51	89.53	95.14
T_6 (Orchard+Vegetable- Vegetable)	91.27	91.09	96.29	86.41	91.27
T_7 (Pure Orchard)	89.73	87.50	89.59	89.50	89.08
Mean	61.21	63.05	62.21	53.75	

	SE±	$CD_{0.05}$
T	0.90	1.80
A	0.68	1.37
TxA	1.80	3.61

Irrespective of the land use treatment, in the altitudinal ranges maximum mean total above ground biomass was recorded in the altitudinal range of 1300-1600 m a.s.l., which is found to be significantly higher than A_1 and A_4 altitudinal ranges. Minimum mean total biomass (53.75 t ha^{-1}) is recorded in the highest altitudinal range i.e. A_4.

In different land use system, the total biomass production increased from A_1 to A_2 or A_3 and then declined thereafter. This rate of decline is appreciably higher in T_1, T_2 and T_3 than any other fruit based land use system viz., T_4, T_5, T_6 or T_7. Maximum total biomass (105 t ha^{-1}) is displayed by the treatment combination of orchard+ cereal-cereal at the elevation range of A_2 (1300-1600 m a.s.l), which, however remained statistically at par with the T_4A_1, only. Whereas, minimum total biomass (4.46 t ha^{-1}) was displayed by the treatment combination of T_2A_4.

4.1.1.4 Rate of biomass production (t $ha^{-1}yr^{-1}$)

It is crystal clear from the data presented in the Table 7 that rate of biomass accumulation is significantly influenced by land use system, altitudinal range and their interaction effects.

Rate of biomass accumulation is found to be maximum mean in the cropping system of cereal-cereal (22.66 t $ha^{-1}yr^{-1}$), which was found to be significantly higher than all other treatments. Rate of biomass accumulation was found to be minimum mean in T_1 (4.44 t $ha^{-1}yr^{-1}$), which is followed by the treatment of T_7, T_6, T_3, T_5, and T_2, respectively, in the ascending order.

In the altitudinal effect, the rate of biomass accumulation increased from A_1 to A_2 and showed a declining trend thereafter. However A_2 and A_3 altitudinal ranges remained statistically at par with one another.

Table 7: Effect of land use system, altitudinal gradient and their interaction effect on the rate of biomass Production (t $ha^{-1}yr^{-1}$) in the valley ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	27.03	28.30	25.51	9.80	22.66
T_2 (Cereal – Vegetable)	14.81	16.39	15.20	4.46	12.71
T_3 (Vegetable – Vegetable)	8.20	12.92	14.33	5.70	10.28
T_4 (Orchard+Cereal-Cereal)	19.83	19.67	18.95	8.81	16.82
T_5 (Orchard+Cereal - vegetable)	12.11	13.22	13.34	7.91	11.65
T_6 (Orchard+Vegetable- Vegetable)	8.86	11.61	13.24	5.48	9.80
T_7 (Pure Orchard)	4.48	4.37	4.44	4.47	4.44
Mean	13.62	15.21	15.00	6.66	

	SE±	$CD_{0.05}$
T	0.23	0.39
A	0.17	0.35
TxA	0.46	0.96

In the interaction effect between land use system and altitudinal ranges, the rate of biomass production is significantly higher in the treatment combinations of T_1A_1, T_1A_2, and T_1A_3 than all other treatment combinations. Rate of biomass production is found to be significantly lower in the pure orchard based

treatments at all the altitudinal level than all other treatment combinations under investigation.

4.1.1.5 Rate of biomass removal (t $ha^{-1}yr^{-1}$)

Data in the Table 8 evinced that rate of the biomass removal in significantly influenced by the land use system, altitudinal range and their interaction affect.

Maximum mean biomass removal (21.90 t $ha^{-1}yr^{-1}$) is exhibited by the cropping system of cereal-cereal (T_1), which is followed by the treatments of T_4, T_2, T_3, T_5, T_6 and T_7, respectively in the descending order. All the land use systems varied significantly in respect of the rate of the biomass removal. Mean minimum biomass removal (1.35 t $ha^{-1}yr^{-1}$) is in the pure orchard land use.

In the altitudinal gradient, rate of biomass removal irrespective of the land use systems is maximum at the altitudinal range of 1300-1600 m, which is however closely followed by altitudinal gradients of A_3 and A_1, respectively in the descending order. The rate of biomass removal is minimum at the altitudinal range of 1900-2200 m a.s.l.

Table 8: Effect of land use system, altitudinal gradient and their interaction effect on the rate of biomass removal (t $ha^{-1}yr^{-1}$) in the valley ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	26.31	27.62	24.66	9.03	21.90
T_2 (Cereal – Vegetable)	14.18	15.76	14.46	3.94	12.09
T_3 (Vegetable – Vegetable)	7.70	12.06	13.53	2.04	8.83
T_4 (Orchard+Cereal-Cereal)	15.83	15.67	14.90	4.55	12.74
T_5 (Orchard+Cereal - vegetable)	8.23	9.44	9.14	4.40	7.80
T_6 (Orchard+Vegetable- Vegetable)	5.21	8.14	9.25	1.74	6.08
T_7 (Pure Orchard)	1.33	1.33	1.36	1.35	1.35
Mean	11.26	12.86	12.47	3.86	

	SE±	$CD_{0.05}$
T	0.27	0.45
A	0.17	0.34
TxA	0.45	0.90

In the interaction effect between land use system and altitudinal ranges, rate of biomass removal from the system is very high in the cropping system of cereal-cereal at the altitudinal range of A_1, A_2 and A_3 than all other treatment combinations under study. Land use system of pure orchard at all the altitudinal range accounted for minimum biomass removal (1.33 – 1.36 t $ha^{-1}yr^{-1}$). However, difference in the rate of biomass removal in pure orchard based land use system does not varied significantly between any of altitudinal ranges.

4.1.1.6 Rate of biomass retention (t $ha^{-1}yr^{-1}$)

The effect of land use system, altitudinal gradient and their interaction effect exerted a significant influence on the rate of biomass retention.

Data presented in the Table 9 evinced that fruit based land use systems viz., T_4, T_5, T_6 and T_7 accounted for retention of 6-8 times more biomass than annual cropping systems of T_1 (cereal-cereal), T_2 (cereal - vegetable), T_3 (vegetable-vegetable), however, the rate of biomass removal in the annual based land use systems does not varied significantly among themselves. Maximum mean biomass retention in the altitudinal ranges is recorded at T_4 (4.25 t $ha^{-1}yr^{-1}$), which, however, remained statistically at par with T_5 and T_6, only. Biomass retention at different altitudinal level remained statistically at par with one another.

Table 9: Effect of land use system, altitudinal gradient and their interaction effect on the rate of biomass retention (t $ha^{-1}yr^{-1}$) in the valley ecosystem of Kullu district (H.P

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	0.67	0.76	0.85	0.76	0.74
T_2 (Cereal – Vegetable)	0.62	0.62	0.74	0.67	0.65
T_3 (Vegetable – Vegetable)	0.50	0.72	0.80	0.57	0.61
T_4 (Orchard+Cereal-Cereal)	3.99	3.91	4.05	4.25	4.05
T_5 (Orchard+Cereal - vegetable)	3.88	3.78	4.20	3.51	3.84
T_6 (Orchard+Vegetable- Vegetable)	3.65	3.47	3.98	3.74	3.71
T_7 (Pure Orchard)	3.08	3.12	3.14	3.42	3.12
Mean	2.34	2.33	2.54	2.37	

	SE±	$CD_{0.05}$
T	0.22	0.44
A	0.16	NS
TxA	0.44	0.88

Interaction effect between land use system and altitudinal ranges reveals that fruit based land use systems demonstrated many times more biomass retention potential than annual based cropping systems. Maximum biomass retention (t $ha^{-1}yr^{-1}$) is displayed by T_5 (orchard + cereal – vegetable) at the altitudinal range of 1600-1900 m a.s.l. which differed significantly from all annual and pure fruit based land use systems, only.

4.1.2 Biomass carbon density

4.1.2.1 Above ground biomass carbon density

Data presented in the Table 10 evinced that the above ground biomass carbon stock production is influenced significantly by land use system, altitudinal gradient and their interaction effect.

Table 10: Effect of land use systems, altitudinal gradient and their interaction effect on above ground biomass carbon density (t ha^{-1}) in the valley ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	10.01	10.05	9.04	3.49	8.151
T_2 (Cereal – Vegetable)	6.11	6.22	5.72	1.71	4.942
T_3 (Vegetable – Vegetable)	3.31	4.40	4.85	1.53	3.182
T_4 (Orchard+Cereal-Cereal)	39.11	39.92	37.44	34.81	37.82
T_5 (Orchard+Cereal - vegetable)	36.37	37.96	37.12	34.42	36.47
T_6 (Orchard+Vegetable- Vegetable)	35.25	35.03	36.76	32.83	34.97
T_7 (Pure Orchard)	34.46	33.65	34.46	34.42	34.25
Mean	23.52	23.89	23.63	20.46	

	SE±	$CD_{0.05}$
T	0.36	0.72
A	0.27	0.54
TxA	0.72	1.42

In the land use system, maximum above ground biomass (37.82 t ha^{-1}) carbon density is exhibited by orchard + cereal – cereal land use system, which, differed significantly from all other land use systems. Carbon density (t ha^{-1}) in the fruit based land use systems is more than 10 times then the carbon density as observed in the vegetable based land use systems.

Irrespective of the land use systems, maximum carbon density in the altitudinal range in recorded at the 1300-1600 m a.m.s.l, which however remained statistically at par with the carbon density as observed at the altitudinal range of A_1 (1000-1300 m) a.s.l. and A_2 (1600-1900 m) a.s.l.

In the interaction effect, fruit based land use systems at all the altitudinal ranges displayed more than 10 times carbon density than the annual based land use systems. Minimum carbon density (1.53 t ha^{-1}) is observed in the vegetable based land use system at the altitudinal range of 1900-2200 m a.s.l. which is found to be significantly lower than all other treatment combinations, excepting T_3 A_4.

4.1.2.2 Below ground biomass carbon density (t ha^{-1})

Below ground carbon accumulation is significantly influenced by land use system, altitudinal level and interaction effect between land use system and altitudinal gradient (Table 11).

Table 11: Effect of land use systems, altitudinal gradient and their interaction effect on below ground biomass carbon density (t ha^{-1}) in the valley ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	3.50	4.21	3.70	1.40	3.20
T_2 (Cereal – Vegetable)	1.29	1.96	1.82	0.52	1.39
T_3 (Vegetable – Vegetable)	0.80	2.05	2.30	1.29	1.60
T_4 (Orchard+Cereal-Cereal)	12.40	12.66	11.55	10.62	11.80
T_5 (Orchard+Cereal - vegetable)	10.84	11.43	11.17	10.33	10.94
T_6 (Orchard+Vegetable- Vegetable)	10.39	10.50	11.54	10.56	10.75
T_7 (Pure Orchard)	10.35	10.09	10.33	10.32	10.27
Mean	7.08	7.56	7.49	6.66	

	SE±	$CD_{0.05}$
T	0.25	0.50
A	0.19	0.38
TxA	0.50	1.00

In the land use systems, mean maximum below ground carbon density (11.80 t ha^{-1}) is in the T_4 (orchard + cereal – cereal) land use system which is

found to be significantly higher than all other land use treatments. Although significant, but it was closely followed by the land use systems of T_5, T_6 and T_7. All of these land use systems displayed quite higher carbon density than the annual based cropping systems. In the altitudinal gradient maximum carbon density is found in 1300-1600 m a.s.l. altitudinal range which differed significantly from all other altitudinal ranges. Minimum below ground carbon density (6.66 t ha^{-1}) is at the 1900-2200 m a.s.l.

In the interaction effect between land use system and altitudinal range, maximum below ground carbon density (12.66 t ha^{-1}) is observed in the orchard + cereal – cereal land use system situated at the altitudinal range of 1000-1300 m a.s.l. Minimum below ground carbon density (0.52 t ha^{-1}) is in the cereal – cereal land use system lying at the elevation range of 1900-2200 m a.s.l (T_2 A_4).

4.1.3.3 Total biomass carbon density

Total biomass based carbon density (t ha^{-1}) is significantly influenced due to land use system, altitudinal ranges and their interaction effect (Table 12).

Table 12: Effect of land use systems, altitudinal gradient and their interaction effect on total biomass carbon density (t ha^{-1}) in the valley ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	13.51	14.14	12.75	4.89	11.33
T_2 (Cereal – Vegetable)	7.40	8.19	7.60	2.23	6.35
T_3 (Vegetable – Vegetable)	4.10	6.46	7.16	2.85	5.14
T_4 (Orchard+Cereal-Cereal)	51.51	52.52	48.99	45.43	49.61
T_5 (Orchard+Cereal - vegetable)	47.20	50.06	48.25	44.76	47.57
T_6 (Orchard+Vegetable- Vegetable)	45.63	45.54	48.14	43.18	45.62
T_7 (Pure Orchard)	44.86	43.74	44.79	44.75	44.54
Mean	30.60	31.52	31.10	26.87	

	SE±	$CD_{0.05}$
T	0.45	0.90
A	0.34	0.68
TxA	0.90	1.80

In the land use systems, total biomass carbon density in the fruit based land use systems is in the treatments of T_4 – T_7 ranged between 44.54-49.61 t ha^{-1}. Significantly lowest biomass carbon density (5.14 t ha^{-1}) is displayed by vegetable-vegetable cropping system. Among the annual cropping system treatment cereal – cereal (T_1) exhibited significantly highest carbon density (11.33 t ha^{-1}), which differed significantly than T_2 (cereal – vegetable) and T_3 (vegetable - vegetable) land uses.

In the altitudinal range, the biomass carbon density increased from A_1 to A_2 and declined thereafter. Maximum biomass carbon stock (31.52 t ha^{-1}) recorded at A_2 (1300-1600m) remained statistically on a par with A_3 (1600-1900m), only. Significantly lowest total carbon biomass (26.87 t ha^{-1}) is recorded at the elevation range of 1900-2200 m a.s.l.

In the interaction effect between land use system and altitudinal range, maximum total biomass carbon stock (52.52 t ha^{-1}) is displayed by the land use system of orchard + cereal – cereal at the elevation range of A_2 (1300-1600 m a.s.l.), which, however remained statistically at par with the T_4 A_1, only.

4.1.3 Rate of C and CO_2, sequestration, removal and retention

4.1.3.1 Rate of carbon sequestration (t $ha^{-1}yr^{-1}$)

Data in the Table 13 evinced that the rate of biomass carbon stock (t ha^{-1} yr^{-1}) is significantly influenced by land use system, altitudinal range and their interaction effect.

Maximum mean carbon sequestration rate (11.33 t $ha^{-1}yr^{-1}$) in the cropping system of cereal – cereal which is found to be significantly higher than all other land use systems and followed the trend $T_1 > T_4 > T_2 > T_5 > T_3 > T_6 >$ and T_7. In the altitudinal ranges, maximum rate of carbon sequestration (7.60 t $ha^{-1}yr^{-1}$) is at the altitudinal range of 1300-1600 m.a.s.l., which remained statistically on a par with A_3, only. Mean minimum rate of carbon (3.15 t $ha^{-1}yr^{-1}$) sequestration is in the elevation range of 1900-2200 m a.s.l.

Table 13: Effect of land use systems, altitudinal gradient and their interaction effect on the rate of carbon sequestration (t $ha^{-1}yr^{-1}$) in the valley ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	13.51	14.14	12.75	4.89	11.33
T_2 (Cereal – Vegetable)	7.40	8.19	7.60	2.23	6.35
T_3 (Vegetable – Vegetable)	4.10	6.46	7.16	2.85	5.14
T_4 (Orchard+Cereal-Cereal)	9.91	9.83	9.47	4.40	8.40
T_5 (Orchard+Cereal - vegetable)	6.05	6.61	6.67	3.96	5.83
T_6 (Orchard+Vegetable- Vegetable)	4.40	5.80	6.61	2.74	4.90
T_7 (Pure Orchard)	2.24	2.18	2.22	2.23	2.22
Mean	6.80	7.60	7.50	3.33	

	SE±	$CD_{0.05}$
T	0.16	0.32
A	0.12	0.24
TxA	0.32	0.64

In the interaction effect between land use system and altitudinal ranges, cereal – cereal land use system at A_1 - A_2 elevation ranges and pure orchard at the same elevation ranges displayed higher and lower rate carbon sequestration, respectively.

4.1.3.2 Rate of carbon stock removal (t $ha^{-1}yr^{-1}$)

It is quite clear from the data in the Table 14 that rate of carbon stock removal from the valley ecosystems of temperate north-western Himalaya is significantly influenced due to land use system, altitudinal gradient and their interaction effect between land use system and altitudinal ranges (Plate 4).

Rate of carbon stock removal from the system is mean maximum (10.94 t ha^{-1} yr^{-1}) in the cereal – cereal based land use system, which is found to be significantly higher than all other land use systems. The rate of carbon stock removal from the system followed the trend $T_1 > T_4 > T_2 > T_3 > T_5 > T_6 >$ and T_7.

Irrespective of the land use system, maximum rate of carbon stock removal is from the elevation range of 1300 – 1600 m. a.s.l. which, however,

remained statistically on a par with A_3 (6.23 t $ha^{-1}yr^{-1}$). Mean minimum rate of biomass removal is at the elevation range of 1900-2200 m a.s.l.

Table 14: Effect of land use systems, altitudinal gradient and their interaction effect on the rate of carbon stock removal (t $ha^{-1}yr^{-1}$) in the valley ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	13.18	13.75	12.33	4.51	10.94
T_2 (Cereal – Vegetable)	7.09	7.88	7.23	1.90	6.02
T_3 (Vegetable – Vegetable)	3.85	6.09	6.76	1.02	4.43
T_4 (Orchard+Cereal-Cereal)	7.91	7.88	7.45	2.28	6.38
T_5 (Orchard+Cereal - vegetable)	4.11	4.72	4.57	2.20	3.90
T_6 (Orchard+Vegetable- Vegetable)	2.60	4.07	4.63	0.87	3.04
T_7 (Pure Orchard)	0.70	0.62	0.65	0.73	0.61
Mean	5.63	6.43	6.23	1.92	

	SE±	$CD_{0.05}$
T	0.13	0.26
A	0.09	0.18
TxA	0.25	0.50

In the interaction effect between land use system and altitudinal ranges cereal – cereal land use system at 1000-1300 to 1600-1900 m a.s.l. displayed significantly highest carbon stock removal in comparison to all other land use system. Whereas, pure orchard in general at all the elevation ranges displayed quite low carbon stock removal than other treatment combinations. Similarly land use system from T_1 - T_6 at the elevation range of 1900 - 2200 m a.s.l. displayed significantly lower values than at the elevation range of 1000-1300m, 1300-1600m and 1600-1900 m. a.s.l.

4.1.3.3 Rate of carbon stock retention (t $ha^{-1}yr^{-1}$)

Table 15 shows that rate of carbon stock retention (t $ha^{-1}yr^{-1}$) is significantly influenced by land use system, altitudinal ranges and the interaction effect between land use system and altitudinal range.

Land use system, irrespective of altitudinal ranges displayed their mean maximum value (2.02 t $ha^{-1}yr^{-1}$), which, however remained statistically at par

Pruning in plum + vegetable–vegetable based land use system

Stacked pruned wood ready to be removed from the land use system

Plate 4. Removal of C stock from the land use system

with T_5 and T_6, only. Whereas, mean minimum value of rate of carbon retention (0.32 t $ha^{-1}yr^{-1}$) is in the vegetable-vegetable cropping system which is found to be statistically at par with T_1 and T_2, only. In the altitudinal ranges, rate of carbon stock retention remained statistically alike at A_1 and A_2 but increased thereafter. Rate of carbon stock retention is maximum (1.90 t $ha^{-1}yr^{-1}$) at the elevation range of 1900-2200 m a.s.l.

Table 15: Effect of land use systems, altitudinal gradient and their interaction effect on the rate of carbon stock retention (t $ha^{-1}yr^{-1}$) in the valley ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	0.28	0.34	0.43	0.38	0.36
T_2 (Cereal – Vegetable)	0.31	0.32	0.37	0.32	0.33
T_3 (Vegetable – Vegetable)	0.25	0.36	0.40	0.29	0.32
T_4 (Orchard+Cereal-Cereal)	2.0	1.95	2.02	2.13	2.02
T_5 (Orchard+Cereal - vegetable)	1.94	1.89	2.10	1.75	1.92
T_6 (Orchard+Vegetable- Vegetable)	1.82	1.74	1.99	1.87	1.85
T_7 (Pure Orchard)	1.54	1.56	1.82	1.56	1.56
Mean	1.16	1.16	1.27	1.90	

	SE±	$CD_{0.05}$
T	0.11	0.22
A	0.08	0.16
TxA	0.21	0.42

In the interaction effect, annual cropping system based land use system at all the elevation ranges displayed significantly lower carbon retention than fruit based land the systems.

4.1.3.4 Above ground CO_2 sequestration potential

Table 16 shows that CO_2 sequestration potential in the valley area of the temperate north western Himalaya is significantly influenced by land use system, altitudinal ranges and their interaction effect.

Irrespective of the altitudinal gradient, maximum CO_2 sequestration potential is exhibited by orchard + cereal-cereal cropping system, which is found to be

significantly higher than all other land use systems. Among the fruit based land use systems, minimum CO_2 sequestration potential (125.7 t ha^{-1}) is displayed by pure orchard followed by land use systems of orchard + vegetable – vegetable (128.3 t ha^{-1}), orchard + cereal – cereal - vegetable (133.8 t ha^{-1}) and orchard + cereal-cereal (138.60 t ha^{-1}), respectively in the ascending order. CO_2 sequestration of annual cropping system displayed quite lower values than perennial land use system.

Table 16: Effect of land use systems, altitudinal gradient and their interaction effect on above ground CO_2 sequestration potential (t ha^{-1}) in the valley ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	36.73	36.89	33.21	12.82	29.91
T_2 (Cereal – Vegetable)	22.42	22.86	21.00	6.28	18.14
T_3 (Vegetable – Vegetable)	12.15	16.18	17.83	5.70	11.68
T_4 (Orchard+Cereal-Cereal)	143.5	146.5	136.7	127.8	138.60
T_5 (Orchard+Cereal - vegetable)	133.5	139.3	136.2	126.3	133.8
T_6 (Orchard+Vegetable- Vegetable)	129.4	128.6	134.9	120.5	128.3
T_7 (Pure Orchard)	126.5	123.5	126.5	126.3	125.7
Mean	86.61	87.69	86.63	74.37	

	SE±	$CD_{0.05}$
T	1.31	2.63
A	0.99	1.99
TxA	2.63	5.27

In the altitudinal gradient, CO_2 sequestration potential increased from A_1 to A_2 and thereafter showed a declining trend. CO_2 sequestration potential at the highest elevation range showed about 12 tons lower CO_2 sequestration than the land use system at the lower altitudinal range.

In the interaction effect between land use system and altitudinal ranges, maximum CO_2 sequestration potential (146.5 t ha^{-1}) was displayed by orchard + cereal – cereal land use system at 1300-1600 m a.s.l., which is found to be statistically at par with same land use system at 1000-1300 m a.s.l. Whereas, the minimum CO_2 sequestration potential is exhibited by vegetable-vegetable land

use system at the highest elevation range of the present study i.e. 1900-2200 m a.s.l.

4.1.3.5 Below ground CO_2 sequestration potential

Data in the Table 17 evinced that the below ground CO_2 sequestration potential of different land use system at different elevation ranges is significantly influenced by land use system, attitudinal ranges and their interaction effect.

Table 17: Effect of land use systems, altitudinal gradient and their interaction effect on below ground CO_2 sequestration potential (t ha^{-1}) in valley area of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	12.85	15.47	13.54	5.14	11.76
T_2 (Cereal – Vegetable)	4.73	7.19	6.70	1.89	5.05
T_3 (Vegetable – Vegetable)	2.91	7.52	8.46	4.72	5.94
T_4 (Orchard+Cereal-Cereal)	45.49	46.41	42.39	38.96	43.32
T_5 (Orchard+Cereal - vegetable)	39.76	41.95	41.09	37.88	40.15
T_6 (Orchard+Vegetable- Vegetable)	38.11	38.55	42.35	35.83	39.43
T_7 (Pure Orchard)	37.98	37.05	37.92	37.89	37.71
Mean	25.98	27.74	27.49	23.60	

	SE±	$CD_{0.05}$
T	0.91	1.82
A	0.69	1.38
TxA	1.82	3.65

The data on below ground CO_2 sequestration potential followed the trend as that of below ground carbon density.

4.1.3.6 Total CO_2 sequestration potential (t ha^{-1})

Total CO_2 sequestration potential is significantly influenced by land use system, altitudinal ranges and their interaction effect (Table 18).

In the land use system, mean maximum CO_2 sequestration potential is exhibited by orchard + cereal – vegetable (182.09 t ha^{-1}), which, however remained statistically at par with T_4, only. Lowest CO_2 sequestration potential is

demonstrated by T_3 (vegetable – vegetable) land use system, which is found to be statistically at par with T_2 (23.32 t ha^{-1}), only. Among the annual land use system cereal – cereal demonstrated significantly highest CO_2 sequestration potential. In the altitudinal range CO_2 sequestration potential increased from A_1 to A_2 and their after showed a declining trend.

In the interaction effect between land use system and altitudinal ranges, maximum and minimum CO_2 sequestration potential is exhibited by T_4A_2 and T_2A_4, respectively.

Table 18: Effect of land use systems, altitudinal gradient and there interaction effect on total CO_2 sequestration potential (t ha^{-1} in the valley ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	49.59	51.92	46.81	17.98	41.57
T_2 (Cereal – Vegetable)	27.16	30.06	27.89	8.18	23.32
T_3 (Vegetable – Vegetable)	15.05	23.07	26.30	10.46	18.86
T_4 (Orchard+Cereal-Cereal)	189.0	192.8	179.83	166.75	182.09
T_5 (Orchard+Cereal - vegetable)	173.24	183.68	177.10	164.29	174.58
T_6 (Orchard+Vegetable- Vegetable)	167.48	167.15	176.69	158.56	167.48
T_7 (Pure Orchard)	164.65	160.56	164.40	164.23	163.46
Mean	112.32	115.70	114.16	98.63	

	SE+	$CD_{0.05}$
T	3.86	7.75
A	2.92	5.86
TxA	7.73	15.49

4.1.3.7 Rate of CO_2 sequestration potential (t ha^{-1} yr^{-1})

Data presented in the Table 19 evinced that rate of CO_2 sequestration potential is significantly influenced due to land use system, altitudinal range and interaction effect between land use system and altitudinal range.

In the land use system, mean maximum rate of CO_2 sequestration potential (41.58 t $ha^{-1}yr^{-1}$) is demonstrated by cereal-cereal land use system followed by T_4 (orchard + cereal-cereal), T_2 (cereal – vegetable), T_5 (orchard + cereal – vegetable), T_3 (vegetable – vegetable), T_6 (orchard + vegetable – vegetable) and T_7 (pure orchard), respectively in the descending order.

Table 19: Effect of land use systems, altitudinal gradient and their interaction effect on the rate of CO_2 sequestration potential (t $ha^{-1}yr^{-1}$) in the valley ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	49.59	51.92	46.81	17.98	41.58
T_2 (Cereal – Vegetable)	27.16	30.08	27.89	8.18	23.32
T_3 (Vegetable – Vegetable)	15.05	23.70	26.30	10.46	18.88
T_4 (Orchard+Cereal-Cereal)	36.38	36.09	34.77	16.17	30.86
T_5 (Orchard+Cereal - vegetable)	22.21	24.26	24.48	14.51	21.37
T_6 (Orchard+Vegetable- Vegetable)	16.26	21.30	24.29	10.08	17.98
T_7 (Pure Orchard)	8.22	8.01	8.15	8.20	8.15
Mean	24.70	27.90	27.53	12.22	

	SE±	$CD_{0.05}$
T	0.54	1.09
A	0.41	0.83
TxA	1.09	2.19

Irrespective of the land use system, mean maximum CO_2 sequestration potential (27.90 t $ha^{-1}yr^{-1}$) is exhibited at 1300-1600 m.a.s.l, which, however remained statistically at par with A_3 (27.53 t $ha^{-1}yr^{-1}$) followed by A_1 and A_4, respectively in the descending order. Rate of CO_2 sequestration potential at 1900-2200 m a.s.l. is quite low in comparison to CO_2 sequestration at the lower elevation ranges.

In the interaction effect, maximum CO_2 sequestration potential is demonstrated by cereal – cereal land use system at the altitudinal range of 1300-1600 m a.s.l., which however remained on a par with 1000-1300 m a.s.l. and followed closely by same land use system at 1600-1900 m a.s.l. Minimum rate of CO_2 sequestration is displayed by the cereal - vegetable land use system at the highest elevation range i.e. 1900-2200 m a.s.l.

4.1.3.8 Rate of CO_2 release (t $ha^{-1}yr^{-1}$)

Land use systems, altitudinal ranges and their interaction effect significantly influenced the rate of CO_2 release in the valley area of north western temperate ecosystem (Table 20).

In the land use system, mean maximum CO_2 release (40.21t $ha^{-1}yr^{-1}$) is depicted by cereal – cereal (T_1) land use system, which however remained significantly higher than all other land use system under consideration. Whereas, mean minimum CO_2 release is recorded in pure orchard (2.42 t $ha^{-1}yr^{-1}$), which is found to be significantly lower than all other land use systems. In the altitudinal ranges, the CO_2 release is maximum at A_2 (23.63 t $ha^{-1}yr^{-1}$) followed by A_3 (22.88 t ha^{-1} yr^{-1}), A_1 (20.69 t $ha^{-1}yr^{-1}$) and A_4 (7.05 t $ha^{-1}yr^{-1}$), respectively.

In the interaction effect between land use system and altitudinal range, cereal – cereal based land use system at the altitudinal ranges of 1000-1300 m, 1300-1600 m and 1600-1900 m shows quite higher CO_2 release from the system. Whereas, rate of CO_2 release from the pure orchard at all elevation ranges excepting treatment combination of T_6A_4 displayed significantly lower CO_2 release.

Table 20: Effect of land use systems, altitudinal gradient and their interaction effect on the rate of CO_2 release (t $ha^{-1}yr^{-1}$) in the valley ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	48.35	50.68	45.25	16.57	40.21
T_2 (Cereal – Vegetable)	26.02	28.92	26.54	6.99	22.12
T_3 (Vegetable – Vegetable)	14.14	22.38	24.82	3.74	16.27
T_4 (Orchard+Cereal-Cereal)	29.05	28.92	27.35	8.35	23.42
T_5 (Orchard+Cereal - vegetable)	15.11	17.31	16.84	8.07	14.33
T_6 (Orchard+Vegetable- Vegetable)	9.56	14.93	16.99	3.20	11.17
T_7 (Pure Orchard)	2.57	2.28	2.38	2.46	2.42
Mean	20.69	23.63	22.88	7.05	

	SE±	$CD_{0.05}$
T	0.44	0.88
A	0.33	0.66
TxA	0.88	1.76

4.1.3.9 Rate CO_2 mitigation potential

Rate of CO_2 mitigation potential is significantly influenced by land use system and interaction affect between land use system and altitudinal ranges. (Table 21).

Mean maximum CO_2 mitigation potential (7.43 t $ha^{-1}yr^{-1}$) is displayed by orchard + cereal – cereal land use system, but its difference from other orchard based land use systems, excepting pure orchard remained statistically, alike. Whereas, mean minimum CO_2 mitigation potential (1.19) is exhibited by vegetable-vegetable land use system but its differences from other annual based land use system viz., T_1 and T_2 remained statistically alike. CO_2 mitigation potential at all the elevation ranges remained statistically alike.

Table 21: Effect of land use systems, altitudinal gradient and their interaction effect on the rate of CO_2 mitigation potential (t $ha^{-1}yr^{-1}$) in the valley ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	1.24	1.24	1.56	1.80	1.36
T_2 (Cereal – Vegetable)	1.15	1.14	1.35	1.72	1.21
T_3 (Vegetable – Vegetable)	0.92	1.33	1.48	1.04	1.19
T_4 (Orchard+Cereal-Cereal)	6.33	7.18	7.43	7.81	7.43
T_5 (Orchard+Cereal - vegetable)	7.12	6.94	6.38	6.44	6.72
T_6 (Orchard+Vegetable- Vegetable)	6.69	6.36	7.30	6.86	6.80
T_7 (Pure Orchard)	5.66	5.74	5.68	5.74	5.68
Mean	4.30	4.27	4.44	4.35	

	SE±	$CD_{0.05}$
T	0.39	0.78
A	0.29	NS
TxA	0.78	1.56

In the interaction effect, maximum CO_2 mitigation potential (7.81 t ha^{-1} yr^{1}) is displayed by orchard + cereal – cereal based at the altitudinal range of 1900-2200 m a.s.l., however, its difference from other orchard+ annual based land use systems at all of their altitudinal ranges remained statistically alike. All the annual based land use system at all the elevation ranges displayed statistically identical CO_2 mitigation potential.

4.1.4 Soil physico-chemical properties

4.1.4.1 Soil organic carbon (%)

It is evidently clear from the data presented in the Table 22 that organic carbon (%) is significantly influenced by the average effect of land use system,

altitudinal ranges, soil layer and due to interaction between altitudinal range and soil layer.

Table 22 reveals that mean maximum organic carbon (0.85 %) is recorded in the pure orchard, which, however remained statistically at par with the organic carbon contents as observed in the T_6 (orchard + vegetable – vegetable), T_5 (orchard + cereal – vegetable) and differed significantly from all other land use systems. Mean minimum organic carbon content (0.72 %) is found in the cereal – cereal cropping system, which however, remained statistically at par with the land use system of T_2 (cereal – vegetable) and T_3 (vegetable – vegetable).

Table 22: Soil organic carbon, bulk density and soil organic carbon density (SOC) as influenced by average affect of land use system, altitudinal ranges and soil layer in the valley ecosystem of Kullu district (H.P.)

(A)Land use systems (T)	Soil Organic Carbon (%)	Bulk Density (gcm^{-3})	Soil Organic Carbon stock ($t\ ha^{-1}$)	Available nitrogen ($kg\ ha^{-1}$)
T_1 (Cereal- Cereal)	0.72 c	1.23 b	17.73 g	431.7 c
T_2 (Cereal – Vegetable)	0.74 bc	1.24 b	18.23 f	437.4 c
T_3 (Vegetable – Vegetable)	0.75 bc	1.26 b	18.32 e	478.7 b
T_4 (Orchard+Cereal-Cereal)	0.77 b	1.22 b	18.84 d	492.1 b
T_5 (Orchard+Cereal - vegetable)	0.79 ab	1.20 b	19.78 b	474.7 b
T_6 (Orchard+Vegetable- Vegetable)	0.82 a	1.92 a	20.02 a	511.2 ab
T_7 (Pure Orchard)	0.85 a	1.23 b	19.52 c	523.7 a
SE±	0.02	0.02	0.05	13.1
$CD_{0.05}$	0.04	0.04	0.01	26.0
(B)Altitudinal range(A)				
A_1 (1000-1300 m)	0.64 b	1.31 a	16.96 c	468 b
A_2 (1300-1600 m)	0.79 a	1.26 a	19.51 ab	469.5 b
A_3 (1600-1900 m)	0.82 a	1.17 b	19.06 b	511.5 a
A_4 (1900-2200 m)	0.82 a	1.16 b	20.15 a	464.7 b
SE±	0.02	0.02	0.41	9.9
$CD_{0.05}$	0.03	0.03	0.81	19.6
(C) Soil Layer (L)				
L_1 (0-20 cm)	0.90 a	1.18 a	21.36 a	515.3 a
L_2 (20-40 cm)	0.66 b	1.26 b	16.48 b	441.5 b
SE±	0.01	0.01	0.29	7.02
$CD_{0.05}$	0.02	0.02	0.57	13.9

*similar alphabets denotes at par value

In the altitudinal range, the range of 1600-1900 m and 1900-2200 m a.s.l. displayed equal value of per cent carbon (0.82 %), which is found to be

significantly higher than the elevation range of A_1 (0.64 %), only. In the soil layer, soil depth of L_1 (0-20 cm) depicted significantly higher values of organic carbon than L_2.

Interaction effect due to altitudinal range and soil layer resulted in significant influence on the soil organic carbon (%) (Table 23). L_1 (0-20 cm) soil range at all the altitudinal ranges displayed significantly higher organic carbon per cent than L_2 (20-40 cm layer). The rate of increase in organic carbon in L_1 layer is quite higher from $A_1$to A_4 altitudinal level than in the L_2 layer.

Table 23: Effect of interaction between altitudinal gradient and soil depth (cm) on soil organic carbon (%) in the valley ecosystem of Kullu district (H.P.)

Altitudinal ranges (A)	Soil layer (L)	
	L_1 (0-20 cm)	L_2 (20-40 cm)
A_1 (1000-1300 m)	0.73	0.56
A_2 (1300-1600 m)	0.91	0.64
A_3 (1600-1900 m)	0.98	0.66
A_4 (1900-2200 m)	0.99	0.75
SE±	0.02	
$CD_{0.05}$	0.04	

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

Bulk density in valley ecosystem of north-western temperate Himalaya (Table 22) is significantly influenced due to average effect of land use system, altitudinal range, soil depth and interaction effect between altitudinal range and soil layer.

A perusal of the data presented in the Table 22 indicate that maximum mean bulk density (1.92 g cm^{-3}) is recorded in orchard + vegetable – vegetable land use system, which is found to be significantly higher than all other land use systems. Whereas, in the altitudinal ranges bulk density kept on decreasing from A_1 to A_4. A_1 and A_2 elevation ranges displayed significantly higher bulk density than A_3 and A_4 levels. In soil depth, L_2 (20-40 cm) layer displayed significantly higher bulk density than L_1 layer.

Table 24: Effect of interaction between altitudinal gradient and soil depth (cm) on bulk density (g cm^{-3}) in the valley ecosystem of Kullu district (H.P.)

Altitudinal ranges (A)	Soil layer (L)	
	L_1 (0-20 cm)	L_2 (20-40 cm)
A_1 (1000-1300 m)	1.26	1.35
A_2 (1300-1600 m)	1.20	1.31
A_3 (1600-1900 m)	1.17	1.18
A_4 (1900-2200 m)	1.11	1.21
SE±	0.022	
$CD_{0.05}$	0.043	

Interaction between altitudinal range and soil layer (Table 24) indicate that in L_1 (0-20 cm) layer the bulk density kept on declining from A_1 to A_4 level, whereas in L_2 (20-40 cm) it declined from 1000-1300 to 1600-1900 m and then showed a slight increase.

4.1.4.3 Soil organic carbon density (t ha^{-1})

It is clear from the data presented in the Table 22 that soil organic carbon density is significantly influenced by the average effect of land use system, altitudinal gradient and by the interaction effects of land use system and altitudinal gradient and soil layer (Tables 24 & 26).

Table 25 : Effect of interaction between treatment and altitudinal gradient on soil organic carbon density (t ha^{-1}) in the valley ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)			
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)
T_1 (Cereal- Cereal)	15.47	19.00	17.45	19.01
T_2 (Cereal – Vegetable)	16.66	17.90	18.13	19.23
T_3 (Vegetable – Vegetable)	16.86	17.29	18.61	19.66
T_4 (Orchard+Cereal-Cereal)	17.30	19.84	19.00	19.89
T_5 (Orchard+Cereal - vegetable)	18.07	21.45	19.92	20.51
T_6 (Orchard+Vegetable- Vegetable)	18.00	21.34	20.83	22.50
T_7 (Pure Orchard)	16.35	19.75	19.50	20.23
SE±	1.04			
$CD_{0.05}$	2.12			

In the land use system, mean maximum soil organic carbon density (20.02 t ha^{-1}) is recorded in the orchard + vegetable – vegetable land use system, which was found to be significantly higher than all other land use systems. Mean minimum soil organic carbon density (17.73 t ha^{-1}) is recorded in T_1 (cereal – cereal) land use system, soil organic carbon density in different land use systems differed significantly from one another. In the altitudinal ranges, 1900-2200 m altitudinal range displayed significantly higher soil organic carbon density than the altitudinal range of 1000-1300 m a.s.l. and 1600-1900 m a.s.l. In soil depth, the soil carbon density declined significantly from L_1 to L_2 layer.

In the interaction effect between land use system and altitudinal ranges (Table 25), maximum soil organic carbon density is displayed by the land use system of T_6 (orchard + vegetable – vegetable) at the elevation range of 1900-2200 m a.s.l. which, however, remained statistically identical to the treatment combinations of T_5A_2, T_6A_2, T_6A_3 and T_5A_4, only. Minimum value of the carbon density is demonstrated by the cereal – cereal land use system at 1000-1300 m a.s.l, which is found to be statistically at par with the treatment combinations of T_2A_1, T_4A_1, T_7A_1, T_3A_2, and T_1A_3, only.

4.1.4.4 Available nitrogen (Kg ha^{-1})

Table 22 indicates that available N content (Kg ha^{-1}) is significantly influenced by land use system, altitudinal range and soil depth effect.

Maximum mean available N (523.7 kg ha^{-1}) is recorded in the pure orchard, which, however, remained statistically identical to the N status of T_6, only. Nitrogen status in the land use systems of T_3, T_4, T_5 and T_6 remained statistically identical. Minimum level of N is in the treatment T_1 (cereal – cereal), which, however, remained statistically on a par with T_2, only. In the altitudinal ranges, maximum available nitrogen is found at the altitudinal range of A_3 (511.5 kg ha^{-1}), which differed significantly from all other treatment combinations. In the soil depth nitrogen status at the L_1 (0-20 cm) layer is significantly higher than L_2 layer.

Table 26: Effect of interaction between altitudinal gradient and soil depth (cm) on soil organic carbon density (t ha^{-1}) in the valley ecosystem of Kullu district (H.P.)

Altitudinal ranges (A)	Soil layer (L)	
	L_1 (0-20 cm)	L_2 (20-40 cm)
A_1 (1000-1300 m)	18.81	15.11
A_2 (1300-1600 m)	21.71	15.18
A_3 (1600-1900 m)	22.94	17.31
A_4 (1900-2200 m)	21.99	18.30
SE±	0.57	
$CD_{0.05}$	1.13	

Data presented in the Table 26 shows that L_1 (0-20 cm) soil layer at all the altitudinal level displayed significantly higher soil organic carbon density over L_2 (20-40 cm) soil layer. The soil organic carbon density at the L_1 (0-20 cm) level showed an increasing trend from A_1 to A_3 and then declined, whereas, in L_2 (20-40 cm) layer soil organic carbon density showed an increasing trend from A_1 to A_4. But, significant differences were observed from A_2 onward, only.

4.1.5 Carbon inventory

4.1.5.1 Soil organic carbon pool inventory (t ha^{-1})

Data presented in the Table 27 gives the soil organic carbon status in different soil layers i.e.. 0-20, 20-40 and 0-40 cm at different altitudinal ranges. Irrespective of the altitudinal ranges, maximum soil carbon (40.87 t ha^{-1}) in 0-40 cm soil layer is recorded in the T_6 (orchard + vegetable – vegetable) land use system followed by the treatments – T_5, T_4, T_7, T_3 T_2 and T_1, respectively in the descending order. In altitudinal ranges the soil organic carbon increased with increase in the altitudinal range from A_1 to A_3 and then showed a slight decline.

In each land use system, the soil organic carbon (SOC) was found to be higher in 0-20 cm soil layer than 20-40 cm layer at all the altitudinal ranges. In general, soil organic carbon at A_2 (1300-1600), A_3 (1600-1900) and A_4 (1900-2200) altitudinal ranges is found to be higher than at the lowest elevation range i.e. 1000-1300 m a.s.l.

Table 27: Soil carbon inventory (t ha^{-1}) under different land use systems along an altitudinal gradient in the valley ecosystem of Kullu district (H.P.)

Land use Systems	Altitudinal gradient (A)												Mean
	A_1(1000-1300m)			A_2(1300-1600m)			A_3(1600-1900m)			A_4(1900-2200 m)			
	0-20 cm	20-40 cm	0-40 cm	0-20 cm	20-40 cm	0-40 cm	0-20 cm	20-40 cm	0-40 cm	0-20 cm	20-40 cm	0-40 cm	
T_1 (Cereal- Cereal)	16.95	13.99	30.94	19.63	15.38	35.01	21.26	13.64	34.90	19.88	14.14	34.02	33.72
T_2 (Cereal – Vegetable)	18.49	14.82	33.31	20.26	15.54	35.80	21.75	14.50	36.25	20.46	15.01	35.47	35.21
T_3 (Vegetable – Vegetable)	18.11	15.61	33.72	21.06	16.12	37.18	21.95	14.47	36.42	20.75	15.44	36.19	35.88
T_4 (Orchard+Cereal-Cereal)	18.88	15.73	34.61	21.67	18.00	39.67	24.20	18.27	42.47	21.86	18.60	40.46	39.30
T_5 (Orchard +Cereal - vegetable)	20.55	14.71	35.26	23.28	19.63	42.91	24.62	18.22	42.84	22.45	16.87	39.32	40.08
T_6 (Orchard+Vegetable-Vegetable)	21.43	15.45	36.88	23.40	19.29	42.61	23.74	19.46	43.2	22.15	18.63	40.78	40.87
T_7 Pure Orchard	18.24	15.47	33.71	21.67	17.79	39.46	23.28	16.72	40.00	24.56	17.43	41.99	38.79
Mean	18.95	15.11	34.06	21.57	17.39	38.95	22.97	16.47	39.44	21.73	16.59	38.32	

Table 28: Soil (+leaf litter) and biomass carbon inventory (t ha^{-1}) under different land use systems along an altitudinal gradient in the valley ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal Gradient (A)																Mean Soil: plant ratio	Mean Total
	A_1 (1000-1300m)				A_2 (1300-1600m)				A_3 (1600-1900m)				A_4 (1900-2200m)					
	Plant	Soil	Total	Soil: plant ratio	Plant	Soil	Total	Soil: plant ratio	Plant	Soil	Total	Soil: plant ratio	Plant	Soil	Total	Soil: plant ratio		
T_1	13.51	31.79	45.30	2.35	14.14	35.90	50.04	2.54	12.75	35.82	48.57	2.81	4.89	34.78	39.67	7.11	**3.70**	**45.89**
T_2	7.40	34.09	41.49	4.16	8.19	36.58	44.77	4.47	7.60	37.17	44.77	4.89	2.23	36.36	38.59	16.30	**7.57**	**42.40**
T_3	4.10	34.34	38.44	8.38	6.46	38.02	44.48	5.89	7.16	37.26	44.42	5.20	1.28	37.14	38.42	29.02	**12.10**	**41.44**
T_4	51.51	36.59	88.10	0.71	52.52	41.45	93.97	0.79	48.99	43.73	92.72	0.89	45.43	43.31	88.74	0.95	**0.84**	**90.88**
T_5	47.20	36.76	83.96	0.78	50.06	44.19	94.25	0.88	48.25	44.19	92.44	0.92	44.76	42.17	86.93	0.94	**0.88**	**89.39**
T_6	45.63	38.53	84.16	0.84	45.54	43.96	89.50	0.97	48.14	44.54	92.68	0.93	43.18	43.03	86.21	1.00	**0.87**	**88.14**
T_7	44.86	34.53	79.39	0.77	43.74	39.84	83.58	0.91	44.79	40.84	85.63	0.91	44.75	42.51	87.26	0.95	**0.83**	**83.97**
Mean	**30.620**	**35.23**	**65.85**	**1.15**	**31.52**	**39.99**	**71.51**	**1.27**	**31.10**	**40.51**	**71.61**	**1.30**	**26.65**	**39.90**	**66.55**	**1.50**		

4.1.5.2 Soil (+ leaf liter) and plant carbon pool inventory (t ha^{-1}).

The data in the Table 28 gives the soil (+ leaf liter) and plant carbon pool inventory of different altitudinal ranges of temperate north western Himalaya.

Data evinced that irrespective of the altitudinal ranges, mean maximum total carbon density (90.88 t ha^{-1}) is observed in orchard + cereal – cereal land use system, which is closely followed by other land use systems viz., orchard + cereal – vegetable, orchard + vegetable – vegetable. Total carbon stock (soil + plant) as observed in the agroforestry systems is appreciable higher than sole cropping systems i.e. pure orchard, cereal – cereal, cereal – vegetable, vegetable – vegetable at all altitudinal ranges.

Irrespective of the land use systems, total carbon stock at the elevation ranges of 1300-1600 and 1600-1900 m a.s.l. is found to be 5-6 tons/ha more than that at 1000-1300 and 1900-2200 m a.s.l. Plant carbon stock is calculated to be maximum (31.52 t ha^{-1}) at 1300-1600, whereas, total (soil+ plant) carbon is found to be maximum at 1600-1900 m a.s.l. Soil: Plant carbon ratio increased with increase in the altitudinal ranges in each of the land use system. Highest soil: plant carbon ratio is observed in the vegetable – vegetable land use system at all the altitudinal ranges.

4.1.6 Relative carbon dioxide mitigation potential

4.1.6.1 Relative carbon dioxide mitigation potential of different land use system with respect to cereal – cereal cropping system

Data presented in Table 29 depicts the relative carbon mitigation potential of different land system with respect to cereal – cereal taken as 1. Table shows that relative carbon mitigation potential of different land use systems and pure orchard is 4-5 times more than cereal – cereal based land use systems. Carbon mitigation potential of cereal – vegetable and vegetable – vegetable is lower than cereal based cropping system. It is also evidently clear from the table 29 that in general CO_2 mitigation potential at 1000-1300 m a.s.l. and 1300-1600 m a.s.l. is higher than at 1600-1900 and 1900-2200 m a.s.l.

Table 29: Relative CO_2 mitigation potential of different land use systems with respect to agriculture in the valley ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	1.00 (±0.00)*	1.00 (±0.00)	1.00 (±0.00)	1.00 (±0.00)	1.00 (±0.00)
T_2 (Cereal – Vegetable)	0.93 (-0.07)	0.92 (-0.08)	0.87 (-0.13)	0.96 (-0.04)	0.89 (-0.11)
T_3 (Vegetable – Vegetable)	0.74 (-0.26)	1.07 (+0.07)	0.95 (-0.05)	0.58 (-0.42)	0.88 (-0.13)
T_4 (Orchard+Cereal-Cereal)	5.10 (+4.10)	5.79 (+4.79)	4.76(+3.76)	4.34 (+3.34)	5.46 (+4.46)
T_5 (Orchard+Cereal - vegetable)	5.74 (+4.74)	5.60 (+4.60)	4.09(+3.09)	3.58 (+2.58)	4.94 (+3.94)
T_6 (Orchard+Vegetable- Vegetable)	5.40 (+4.40)	5.13 (+4.13)	4.68 (+3.68)	3.81 (+2.81)	5.00 (+4.00)
T_7 (Pure Orchard)	4.56 (+3.56)	4.63 (+3.63)	3.64 (+2.64)	3.19 (+2.19)	4.18(+3.18)

Relative CO_2 mitigation potential of different land use systems considering the value of agriculture as 1.
*values in parentheses are increase/decrease over the cereal-cereal based land use system

4.1.6.2 Relative CO_2 mitigation potential of different land use system with respect to orchard

Data in the Table 30 evinced that different agroforestry land use systems exhibited more CO_2 mitigation potential at all the elevation ranges than annual cropping systems viz., T_1 (cereal – cereal), T_2 (cereal – vegetable), T_3 (vegetable – vegetable). Orchard + cereal – cereal land use system at 1900-2200 m a.s.l. elevation ranges demonstrated highest CO_2 mitigation potential in comparison to pure orchard based land use system. Minimum relative CO_2 mitigation potential is displayed by the vegetable – vegetable based land use system with reference to the pure orchard.

Table 30: Relative CO_2 mitigation potential of different land use systems with respect to horticulture in the valley ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	0.22 (-0.78)	0.22 (-0.78)	0.27 (-0.73)	0.31 (-0.69)	0.24 (-0.76)
T_2 (Cereal – Vegetable)	0.20 (-0.80)	0.20 (-0.80)	0.24 (-0.76)	0.30 (-0.70)	0.21 (-0.79)
T_3 (Vegetable – Vegetable)	0.16 (-0.84)	0.23 (-0.77)	0.26 (-0.74)	0.18 (-0.82)	0.21 (-0.79)
T_4 (Orchard+Cereal-Cereal)	1.12 (+0.12)	1.25(+0.25)	1.31 (+0.31)	1.36 (+0.36)	1.31 (+0.31)
T_5 (Orchard+Cereal - vegetable)	1.26 (+0.26)	1.21 (+0.21)	1.12 (+0.12)	1.12 (+0.12)	1.18 (+0.18)
T_6 (Orchard+Vegetable- Vegetable)	1.18 (+0.18)	1.11 (+0.11)	1.29 (+0.29)	1.20 (+0.20)	1.20 (+0.20)
T_7 (Pure Orchard)	1.00 (±0.00)*	1.00 (±0.00)	1.00 (±0.00)	1.00 (±0.00)	1.00 (±0.00)

Relative CO_2 mitigation potential of different land use systems considering the value of horticulture as 1
*values in parentheses are increase/decrease over the pure orchard based land use system

4.1.7 Carbon credit

One ton of CO_2 mitigation is equal to one ton carbon credit. These carbon credits can be sold in the international carbon market and the average value for 1 carbon credit is US$ 15.00. Carbon credits calculated on per hectare basis have been described in this section.

Data presented in the Table 31 shows that carbon credit (Rs $ha^{-1}yr^{-1}$) varied appreciably under different land use system. Maximum mean carbon credit (Rs 5015) can be released from orchard + cereal – cereal land use system, which is however closely followed by other AFs land use systems viz., orchard + cereal – vegetable (Rs 4536), orchard + vegetable – vegetable (Rs 4590), etc. Carbon credit which can be achieved from orchard based AF land use systems in temperate Himalayas is slightly higher than carbon credit from pure orchard. Annual cropping system viz., cereal – cereal, cereal – vegetable and vegetable – vegetable are eligible for only a meager amount of carbon credits only. Altitudinal gradients do not have much impact on the value of carbon credits.

Table 31: Effect of land use systems, altitudinal gradient and their interaction effect on the rate of production of carbon credits (Rs $ha^{-1}yr^{-1}$) in the valley ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	837	837	1053	1215	918
T_2 (Cereal – Vegetable)	776	770	911	1161	816
T_3 (Vegetable – Vegetable)	621	897	999	702	803
T_4 (Orchard+Cereal-Cereal)	4272	4847	5049	5271	5015
T_5 (Orchard+Cereal - vegetable)	4806	4685	4307	4347	4536
T_6 (Orchard+Vegetable- Vegetable)	4516	4293	4928	4631	4590
T_7 (Pure Orchard)	3821	3875	3834	3875	3834
Mean	2903	2882	2997	2936	

Data presented in the Table 31 also evinced that carbon credits from different agroforestry systems –T_4, T_5 and T_6 are quite higher than pure orchard (T_7) and annual cropping systems at all the altitudinal gradients. Maximum carbon credits (Rs 5271 $ha^{-1}yr^{-1}$) basis can be achieved through orchard + cereal –

cereal based land use system at the elevation range of 1900-2000 m a.s.l. Vegetable – vegetable cropping system at the 1900-2200 m a.s.l. in the valley area of Kullu district is eligible for minimum carbon credits.

4.1.8. Economic analysis

Economic analysis of different land use system along the altitudinal gradients of the Kullu valley of Himachal Pradesh is dealt with in this section under the following sub head:

4.1.8.1 Gross returns (Rs $ha^{-1}yr^{-1}$)

Gross return varied markedly with respect to land use system and altitudinal gradients (Table 32). Gross returns as achieved from agroforestry land use systems and pure orchard at their respective altitudinal ranges is markedly higher than in the annual cropping systems viz., cereal – cereal, cereal - vegetable, vegetable – vegetable. In all the fruit based agroforestry system, gross returns at 1300-1600, 1600-1900 and 1900-2200 m a.s.l. is quite higher than at 1000-1300 m a.s.l. In pure orchard, gross returns increased with increase in the altitudinal ranges. Minimum returns (Rs 66,772 $ha^{-1}yr^{-1}$) are attained in cereal – cereal cropping system at 1900-2200 m a.s.l.

Table 32: Gross return (Rs $ha^{-1}yr^{-1}$) under different land use systems along an altitudinal gradient in the valley ecosystem of Kullu district (H.P.)

Land use systems	Gross return (Rs $ha^{-1}yr^{-1}$)				Mean
	Altitudinal ranges (A)				
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	122760	123165	111300	66772	105999.3
T_2 (Cereal – Vegetable)	231100	497700	484100	494320	426805
T_3 (Vegetable – Vegetable)	394000	866600	844000	525000	657400
T_4 (Orchard+Cereal-Cereal)	444708	838680	1036900	1043200	840872
T_5 (Orchard+Cereal - vegetable)	505400	1066400	1331000	1371400	1068550
T_6 (Orchard+Vegetable- Vegetable)	538000	1345000	1599000	1400000	1220500
T_7 (Pure Orchard)	405000	803000	1037500	1062500	827000
Mean	377281.1	791506.4	920542.9	851884.6	

4.1.8.2 Total expenses (Rs ha^{-1} yr^{-1})

A perusal of the data presented in the Table 33 indicate the total expenses in cereal – cereal based cropping system at all of the four altitudinal ranges are quite less than all other land use systems. In corporation of the vegetable crop component into the land use system increases the cost of production appreciably at each altitudinal range.

Table 33: Total expenses (Rs $ha^{-1}yr^{-1}$) under different land use systems along an altitudinal gradient in the valley ecosystem of Kullu district (H.P.)

Land use systems	Total expenses (Rs $ha^{-1}yr^{-1}$) Altitudinal ranges (A)				Mean
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	95410	95410	95410	44190	82605
T_2 (Cereal – Vegetable)	142260	290720	290720	323985	261921.3
T_3 (Vegetable – Vegetable)	190292	465084	465094	291110	352895
T_4 (Orchard+Cereal-Cereal)	189887	325122	385117	407562	326922
T_5 (Orchard+Cereal - vegetable)	211762	425019	485014	569611	422851.5
T_6 (Orchard+Vegetable- Vegetable)	240038	515575	575570	541767	468237.5
T_7 (Pure Orchard)	140290	254497	314520	364800	268526.8
Mean	172848.4	338775.3	373063.6	363289.3	

4.1.8.3 Net profit (Rs $ha^{-1}yr^{-1}$)

The data for net profit from different land use systems at their respective altitudinal range is presented in table 34. It reveals that in T_6 (Orchard + vegetable -vegetable), T_5 (orchard + cereal - vegetable), T_7 (pure orchard) and T_4 (orchard + cereal - cereal) land use systems, the net profit (Rs $ha^{-1}yr^{-1}$) are markedly higher than the annual cropping systems viz., cereal-cereal, cereal - vegetable and vegetable-vegetable.

The net profit in the altitudinal ranges enhanced markedly from A_1 to A_2 and reached its maxima at A_3 and declined slightly thereafter. The data evinced that incorporation of fruits component in the land use system having cereal and vegetable component markedly enhances the net profit. Maximum net profit is released from the land use system of orchard+ vegetable-vegetable at 1600-1900

m a.s.l., Whereas, various combinations of cereal-cereal at different altitudinal ranges (T_1A_1, T_1A_2, T_1A_3, and T_1A_4) gave quite low values of net profit.

Table 34: Net profit (Rs $ha^{-1}yr^{-1}$) under different land use systems along an altitudinal gradient in the valley ecosystem of Kullu district of (H.P.)

Land use systems	Net profit (Rs $ha^{-1}yr^{-1}$)				Mean
	Altitudinal ranges (A)				
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	27350	27755	15890	22582	23394.25
T_2 (Cereal – Vegetable)	88840	206980	193380	17035	126558.8
T_3 (Vegetable – Vegetable)	203748	401516	378916	233890	304517.5
T_4 (Orchard+Cereal-Cereal)	258821	513558	651783	635638	514950
T_5 (Orchard+Cereal - vegetable)	293638	641381	835986	801789	643198.5
T_6 (Orchard+Vegetable- Vegetable)	297920	829424	1023430	858233	752251.8
T_7 (Pure Orchard)	264710	548503	722980	697700	558473.3
Mean	205003.9	452731	546052.1	466695.3	

4.1.8.4 Benefit- Cost ratio

The estimates of the benefit-cost ratio in the valley ecosystem of Kullu valley are presented in the table 35.

Table 35: Benefit-cost ratio under different land use systems along an altitudinal gradient in the valley ecosystem of Kullu district of (H.P)

Land use systems	Benefit-Cost ratio				Mean
	Altitudinal ranges (A)				
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	1.28	1.29	1.16	0.66	1.41
T_2 (Cereal – Vegetable)	1.62	1.71	1.67	1.52	1.73
T_3 (Vegetable – Vegetable)	2.07	1.86	1.81	1.80	2.02
T_4 (Orchard+Cereal-Cereal)	2.39	2.58	2.69	2.56	1.92
T_5 (Orchard+Cereal - vegetable)	2.39	2.51	2.72	2.42	1.91
T_6 (Orchard+Vegetable- Vegetable)	2.24	2.60	2.77	2.58	1.90
T_7 (Pure Orchard)	2.88	3.15	3.30	2.92	2.33
Mean	2.12	2.24	2.30	2.07	

It is evident from the data presented in the table that benefit–cost ratio is mean maximum in pure orchard based land use system, which is closely followed by vegetable-vegetable (T_3), orchard+cereal-cereal (T_4), orchard + cereal - vegetable (T_5), orchard + vegetable - vegetable (T_6), cereal - vegetable (T_2), and cereal-cereal (T_1), respectively. In the altitudinal gradient, the benefit-cost ratio shows an increasing trend from A_1 to A_2 and reached maximum at A_3 (2.3) and declined thereafter. Mean maximum benefit-cost ratio (2.3) is estimated at 1600-1900 m a.s.l. Minimum (0.66) benefit-cost in cereal-cereal at 1900-2200 m a.s.l.

4.1.8.5 Total Benefit (Net profit + carbon credits) (Rs $ha^{-1}yr^{-1}$)

The data in respect of total benefits (Net profit + carbon credits) from different land use systems at their respective altitudinal range is presented in table 36. It reveals that in the T_6 (orchard + vegetable - vegetable), T_5 (orchard + cereal - vegetable), T_7 (pure orchard) and T_4 (orchard+ cereal-cereal) land use systems, the total benefit (Net profit + carbon credits) are higher than the all annual cropping systems viz., cereal-cereal (T_1), cereal - vegetable (T_2), and vegetable - vegetable (T_3). Maximum total profit (7,56,841.8 Rs $ha^{-1}yr^{-1}$) is recorded in T_6 (orchard + vegetable - vegetable) land use system. In the altitudinal effect, maximum total profit (5,49,063.7 Rs $ha^{-1}yr^{-1}$) is recorded at 1600-1900 m a.s.l. In

Table 36: Total benefits (Net profit + carbon credits) under different land use system along an altitudinal gradient in the valley ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1000-1300 m)	A_2 (1300-1600 m)	A_3 (1600-1900 m)	A_4 (1900-2200 m)	
T_1 (Cereal- Cereal)	28,187	28,592	16,943	23,797	24379.75
T_2 (Cereal – Vegetable)	89,616	20,775	1,94,291	18,196	80719.5
T_3 (Vegetable – Vegetable)	2,04,370	4,02,413	3,79,915	2,34,592	305322.5
T_4 (Orchard+Cereal-Cereal)	2,63,093	5,18,405	6,56,832	6,40,909	519809.8
T_5 (Orchard+Cereal - vegetable)	2,98,444	6,46,066	8,40,293	8,06,136	647734.8
T_6 (Orchard+Vegetable- Vegetable)	3,02,436	8,33,717	10,28,358	8,62,864	756843.8
T_7 (Pure Orchard)	2,68,531	5,52,378	7,26,814	7,01,575	562324.5
Mean	2,07,811	4,28,906.6	5,49,063.7	4,69,724	

the interaction between land use system and altitudinal ranges, maximum benefit is realized from T_6 (orchard + vegetable - vegetable) land use system situated at the altitudinal range of 1600-1900m a.s.l; and minimum in cereal-cereal (T_1) based cropping system situated at 1600-1900 m a.s.l. In general various combinations of cereal-cereal and cereal - vegetable and altitudinal ranges accounted for minimum benefits (Net profit + Carbon credits). Whereas, quite higher total benefits are shown by the treatment of T_4, T_5, T_6, and T_7 at the altitudinal ranges of 1300-1600, 1600-1900 and 1900-2200 m a.s.l.

4.2 BIO-ECONOMIC APPRAISAL AND CARBON SEQUESTRATION POTENTIAL OF DIFFERENT LAND USE SYSTEMS IN MOUNTAINOUS REGION OF KULLU DISTRICTS OF HIMACHAL PRADESH

Survey carried out prior to planning and execution of the study in the four different mountainous ranges of Kullu districts along an altitudinal gradient revealed that land use systems in these regions has under gone a slight change but significant change consequent upon introduction of apple in large scale and vegetable to some extent. The common land use systems, viz., agriculture (T_1), agri-horticulture (T_2), horticulture (T_3), silvi-pasture (T_4) and forest (T_5), which are common in all altitudinal gradient are selected for the present investigation and the results emerging out of the same are discussed as below :

4.2.1 Biomass production level

4.2.2 Biomass carbon density and CO_2 sequestration

4.2.3 Rates of C and CO_2 sequestered, removal and retention

4.2.4 Soil physico-chemical properties

4.2.5 Carbon inventory

4.2.6 Relative CO_2 mitigation potential

4.2.7 Carbon credits

4.2.8 Economic analysis

4.2.1 Biomass production levels

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

A perusal of the data presented in the table 37 reveals that different land use systems, altitudinal gradient and their interaction effect significantly influenced the above ground biomass production.

Table 37: Effect of land use system, altitudinal gradient and their interaction affect on above ground biomass production (t ha^{-1}) in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	20.52	20.45	10.00	4.02	13.75
T_2 (Agri-horticulture)	72.11	78.51	78.19	69.70	73.92
T_3 (Horticulture)	68.91	72.94	73.34	66.86	71.22
T_4 (Silvi-pasture)	84.56	96.06	108.7	118.8	102.0
T_5 (Forest)	268.40	293.80	305.5	478.10	336.4
Mean	102.9	112.3	115.2	147.5	

	SE±	$CD_{0.05}$
T	3.72	7.54
A	3.33	6.74
TxA	7.54	15.26

In the land use system, mean maximum above ground biomass production (336.4 t ha^{-1}) is demonstrated by forest land use system, this is found to be significantly higher than all other land use systems. Above ground biomass production in land use systems followed the trend: forest > silvi-pasture system > agri-horticulture > horticulture > agriculture. Above ground biomass production in horticulture and agri-horticulture remained statistically, alike.

Irrespective of the land use systems, mean above ground biomass production increased with increasing altitudinal ranges. It started from 102.9 t ha^{-1} at 1100-1400 m a.s.l and reached a maximum of 147.5 t ha^{-1} at 2000-2300 m a.s.l. above ground biomass production at 1400-1700 m a.s.l and 1700-2000 m a.s.l remained statistically alike, however their difference to either A_1 or A_4 remained statistically, identical.

Interaction effect between land use system and altitudinal range indicate that forest tree based land use system (T_5) displayed significantly higher values of above ground biomass production than any other treatment combination under

study. The data also evinced that in forest and silvi-pasture land use systems, the above ground biomass increased with increasing altitudinal ranges. Whereas, in horticulture (T_3) and agriculture (T_2), it increased from A_1 to A_3 and then declined. In agriculture based land use system, the above ground biomass production shows a declining trend with the increase in the altitudinal ranges. Above ground biomass production at A_1 and A_2 altitudinal ranges remains statistically higher than A_4.

4.2.1.2 Below ground biomass production (t ha^{-1})

Below ground biomass production is also found to be significantly influenced by land use system, altitudinal gradient and interaction effect between land use system and altitudinal gradient (Table 38).

Table 38: Effect of land use system, altitudinal gradient and their interaction affect on below ground biomass production (t ha^{-1}) in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	8.47	8.00	5.33	4.63	6.60
T_2 (Agri-horticulture)	21.73	24.66	25.11	21.90	23.35
T_3 (Horticulture)	20.10	21.75	22.00	20.89	21.18
T_4 (Silvi-pasture)	17.61	20.09	22.79	24.44	21.23
T_5 (Forest)	54.19	59.23	61.77	96.42	67.90
Mean	24.42	26.75	27.40	33.66	

	SE±	$CD_{0.05}$
T	0.73	1.48
A	0.56	1.32
TxA	1.46	2.95

In the land use system, mean maximum below ground biomass production (67.90 t ha^{-1}) is depicted by forest based land use system, which is found to 3 times higher than the other tree based land use systems viz., agri-horticulture, horticulture, and silvi-pasture, whereas in comparison to annual cropping system, forest accumulated 10 times more below ground biomass.

In the effect of the altitudinal gradient, the below ground biomass production enhanced with increasing altitude. Maximum below ground biomass (33.66 t ha^{-1}) recorded at the 2000-2300 (A_4) altitude is found to be significantly

higher than at A_1, A_2 and A_3. 1400-1700 m and 1700-2000 m altitudinal ranges remained statistically identical.

Table 38 also depicted that below ground biomass production increases with increasing altitudinal ranges from A_1 to A_4 for silvi-pasture (T_4) and forest (T_5) land use systems. Maximum below ground biomass (96.42 t ha^{-1}) is recorded in the forest land use system at 2000-2300 m altitudinal range, which is found to be statistically higher than all other treatment combinations. In general, below ground biomass production in the land use systems of agri-horticulture, horticulture and silvi pastoral remained statistically alike. Agriculture land use system at all altitudinal ranges produced significantly lowest below ground biomass production than any of the other land use system and altitudinal range combination.

4.2.1.3 Total biomass production (t ha^{-1})

Total biomass production (t ha^{-1}) is found to be significantly influenced by land use system, altitudinal gradient and their interaction effect (Table 39).

Table 39: Effect of land use system, altitudinal gradient and their interaction affect on total biomass production (t ha^{-1}) in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	29.00	28.45	15.33	8.38	20.28
T_2 (Agri-horticulture)	93.84	103.2	103.3	91.60	97.51
T_3 (Horticulture)	87.49	94.69	95.33	89.92	91.32
T_4 (Silvi-pasture)	102.10	116.15	131.50	143.29	123.31
T_5 (Forest)	322.50	353.03	367.37	574.52	404.35
Mean	126.60	139.09	142.54	181.11	

	SE±	$CD_{0.05}$
T	4.44	8.99
A	3.97	8.04
TxA	8.88	17.94

In the land use systems, forest based land use system demonstrated 3.5 time to 4 times more total biomass accumulation over other perennials component based land use systems of agri-horticulture (T_2), horticulture (T_3),

silvi-pasture (T_4) and 20 times more than annual cropping system (T_1). In altitudinal gradient total biomass accumulation enhanced with increase in the altitudinal ranges from A_1 to A_4. Altitudinal range of A_1 to A_2 remained statistically at par with one another and differed significantly from A_4.

Interaction between land use system and altitudinal gradient are found to have significant influence on total biomass accumulation. In the land use systems, of silvi-pasture (T_4) and forest (T_5), the total biomass production enhanced with increasing altitude. But in agriculture (T_2) and horticulture (T_3), land use systems, the total biomass production increased from A_1 (1100-1400m) to A_3 (1700-2000m) and declined thereafter. Whereas, in agriculture land use system it increase from A_1 to A_2 and then declined.

4.2.1.4 Rate of biomass production (t $ha^{-1}yr^{-1}$)

Data in the Table 40 evinced that rate of biomass accumulation in mountainous ecosystem is significantly influenced due to land use system, altitudinal range and interaction effect between land use system and altitudinal range.

Table 40: Effect of land use system, altitudinal gradient and their interaction affect on the rate of biomass production (t $ha^{-1}yr^{-1}$) in hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	29.00	28.45	15.28	8.62	20.03
T_2 (Agri-horticulture)	17.10	17.81	15.56	8.96	13.86
T_3 (Horticulture)	4.58	4.73	4.76	3.59	4.42
T_4 (Silvi-pasture)	4.01	3.84	3.94	3.06	3.72
T_5 (Forest)	4.6	4.41	4.31	3.91	4.31
Mean	11.86	11.74	8.77	5.63	

	$SE\pm$	$CD_{0.05}$
T	0.17	0.35
A	0.15	0.32
TxA	0.35	0.71

It is evidently clear from the data presented in the Table 40 that the rate of biomass accumulation is highest (20.03 t^{-1} yr^{-1}) in the agriculture based land use

system, which is found to be significantly higher than all other land use systems. The rate of biomass accumulation in agriculture (T_1) is followed by T_2 (13.86 t $ha^{-1}yr^{-1}$), T_3 (4.42 t $ha^{-1}yr^{-1}$), T_5 (4.31 t $ha^{-1}yr^{-1}$) and T_4 (3.72 t $ha^{-1}yr^{-1}$), respectively in the descending order. Irrespective of the land use system, rate of biomass accumulation declined with the increasing altitudinal ranges from the A_1 to A_4. However, significant differences could be detected from A_2 onward, only. Rate of biomass accumulation at 2000-2300 m a.s.l is half of the A_1 and A_2.

Interaction between land use system and altitudinal gradient shows that maximum rate of biomass (29.0 t $ha^{-1}yr^{-1}$) production is recorded in agriculture based land use system at the altitudinal range of 1100-1400 m a.s.l. Land use combinations of horticulture, silvi-pasture, forest and altitudinal ranges synthesized significantly higher biomass (t $ha^{-1}yr^{-1}$) than combinations of agriculture, agri-horticulture and altitudinal gradient. Significantly lowest rate of biomass accumulation (3.06 t $ha^{-1}yr^{-1}$) is displayed by silvi-pasture system at 2000-2300 m a.s.l.

4.2.1.5 Rate of biomass removal (t $ha^{-1}yr^{-1}$)

Rate of biomass removal (t $ha^{-1}yr^{-1}$) as influenced by land use system, altitudinal gradient and their interaction effect is presented in Table 41.

Irrespective of altitudinal gradient, mean maximum biomass removal (19.19 t ha^{-1} yr^{-1}) is recorded in (T_1) agriculture land use system, which is followed by the agri-horticulture (T_2), horticulture (T_3), silvi-pasture (T_4) and forest (T_5) land use systems, respectively in the descending order. Mean minimum rate of biomass removal (0.85 t ha^{-1} yr^{-1}) is recorded in forest land use system. In altitudinal ranges, rate of biomass removal decreased with the increasing altitudinal ranges. However, significant differences could be detected only from A_2 onwards, only.

In interaction effect between land use systems and altitudinal ranges, rate of biomass removal is very high in agriculture (T_1) land use system at A_1, A_2 and A_3 elevation ranges than all other treatment combinations under investigation.

Table 41: Effect of land use system, altitudinal gradient and their interaction affect on the rate of biomass removal (t $ha^{-1}yr^{-1}$) in hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	28.20	26.84	14.24	7.48	19.19
T_2 (Agri-horticulture)	13.29	13.59	11.32	4.61	10.70
T_3 (Horticulture)	1.34	1.61	1.62	1.62	1.53
T_4 (Silvi-pasture)	1.48	1.41	1.19	1.08	1.29
T_5 (Forest)	1.03	0.87	0.80	0.69	0.85
Mean	9.06	8.86	5.83	3.10	

	SE±	$CD_{0.05}$
T	0.14	0.29
A	0.13	0.26
TxA	0.29	0.58

4.2.1.6 Rate of biomass retention (t $ha^{-1}yr^{-1}$)

It is clear from the results in the Table 42 that rate of biomass retention is significantly influenced by the land use system, altitudinal gradient and their interaction effect.

Table 42: Effect of land use system, altitudinal gradient and their interaction affect on the rate of biomass retention (t $ha^{-1}yr^{-1}$) in hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	0.80	1.61	1.03	1.14	1.12
T_2 (Agri-horticulture)	3.81	4.22	4.24	4.35	4.16
T_3 (Horticulture)	3.24	3.12	3.15	1.96	2.87
T_4 (Silvi-pasture)	2.53	2.43	2.75	1.88	2.40
T_5 (Forest)	3.57	3.54	3.30	3.22	3.40
Mean	2.80	2.88	2.89	2.53	

	SE±	$CD_{0.05}$
T	0.12	0.25
A	0.11	0.22
TxA	0.24	0.48

Irrespective of the altitudinal gradient, mean maximum rate of biomass accumulation (4.16 t ha^{-1} yr^{-1}) is demonstrated by agri-horticulture land use system, which differed significantly from all other land use systems. The rate of

biomass retention in hilly areas of Kullu district followed the trend: agri-horticulture > forest > horticulture> silvi-pasture and agriculture. Rate of biomass retention (t $ha^{-1}yr^{-1}$) is quite low in agriculture system. In altitudinal gradient, rate of biomass accumulation enhanced from A_1 to A_3 and than declined up to A_4.

Interaction effect between land use system and altitudinal gradient reveals that different combinations of forest, agri-horticulture, horticulture and silvi-pasture and altitudinal ranges (A_1, A_2, A_3 and A_4) displayed significantly higher biomass retention than any combination of agriculture based cropping system and altitudinal gradient. Maximum biomass retention (4.35 t $ha^{-1}yr^{-1}$) was recorded in agri- horticulture (T_2) at 2000-2300 m a.s.l and minimum (0.80 t $ha^{-1}yr^{-1}$) at 1100-1400 m a.s.l.

4.2.2 Biomass carbon density

4.2.2.1 Above ground biomass carbon density (t ha^{-1})

Above ground biomass carbon density (t ha^{-1}) as influenced by land use system, altitudinal gradient and their interaction effect is presented in Table 43.

Table 43: Effect of land use systems altitudinal gradient and their interaction effect on above ground carbon density (t ha^{-1}) in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	10.27	10.22	5.00	2.01	6.87
T_2 (Agri-horticulture)	33.46	39.25	39.09	33.43	36.31
T_3 (Horticulture)	35.30	36.47	36.67	34.87	35.82
T_4 (Silvi-pasture)	42.82	48.03	54.37	59.4	51.15
T_5 (Forest)	134.20	146.90	152.70	239.00	168.20
Mean	51.10	56.17	57.57	73.74	

	SE±	$CD_{0.05}$
T	5.82	11.79
A	5.21	10.55
TxA	11.65	23.53

Table 43 evinced that significantly higher above ground biomass carbon density is observed in the forest (168.20 t ha^{-1}) land use system. The above ground carbon density as observed in the land use system of agri-horticulture

(T_2), horticulture (T_3), and silvi-pasture (T_4) remained statistically alike. Whereas, minimum above ground biomass carbon density (6.87 t ha^{-1}) is observed under agriculture (T_1) land use system. Above ground carbon density increased with increase in the altitudinal gradient from A_1 to A_4. However, significant increase can only be detected between A_4 and either of the lower level attitudinal gradients.

In the interaction effect, significantly higher above ground carbon stock is observed in forest land use systems at all the altitudinal ranges. In this land use system, the above ground carbon stock enhanced with rise in the altitudinal gradient and this increase is very sharp from A_3 (1700-2000 m a.s.l) to A_4 (2000-2300 m a.s.l). However, in agriculture land use system this trend is just reverse. Maximum above ground carbon stock (239.0 t ha^{-1}) is observed in forest situated at an elevation range of 2000-2300 m a.s.l. The above ground biomass in the various combinations of agri-horticulture, horticulture and silvi-pasture system and altitudinal ranges (A_1, A_2, A_3 and A_4) remained statistically alike.

4.2.2.2 Below ground biomass carbon density (t ha^{-1})

It is clearly evident from the data presented in the Table 44 that below ground biomass carbon density (t ha^{-1}) is significantly influenced by the land use system, altitudinal gradients and interaction effect between the land use system and altitudinal ranges.

Table 44: Effect of land use systems, altitudinal gradient and their interaction effect on below ground biomass carbon density (t ha^{-1}) in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	4.233	4.20	2.66	2.31	3.30
T_2 (Agri-horticulture)	10.15	12.33	12.55	10.95	11.49
T_3 (Horticulture)	10.70	10.87	11.00	10.44	10.75
T_4 (Silvi-pasture)	8.87	10.04	11.39	12.23	10.63
T_5 (Forest)	27.09	29.61	30.88	48.21	33.95
Mean	12.21	13.37	13.70	16.83	

	$SE\pm$	$CD_{0.05}$
T	0.36	0.72
A	0.32	0.64
TxA	0.71	1.43

Maximum below ground carbon density (33.95 t ha^{-1}) is accumulated by forest land use system, which is found to be significantly higher than all other land use treatments. The below ground biomass carbon density as observed in the land use system of agri-horticulture (T_2) and silvi-pasture (T_4) remained statistically alike. Minimum below ground carbon density (3.30 t ha^{-1}) is recorded in agriculture (T_1) land use. In the altitudinal range effect, the below ground carbon density enhanced significantly from A_1 to A_2 and than remained statistically alike between A_2 to A_3 and than again enhanced significantly from A_3 and A_4.

Interaction effect also depicted significant influence of land use and altitudinal ranges and their trend are same as that of above ground carbon density.

4.2.2.3 Total biomass carbon density (t ha^{-1})

Table 45 evinced that land use system, altitudinal gradient and their interaction effect significantly influenced the total carbon density (t ha^{-1}) in the hills of Kullu districts.

Table 45: Effect of land use systems, altitudinal gradient and their interaction effect on total biomass carbon density l (t ha^{-1}) in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	14.50	13.61	7.63	4.31	10.01
T_2 (Agri-horticulture)	46.92	51.58	51.65	46.04	49.05
T_3 (Horticulture)	44.51	47.41	47.66	44.96	46.13
T_4 (Silvi-pasture)	51.16	58.09	65.77	71.61	61.66
T_5 (Forest)	161.30	176.5	183.6	287.3	202.2
Mean	63.67	69.44	71.27	90.57	

	$SE\pm$	$CD_{0.05}$
T	2.20	4.45
A	1.96	3.98
TxA	4.40	8.89

Forest based land use system displayed the maximum carbon density (202.2 t ha^{-1}), which is found to be 3-4 times higher than other woody component based land use systems viz., agri-horticulture, horticulture and silvi-pasture and

twenty times higher than agriculture land use. Irrespective of land use systems, carbon stock enhanced with increase in the altitudes of the Kullu district of H. P. Carbon density in the altitudinal range of 1400-1700 m and 1700-2000 m a.s.l. remained statistically at par. The altitudinal range of 2000-2300 m that displayed the maximum density (90.57 t ha^{-1}) which is found to be significantly higher than other altitudinal ranges.

In the interaction effect between land use system and altitudinal ranges, it is found that in both T_5 (forest) and T_4 (silvi-pasture system) the carbon density enhanced with the increase in the altitude. Whereas, in agriculture, the trend is just reverse. While in both agriculture (T_1) and agri-horticulture (T_2) it enhanced from A_1 to A_3 and then declined at A_4.

4.2.3 Rates of C and CO_2 sequestration, removal and retention

4.2.3.1 Rate of carbon accumulation (t $ha^{-1}yr^{-1}$)

Table 46 reveals that the rate of carbon accumulation (t $ha^{-1}yr^{-1}$) was significantly influenced by the land use system, altitudinal gradient and interaction effect between land use system and altitudinal ranges.

Table 46: Effect of land use systems, altitudinal gradient and their interaction effect on the rate of carbon sequestration (t $ha^{-1}yr^{-1}$) in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	14.50	13.94	7.60	4.31	10.09
T_2 (Agri-horticulture)	8.55	8.90	7.77	4.48	6.93
T_3 (Horticulture)	2.29	2.36	2.38	1.90	2.21
T_4 (Silvi-pasture)	2.00	1.92	1.97	1.53	1.85
T_5 (Forest)	2.29	2.20	2.14	1.95	2.15
Mean	5.93	5.46	4.37	2.81	

	SE±	$CD_{0.05}$
T	0.35	0.70
A	0.31	0.63
TxA	0.69	1.40

Mean maximum rate of carbon accumulation (10.09 t $ha^{-1}yr^{-1}$) is in the agriculture (T_1) land use system, which was found to be 4-5 times higher over the

other land use system under study and followed these trend: $T_1 > T_2 > T_3 > T_5 > T_4$. In the altitudinal ranges irrespective of the land use system, rate of carbon sequestration increased with increase in the altitudinal range. However, significant differences can be detected from A_2 onward, only.

It is evidently clear from the data in the Table 43 that various combinations of agriculture, agri-horticulture and their altitudinal ranges demonstrated significantly higher rate of biomass accumulation than all other treatment combinations.

4.2.3.2 Rate of carbon stock removal (t $ha^{-1}yr^{-1}$)

It is clearly evident the data presented in the Table 47 that the rate of carbon stock removal (t $ha^{-1}yr^{-1}$) from the hill ecosystem of north western Himalaya of Kullu district (H.P) is significantly influenced by the land use system, altitudinal ranges and interaction effect between the land system and altitudinal ranges.

Rate of carbon stock removal from the system is maximum (9.59 t ha^{-1} yr^{-1}) in the agriculture land use system, which is found to be significantly higher than all other land use and followed the trend: $T_1 > T_2 > T_3 > T_4 > T_5$.

Table 47: Effect of land use systems, altitudinal gradient and their interaction effect on the rate of carbon removal (t $ha^{-1}yr^{-1}$) in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	14.10	13.42	7.12	3.74	9.59
T_2 (Agri-horticulture)	6.61	6.79	5.66	2.31	5.34
T_3 (Horticulture)	0.67	0.80	0.80	0.81	0.74
T_4 (Silvi-pasture)	0.74	0.65	0.59	0.59	0.64
T_5 (Forest)	0.52	0.41	0.36	0.46	0.41
Mean	4.52	4.42	2.90	1.56	

	$SE\pm$	$CD_{0.05}$
T	0.07	0.14
A	0.06	0.13
TxA	0.14	0.28

In the altitudinal gradient effect, irrespective of the land use, the rate of carbon stock removal decreased with increasing altitudinal range from A_1 to A_4. Altitudinal range of A_1 (1100–1400 m and 1400-1700 m a.s.l.) demonstrated significantly higher carbon removal from the system than either A_3 or A_4.

In the interaction effect between land use system and altitudinal range, agriculture (T_1) land use system at 1100-1400 m a.s.l. displayed significantly higher (14.10 t $ha^{-1}yr^{-1}$) carbon stock removal in comparison to all other land use systems. Whereas, forest (T_5) at all the elevation ranges displayed quite low carbon stock removal than all other treatment combinations. Carbon stock removal in silvi-pasture (T_4) and forest (T_5), in general, remained statistically alike.

4.2.3.3 Rate of carbon stock retention (t $ha^{-1}yr^{-1}$)

Table 48 shows that the rate of biomass carbon stock retained (t $ha^{-1}yr^{-1}$) is significantly influenced by land use system, altitudinal gradient and interaction effect between land use system and altitudinal gradient.

Table 48: Effect of land use systems, altitudinal gradient and their interaction effect on the rate of biomass carbon retained (t $ha^{-1}yr^{-1}$) in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	0.40	0.52	0.51	0.56	0.56
T_2 (Agri-horticulture)	1.94	2.11	2.12	2.26	2.08
T_3 (Horticulture)	1.62	1.55	1.58	0.98	1.43
T_4 (Silvi-pasture)	1.26	1.27	1.38	0.89	1.20
T_5 (Forest)	1.78	1.82	1.78	1.61	1.70
Mean	1.40	1.45	1.47	1.26	

	$SE\pm$	$CD_{0.05}$
T	0.05	0.11
A	0.05	0.11
TxA	0.10	0.20

Data presented in the Table 48 shows that mean maximum biomass carbon stock retention (2.08 t $ha^{-1}yr^{-1}$) is in the agri-horticulture based land used system, which is followed by the land use system of forest, horticulture, silvi-

pasture and agriculture respectively, in the descending order. All the land systems differed significantly in respect of biomass based carbon retention. In the altitudinal range, rate of carbon stock retention enhanced with increase in the altitudinal range. However, significant differences can be observed of A_4 with all other altitudinal ranges. Maximum (1.47 t $ha^{-1}yr^{-1}$) was recorded at 1700-2000 m (A_3), which is found to be statistically at par with A_1 and A_2 altitudinal ranges.

In the interaction effect, agriculture land use system at all the elevation ranges displayed lower carbon retention than all other land used systems. Maximum carbon stock retention (2.26 t $ha^{-1}yr^{-1}$) is recorded in agri-horticulture land use at 2000-2300 m a.s.l., which, however remained statistically at par with treatment combinations of T_2 A_2 and T_2 A_3, only.

4.2.3.4 Above ground CO_2 sequestration potential (t ha^{-1})

It is evinced from the data presented in the Table 49 that CO_2 sequestration potential in hill ecosystem of the temperate north western Himalaya is significantly influenced by the land use system, altitudinal gradient and by their interaction effect.

Table 49: Effect of land use systems, altitudinal gradient and their interaction effect on above ground CO_2 sequestration potential (t ha^{-1}) in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	37.66	37.52	18.34	7.37	25.22
T_2 (Agri-horticulture)	123.20	144.2	143.5	122.7	133.4
T_3 (Horticulture)	129.6	133.8	134.6	127.9	131.5
T_4 (Silvi-pasture)	155.2	176.3	199.5	217.9	187.2
T_5 (Forest)	492.4	539.0	563.9	877.3	618.2
Mean	187.6	206.0	212.0	270.6	

	SE±	$CD_{0.05}$
T	6.83	13.84
A	6.12	12.38
TxA	13.68	27.63

Mean maximum CO_2 sequestration by above ground biomass (618.2 t ha^{-1}) is recorded by forest land use system followed by silvi-pasture (187.2 t ha^{-1}),

agri-horticulture (133.4 t ha^{-1}) and horticulture (131.5 t ha^{-1}). Above ground CO_2 sequestration potential shows increasing trend with the increase in the altitudinal ranges. However, the altitudinal ranges of A_2 and A_3 remained statistically at par with one another and differed significantly from A_1 and A_4.

In the interaction effect between land use system and altitudinal ranges, maximum above ground CO_2 sequestration potential (877.3 t ha^{-1}) in displayed by forest (T_5) land use system at 2000-2300 m a.s.l. Whereas, minimum above ground CO_2 sequestration potential (7.37 t ha^{-1}) is recorded by agriculture land use at 2000-2300 m a.s.l. elevation range. The trends of land use systems, altitudinal ranges and their interactions are similar to above ground carbon stock.

4.2.3.5 Below ground CO_2 sequestration potential (t ha^{-1})

Below ground CO_2 sequestration potential is significantly influenced by land use system and altitudinal gradient and by interaction effect between land use system and altitudinal gradient (Table 50).

Table 50: Effect of land use systems, altitudinal gradient and their interaction effect on below ground biomass CO_2 sequestration potential (t ha^{-1}) in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	15.54	14.68	9.78	8.49	12.12
T_2 (Agri-horticulture)	37.26	45.24	46.06	40.18	42.19
T_3 (Horticulture)	39.25	39.91	40.36	38.34	39.46
T_4 (Silvi-pasture)	32.58	36.86	41.82	44.87	39.03
T_5 (Forest)	99.43	108.7	113.3	176.9	124.6
Mean	44.81	49.07	50.27	61.76	

	SE±	$CD_{0.05}$
T	1.34	2.71
A	1.19	2.42
TxA	6.91	13.99

In the land use system, maximum below ground CO_2 sequestration potential is exhibited by forest (T_5) land use (124.6 t ha^{-1}) and minimum by agriculture (T_1) land use system (12.12 t ha^{-1}). In the altitudinal ranges, CO_2 sequestration shows an increasing trend with increase in the altitudinal range. In

the interaction effect, all the interaction combination shows a similar trend as found in respect of above ground CO_2 sequestration, excepting in the treatment combination of T_1 A_4.

4.2.3.6 Total CO_2 sequestration potential (t ha^{-1})

Total CO_2 sequestration potential (t ha^{-1}) is significantly influenced due to land use system, altitudinal range and interaction effect between land use system and altitudinal range (Table 51).

Table 51: Effect of land use systems, altitudinal gradient and their interaction effect on CO_2 sequestration potential (t ha^{-1}) in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	53.21	49.94	28.04	15.82	36.75
T_2 (Agri-horticulture)	172.2	189.3	162.9	162.2	178.5
T_3 (Horticulture)	163.3	174.0	174.9	165.0	169.3
T_4 (Silvi-pasture)	188.1	213.1	241.4	262.8	226.4
T_5 (Forest)	591.9	647.7	673.9	1064	744.4
Mean	233.7	254.8	261.6	334.2	

	SE±	$CD_{0.05}$
T	6.91	13.99
A	6.18	12.52
TxA	13.83	27.94

Irrespective of the altitudinal range, forest based land use system (T_5) demonstrated mean maximum total CO_2 sequestration potential (744.4 t ha^{-1}), which is found to be 3-4 times higher than other perennial land use systems viz., agri-horticulture, horticulture and silvi-pasture system and about twenty times higher than agriculture system. In the altitudinal ranges, irrespective of land use, 2000-2300 m a.s.l. elevation range exhibited significantly highest CO_2 sequestration potential than any other elevation range.

In the interaction effect, the trend of CO_2 sequestration potential is same as that of total biomass carbon density, since CO_2 sequestration potential is simply a derivatives of total carbon stock.

4.2.3.7 Rate of CO_2 sequestration potential (t $ha^{-1}yr^{-1}$)

Rate of CO_2 sequestration potential is significantly influenced due to land use system, altitudinal range and interaction effect between land use system and altitudinal range (Table 52).

Table 52: Effect of land use systems, altitudinal gradient and their interaction effect on rate of CO_2 sequestration potential (t $ha^{-1}yr^{-1}$) in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	53.21	51.16	28.04	15.82	37.06
T_2 (Agri-horticulture)	31.37	32.69	28.55	16.45	27.27
T_3 (Horticulture)	8.42	8.69	8.74	6.59	8.11
T_4 (Silvi-pasture)	7.36	7.05	7.24	5.62	7.91
T_5 (Forest)	8.45	8.12	7.91	7.18	6.82
Mean	21.76	21.54	16.10	10.34	

	$SE\pm$	$CD_{0.05}$
T	0.32	0.65
A	0.28	0.57
TxA	0.64	12.92

In the land use systems, mean maximum CO_2 sequestration potential (37.06 t ha^{-1} yr^{-1}) is demonstrated by agriculture (T_1) followed by agri-horticulture (T_2), horticulture (T_3), silvi-pasture (T_4) and forest (T_5), respectively in the descending order. Irrespective of the land use system, maximum CO_2 sequestration potential (21.76 t ha^{-1} yr^{-1}) is exhibited at 1100-1400 m a.s.l. elevation range which, however, remained statistically at par with A_2 (21.54 t ha^{-1} yr^{-1}). CO_2 sequestration potential at 2000-2300 m a.s.l. is quite low in comparison to CO_2 sequestration potential at the lower elevation ranges.

In the interaction effect, maximum CO_2 sequestration potential (53.21 t ha^{-1} yr^{-1}) is demonstrated by agriculture (T_1) land use at the altitudinal range of 1100 – 1400 m a.s.l. which is at par with 1400-1700 m a.s.l. of the same land use system. However, minimum rate of CO_2 sequestration (5.62 t ha^{-1} yr^{1}) is displayed by the silvi-pasture (T_4) land use system at the highest elevation range i.e. 2000-2300 m a.s.l.

4.2.3.8 Rate of CO_2 leakage (t $ha^{-1}yr^{-1}$)

Land use system, altitudinal range and their interaction effect significantly influenced the rate of CO_2 release in the hilly area of north western temperate Himalayas (Table 53).

Table 53: Effect of land use systems, altitudinal gradient and their interaction effect on the rate of CO_2 leakage (t $ha^{-1}yr^{-1}$) in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	51.74	49.45	26.14	13.74	35.37
T_2 (Agri-horticulture)	24.25	24.93	20.77	8.15	19.53
T_3 (Horticulture)	2.46	2.96	2.94	2.92	2.84
T_4 (Silvi-pasture)	2.71	2.38	2.19	2.35	2.41
T_5 (Forest)	1.89	1.40	1.34	1.27	1.47
Mean	16.61	16.23	10.68	5.70	

	SE±	$CD_{0.05}$
T	0.26	0.54
A	0.24	0.48
TxA	0.53	1.07

In the land use systems, mean maximum CO_2 release (35.37 t $ha^{-1}yr^{-1}$) from the system is depicted by agriculture (T_1) land use, which remained significantly higher than all other land use system under considerations. Whereas, mean minimum CO_2 release is recorded in forest (T_5) (1.47 t $ha^{-1}yr^{-1}$), which is found to be significantly lower than all other land use systems. In the altitudinal ranges, the CO_2 release is maximum (16.61 t $ha^{-1}yr^{-1}$) at A_1. Rate of CO_2 release decreased as we shift from lower altitude to higher altitudinal ranges.

In the interaction effect between land use system and altitudinal range, agriculture (T_1) land use at the altitudinal ranges of 1100-1400 m and 1400-1700 m a.s.l. shows quite higher CO_2 release from the system. Minimum CO_2 release (1.27 t $ha^{-1}yr^{-1}$) is registered by T_5A_4 treatment combination, whereas horticulture (T_3), silvi-pasture (T_4), and forest (T_5) are found to be statistically at par with each other.

4.2.3.9 Rate of CO_2 mitigation potential (t $ha^{-1}yr^{-1}$)

It is evinced from the data presented in the Table 54 that the rate of CO_2 mitigation potential is significantly influenced by land use system, altitudinal range and interaction effect between land use system and altitudinal ranges.

Table 54: Effect of land use systems, altitudinal gradient and their interaction effect on the rate of CO_2 mitigation potential (t $ha^{-1}yr^{-1}$) in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	1.46	1.91	1.90	2.09	1.84
T_2 (Agri-horticulture)	7.09	7.75	7.78	7.98	7.63
T_3 (Horticulture)	5.95	5.72	5.79	3.59	5.26
T_4 (Silvi-pasture)	4.65	4.46	5.05	3.44	4.40
T_5 (Forest)	6.54	6.50	6.05	5.90	6.23
Mean	5.14	5.28	5.30	4.64	

	$SE\pm$	$CD_{0.05}$
T	0.20	0.40
A	0.18	0.37
TxA	0.40	0.81

Mean maximum CO_2 mitigation (7.63 t $ha^{-1}yr^{-1}$) is demonstrated by Agri-horticulture (T_2) land use system followed by forest (6.23 t ha^{-1} yr^{-1}), horticulture (5.26 t $ha^{-1}yr^{-1}$), silvi-pasture (4.40 t $ha^{-1}yr^{-1}$) and agriculture (1.84 t $ha^{-1}yr^{-1}$), respectively. In the altitudinal ranges, the rate of CO_2 mitigation potential is maximum at A_3 (5.30 t $ha^{-1}yr^{-1}$). CO_2 mitigation potential of three elevation ranges viz., A_1, A_2 and A_3 remained statistically alike. However, all of three ranges differed significantly with A_4 elevation range.

In the interaction effect, maximum CO_2 mitigation potential (7.98 t ha^{-1} yr^{-1}) is recorded in T_2A_4 treatment combination; whereas the minimum rate of CO_2 mitigation potential (1.46 t $ha^{-1}yr^{-1}$) is displayed by agriculture (T_1) land use system at the altitudinal range of 1100-1400 m a.s.l.

2.2.4 Soil physico-chemical properties

2.2.4.1 Soil organic carbon (%)

Study of the ANOVA table (appendix V11) reveals that average effect of land use system, altitudinal range and soil layer significantly influenced the soil

organic carbon (%). In the interaction effect, two way interactions between land use system and soil depth, land use system and altitudinal range, altitudinal range and soil depth and the three way interactions of land use system, altitudinal range and soil depth exercised significant influence on soil organic carbon (%).

A perusal of the data presented in the Table 55 reveals that soil organic carbon (%) is significantly influenced by average effect of land use system, altitudinal range and soil layer. In the land use systems, mean maximum soil organic carbon (2.5 %) is sequestered by the forest land use system, which is found to be significantly higher than all other land use systems. Soil organic carbon (0.89 %) in agri-horticulture land use system remained statistically identical to horticulture based land use system. Minimum soil organic carbon (0.68%) is found in the agriculture land use system.

Table 55: Soil organic carbon, bulk density and soil organic carbon density (SOC) as influenced by average effect* of land use system, altitudinal ranges and soil layer in the hill ecosystem of Kullu district (H.P.)

A) Land use systems (T)	Soil Organic Carbon (%)	Bulk Density (g cm^{-3})	Soil Organic Carbon stock (t ha^{-1})	Available nitrogen (kg ha^{-1})
T_1 (Agriculture)	0.68 e	1.25 a	16.94 e	425.2 bc
T_2 (Agri-horticulture)	0.89 b	1.16 c	20.59 b	510.4 a
T_3 (Horticulture)	0.87 c	1.20 b	20.52 c	510.4 a
T_4 (Silvi-pasture)	0.81 d	1.12 d	17.90 d	392.6 d
T_5 (Forest)	2.50 a	0.97 e	49.04 a	443.2 b
SE± **CD0.05**	0.03 0.05	0.01 0.03	0.56 1.11	11.2 22.3
B) Altitudinal range(A)				
A_1 (1100-1400) m	1.03 d	1.20 a	23.06 d	419.4 bc
A_2 (1400-1700) m	1.09 c	1.19 b	25.20 bc	438.2 b
A_3 (1700-2000) m	1.15 b	1.14 c	25.96 ab	484.7 a
A_4 (2000-2300) m	1.34 a	1.04 d	26.77a	480.0 a
SE± **CD 0.05**	0.02 0.05	0.013 0.025	0.51 1.02	10.0 20.0
A) Soil Layer (L)				
L_1 (0-20 cm)	1.32 a	1.13 b	28.42 a	495.5 a
L_2 (20-40 cm)	0.98 b	1.15 a	21.58 b	415.6 b
SE± **CD 0.05**	0.02 0.03	0.01 NS	0.35 0.71	7.1 14.1

Average effect* means mean values irrespective of other treatments

In the altitudinal ranges, mean maximum soil organic carbon (1.34 %) is recorded at the altitudinal level of the 2000-2300 m a.s.l., which is found to be significantly higher than all other altitudinal ranges. Status of soil organic carbon (%) enhanced significantly with each 300 meter rise in the elevation range from 1100-1400 to 2000-2300 m a.s.l. Irrespective of the land use system and altitudinal range, soil organic carbon declined significantly at L_2 (20-40 m) in comparison to L_1 (0-20 cm) soil layer.

A perusal of the data in the Table 56 reveals that in all the land use systems L_1 (0-20 cm) layer, displayed higher soil organic carbon than L_2 (20-40 cm) layer. Though, their difference is found to be non significant. Maximum soil organic carbon (2.78%) is displayed by forest land use system, which is found to be significantly higher than all other treatment combinations, excepting T_5L_2.

Table 56: Effect of interaction between treatment and soil depth on soil organic carbon (%) in the hill ecosystem of Kullu district (H.P.)

Land use systems (T)	Soil depth	
	L_1(0-20 cm)	L_2(20-40 cm)
T_1 (Agriculture)	0.778	0.583
T_2 (Agri-horticulture)	1.048	0.731
T_3 (Horticulture)	1.057	0.691
T_4 (Silvi-pasture)	0.955	0.673
T_5 (Forest)	2.780	2.225
SE±	**0.36**	
CD 0.05	**0.72**	

Data presented in the Table 57 evinced that in each land use system the percent organic carbon increases with rise in each altitudinal range. However, this

Table 57: Effect of interaction between treatment and altitudinal gradient on soil organic carbon (%) in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)			
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)
T_1 (Agriculture)	0.592	0.633	0.666	0.832
T_2 (Agri-horticulture)	0.777	0.855	0.903	1.025
T_3 (Horticulture)	0.734	0.760	0.848	1.133
T_4 (Silvi-pasture)	0.739	0.790	0.825	0.902
T_5 (Forest)	2.306	2.393	2.517	2.794
SE±	**0.05**			
$CD_{0.05}$	**0.10**			

increase is quite marked as we moves in from 1700-2000 m to 2000-2300 m a.s.l. Maximum per cent organic carbon (2.79 %) is recorded at the treatment combination of forest land use at 2000-2300 m a.s.l. and minimum (0.59 %) at T_1A_1 treatment combination.

It is quite clear from the data in the Table 58 that per cent soil organic carbon is significantly higher in L_1 (0-20 cm) than L_2 (20-40 cm) layer. It is also evident from the table that in both the layers, the per cent organic carbon increases with altitudinal ranges but this increase is more sharp in the L_1 (0-20 cm) than L_2 (20-40 cm) layer.

Table 58: Effect of interaction between altitudinal gradient and soil depth on soil organic carbon (%) in the hill ecosystem of Kullu district (H.P.)

Altitudinal ranges (A)	Soil layer(L)	
	L_1 (0-20 cm)	L_2 (20-40 cm)
A_1 (1100-1400 m)	1.15	0.91
A_2 (1400-1700 m)	1.22	0.95
A_3 (1700-2000 m)	1.34	0.97
A_4 (2000-2300 m)	1.58	1.10
SE±	0.02	
$CD_{0.05}$	0.05	

Table 59 presents the three way interaction between land use system, altitudinal gradient and soil depth. It's evident from the Table 59 that per cent carbon shows quite variation in the different treatment combinations. However,

Table 59: Effect of interaction between treatment, altitudinal gradient and soil depth (cm) on soil organic carbon (%) in the hill ecosystem of Kullu district (H.P.)

Land use Systems	Altitudinal ranges (A)							
	A_1 (1100-1400 m)		A_2 (1400-1700 m)		A_3 (1700-2000 m)		A_4 (2000-2300 m)	
	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm
T_1 (Agriculture)	0.686	0.499	0.778	0.488	0.746	0.585	0.902	0.761
T_2 (Agri-horticulture)	0.886	0.667	0.988	0.723	1.109	0.697	1.211	0.838
T_3 (Horticulture)	0.839	0.630	0.894	0.625	0.998	0.699	1.456	0.810
T_4 (Silvi-pasture)	0.845	0.634	0.892	0.689	0.980	0.670	1.104	0.700
T_5 (Forest)	2.507	2.105	2.550	2.237	2.850	2.185	3.214	2.373
SE±	0.07							
$CD_{0.05}$	0.15							

various combinations of the forests were found to be significantly higher than other land use and altitudinal range, treatment combinations, only.

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

Bulk density (g cm^{-3}) is significantly influenced by average effects of land use system and altitudinal range (Table 55). In the interaction effect only two way interactions between land use systems and soil depth exercised a significant influence on the bulk density.

Maximum bulk density (1.25 g cm^{-3}) is recorded in the land use system of agriculture, which is followed by the land use system of horticulture, agri-horticulture, silvi-pasture and forest land use systems, respectively in the descending order (Table 55). All the land use system differed significantly from one another. In the altitudinal ranges, bulk density declined with the increase in the altitudinal gradient. Altitudinal gradient of A_1 and A_2 recorded statistically alike values but both differed significantly from A_3 and A_4.

Data presented in the Table 60 depicts that in general land use systems involving high intercultural intensities viz., agriculture, agri-horticulture and horticulture gave significantly higher values of bulk density than low intensity based silvi-pasture and forest land use system at all the altitudinal gradient. Agriculture land use system at 1100-1400 m a.s.l. displayed maximum values of bulk density whereas, minimum values are displayed by forest land use system at the altitudinal range of 2000-2300 m a.s.l.

Table 60: Effect of interaction between treatment, and altitudinal gradient on bulk density (g cm^{-3}) in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)			
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)
T_1 (Agriculture)	1.339	1.279	1.247	1.151
T_2 (Agri-horticulture)	1.247	1.164	1.213	1.028
T_3 (Horticulture)	1.258	1.253	1.219	1.083
T_4 (Silvi-pasture)	1.197	1.236	1.041	0.994
T_5 (Forest)	0.975	1.005	0.966	0.923
SE±	0.03			
$CD_{0.05}$	0.06			

2.2.4.3 Soil organic carbon density (t ha^{-1})

In the average effect, soil organic carbon density is significantly influenced by land use system, altitudinal range and soil layer (Table 55). In the interaction effect, two way interaction between land use system and soil depth exercised a significant influence.

Data presented in the Table 55 evinced that soil organic carbon density is maximum (49.04 t ha^{-1}) in forest based land use system, which is followed by horticulture (20.59 t ha^{-1}), agri-horticulture (20.52 t ha^{-1}), silvi-pasture (17.90 t ha^{-1}) and agriculture (16.94 t ha^{-1}), respectively in the descending order. In the altitudinal ranges, maximum soil organic carbon density (26.77 t ha^{-1}) is recorded at the altitudinal range of 2000-2300 m a.s.l. which differed significantly from all other altitudinal ranges. A_2 and A_3 altitudinal ranges remained statistically on a par with one another but differed significantly from A_1 and A_4 L_1 soil layer (0-20 cm) displayed significantly higher carbon density than L_2 (20-40 cm).

It is evinced from the data presented in the Table 61 that all land use systems displayed significantly higher soil carbon density at L_1 (0-20 cm) level than L_2 (20-40 cm). Treatment combinations of forest based land use i.e. T_5 L_1 and T_5 L_2 demonstrated significantly higher values than all other treatment combinations under consideration, whereas agriculture land use system at L_2 depth (T_1 L_2) gave significantly lowest (14.58 t ha^{-1}) carbon density than any other land use system.

Table 61: Effect of interaction between treatment and soil depth on soil organic carbon density (t ha^{-1}) in the hill ecosystem of Kullu district (H.P.)

Altitudinal ranges (A)	Soil layer(L)	
	L_1 (0-20 cm)	L_2 (20-40 cm)
T_1 (Agriculture)	19.30	14.58
T_2 (Agri-horticulture)	23.90	17.15
T_3 (Horticulture)	24.52	16.67
T_4 (Silvi-pasture)	20.80	14.99
T_5 (Forest)	53.56	44.52
SE±	0.79	
$CD_{0.05}$	1.57	

A perusal of the data presented in the Table 62 reveals that soil organic carbon density varied significantly in response to interaction between land use system and altitudinal range. In general, carbon density enhanced in all land uses with the increase in the altitude, excepting at the treatment combinations of T_2A_4, T_4A_3 and T_4A_4.

Table 62: Effect of interaction between treatment and altitudinal gradient on soil organic carbon density (t ha^{-1}) in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)			
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)
T_1 (Agriculture)	15.84	16.21	16.62	19.09
T_2 (Agri-horticulture)	19.32	19.87	21.88	21.03
T_3 (Horticulture)	18.44	19.04	20.65	24.25
T_4 (Silvi-pasture)	16.88	19.70	17.10	17.91
T_5 (Forest)	44.82	48.56	51.18	51.59
SE±	1.12			
$CD_{0.05}$	2.24			

Data in the Table 63 shows that all the land use at L_1 (0-20 cm) layer displayed significantly higher soil carbon stock than L_2 (20-40 cm) layer. Maximum soil carbon density (31.35 t ha^{-1}) is demonstrated at 2000-2300 m a.s.l., which is found to be significantly higher than any other treatment combinations under consideration.

Table 63: Effect of interaction between altitudinal gradient and soil depth (cm) on soil organic carbon density (t ha^{-1}) in the hill ecosystem of Kullu district (H.P.)

Altitudinal ranges (A)	Soil layer(L)	
	L_1 (0-20 cm)	L_2 (20-40 cm)
1100-1400 m	25.58	20.56
1400-1700 m	27.96	22.44
1700-2000 m	28.80	21.13
2000-2300 m	31.35	22.20
SE+	0.71	
$CD_{0.05}$	1.41	

Table 64 shows that soil carbon stock is significantly influenced by three way interaction between land use system, altitudinal ranges and soil depth. Data

presented in the table evinced that all the land uses at each elevation ranges depicted significantly higher soil carbon stock at L_1 (0-20 cm) in comparison L_2 (20-40 cm) layer. Forest land use at 2000-2300 m a.s.l. in 0-20 cm layer displayed significantly highest soil organic carbon density than any other treatment combinations.

Table 64: Effect of interaction between treatment, altitudinal gradient and soil depth (cm) on soil organic carbon density (t ha^{-1}) in the hill ecosystem of Kullu district (H.P.)

Land use Systems	Altitudinal ranges (A)							
	A_1 (1100-1400 m)		A_2 (1400-1700 m)		A_3 (1700-2000 m)		A_4 (2000-2300 m)	
	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm
T_1 (Agriculture)	18.20	13.48	19.96	12.46	18.57	14.66	20.48	17.71
T_2 (Agri-horticulture)	21.69	16.95	22.56	17.18	26.81	16.96	24.55	17.50
T_3 (Horticulture)	20.82	16.06	22.31	15.77	24.21	17.08	30.72	17.78
T_4 (Silvi-pasture)	19.41	14.34	22.08	17.31	19.95	14.26	21.77	14.05
T_5 (Forest)	47.67	41.98	52.90	49.46	54.44	42.69	59.24	43.95
SE±	1.59							
$CD_{0.05}$	3.16							

2.2.4.4 Available nitrogen (kg ha^{-1})

Available nitrogen content is significantly influenced by average affect of land use system, altitudinal range and soil layer (Table 55). Maximum available nitrogen contents are found in horticulture and agri-horticulture based land use systems each displaying identical value of available nitrogen i.e. 510.4 kg ha^{-1}, which is found to be significantly higher than the available nitrogen status of forest (443.2 kg ha^{-1}), agriculture (425.2 kg ha^{-1}) and silvi-pasture system (392.6 kg ha^{-1}), respectively. In the altitudinal ranges, maximum available nitrogen (484.7 kg ha^{-1}) is record at the elevation range of 1700-2000 m a.s.l. which, however, remained statistically at par with the A_4 (480.0 kg ha^{-1}) and differed significantly from A_2 (438.2 kg ha^{-1}) and A_1 (41.94 kg ha^{-1}). Irrespective of land use system and altitudinal range, maximum available nitrogen (495.5 kg ha^{-1}) is found in the L_1 (0-20 cm) layer which is significantly higher than L_2 (415.6 kg ha^{-1}) layer.

Effect of two way interaction between land use system and altitudinal range is presented in the Table 65. The data evinced that there is no discernible trends in the amount of available nitrogen in different land uses with respect to increasing level of altitude, excepting in forest based land use system. In forest based land use system the available nitrogen increased with the increasing altitudinal range whereas, in T_2 and T_4 it increased from A_1 to A_3 and than declined.

Table 65: Effect of interaction between treatment and altitudinal gradient on the available nitrogen (kg ha^{-1}) in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)			
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)
T_1 (Agriculture)	447.4	426.5	456.9	370.0
T_2 (Agri-horticulture)	480.8	493.4	542.5	524.8
T_3 (Horticulture)	478.8	472.5	520.9	551.9
T_4 (Silvi-pasture)	328.4	378.4	443.2	420.2
T_5 (Forest)	359.8	421.0	459.9	533.1
SE±	22.4			
$CD_{0.05}$	44.7			

4.2.5 Carbon Inventory

4.2.5.1 Soil organic pool inventory (t ha^{-1})

Data presented in the Table 66 depicts the status of soil organic carbon in different soil layers i.e. 0-20, 20-40 and 0-40 cm in different land use system along an altitudinal gradient. Irrespective of the altitudinal ranges, maximum soil carbon (98.08 t ha^{-1}) in 0-40 cm soil layer is recorded in the perennial land use system (forest), which is closely followed by the treatments T_2 (41.05 t ha^{-1}), T_3 (39.16 t ha^{-1}), T_4 (35.79 t ha^{-1}) and T_1 (33.88 t ha^{-1}), respectively in the descending order. In altitudinal ranges, the soil organic carbon in the 0-40 cm did not showed a consistent trend. It first showed an increase from A_1 to A_2 and then declined from A_2 to A_3 and then again showed an increasing trend from A_3 to A_4.

In each land use system, the soil organic carbon (SOC) was found to be higher in 0-20 cm layer than 20-40 cm layer at all the altitudinal ranges. In general, soil organic carbon at A_2, A_3 & A_4 altitudinal ranges is found to be higher than at the lowest elevation ranges i.e. 1100-1400 m a.s.l. The total soil organic carbon stock (SOC) as observed in the forest (T_5) land use system is found to be 2-3 times higher over other land use systems at all the altitudinal ranges.

4.2.5.2 Soil (+ leaf litter) and plant carbon pool inventory (t ha^{-1})

The data in Table 67 presents the soil (+ leaf litter) and plant carbon pool inventory of different land use systems spread along the altitudinal gradient of ranges of temperate north-western Himalaya in mountainous eco-system of Kullu districts. Data reveals that in all perennial plant based land use systems viz., agri-horticulture, horticulture, silvi-pasture, and forest based land use systems carbon pool is higher in plants than in the soil, whereas, in the annual cropping system i.e. agriculture the carbon stock is quite higher (2.61) in soil than in the plant system.

It is also evident from the data presented in the table that irrespective of altitudinal gradient maximum carbon density is (303.39 t ha^{-1}) in the forest based land use system, which is found to be around 3.5-4 times higher over other Perennials land use systems viz., agri-horticulture, (72.8 t ha^{-1}) horticulture (68.6t ha^{-1}) and silvi-pastoral (80.1 t ha^{-1}) and about 6.5 times than agriculture land use. In the altitudinal ranges, irrespective of the land use system total carbon density shows an increasing trend from A_1 to A_4. However, greatest increment is recorded from A_3 to A_4, only. The interaction between land use system and altitudinal gradient reflects a marked variation in respect of plant, soil and total (soil + plant) carbon density as well as soil: plant carbon ratios.

Table 66: Soil carbon inventory (t ha^{-1}) under different land use systems along an altitudinal gradient in the hill ecosystem of Kullu district (H.P.)

Land use Systems	A_1 (1100-1400 m)			A_2 (1400-1700 m)			A_3 (1700-2000 m)			A_4 (2000-2300 m)			Mean
	0-20 cm	20-40 cm	0-40 cm	0-20 cm	20-40 cm	0-40 cm	0-20 cm	20-40 cm	0-40 cm	0-20 cm	20-40 cm	0-40 cm	
T_1 (Agriculture)	18.20	13.48	31.68	19.96	12.46	32.42	18.57	14.66	33.23	20.48	17.71	38.19	**33.88**
T_2 (Agri-horticulture)	21.69	16.95	38.64	22.56	17.18	39.74	26.81	16.96	43.77	24.55	17.85	42.05	**41.05**
T_3 (Horticulture)	20.82	16.06	36.88	22.31	15.77	38.08	24.21	17.08	41.29	24.21	16.25	40.37	**39.16**
T_4 (Silvi-pasture)	19.41	14.34	33.75	22.08	17.31	39.39	19.95	14.26	34.21	21.77	14.05	35.82	**35.79**
T_5 (Forest)	47.67	41.98	89.65	52.90	49.46	102.36	54.44	42.69	97.13	59.24	43.95	103.19	**98.08**
Mean	**25.66**	**20.56**	**46.12**	**27.96**	**22.44**	**50.40**	**28.80**	**21.13**	**49.93**	**31.35**	**22.20**	**53.55**	

Table 67: Soil (+leaf litter) and biomass carbon inventory (t ha^{-1}) under different land use systems along an altitudinal gradient in the hill ecosystem of Kullu district (H.P.)

Land use systems	A_1 (1100-1400)				A_2 (1400-1700)				A_3 (1700-2000)				A_4 (2000-2300)				Mean Soil: plant ratio	Mean Total
	Plant	Soil	Total	Soil: plant ratio	Plant	Soil	Total	Soil: plant ratio	Plant	Soil	Total	Soil: plant ratio	Plant	Soil	Total	Soil: plant ratio		
T_1 – A	14.50	32.53	47.03	2.24	13.61	33.34	46.95	2.45	7.64	33.88	41.52	4.43	10.01	39.14	49.15	3.19	**2.61**	**36.93**
T_2 –AH	45.89	40.49	86.38	0.88	51.58	41.19	92.77	0.80	51.65	45.02	96.67	0.87	44.96	43.33	88.29	0.96	**0.70**	**72.82**
T_3 – H	43.83	37.53	81.36	0.81	47.41	38.86	86.27	0.82	47.66	42.09	89.75	0.88	44.38	41.23	85.61	0.93	**0.71**	**68.60**
T_4 – SP	51.06	36.25	87.31	0.71	58.09	42.19	100.28	0.73	65.77	37.41	103.18	0.57	71.61	38.32	109.93	0.54	**0.51**	**80.14**
T_5 – F	161.30	94.15	255.45	0.58	176.50	104.14	280.64	0.59	183.60	98.98	282.58	0.54	287.30	105.99	393.29	0.37	**0.42**	**303.39**
Mean	**63.31**	**48.19**	**111.51**	**1.06**	**69.44**	**51.94**	**121.38**	**1.08**	**71.27**	**51.48**	**122.74**	**1.46**	**63.31**	**53.60**	**145.25**	**1.34**		

4.2.6 Relative CO_2 mitigation potential

4.2.6.1 Relative CO_2 mitigation potential of different land use system with respect to forest

The data in Table 68 shows the carbon density in different land use system relative to forest system taken as 1. The table shows that all the systems shows quite low carbon density in comparison to forest land use system. The relative carbon mitigation potential of agriculture land use system is very low than the perennial tree based land use systems viz., forest, horticulture and silvi-pasture at all the altitudinal ranges. It is also evidently clear from the Table 68 that CO_2 mitigation potential of agri-horticulture increase with increase in altitudinal ranges as compared to forest based land use system, whereas, horticulture and silvi-pasture system do not shows any consistent trend.

Table 68: Relative CO_2 mitigation potential of different land use systems with respect to forest in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	0.22 (-0.78)	0.29 (-0.71)	0.29 (-0.71)	0.35 (-0.65)	0.29 (-0.71)
T_2 (Agri-horticulture)	1.08 (0.08)	1.16 (0.16)	1.19 (0.19)	1.41 (0.41)	1.20 (0.20)
T_3 (Horticulture)	0.91 (-0.09)	0.86 (-0.14)	0.88 (-0.12)	0.61 (-0.39)	0.82 (-0.18)
T_4 (Silvi-pasture)	0.71 (-0.29)	0.70 (-0.30)	0.77 (-0.23)	0.59 (-0.41)	0.70 (-0.30)
T_5 (Forest)	1.00 (±0.00)*	1.00 (±0.00)	1.00 (±0.00)	1.00 (±0.00)	1.00 (±0.00)

Relative CO_2 mitigation potential of different land use systems considering the value of forest as 1
*values in parentheses are increase/decrease over the forest land use system

4.2.6.2 Relative CO_2 mitigation potential of different land use system with respect to agriculture

The Table 69 depicts the CO_2 mitigation potential of different land use system with respect to agriculture at different altitudinal ranges in the mountainous ecosystem of the Kullu district of Himachal Pradesh.

Table 69: Relative CO_2 mitigation potential of different land use systems with respect to agriculture in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	1.00 (±0.00)*	1.00 (±0.00)	1.00 (±0.00)	1.00 (±0.00)	1.00 (±0.00)
T_2 (Agri-horticulture)	4.86 (3.86)	4.06 (3.06)	4.09 (3.09)	3.97 (2.97)	4.20 (3.20)
T_3 (Horticulture)	4.08 (3.08)	2.99 (1.99)	3.05 (2.05)	1.73 (0.73)	2.86 (1.86)
T_4 (Silvi-pasture)	3.18 (2.18)	2.45(1.45)	2.66 (1.66)	1.67 (0.67)	2.43 (1.43)
T_5 (Forest)	4.48 (3.48)	3.50 (2.50)	3.45 (2.45)	2.82 (1.82)	3.49 (2.49)

Relative CO_2 mitigation potential of different land use systems considering the value of agriculture as 1

*values in parentheses are increase/decrease over the agriculture based land use system

The data presented evinced that the CO_2 mitigation potential of all the perennial component based land use systems is 2-4 times higher than agriculture and followed the trend agri-horticulture > forest > horticulture > silvi-pasture. It is also evident from the data that there is no consistent trend in respect of different land use systems and altitudinal gradient, excepting in forest based land use system. In forest based land use system, the relative carbon dioxide mitigation potential with respect to agriculture taken as 1 declined with the increase in the altitudinal ranges.

4.2.7 Carbon credit

Data presented in the Table 70 shows that carbon credit (Rs $ha^{-1}yr^{-1}$) varied appreciably under different land use systems. Mean maximum carbon

Table 70: Effect of land use systems, altitudinal gradient and their interaction effect on the rate of production of carbon credits (Rs $ha^{-1}yr^{-1}$) in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	986	1289	1282	1411	1242
T_2 (Agri-horticulture)	4786	5231	5252	5596	5218
T_3 (Horticulture)	4016	3861	3908	2437	3551
T_4 (Silvi-pasture)	3139	3152	3409	2363	3017
T_5 (Forest)	4415	4509	4428	3983	4334
Mean	3470	3611	3659	3159	

credit (Rs 5218 $ha^{-1}yr^{-}$) can be realized from agri-horticulture land use system, followed closely by forest (Rs 4333 $ha^{-1}yr^{-}$), horticulture (Rs 3550 $ha^{-1}yr^{-}$), Silvi-pasture (Rs 3017 $ha^{-1}yr^{-}$) and agriculture (Rs 1242 $ha^{-1}yr^{-}$), respectively in the descending order. An altitudinal gradient does not have much impact on the value of carbon credits.

It is also evident from the table that carbon credits, which can be released from agri-horticulture is higher than all other land use system at all the altitudinal ranges. Agriculture based land use system is eligible for least carbon credit. Carbon credits are minimum at A_1 and the value of the carbon credit enhanced from A_1 toA_2 and then shows a declining trend thereafter.

Data presented in table 70 also evinced that carbon credits from different perennial land use system T_2, T_3, T_4 & T_5 are higher than agriculture (T_1) annual cropping systems at all the altitudinal gradients. Maximum carbon (Rs 5596 $ha^{-1}yr^{-1}$) can be achieved through T_2 (Agri-horticulture) based land use system at the elevation range of 2000-2300 m a.s.l. Agriculture (T_1) land use system at the A_1 (1100-1400 m) in the hilly area of Kullu districts is eligible for minimum (Rs 986 $ha^{-1}yr^{-1}$) carbon credits.

4.2.8 Economic analysis

Economic analysis of different land use systems along the altitudinal gradients of the mountainous region of Kullu district of Himachal Pradesh is dealt with in this section under the following sub heads:

4.2.8.1 Gross return (Rs $ha^{-1}yr^{-1}$)

The data in respect of gross return (Rs $ha^{-1}yr^{-1}$) in different land use systems at different altitudinal ranges is presented in the Table 71. The table evinced that irrespective of land use system, rate of gross return is maximum (Rs 11,03,800) in agri-horticulture system, which is closely followed by the land use systems of horticulture, agriculture, forest and silvi-pasture system, respectively in the descending order. It is also evident from the interaction between the land use system and altitudinal gradient that agri-horticulture and horticulture based

land use systems yields very high gross return at all the altitudinal ranges. These gross returns at A_2, A_3 and A_4 altitudinal ranges is more than two times than at A_1. In agriculture land use the returns at A_3 and A_4 altitudinal ranges is more than 3 times than at A_1.

Table 71: Gross return under different land use system along an altitudinal gradient in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	123600	119700	399600	464600	276875
T_2 (Agri-horticulture)	510100	1120000	1394900	1390200	1103800
T_3 (Horticulture)	430000	1085000	1105000	1095000	928750
T_4 (Silvi-pasture)	47256	63604	116438	127954	88813
T_5 (Forest)	101393	161425	177742	210833	162848
Mean	242469	509946	638736	657717	

4.2.8.2 Total expenses (Rs $ha^{-1}yr^{-1}$)

A perusal of the data presented in the Table 72 reveals that total expenses in different land use systems at different altitudinal ranges varied appreciably.

Irrespective of the altitudinal ranges maximum expenses are involved in the agri-horticulture, (Rs. 3, 72,990) based land use system, which is closely followed by horticulture (Rs 2, 56,897), agriculture (Rs 1, 91,776), forest (Rs 31,930) and silvi-pasture systems, respectively. In the altitudinal ranges, expenses show a consistent increasing trend in respect of total expenses incurred.

Table 72: Total expenses under different land use system along an altitudinal gradient in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	95410	95410	254994	321290	191776
T_2 (Agri-horticulture)	210880	325390	429706	525986	372990
T_3 (Horticulture)	140290	254800	312500	320000	256897
T_4 (Silvi-pasture)	16802	18060	18560	20260	18420
T_5 (Forest)	27464	29530	32470	38255	31930
Mean	98169	144638	209646	245158	

In the interaction effect between the land use system and altitudinal ranges, expenses are quite higher in respect of agri-horticulture and horticulture land use system at all the altitudinal ranges followed by agriculture, forest and silvi-pasture land use systems respectively.

4.2.8.3 Net profit (Rs $ha^{-1}yr^{-1}$)

Net profit achieved in different land use systems along an altitudinal gradient in the mountainous ecosystem of Kullu district is presented in the Table 73.

It is evident from the data that irrespective of the altitudinal gradient maximum profit is attained in agri-horticulture system (Rs, 7, 31, 809.5), which is closely followed by horticulture (Rs 6, 71,852), only. Net returns as achieved in other land use systems viz., agriculture, silvi-pasture and forest is quite low in comparison to fruit based land use systems. In altitudinal ranges, the net profit obtained increased appreciably from A_1 to A_2 and then increased but at the less rate from A_2 to A_3 and A_3 to A_4. A_3 altitudinal range has highest net profit.

Table 73: Net profit under different land use system along an altitudinal gradient in the hill ecosystem of Kullu district (H.P.)

Net profit (Rs $ha^{-1}yr^{-1}$)					Mean
Land use systems	Altitudinal ranges (A)				
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	28170	24290	144606	143310	85094
T_2 (Agri-horticulture)	299220	794610	969194	864214	731809
T_3 (Horticulture)	289710	830200	792500	775000	671852
T_4 (Silvi-pasture)	30454	45544.4	97877	107694	70392
T_5 (Forest)	73928	131894	145272	172578	130918
Mean	144296	365307	429890	412559	

Net profit in agri-horticulture and horticulture land use systems are quite higher than all other land use system at all the altitudinal ranges than fruit component based land use system i.e. horticulture and agri-horticulture. Net profit is maximum (Rs. 9,69,194) in agri-horticulture land use system at the altitudinal gradient of 1700-2000 m a.s.l. Net return are quite low (Rs 24,290) in

agriculture based land use system situated at 1400-1700 m a.s.l., which is closely followed by the treatment combination of T_1 $A_{1,}$ only.

4.2.8.4 Benefits: cost ratio

The estimates of benefits: cost ratio in relation to land use system, altitudinal ranges and their combination is depicted in the Table 74.

Data presented in the table evinced that benefit-cost ratio is maximum (5.03) in the forest based land use system, which is closely followed by the land use systems of silvi-pasture (4.73) horticulture (3.56) agri-horticulture (2.94) and agriculture (1.39), respectively, in the descending order. In the altitudinal ranges the benefit: cost ratio showed an increasing trend initially from A_1 to A_3 and then declined marginally. In the interaction between land use system and altitudinal ranges, the benefits cost ratio varied appreciably with land use and altitudinal ranges. Different land use systems show a different trend with increasing altitudinal ranges. Benefit-cost ratio is minimum (1.25) at the treatment combination of T_1A_2 and maximum in the combination of T_4A_4 (6.31). The benefit cost ratio at the treatment combinations of T_4A_3, T_4T_5 A_3 and T_5A_4 is higher than all other treatment combinations.

Table 74: Benefit-Cost ratio under different land use system along an altitudinal gradient in the hill ecosystem of Kullu district (H.P.)

Benefit-Cost ratio					Mean
Land use systems	Altitudinal ranges (A)				
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	1.29	1.25	1.56	1.45	1.39
T_2 (Agri-horticulture)	2.42	3.44	3.27	2.64	2.94
T_3 (Horticulture)	3.06	4.25	3.51	3.42	3.56
T_4 (Silvi-pasture)	2.81	3.52	6.27	6.31	4.73
T_5 (Forest)	3.69	5.46	5.47	5.51	5.03
Mean	2.65	3.58	4.02	3.87	

4.2.8.5 Total benefits (net profit + carbon credits)

Total benefit (net profit + carbon credits) for different level use systems at their respective altitudinal ranges is presented in Table 75. It reveals that T_2 (agri-horticulture) land use system have higher total benefits at all four altitudinal

ranges, whereas the minimum total benefits (29,156 Rs $ha^{-1}yr^{-1}$) are recorded for the annual based cropping system of agriculture at 1100-1400 m a.s.l.

Table 75: Total benefits (Net profit+ carbon credits) under different land use system along an altitudinal gradient in the hill ecosystem of Kullu district (H.P.)

Land use systems	Altitudinal ranges (A)				Mean
	A_1 (1100-1400 m)	A_2 (1400-1700 m)	A_3 (1700-2000 m)	A_4 (2000-2300 m)	
T_1 (Agriculture)	29,156	25,579	1,45,889	1,44,721	86,336
T_2 (Agri-horticulture)	3,04,006	7,99,841	9,74,446	8,69,810	7,37,027
T_3 (Horticulture)	2,93,726	8,34,061	7,96,408	7,77,437	6,75,403
T_4 (Silvi-pasture)	33,594	48,697	1,01,287	1,10,057	73,410
T_5 (Forest)	78,343	1,36,403	1,49,700	1,76,561	1,35,252
Mean	1,47,766	3,68,919	4,33,549	4,15,718	

In the altitudinal ranges, total benefits enhanced markedly from A_1 (1100-1400 m a.s.l) to A_2 (1400-1700 m a.s.l) elevation ranges and then at a slower rate from A_2 (1400-1700 m a.s.l) to A_3 (1700-2000 m a.s.l) and then declined marginally from A_3 (1700-2000 m a.s.l) to A_4 (2000-2300 m a.s.l). in the hill ecosystem maximum total benefits (Rs 9,74,446 ha^{-1} yr^{-1}) can be accrued by practicing apple based agri-horticulture system at the elevation range of 1700-2000 m a.s.l. Whereas, agriculture land use at lower elevation ranges i.e. A_1 and A_2 gave quite low total benefits than any other treatment combination.

Chapter-5

DISCUSSION

The investigations on **"Bio-economic appraisal and carbon sequestration potential of different land use systems in temperate north-western Himalayas"** were carried out in Kullu district of Himachal Pradesh during the years of 2008-2009. Kullu district of Himachal Pradesh, which lies in the transition zone between lesser to greater Himalaya, is well known for its richness of flora and fauna, variety of fruits, majestic mountains, perennial river systems, hydroelectric and tourism potential, etc. Over the past 30-40 years, the cropping pattern of this district has seen a drastic change because of adoption of high tech agriculture, integration of commercial crops- apple and off season vegetables and changed mindset of the people. In the coming years, these cropping systems will be further subjected to change due to increased threat of climate change but at the same time it also offers adoption options because of available resources. But, in order to provide effective adaptation measure, first we need to develop a database of these land use systems. The present study is a maiden attempt to know the biomass and carbon stocks, carbon mitigation potential and economic return from different land use systems of valley and mountainous ecosystem of temperate north-western Himalayas. This chapter has been devoted to examine the results of the current study based on logical arguments in the light of the scientific evidences available in the literature. The results have been proved by establishing the cause and effect relationship between them to derive out the fruitful conclusions under the following head 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 Table 4-6 and 37-39. 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 both valley and mountainous ecosystem of the north-western Himalayas.

In the valley ecosystem of the north-western temperate Himalaya, above ground biomass production was found to be maximum under the orchard + cereal – cereal (75.64 t ha^{-1}), which was followed by orchard + cereal – vegetable, orchard + vegetable – vegetable, pure orchard, cereal – cereal, cereal – vegetable and vegetable – vegetable land use systems, respectively. In the valley ecosystem, fruit based agroforestry systems exhibited significantly higher values of above, below and total biomass than the pure orchard and annual based cropping systems.

In the mountainous ecosystem, maximum above ground biomass (336.4 t ha^{-1}) was recorded under the forest ecosystem, which was closely followed by silvi-pasture, agri-horticulture, horticulture and agriculture land use system in the descending order, respectively. Amongst the various agroforestry systems, significantly highest above ground biomass (103.20 t ha^{-1}) was displayed by silvi-pasture system. The above ground biomass production level of agri-horticulture and horticulture remained statistically, alike (Table 37).

The data presented in Table 5 revealed that below ground biomass, in general, followed the same trend as that of above ground biomass, in both valley and mountainous ecosystems of Kullu district, excepting that for vegetable-vegetable based cropping system prevailing in the valley ecosystem. Maximum below ground biomass (23.60 t ha^{-1}) was found in orchard + cereal – cereal cropping system (Table 5). In the mountainous ecosystem, maximum below ground biomass (67.90 t ha^{-1}) was recorded in the forest land use system (Table 38).

The data in the Table 6 also indicated that total biomass in Kullu valley was maximum (99.23 t ha^{-1}) in orchard + cereal – cereal land use system, which followed more or less same trend as that recorded in respect of above and below ground biomass (Tables 4 & 5). On the other hand, in the mountainous region of Kullu district, forest land use systems produced highest total biomass (404.35 t

ha^{-1}), which was followed by silvi-pasture system (123.31 t ha^{-1}). The minimum total biomass in valley and mountainous ecosystem of Kullu was found in vegetable – vegetable (10.28 t ha^{-1}) and agriculture based cropping system (20.28 t ha^{-1}), respectively.

The above results thus have indicated that biomass components 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 the crop grown therein; combinations of the crops; structure of the system; nature and number of woody components and soil type, 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 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 interception and water use efficiency (Sehgal, 1999). The average total biomass as recorded in our case in the forest ecosystem (404.35 t ha^{-1}) is on the higher side than temperate and boreal forest ecosystems (326.0 t ha^{-1}) of the world (Anonymous, 1999). The higher average total biomass of our temperate forest ecosystem can be ascribed to low population density of the mountain ecosystem and in accessibility of these landscapes in the past

5.1.2 Rate of biomass accumulation, removal and retention (t $ha^{-1}yr^{-1}$)

The rate of biomass of each land use system has been studied on the basis of rate of accumulation, removal and retention on per year basis and was presented in the Table 7-9 for valley and Table 40-42 for mountainous region of Kullu district of Himachal Pradesh.

In Kullu valley, the cereal – cereal based land use systems produced the maximum rate of biomass accumulation (22.66 t $ha^{-1}yr^{-1}$) followed by orchard + cereal – cereal, cereal – vegetable, orchard + cereal – vegetable, vegetable –

vegetable, orchard + vegetable – vegetable, respectively in the descending order. The pure orchard based land use system showed the least biomass accumulation (4.44 t $ha^{-1}yr^{-1}$).

The above grouping of the different land use systems on the basis of their annual rate of biomass production have shown that the pure agriculture land use system produced maximum biomass over the remaining systems. Similarly, in the mountainous region also maximum (20.03 t $ha^{-1}yr^{-1}$) rate of biomass accumulation was in agriculture land use system and minimum was (3.72 t $ha^{-1}yr^{-1}$) in perennial based land use system.

In both the experiments, annual based cropping systems exhibited higher rate of biomass accumulation (t $ha^{-1}yr^{-1}$) than the woody perennial based land use systems. This may be ascribed to the reason that the biomass accumulation calculated under different land use systems was on per hectare per year basis i.e. the total biomass accumulation on per hectare basis divided by the age of the woody components. Therefore, with the increase of age in woody components, the rate of biomass accumulation (t $ha^{-1}yr^{-1}$) decreases. Thus the rate of biomass accumulation in the present study is the average over time and space. In addition to it, the annual crops are grown on the most productive lands and managed intensively and thus have potential to produce higher biomass than annual biomass increment produced by the woody perennials. Thus we can say that the rate of biomass accumulation depend upon the nature of the crop, intensity of the management and soil types.

The rate of biomass removal by the pure orchard (1.35 t $ha^{-1}yr^{-1}$) (Table 8) in the valley ecosystem showed lesser value as compared to the annually based cropping system. Whereas, the maximum (21.90 t $ha^{-1}yr^{-1}$) biomass removal is by the cereal – cereal cropping system. This pattern was also same in the mountainous region of the Kullu districts. The minimum biomass removal (0.85 t $ha^{-1}yr^{-1}$) was in the forest land use system (Table 41). The rate of biomass removal again depends upon types of the crop, nature of produce and intensity of the management.

In the Kullu valley, the rate of biomass retention showed maximum value (4.05 t $ha^{-1}yr^{-1}$) in orchard + cereal – cereal land use system. Whereas, in the mountainous ecosystem the maximum biomass retention was (3.40 t $ha^{-1}yr^{-1}$) in the agri-horticulture land use system. In both the ecosystems, fruit based agroforestry land use systems showed higher biomass retention than the annual based cropping system because the biomass removal (t $ha^{-1}yr^{-1}$) was the maximum in the sole cropping systems. The rate of biomass retention depends on the accumulation and removal of the biomass. Which, further depends upon the planting density and the nature of the crops.

5.1.3 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 above, below and total biomass carbon density in respect of valley and mountainous ecosystem of Kullu district has been presented in the Table 10-12 and 43-45, respectively.

Data presented in the Tables 10-12 and 43-45 revealed that all the traits of biomass i.e. above ground biomass, below ground biomass and total biomass were significantly influenced due to land use system effect. In the valley ecosystem, maximum above ground biomass (37.82 t ha^{-1}) carbon density was exhibited by orchard + cereal – cereal cropping system, which was closely followed by other orchard based cropping systems, only. Whereas, in the mountainous region, maximum biomass (168.20 t ha^{-1}) was in the forest land use system, which differed significantly from other land use systems and followed the trend: forest > silvi-pasture > agri-horticulture > horticulture > agriculture.

Minimum above ground biomass carbon density in both the ecosystems were in annual based cropping systems. Whereas, maximum above ground carbon density in both the ecosystems was exhibited by perennial component based land use systems, which can be attributed to continuous accumulation of biomass in the woody component. In the fruit based agroforesty systems and sole fruit based land use system only a part of the produce is removed in the form of

fruit yield and pruned wood, etc., annually. Whereas, from the agriculture fields and grasses almost all of the above ground biomass carbon stock is removed annually.

The below ground carbon density (Tables 11 and 44) and total biomass carbon density (Tables 12 and 45), in general, followed more or less same trend as depicted by the above ground biomass carbon density. Only slight variation was detected in annually based cropping systems, which can be attributed to their variation in carbon allocation pattern to aerial and below ground component.

It can again be inferred from the above discussion that variability in the carbon stock of different land use system types depends primarily on its age, structure, functional components and their number, intensity of management. The variability in the productivity of agroforestry system as recorded in our case is in consonance with the observations of Albercht and Kandji (2003). They opined that carbon variability in plant biomass can be high with in 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 temperate agroforestry system was similar to the values (60 t ha^{-1} C) calculated by Kursten and Burschel (1993) in two tree combination in Costa Rica Cacao (*Theobroma cacoa*) - laurel (*Cordia allieadora*) and Cocopora (*Erythrina poeppigiana*) and by Sanneh (2007) for fruit based agroforestry systems (51.85 t ha^{-1}) of wet temperate north western Himalaya.

The total biomass carbon storage potential (202.2t ha^{-1}) as recorded in our Himalayan temperate forest ecosystem is almost same as given by Singh *et al.* (1994) for Himalayan forest i.e. 190 t ha^{-1} and Sanneh (2007) for wet temperate Himalayan forest ecosystem (185.0 t ha^{-1}). But, the value is higher side in comparison to the average value of 160.0 t ha^{-1} given by Houghton, (1995). The variation in the value of our forests and global temperate region coniferous forest is mainly due to difference in the nature of the temperate forest. The average annual temperature of our forest is higher than the temperate forest found in other

parts of the world this may be one of the reasons for their higher productiveness. Our value also falls in between the average carbon storage potential (122-229 t ha^{-1}) of European temperate forest.

5.1.4 Rate of C and CO_2 sequestration, removal and retention (t $ha^{-1}yr^{-1}$)

The rate of C and CO_2 sequestration, removal and retention follows the same trends as that of the above, below and total biomass carbon and rate of biomass production, removal and retention in valley (Table 13-21) and mountainous (Table 46-54) ecosystem of Kullu district. This is because the rate of C and CO_2 sequestration, removal and retention is simply a derivation upon the rate of biomass production, removal and retention.

5.1.5 Soil physico-chemical properties

5.1.5.1 Soil organic carbon

It is crystal clear from the data presented in the Tables 22 and 55 that organic carbon (%) varied significantly under different land use systems, altitudinal ranges and soil layers in both the experiments. In valley agro-ecosystem of the temperate Himalaya, maximum soil organic carbon (0.85 %) was found in the pure orchard system, which, however remained statistically at par with the organic carbon contents as observed in the orchard + vegetable – vegetable and differed significantly from all other land use systems. Whereas, in the mountainous ecosystem, maximum soil organic (2.50 %) was found in the forest land use system, which was followed by agri-horticulture (0.89 %), horticulture (0.87 %), silvi-pasture (0.81 %) and agriculture (0.68 %), respectively in the descending order. Significantly increased organic carbon contents in soils under tree based land use systems may ascribed to more leaf litter deposition followed by decomposition and root turnover from trees (Zegeye, 1999), Kater *et al*. (1992), Rhodes (1995) and Sood (1999) These findings are also in consonance with the findings of Kumar (2003), Sanneh (2007) and Minj (2008), who reported significantly higher organic carbon in forest and fruit tree based land use systems than in annual cropping systems. Low soil organic carbon

under arable land use systems may be attributed to the intensive cropping in annuals based land use systems (Lal *et al.*, 1998).

The carbon fixed by the plant is the primary source of organic matter input into the soil, which provides substrate for microbial process and 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 surface layer of valley ecosystem (0.90 %) and mountainous ecosystem (1.32 %), which decreased with increasing soil depth (Table 22 and 55). 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. decrease in organic carbon content with increase in soil depth have also been reported by Minhas *et al*. (1997). Organic carbon content is affected by leaf litter, higher rate of turnover of minute rootlets, death and decomposition of roots and exudation of organic chemicals and hence organic carbon of soil will also increase (Huck, 1983 and Waisel *et al*., 1991).

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

The data presented in the Tables 22 and 55 showed that the bulk density (g cm^{-3}) varied significantly under different land use systems, altitudinal ranges and soil layers.

The bulk density in the Kullu valley ecosystem of the Himachal Pradesh followed the trend: orchard + vegetable-vegetable > vegetable – vegetable > cereal – vegetable > cereal – cereal > pure orchard > orchard + cereal – cereal > orchard + cereal – vegetable. Whereas, in the mountainous ecosystem the trend was: agriculture > horticulture > agri-horticulture > silvi-pasture > forest.

Thus the findings clearly indicated that the land use systems which are intensively managed have higher bulk density and it declined as the intensity of land management system declined. The high value of bulk density in the soils can also be ascribed to lower soil organic carbon content in these systems. These

findings are in agreement with the findings of Karan *et al*. (1991), Cihacek and Ulmer (1998) and Sanneh (2007), who also reported higher values of bulk density in cultivated soil in comparison to grass land and forest ecosystems. Higher bulk density in horticulture based land use systems as reported in our case have also been reported by Kumar (2003) and Sanneh (2007)

5.1.5.3 Soil organic carbon density

Soil organic carbon density was determined by multiplying organic carbon with soil weight for a particular depth. It is evident from the data presented in the Tables 22 and 55 that soil organic carbon was significantly influenced by land use system effects.

Maximum soil organic carbon density in the valley ecosystem was recorded in orchard + vegetable – vegetable (20.02 t ha^{-1}) cropping pattern, which was found to be significantly higher than all other land use systems. Whereas, in the mountainous ecosystem, maximum organic carbon density was recorded in the forest (49.04 t ha^{-1}) land use systems, which was followed by agri–horticulture (20.59 t ha^{-1}), horticulture (20.52 t ha^{-1}), silvi-pasture (17.90 t ha^{-1}) and agriculture (16.94 t ha^{-1}), respectively in the descending order. This may have happened because of enhanced accumulation of leaf litter in the tree and fruit based land use systems. The abundant leaf litter or pruned biomass returns to soil, combined with decay of roots contribute to the improvement of organic matter under complex land use systems (Beer *et al.*, 1990; Lehmann *et al.*, 1998; Rao *et al*., 1998; Kumar *et al*., 2001). Low amounts of soil organic carbon density under the agriculture land use system can be ascribed to intensive cropping as also reported by Lal *et al*. (1998) and other workers from time to time.

It was also evident from Table 22 and 55 that soil organic carbon density declines appreciably from L_1 (0-20 cm) to L_2 (20-40 cm) layer. The increase or decrease in the soil organic carbon pool was associated with the bulk density and organic carbon content of the soil of a particular depth. The higher amount of soil organic carbon density on the surface layer i.e. 0-20 cm may be explained in the sense that there is continuous accumulation of leaf litter on the surface, which

keeps on decomposing and thus enriches the upper layer (0-20 cm), continuously. These results are in line with the finding of Joao-Carlos *et al.,* (2001), Nair and Chamuah (1988) and Minhas *et al*. (1997).

The soil of the valley ecosystem is alluvial in nature which gets it depleted in organic contents because of continuous and intensive inter cropping as well as due to higher rates of mineralization resulting due to higher temperature, soil moisture and atmospheric humidity- characteristic features of valley ecosystem. Whereas, in mountainous ecosystem the soil is of forest origin in which the intensity of cultivation is less than in the valley ecosystem. In addition to it, the rate of mineralization is slower because of rapid fall in temperature and humidity with increasing altitudinal gradient hence more soil organic content and soil organic carbon density.

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

Data presented in the table 22 and 55 indicated that available N content varied significantly in both valley and mountainous ecosystem under the influence of land use systems. In the valley ecosystem, maximum available N (523.7 kg ha^{-1}) was recorded in the pure orchard, which however, remained statistically identical to the N status of orchards + vegetable – vegetable cropping systems, only. N status in fruit based AFSs remained statistically identical. Similarly, in the mountainous agro-ecosystem also, maximum available N was in the horticulture and agri-horticulture based land use system, which was found to be significantly higher than the available N status of forest (443.2 kg ha^{-1}), agriculture (425.2 kg ha^{-1}) and silvi-pasture system (392.6 kg ha^{-1}), respectively. Significantly higher N status in fruit based agroforestry systems in both the valley and mountainous agro-ecosystems can be explained on two basis. First, fruit trees in both types of situations are deciduous in nature, which shed their leaves, during the winter months thereby continuously 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 districts does not bother much about field crop because they are least paying amongst all the land use systems (Tables 34 and 73).

5.1.6 Carbon inventory

5.1.6.1 Soil organic carbon pool inventory (t ha^{-1})

The carbon pool inventory of land use system was prepared by adding soil organic stock and plant carbon stock expressed as t ha^{-1} and the same is presented for the valley and mountainous ecosystem in Tables 27 and 66, respectively. The carbon inventory is prepared for four altitudinal ranges of both valley and mountainous ecosystems of Kullu district up to 0-40 cm depth.

In the valley ecosystem of Kullu district, maximum soil organic pool (40.87 t ha^{-1}) in 0-40 cm layer was found in orchard + vegetable – vegetable cropping system followed by the treatments T_5, T_4, T_7, T_3, T_2 and T_1, respectively in the descending order. Whereas, the maximum soil organic pool in 0-40 cm layer was recorded in forest land use system (98.08 t ha^{-1}), which was followed by agri-horticulture (41.05 t ha^{-1}), horticulture (39.16 t ha^{-1}), silvi-pasture (35.79 t ha^{-1}) and agriculture (33.88 t ha^{-1}), respectively in the descending order. The total soil organic carbon stock observed in the forest land use system was found to be 3-4 times higher over other land use systems. Higher soil organic carbon pool in the orchard + vegetable – vegetable and forest land use system in the Kullu districts can be ascribed to greater incorporation of leaf litter and addition of decayed roots to the upper soil layers than in the other land use systems. The soil carbon pool i.e. 98.08 t ha^{-1} in our system is lower than the world average for temperate evergreen forest i.e. 139.9 t c ha^{-1} (Houghton, 1995). This can be mainly due to the nature of temperate forest ecosystem. Our forests are categorized as warm temperate Himalayan forests hence the average temperature is higher than the typical temperate forest ecosystem of the world. Higher temperature may have helped in greater decomposition and loss of the soil organic carbon from our forest land use system. More over, the soil of our study

site is sandy loam, which is known for lower soil organic carbon content because of its low retentivity.

5.1.5.2 Soil (+ leaf-litter) and plant carbon inventory

The data presented in Table 28 in respect of soil + leaf-litter and plant carbon revealed that in the valley ecosystems of the temperate western Himalaya, the perennial plant based land use systems viz., orchard + cereal – cereal, orchard + cereal – vegetable, orchard + vegetable – vegetable and pure orchard land use systems displayed higher carbon density in the plants than in the soil. Similarly, in the mountainous ecosystems of the Kullu district, perennial plant based land use systems viz., agri-horticulture, silvi-pasture, horticulture and forest use systems displayed higher carbon stock in the plant than in soil. Whereas, in the annual or agriculture based land use system, the carbon stock is higher in soil than in the plants for both the ecosystems of the Kullu districts of Himachal Pradesh. These finding are in the same line as that of Houghton (1995) and Sanneh (2007). The concentration of higher carbon stock in the plant aerial part than in the soil suggest that in case of some disturbance in the form of fire, diseases, or climatic changes and land use changes, these land use systems will release quite high carbon dioxide into the atmosphere, which will further contribute towards the global warming process. Therefore, these ecosystems need to be protected and conserved.

5.1.6.3 Total carbon stock (t ha^{-1})

Table 28 demonstrated the total carbon stock in the valley ecosystem of the temperate north-western Himalayas, which showed that in the valley ecosystem, maximum total carbon density (90.88 t ha^{-1}) was observed in orchard + cereal – cereal land use system, which was closely followed by the agroforestry systems viz., orchard + cereal – vegetable, orchard + vegetable – vegetable, respectively. The total carbon stock (soil + plant) as observed in this agroforestry systems is appreciably higher than sole cropping based systems i.e. pure orchard, cereal – cereal, cereal–vegetable and vegetable – vegetable at all the attitudinal ranges.

Whereas, in the mountainous ecosystem (Table 67) maximum total carbon stock (303.39 t ha^{-1}) was observed in the forest land use system, which is around 2.5 times to 4 times higher over other perennials based land use systems. The higher amount of total carbon stock in forest and other perennial plant based system can again be ascribed to regular addition of leaf litter on the surface soil layers over the years that contributed to the build up of soil organic matter and nutrient stocks in the soil, which favours the higher biomass production as reported by Lehmann *et al*. (1998); Rao *et al*. (1998) and Kumar *et al*. (2001). The average total carbon stock of our forest in the mountainous ecosystem is 303.39 t C ha^{-1}, which is slightly higher than reported by Houghton (1995) for temperate evergreen forest (294.1 t C ha^{-1}). The C-sequestration potential of our agroforestry and horticulture land use system ranged between 83.97 – 90.88 t C ha^{-1} and 72.8 – 80.1 t C ha^{-1} in the valley and mountainous ecosystems, respectively. The carbon sequestration potential of tropical agroforestry was also estimated to be between 12 and 228 t ha^{-1} with a medium value of 95 t ha^{-1} by Albrecht and Kandji (2003) too.

5.1.6.4 Carbon pool in soil, vegetation and their ratio

Soil and plant carbon ratio of different land use system was depicted in the Tables 28 and 67 for valley and mountainous ecosystem, respectively. It was evident from the Table 28 that in the valley ecosystem, minimum soil: plant carbon ratio was found to be in the pure orchard land use system (0.83), followed by orchard + cereal – cereal, orchard + vegetable - vegetable and orchard + cereal – vegetable etc. in the ascending order, respectively. Whereas, in the mountainous region of Kullu districts (Table 67), the minimum soil: plant carbon (0.42) was found to be in the forest followed by silvi-pasture, horticulture, agri-horticulture and agriculture in the ascending order, respectively. This means that the plants contained more organic carbon in the plant system than in the soils. The soil-plant carbon ratio in our study coincides with the global carbon stock distribution between vegetation and soil (Houghton, 1995) in the land. However, Kumar (2003), reported more carbon in the soil than in the vegetation for sub tropical sub-temperate conditions of Himachal Pradesh. These differences cab be

owed to the frequency of plant component on the land use systems. Lower soil: plant carbon ratio means in the near future if any accidents or land use conversion takes place then these systems will be major source of CO_2 flux into the atmosphere.

5.1.7 Relative CO_2 mitigation potential

The relative CO_2 mitigation potential of different land use system was worked out by taking the value of cereal – cereal (Table 29) and horticulture (Table 30) as 1 in Kullu valley. The data presented in the Table 29 revealed that cereal–vegetable and vegetable – vegetable systems displayed quite low CO_2 mitigation in comparison to cereal – cereal land use system. Whereas, the land use system of orchard + cereal – cereal, orchard + cereal–vegetable, orchard + vegetable – vegetable and pure orchard based land use systems displayed higher value than the cereal – cereal based land use system. But, when we compared the carbon mitigation potential of different land use systems with respect to orchard than all annual based land systems showed lower values.

In the mountainous region of Kullu districts of Himachal Pradesh, when we assumed the value of forest as 1 (Table 68), then all the systems displayed quite low carbon mitigation potential in comparison to forest land use system. The relative carbon mitigation potential of different tree based systems ranged from 0.70 to 1.2. Whereas, the relative carbon mitigation potential of agriculture (0.29) was found to be least. But when we compared the carbon mitigation potential of different level use system with respect to agriculture than all the woody component based land use system showed higher values.

5.2 EFFECT OF ALTITUDINAL GRADIENT

5.2.1 Biomass production levels

The biomass production pattern as categorized into above ground biomass, below ground biomass and total biomass have been presented in the Table 4-6 and 37-39 for valley and mountainous region of Kullu district of Himachal Pradesh, respectively. A perusal of these tables revealed that all types of biomass in the valley ecosystem, irrespective of land use system increased

from 1000-1300 m to 1300-1600 m and thereafter showed a declining trend with increased in the altitudinal level. This decrease was quite sharp from A_3 to A_4, but in valley ecosystem, only (Fig. 2). The above variation in the biomass level at different altitude can be explained on the basis of density of woody species, variation in soil organic carbon percentage and change in the pattern of temperature and rainfall with the changes in the altitudinal ranges. In the mountainous region of Kullu district a perusal of the data presented in the Table 37-39 and fig. 2 revealed that all types of biomass, increased with altitudinal ranges from A_1 to A_4. Altitudinal ranges of A_1 to A_2 remained statistically at par with one another and differed significantly from A_4.

The above variation in the biomass level at different altitude can be explained on the basis of age of the woody species, soil organic carbon (%) and human population density. As we came to know from table 37-39 and fig 2, that the major contributor of biomass at the different altitudinal ranges are woody perennial. From the Table 2-3 we can observe that with the increasing altitudinal ranges, the average age of the tree species increase. 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 ranges (Table 55). 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 *et al*. (2001) and Sanneh (2007). Thirdly, the level of human interference with nature declines as we moves from lower to higher altitude because of decreasing population density and in hospitability of the site. At higher altitude, the population density is very less because of very cold winter and heavy intensity of snow fall. Fourthly, frequency of rainfall and its intensity keeps on increasing as we moves upward in the higher hills of the Kullu district and lower elevation ranges falls under partial shadow zone.

5.2.2 Rate of biomass production, removal and retention

The data in respect of rate of biomass production (Fig. 3), removal and retention in valley and mountainous ecosystem was presented in the Table 7-9

and Table 40-42, respectively. It is quite clear from the data presented in the Table 7-9 and (Fig. 3) that both rate of biomass accumulation and removal increased from 1000-1300 m a.s.l. to 1300-1600 m a.s.l. and declined thereafter. However, the rate of biomass retention is higher at A_3 and A_4 altitudinal ranges. Whereas, in the mountainous ecosystem, the rate of biomass accumulation as well as biomass removed declined with the increase in the altitudinal ranges (Fig. 3 & 4). However, the rate of biomass retention is maximum at the altitude of 1600-1900 m a.s.l. (Fig. 5). It is well known fact that the rate of biomass production is a function of many growth factors like temperature, rainfall, soil fertility, intensity of the management, etc. The lower altitude because of favorable optimization of these variables might have induced more growth in the plant grown under these land use systems. The biomass removal depends upon productivity, nature of the produce and level of the human interference with the system.

5.2.3 Biomass carbon density (t ha^{-1})

Date presented in the Table 10-12 and 43-45 showed that the above ground carbon biomass, below ground carbon biomass and the total carbon density (Fig. 6) in both valley and mountainous ecosystem of temperate north-western Himalaya were significantly influenced by altitudinal ranges. All types of biomass carbon density in Kullu valley increased from A_1 to A_2 and declined thereafter. Whereas, in the mountainous region of Kullu districts, the biomass carbon density increased up with increasing altitudinal range from A_1 to A_4. Carbon density in the altitudinal range of 1400-1700 m and 1700-2000 m a.s.l. in mountainous ecosystem remained statistically at par. The altitudinal range of 2000-2300 m a.s.l. that displayed the maximum density (90.57 t ha^{-1}) was found to be significantly higher than other altitudinal ranges.

The reasons for the above variation are same as discussed above for the biomass because the biomass carbon is merely derivation upon above, below and total biomass by using multiplication factor of 0.5 for conversion of biomass into carbon stock.

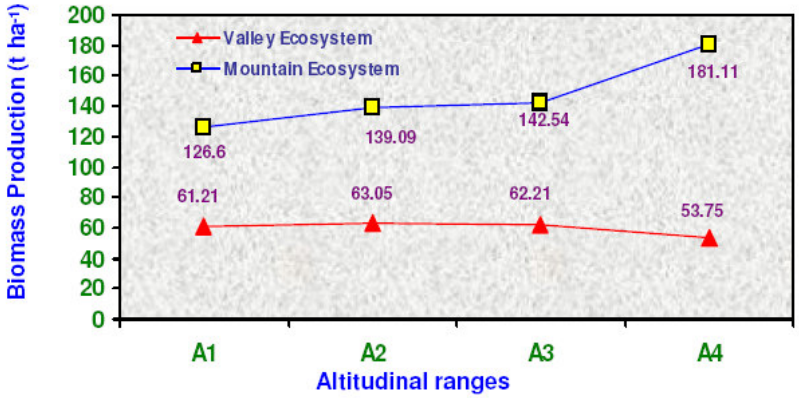

Fig 2. Total biomass production (t ha^{-1}) of valley and mountainous ecosystems in Kullu district (H.P.) at different altitudinal ranges

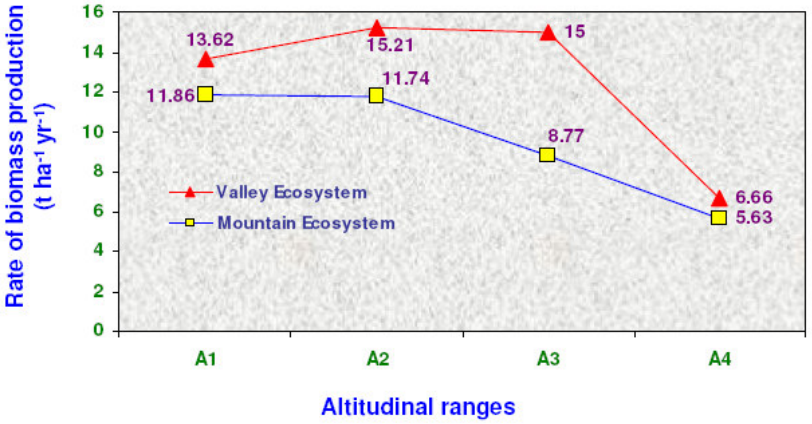

Fig 3. Rate of biomass production (t ha^{-1} yr^{-1}) of valley and mountainous ecosystems in Kullu district (H.P.) at different altitudinal ranges

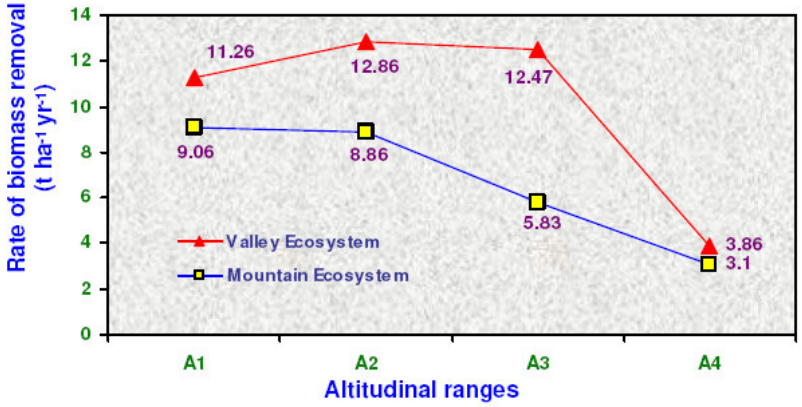

Fig 4. Rate of biomass removal (t ha^{-1} yr^{-1}) from valley and mountainous ecosystems in Kullu district (H.P.) at different altitudinal ranges

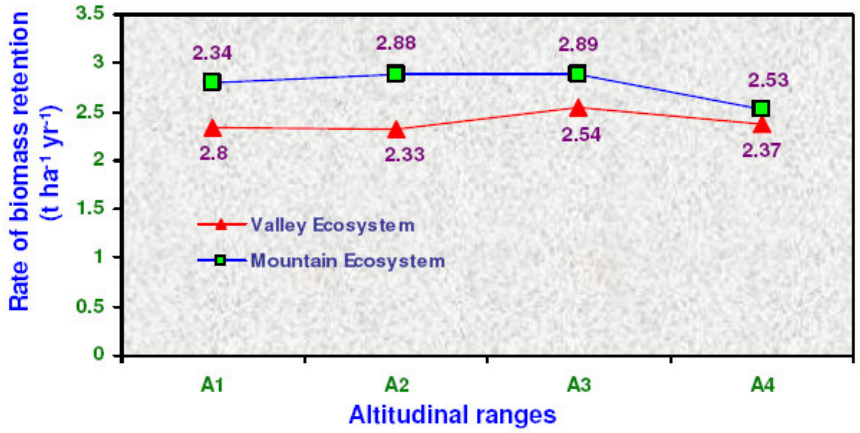

Fig 5. Rate of Biomass retention (t ha^{-1} yr^{-1}) of valley and mountainous ecosystems in Kullu district (H.P.) at different altitudinal ranges

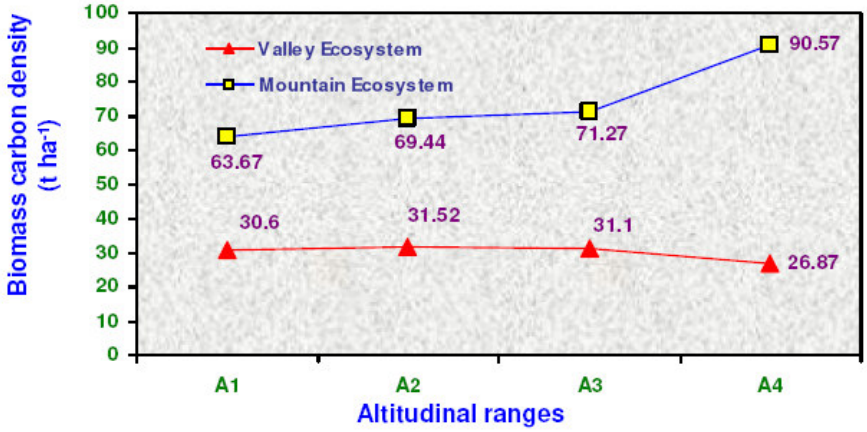

Fig 6. Biomass carbon density (t ha^{-1}) of valley and mountainous ecosystems in Kullu district (H.P.) at different altitudinal ranges

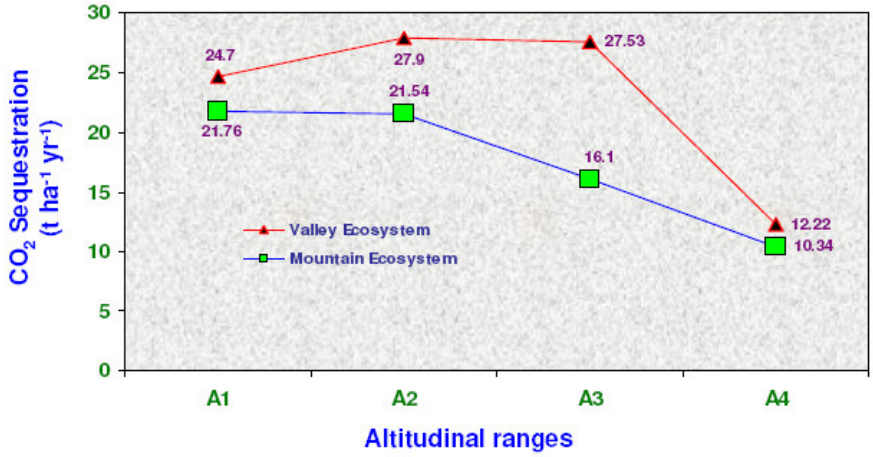

Fig 7. Rate of CO_2 sequestration potential (t ha^{-1} yr^{-1}) of valley and mountainous ecosystems in Kullu district (H.P.) at different altitudinal ranges

5.2.4 Rates of C and CO_2 sequestration, removal and retention

A perusal of the data presented in the Tables 13-21 (Fig. 7-9) for valley ecosystem revealed that as we moved from lower elevation to higher elevation from A_1 to A_4 the rate of C and CO_2 sequestration and removal decreased with increasing altitude. Whereas in the mountainous ecosystem (Table 46-54 and Fig. 7-9), the accumulation and removal rate in Kullu valley increased from A_1 to A_2, thereafter declined. The C and CO_2 mitigation rate on per year basis was maximum at A_3 altitudinal ranges in both the ecosystems (Tables 15, 48 and Fig. 9).

The reasons for above variation are same as discussed above for the rate of biomass accumulation, removal and retention.

5.2.5 Soil physico-chemical properties

5.2.5.1 Soil organic carbon

In our study, we found that the organic carbon increased with increasing attitudinal range (Tables 22 and 55), which can be owed to continuous accumulation of leaf-litter and slower decomposition rate at the higher attitude 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 concentrations.

5.2.5.2 Bulk density

Bulk density showed a decreasing trend with increasing altitudinal ranges (Tables 22 and 55). 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. Tables 22 and 55 also revealed that bulk density, in general, increased with the 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 which resulted in low bulk density values. The reduction of 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 Bhusan 1998 and Sanneh, 2007).

5.2.5.3 Soil organic carbon density

In the valley ecosystem of the Kullu district, the 1900–2000 m a.s.l. range displayed significantly higher soil organic carbon density than the altitudinal range of 1000-1300 m a.s.l. and 1600-1900 m a.s.l. Whereas, in the mountainous ecosystem, maximum soil organic carbon density (26.77 t ha^{-1}) was recorded at the altitudinal range of 2000–2300 m a.s.l, which differed significantly from all other attitudinal ranges. A comparison between soil organic carbon density of valley and mountainous ecosystem showed that soil organic carbon density in the mountainous ecosystem is quite higher than the similar altitudinal range of the valley ecosystem (fig 10). Higher soil organic carbon stock at the higher elevation ranges in both valley and mountainous ecosystem can again be described decreased rate of carbon mineralization at higher elevation ranges and hence lesser loss through erosion. Higher soil organic carbon stock in mountainous ecosystem than valley ecosystem at the similar elevation ranges can be explained on the basis of nature of the soil and climatic factors.

5.2.5.4 Available Nitrogen (kg ha^{-1})

The data demonstrated in Table 22 for the valley and at Table 55 for the mountain agro-ecosystem showed that the available N increased from the A_1 to A_3 altitudinal range and then showed a slight declining trend. Highest available N status at A_3 (1700-2000 m.a.s.l. for valley and 1800-2100 m.a.s.l for mountainous ecosystems) can be due to combined effect both higher biomass production and optimum mineralization at this altitude. At the lower altitude, the rate of mineralization is higher, which may have caused loss of available N through various processes. Whereas, on the upper most altitude level the rate of mineralization may be too low.

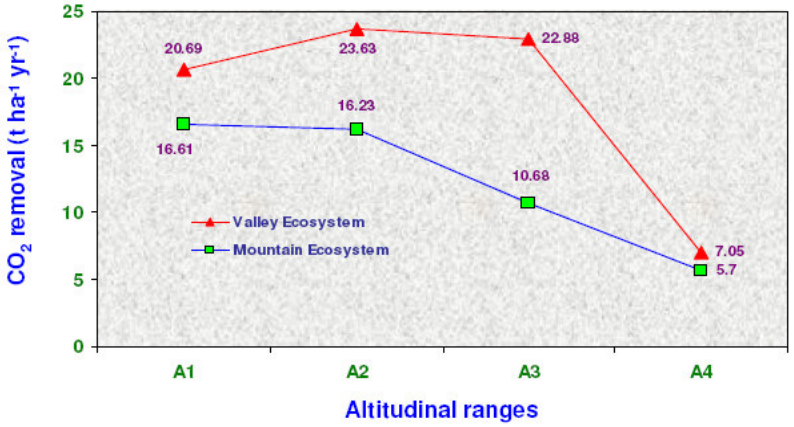

Fig 8. Rate of CO_2 removal (t ha^{-1} yr^{-1}) from valley and mountainous ecosystems in Kullu district (H.P.) at different altitudinal ranges

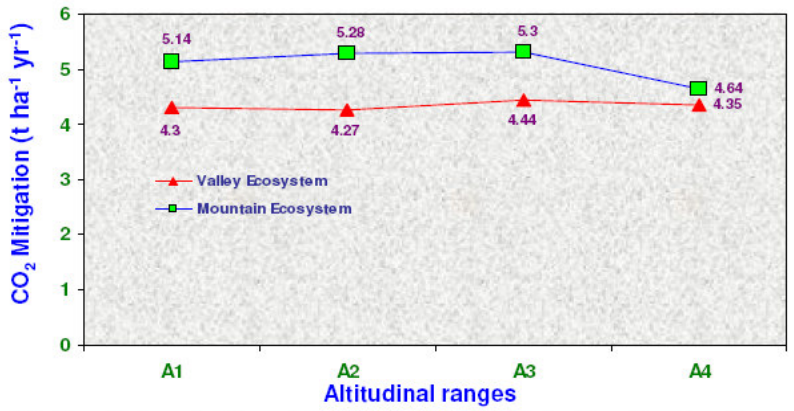

Fig 9. Rate of CO_2 mitigation potential (t ha^{-1} yr^{-1}) of valley and mountainous ecosystems in Kullu district (H.P.) at different altitudinal ranges

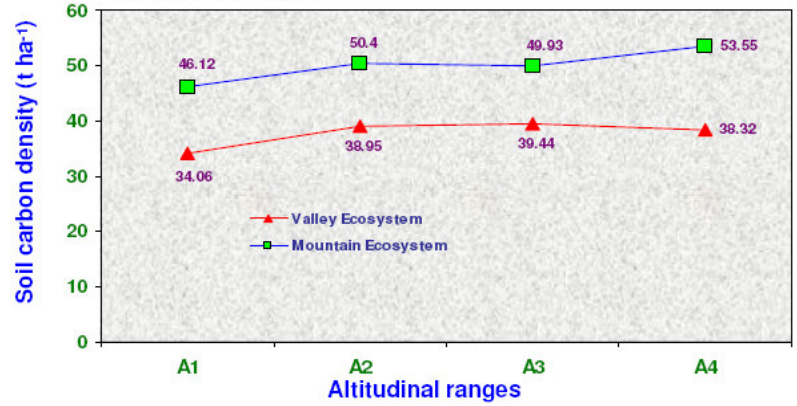

Fig 10. Soil carbon density (t ha^{-1}) of valley and mountainous ecosystems in Kullu district (H.P.) at different altitudinal ranges

Data in the Tables 22 and 55 suggest that available N in both the valley and mountain ecosystem is significantly higher on the upper layer (0-20 cm) than in the lower ones (20-40 cm). This can be due to continued deposition of leaf-litter on the surface layer.

5.2.4 Carbon inventory

5.2.4.1 Soil organic carbon pool inventory

Data presented in the Tables 27, 66 and Fig 10, gave the soil organic carbon status at different altitudinal ranges in valley and mountainous ecosystem, respectively. In altitudinal ranges, the soil organic carbon increased with increase in the altitudinal range from A_1 to A_3 and than showed a slight decline in valley area of Kullu districts (Table 27). Whereas, the soil organic carbon status in the 0-40 cm for mountainous region of Kullu districts of Himachal Pradesh, did not showed any consistent trend. It first showed an increase from A_1 to A_2 and then declined from A_2 to A_3 and then again showed an increasing trend from A_3 to A_4 (Table 66). This may be due to nature of the land use system, influence of age, structure, functional component and their density, soil types as well as climatic conditions. Low soil organic carbon in both experiments (Kullu valley and mountainous region of Kullu district) in the lower altitudinal range may be due to high temperature and humidity which facilitated faster decomposition and mineralization of the soil organic carbon.

5.2.4.2 Soil (+ leaf litter) and biomass carbon pool inventory (t ha^{-1})

It is evidently clear from the Table 28 that the soil: plant carbon ratio increased with increase in the altitudinal ranges from A_1 to A_4 (Table 28). The data presented in the Table 67 also revealed that as we moved from lower elevation range (1100-1400 m) to higher elevation range (1700-2000 m) in the mountainous region, the ratio between soil and plant kept on increasing thereafter slightly down at (2000-2300 m) elevation range. It was found to be (1.06), (1.08) and (1.46) at A_1 (1100–1400 m), A_2 (1400-1700 m) and A_3 (1700-2000 m), respectively. Increasing soil: plant ratio indicates greater vulnerability of the system. If in future temperature increases and vegetation shift takes place then

there will be net emission of CO_2 into the atmosphere, because of greater mineralization from the soil and this emission rate will be higher from 1400-1700 m and 1700-2000 m a.s.l. altitudinal ranges. This shift between one altitudinal range to another altitudinal ranges signifies the difference of approximately one degree centigrade. Because in the Himalayan region the temperature fall by one degree as are climb in the hills by about 270 m upto 1500 m a.s.l. and after its fall is more rapid (1^oC difference for every 300 meter). Fig. 11 shows that there is not much variation in the carbon stock in the valley ecosystem at different altitudinal ranges. Whereas, in the mountainous ecosystem, elevation range of 2000-2300 m a.s.l. shows a very high total carbon density. Thus, this elevation range needs greater attention from environmental point of view.

5.3 INTERACTION EFFECTS

5.3.1 Effect of interaction between land use system and altitudinal gradients on biomass production, biomass carbon and CO_2 mitigation potential

Interaction effect between land use system and altitudinal gradient exercised significant influence on the biomass production, biomass carbon density, C and CO_2 mitigation potential of above, below, total biomass and rate of biomass production removal and retention in both valley (Tables 4-21) and mountainous region (Tables 37-54) of Kullu district of Himachal Pradesh.

Various treatment combinations of orchard + cereal – cereal (T_4) and altitudinal gradients (A) in the valley and forest land use system and altitudinal gradient (T_5A) in the mountainous region exhibited significantly highest value of all the above mentioned traits in comparison to all other land use systems. The registering of higher values of these traits in the cropping system of orchard + cereal - cereal can be ascribed to higher average age of the system, nature of the functional component in question and intensity of management involved. As we know the average age of fruit based system is quite high than annual based cropping system. In addition to it, the biomass and carbon stock production and its removal is very high in case of cereal – cereal crops. The intensity of the management in this cropping system is also very high as it fetches higher

economic returns too (Tables 34-36). It was also seen that in the valley ecosystem the value of above mentioned traits in the land use systems of cereal – cereal, cereal – vegetable, orchard + cereal – cereal and orchard + cereal – vegetable enhanced with increasing altitudinal ranges from A_1 to A_2 and thereafter declined. Whereas, the treatments involving the cropping system of vegetable – vegetable, orchard + vegetable - vegetable and pure orchard, the values of these traits increased from A_1 to A_3 and thereafter declined. The higher values of above mentioned traits of the cropping systems at either A_2 or A_3 can be due to this fact that at these altitudinal ranges both rainfall and temperature are optimum than at A_1 and A_4. A_1 altitudinal range of the valley ecosystem falls under partial shadow zone and thus the rainfall at this level is quite less then A_2, A_3 or A_4 ranges. The lower values at A_4 range can be owed to the fact that at this altitudinal range the temperature is quite low because of its nearness to the great Himalayas (Pir Panzal ranges).

In the mountainous region, the values of biomass related traits silvi-pasture and forest land use systems enhanced with the increasing altitudinal ranges. Highest values of biomass and biomass carbon related traits can be ascribed to more average age of system (Tables 2 & 3) and lesser human interference with increasing altitudinal ranges and increasing rainfall with altitude as discussed earlier, also.

The rate of biomass production and removal is maximum in the cropping system of cereal – cereal (Tables 13 & 14) and agriculture (Tables 40 & 41) land use system, which was followed by different fruit based agroforestry systems in both valley and mountainous region of Kullu districts of Himachal Pradesh. The agriculture based land use systems have shown maximum removal, whereas fruit based land use system have shown maximum mitigation potential at all the altitudes.

This is because of the fact that agriculture crop are put to intensive management practices but whatever it produces is removed annually whereas in the fruit based agroforestry systems, which is again put to intensive management,

the biomass keep on piling year after year in the fruit trees, pruned wood and fruit yield is removed, annually.

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

5.3.2.1 Effect on soil organic carbon (%)

Data presented in the Tables 56, 57, 58, and 59 evinced that maximum organic carbon (%) was observed in the various combinations of forest. Higher organic carbon (%) in the various combinations of forest land use system can be ascribed to continuous addition of leaf-litter and dead organic matter on the surface, which on decomposition enriches the soil organic carbon (%) of the different layers. Minimum organic carbon content in the various combinations of agriculture can be owed to depletion of organic carbon due to continuous cropping, which depletes the soil of its organic carbon content. In the interaction effect between altitudinal range and soil layer (Tables 23 and 58), carbon content declined from L_1 to L_2 layer at all the altitudinal ranges. The rate of increase in organic carbon in L_1 layer is quite higher from A_1 to A_4 altitudinal range than in the L_2 layer; in both valley and mountainous region of Kullu district of Himachal Pradesh. This variation in the decline can be ascribed to temperature differences. At lower most altitudinal range, the temperature is more than higher altitudinal ranges. Because of the higher temperature the rate of mineralization is higher at lower most altitudinal range. The decomposed organic matter percolates into the deeper soil layer, thereby enhancing the carbon status of lower layer, also.

5.3.2.2 Effect on Bulk density (g cm^{-3})

Data presented in the Tables 24 and 60 revealed that bulk density was significantly influenced by the interaction between land use system and altitudinal gradient. Maximum values of bulk density were seen in various combinations of the land use systems viz., agriculture, horticulture and agri-horticulture. Higher values of bulk density in various combinations of these systems can be ascribed to their lower soil organic value (Tables 56 & 57), which may be due to their continuous cropping. Similarly, higher values of bulk density

in the intensively cultivated land use systems in comparison to grassland have also been reported by (Cihacek and Ulmer, 1998 and Sanneh, 2007).

It is clear from Table 24 that in the interaction effect between altitudinal gradient and soil layer in Kullu valley, the bulk density declined significantly with increasing altitudinal range in the 0-20 cm layer. Whereas, in the 20-40 cm layer although, the bulk density declined with the increasing altitudinal ranges but not in significant manner. Significant decline in the bulk density with increasing altitudinal ranges can be ascribed to significant increase in the organic carbon (%) in the soil (0-20 cm layer) with increasing altitude (Tables 23 & 58). Because, the bulk density and soil organic carbon are inversely related.

5.3.2.3 Effect on soil organic carbon density

It is quite clear from the interaction effect between the land use system and altitudinal ranges that in general orchard + vegetable – vegetable in valley (Table 25) and forest land use and all combinations of altitudinal ranges (T_5A) in mountainous ecosystem (Table 62) displayed significantly higher values of soil organic carbon density over all other systems. Whereas, lowest organic carbon content was recorded in annual based cropping system/agriculture land use system at all the altitudinal ranges in both valley and mountainous region of Kullu districts. Higher soil organic carbon content in orchard + vegetable – vegetable and forest land use system in their respective ecosystem can be ascribed to continuous decomposition of leaf-litter also. Whereas, lower soil organic carbon in agriculture can be described on the basis of continuous depletion of organic carbon because of continued cultivation and removal of harvest from agriculture system.

5.3.2.4 Effect on available nitrogen (Kg ha^{-1})

A perusal of the data presented in the Table 65 revealed that available nitrogen was significantly influenced by the interaction effect between land use system and altitudinal gradient. 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, excepting in forest based land use system.

This may be due to the fact that in all the cultivated land use systems the farmers tends to maintain optimum yield through the addition of fertilizer, leaf-litter and farm yard manure on the surface across all the altitudinal gradient. Whereas, in forest land use systems there is no such manipulation and because of the less decomposition of leaf-litter and consequently lower losses through volatilization, leaching and surface runoff with increasing altitudinal ranges its level build up in the soil.

5.4 ECONOMIC ANALYSIS

5.4.1 Carbon credits (Rs $ha^{-1}yr^{-1}$)

Carbon credits as expressed in term of Rs $ha^{-1}yr^{-1}$ were calculated based on the quantum of CO_2 mitigated from the atmosphere and locked in the form of biomass. One ton of CO_2 fixed in biomass is equal to 1 carbon credit and the value of one carbon credit equal to 15 US $. Carbon credits which can be realized through capturing and locking carbon in the land use systems of valley and mountainous ecosystems has been presented in the Tables 31 & 70, respectively.

In the valley ecosystem, maximum carbon credit (Rs. 5015) can be realized from orchard + cereal – cereal land use system, which is closely followed by other AFSs viz., orchard + cereal - vegetable (RS. 4536) and orchard + vegetable – vegetable (Rs. 4590), etc. Whereas, in the mountainous ecosystem, maximum carbon credit (Rs. 5218) was realized from agri-horticulture land use system followed closely by forest (Rs. 4333), horticulture (Rs. 3550), silvi-pasture (Rs. 3017) and agriculture (Rs. 1242), respectively in the descending order.

From above results, it can be inferred that more carbon credit can be realized from all fruit based agroforestry systems in both valley and mountainous ecosystem. The amount of carbon credits which can be realized from a land use system is the function of rate of CO_2 capturing ability of plants and its locking in the form of biomass. The rate of CO_2 capturing ability in the form of woody biomass in fruit based system is more because they are intensively managed at

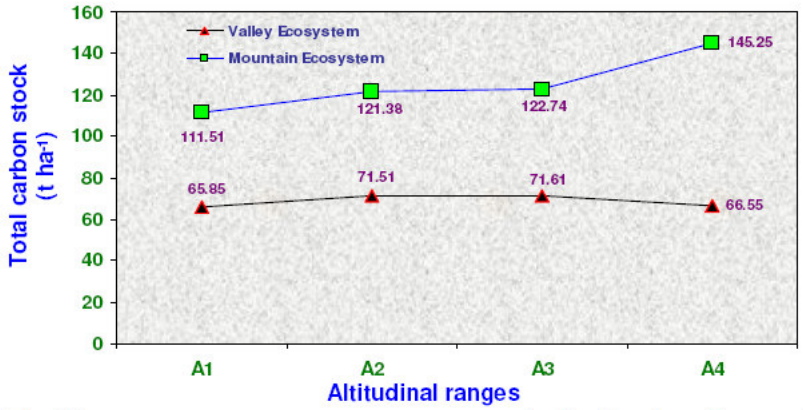

Fig 11. Total carbon stock (Plant +Soil) (t ha^{-1}) of valley and mountainous ecosystems in Kullu district (H.P.) at different altitudinal ranges

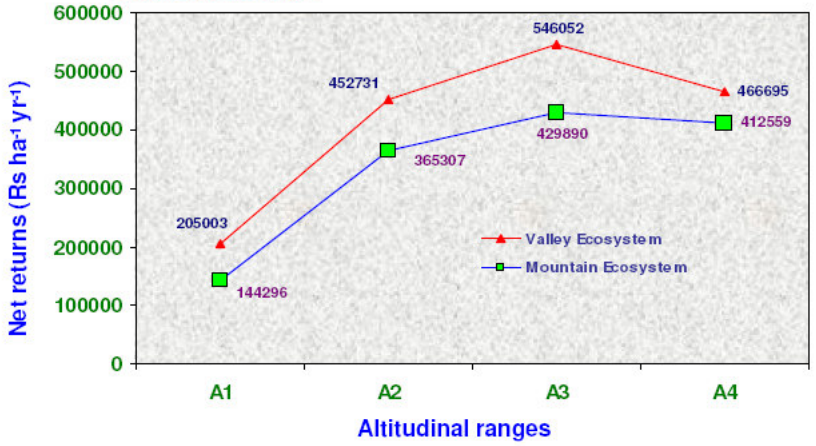

Fig 12. Net returns (Rs ha^{-1} yr^{-1}) from valley and mountainous ecosystems in Kullu district (H.P.) at different altitudinal ranges

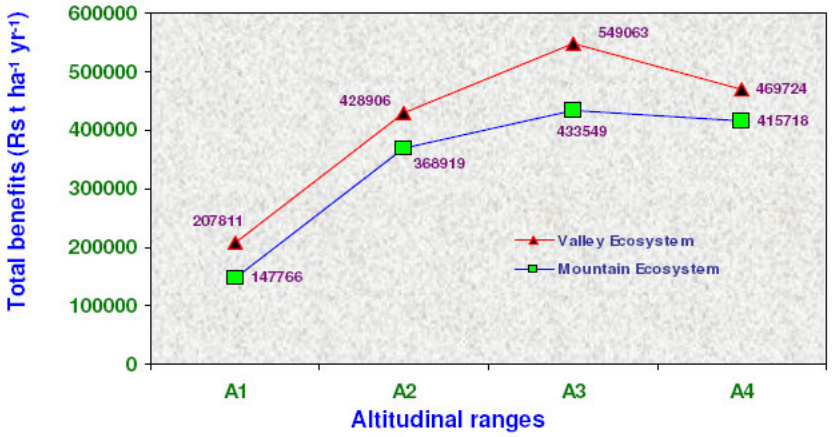

Fig 13. Total benefits (Rs ha^{-1} yr^{-1}) from valley and mountainous ecosystems in Kullu district (H.P.) at different altitudinal ranges

the same time only a small fraction of biomass is removed in the form of pruned wood and fruit yield. Although it is fact that fruit trees lock the carbon only for short term period of 30-40 years, only.

5.4.2 Economic returns

The data for gross returns, total expenses, net profit, benefit-cost ratio and total benefit (net profit + carbon credit), which can be realized from different land use systems is presented in Table 34-36 (Fig 12 & 13). Gross returns, total expenses, net profit, cost-benefit ratio and total benefit (net profit + carbon credits), which can be obtained from agroforestry land use systems as well as pure orchard at their respective altitudinal ranges were markedly higher than in the annual cropping systems viz., cereal – cereal, cereal–vegetable and vegetable – vegetable. Gross returns, net profit, benefit–cost ratio, total benefit (net profit + carbon credits) displayed their minimum values in cereal – cereal land use systems. Maximum net returns (Rs. 10,23.430 $ha^{-1}yr^{-1}$) in the valley ecosystem was demonstrated by orchard + vegetable - vegetable cropping system at 1600-1900 m a.s.l. (Plate 5) The data for gross return, total expenses, net profit, benefit–cost ratio and total returns (net profit + carbon credits) of the mountainous regions is exhibited through Table 71-75 in mountainous region of Kullu district. Maximum gross returns (Rs 11, 03,800 Rs $ha^{-1}yr^{-1}$), total expenses (3, 72,990.05 Rs $ha^{-1}yr^{-1}$), net profit (7, 31,809.5 Rs $ha^{-1}yr^{-1}$), and total benefit (7, 37,027 Rs $ha^{-1}yr^{-1}$) were recorded in the agri horticulture land use system. The benefit-cost ratio (5.03) was recorded to be highest in forest land use systems because in this level of the input were minimum.

From the above results it is clear that the net return, net profit and total benefits were higher in the agroforestry systems involving fruit trees likes plum and apple in association with the agriculture and vegetable crop viz., wheat, maize, mustard, tomato, garlic, pea, cauliflower and cabbage, etc. The higher per unit market prices of fruit, agriculture and vegetable crops and higher yield because of higher intensity of management coupled with irrigation facilities are the some of the reasons, which can be assigned for higher return from them in comparison to silvi-pasture and forest tree based land use systems. It was also

clear from the results that fruit based agroforestry system and pure orchards gave higher returns in both valley and mountainous ecosystems than the agriculture crops involving cereal crops. The reason for the same is again the higher unit market prices of fruits, higher suitability of fruit trees in prevailing climatic conditions than the cereals crops. Sood (1999) conducted an experiment studying tree crop interaction in which he reported that total cost incurred as well as net returns were higher in agri-horticulture system as compared to sole crop. Kumar (1999) reported that total costs, gross returns and net return were higher from combinations with soybean, while least from pomegranate soybean combination. Tomar and Bhatt (2004), recorded the maximum net monetary benefit per hectare when peach was intercropped with rice (Rs, 40, 404), followed by guava (Rs. 27, 087) and Assam lemon. (Rs. 20, 991), respectively, as compared to sole cropping. Under apple trees and ginger inter cropping system (Fan-wie *et al*., 2000) recorded 3 times more income from the system as compared with that of the apple orchard without intercropping.

Orchard + vegetable – vegetable land use system at 1600-1900 m a.s.l. showing highest net returns and total benefits in valley ecosystem

Agri-horticulture land use system at 1700-2000 m a.s.l. showing highest net returns and total benefits in mountain ecosystem

Plate 5. Economically most profitable land use systems in Kullu district of Himachal Pradesh

Chapter-6

SUMMARY AND CONCLUSIONS

The present investigations entitled **"Bio-economic appraisal and carbon sequestration potential of different land use systems in temperate north-western Himalayas"** were carried out through two independent experiments in valley and mountainous ecosystem of Kullu districts of Himachal Pradesh during the year of 2008-2009. These experiments were laid out in Randomized Block Design (Factorial). For conducting the experiment in valley ecosystem, a stretch of about 70 kilometres running along river Beas starting from Bajaura, Kullu and extended to just beyond the Manali was selected. This valley was further divided into four altitudinal gradients viz., 1000-1300 m, 1300-1600 m, 1600-1900 m and 1900-2200 m a.s.l. In each altitudinal gradient, seven cropping systems viz., cereal - cereal, cereal - vegetable, vegetable - vegetable, orchard + cereal - cereal, orchard + cereal - vegetable, orchard + vegetable - vegetable and pure orchard; which were common to all the levels were selected as land use systems at three different sites within each altitudinal range. Whereas, for conducting an experiment in mountainous ecosystem, four mountainous ranges having an altitudinal ranges of more than 1100-2300 m a.s.l. were selected as replicates. Each mountainous range was then further divided into four altitudinal gradients viz., 1100-1400 m, 1400-1700 m, 1700-2000 m and 2000-2300 m a.s.l. In each altitudinal range, five land use systems viz., agriculture, agri-horticulture, horticulture, silvi-pasture and forests were selected. The plot size in each land use system was 50 x10 square meter.

The data was recorded on above ground biomass of all the land use systems. Crop, shrubs and grass biomass was estimated using 1 square metre. Crop and fruit yield of trees was either determined on unit area basis or determined on the basis of interviews of the farmer of the respective land use systems. Litter biomass was also measured in 1m x 1m plot size. Soil attributes viz., bulk density, organic carbon and available nitrogen was also determined.

The same was used for preparing the carbon pool inventory and soil organic carbon density. These soil samples were taken from 0- 20 cm and 20-40 cm soil layers.

The data regarding economics was collected by personal interviews with the farmers of existing research sites. The data on forest related parameters was collected from forest corporation Kullu and divisional manager, Kullu Forest Division. The salient findings of the two experiments are summarized as below:

The results of the experiment in the valley ecosystem have revealed that different land use systems has significant influence on the production of above, below as well as on total biomass, carbon stock and carbon mitigation potential. Maximum above ground (75.64 t ha^{-1}), below ground (23.60 t ha^{-1}) and total biomass (99.23 t ha^{-1}) was accumulated in the orchard + cereal-cereal (T_4) land use system. Whereas, the maximum above ground biomass (336.4 t ha^{-1}), below ground biomass (67.90 t ha^{-1}) and total biomass (404.35 t ha^{-1}) in mountainous region of Kullu district was recorded in forest land use system. Total biomass production of different land use systems in valley ecosystem followed the order: orchard + cereal – cereal > orchard + cereal – vegetable > orchard + vegetable – vegetable > pure orchard > cereal – cereal > cereal – vegetable > vegetable - vegetable. Whereas, in mountainous region the order was: forest > silvi-pasture > agri-horticulture > horticulture > agriculture. Similar trends were also seen in respect of biomass carbon stock and CO_2 mitigation potential of different land use systems.

In the effect of altitudinal ranges, the above ground biomass, below ground biomass and total biomass in the valley ecosystem increased from 1000-1300 m to 1300-1600 m a.s.l. and thereafter showed a declining trend. Whereas, in the mountainous ecosystem all the traits of biomass enhanced with the increase in the altitudinal ranges from A_1 to A_4. The rate of biomass production (t ha^{-1} yr^{-1}) in the valley and mountainous ecosystem was found to be 22.66 t ha^{-1} yr^{-1} and 20.03 t ha^{-1} yr^{-1}, respectively in the field crops based land use systems.

Maximum rate of biomass removal (21.90 t $ha^{-1}yr^{-1}$) in the valley ecosystem was exhibited by the cropping system of cereal- cereal (T_1), which was followed by treatments viz., T_4, T_2, T_3, T_5, T_6 and T_7, respectively in the descending order. Maximum biomass removal (19.19 t $ha^{-1}yr^{-1}$) in mountainous ecosystem is in agriculture (T_1), which was followed by the agri-horticulture (T_2), horticulture (T_3), silvi-pasture (T_4) and forest (T_5) land use systems, respectively in the descending order.

Irrespective of the altitudinal gradient, maximum rate of biomass retention is demonstrated by the fruit based land use systems in both valley (4.05 t $ha^{-1}yr^{-1}$) and mountainous region (4.16 t $ha^{-1}yr^{-1}$) of the Kullu districts of Himachal Pradesh. In altitudinal gradient, rate of biomass retention enhanced from A_1 to A_3 and then declined thereafter. The rate of biomass retention in valley and mountainous ecosystem of Kullu district followed the trend:

Valley ecosystem: $T_4 > T_5 > T_6 > T_7 > T_3 > T_2 > T_1$

Mountainous ecosystem: $T_2 > T_5 > T_3 > T_4 > T_1$

Similar, trends were also seen in respect of rate of biomass carbon stock and CO_2 sequestration potential of different land use systems.

In the valley ecosystem, maximum CO_2 mitigation potential (7.81 t $ha^{-1}yr^{-1}$) was displayed by orchard + cereal-cereal land use system at the altitudinal range of 1900-2200 m a.s.l., but its difference from other orchard based land use systems, excepting pure orchard based land use system remained statistically, alike. Whereas, in the mountainous ecosystem, maximum CO_2 mitigation (7.36 t ha^{-1} yr^{-1}) was demonstrated by agri-horticulture (T_2) land use system followed by forest (6.23 t $ha^{-1}yr^{-1}$), horticulture (5.26 t $ha^{-1}yr^{-1}$), silvi-pasture (4.40 t $ha^{-1}yr^{-1}$) and agriculture (1.84 t $ha^{-1}yr^{-1}$), respectively. In the altitudinal ranges, the rate of CO_2 mitigation potential was maximum at A_3 (5.30 t $ha^{-1}yr^{-1}$).

Maximum soil organic carbon (0.85 %) in valley ecosystem was recorded in the pure orchard, which, however remained statistically at par with the organic content as observed in the orchard + vegetable - vegetable (T_6), orchard + cereal-

vegetable (T_5) and differed significantly from all other land use systems. Whereas, in the mountainous ecosystem, maximum soil organic carbon content (2.5 %) was found in the forest ecosystem, which was followed by the land use systems of agri-horticulture (0.89 %), horticulture (0.87 %), silvi-pasture (0.81 %) and agriculture (0.68 %), respectively, in the descending order. The soil organic carbon percent also declined significantly with ascending altitudinal ranges. The soil organic carbon percent declined from L_1 to L_2 soil layer also.

In the valley ecosystem, maximum bulk density (1.92 g cm^{-3}) was recorded in orchard+ vegetable-vegetable land use system, which was found to be significantly higher than all other land use systems. Whereas, in hill ecosystem of Kullu district, the maximum bulk density (1.25 g cm^{-3}) was recorded in the land use system of agriculture, which is followed by horticulture (1.20 g cm^{-3}), agri-horticulture (1.16 g cm^{-3}), silvi-pasture (1.12 g cm^{-3}) and forest system (0.99 g cm^{-3}), respectively in the descending order. The bulk density declined significantly as we moved from lower to higher elevation ranges. The bulk density as recorded at the upper soil layer (0-20 cm) was found to be significantly lower than the deeper soil layer (20-40 cm) in both valley and mountainous ecosystem of Kullu districts of Himachal Pradesh.

Forest land use system displayed the maximum value of soil organic carbon density (49.04 t ha^{-1}) in the mountainous ecosystem, which was followed by horticulture (20.59 t ha^{-1}), agri-horticulture (20.52 t ha^{-1}), silvi-pasture (17.90 t ha^{-1}) and agriculture (16.94 t ha^{-1}), respectively in the descending order. Whereas, in the valley ecosystem maximum soil organic carbon stock (20.02 t ha^{-1}) was recorded in the orchard + vegetable - vegetable cropping system, which was found to be significantly higher than all other land use systems. In the altitudinal range effect, the total soil organic carbon density increased with ascending altitudinal gradient. In the soil layer effect, SOC stock in (0-20 cm) layer is found to be significantly higher than that of (20-40 cm) layer.

Maximum available N (523.7 kg ha^{-1}) was found in pure orchard in the valley ecosystem. Whereas in the mountainous ecosystem maximum available N (510.4 kg ha^{-1}) was found in the horticulture and agri-horticulture based land use

systems, each displaying equal values. In the altitudinal ranges, maximum available N was found at the altitudinal range of A_3. In the soil depth, nitrogen status at the L_1 (0-20 cm) layer was significantly higher than L_2 (20-40 cm) layer in both valley as well as in mountainous ecosystem of Kullu district.

In the valley ecosystem, maximum soil organic carbon density (40.87 t ha^{-1}) in 0-40 cm soil layer was recorded in the T_6 (orchard+ vegetable-vegetable) land use system, which has followed by the treatments viz., T_5, T_4, T_7, T_3, T_2 and T_1, respectively, in the descending order. Whereas, in the hill ecosystem, the maximum soil carbon density (98.08 t ha^{-1}) in the 0-40 cm soil layer is recorded in the forest land use system, which was closely followed by the agri-horticulture (41.05 t ha^{-1}), horticulture (39.16 t ha^{-1}), silvi-pasture (35.79 t ha^{-1}) and agriculture (33.88 t ha^{-1}), respectively in the descending order. Maximum total soil organic carbon density was observed in the forest land use system (98.08 t ha^{-1}), which was found to be 2-3 times higher over other land use systems.

Maximum total carbon density (90.88 t ha^{-1}) in the valley area was observed in orchard+ cereal- cereal land use system. Whereas, the maximum total carbon density in the mountainous ecosystem of Kullu district was (303.3 t ha^{-1}) in the forest land use system, which was found to be 3-4 times higher than other woody component based land use systems viz., agri-horticulture (72.8 t ha^{-1}), horticulture (68.6 t ha^{-1}) and silvi-pasture (80.1 t ha^{-1}) and ten times higher over the annual plant based land use systems.

All the land use systems presently under consideration showed net deficit of carbon stock in relation to forest. This deficit was higher in agriculture land use system than in perennial tree based land use systems viz., agri-horticulture, silvi-pasture, and horticulture. But, when comparison was made with respect to agriculture all the systems showed the net gains. Net gain in the carbon was in the order of agri-horticulture > forest > horticulture > silvi-pasture, respectively. In the forest land use system, the relative carbon dioxide mitigation potential with respect to agriculture taken as 1 declined with the increase in the altitudinal ranges.

Carbon credit varied appreciably among different land use systems in both valley and mountainous ecosystem. Maximum carbon credit in the valley ecosystem Rs 5015 and in the hill ecosystem was (Rs 5218) in the fruit tree based agroforestry systems. Altitudinal gradient does not have much impact on variation in the value of carbon credits.

Total expenses in valley ecosystem, in cereal - cereal based cropping system at all of four altitudinal ranges are quite less than vegetable based agroforestry system and pure orchard. Irrespective of the altitudinal ranges in mountainous ecosystem, maximum expenses are involved in the agri-horticulture (Rs. 3,72,990) based land use system, which was closely followed by horticulture (Rs. 2,56,897), agriculture (Rs. 1,91,776), forest (Rs. 31,930) and silvi-pasture system (Rs. 18,420), respectively. In the altitudinal ranges, expenses show a consistent increasing trend in respect of total expenses incurred.

Gross returns is maximum (Rs. 12, 20,500) in orchard + vegetable - vegetable land use system in the valley ecosystem, whereas they are maximum (Rs.11,03,800) in agri-horticulture system in mountainous ecosystem, which was closely followed by the land use systems of horticulture, agriculture, forest and silvi-pasture system, respectively in the descending order. In the interaction between the land use system and altitudinal gradient, fruit based agroforestry system and horticulture land use systems yields very high gross return at all the altitudinal ranges in both valley and hill ecosystem of Kullu district.

In the valley ecosystem the net profit (Rs $ha^{-1}yr^{-1}$) from orchard + cereal - cereal (T_4), orchard + cereal - vegetable (T_5), orchard + vegetable - vegetable (T_6) and pure orchard (T_7) land use systems were markedly higher than annual cropping based land use systems viz., cereal-cereal, cereal-vegetable and vegetable-vegetable. Maximum net profit (Rs. 10, 23,430) can be realized from the land use system of orchard + vegetable - vegetable at 1600-1900 m a.s.l. Whereas, in the mountainous ecosystem, maximum net profit can be attained in agri-horticulture system (Rs 7, 31,809), which was closely followed by horticulture (Rs 6,71,852), only. In the altitudinal ranges, the net profit obtained

increased appreciably from A_1 to A_2 and then increased but at the less rate from A_2 to A_3 and A_2 to A_4.

Benefit-cost ratio in the valley ecosystem was maximum (2.33) in pure orchard based land use system, which was closely followed by vegetable-vegetable (T_3), orchard + cereal - cereal (T_4), orchard + cereal - vegetable (T_5), orchard + vegetable - vegetable (T_6), cereal - vegetable (T_2) and cereal - cereal (T_1), respectively in the altitudinal effect in the valley ecosystem was maximum benefit-cost ratio (2.33) estimated at 1600-1900 m a.s.l. Whereas, in the mountainous ecosystem, benefit-cost ratio was maximum (5.03) in the forest based land use system, which was closely followed by the land use systems of silvi-pasture (4.73), horticulture (3.56), agri-horticulture (2.94) and agriculture (1.39), respectively in the descending order. Benefit-cost ratio was minimum (1.25) at the treatment combination of T_1A_2 and maximum in at of T_4A_4 (6.31) level.

CONCLUSIONS

- Maximum biomass production (99.23 t ha^{-1}) in the valley ecosystem was recorded in the orchard + cereal - cereal based cropping system. Whereas, in the mountainous ecosystem maximum total biomass (404.35 t ha^{-1}) was displayed by forest based land use system. In the valley ecosystem an altitudinal range of 1300-1600 m a.s.l. showed the maximum biomass production (63.05 t ha^{-1}). Whereas, in the mountainous ecosystem it was maximum (181.11 t ha^{-1}) at the higher elevation range i.e. 2000-2300 m a.s.l. Minimum biomass was recorded in annual cropping system in both valley and mountainous ecosystem.

- Rate of biomass production in both valley (22.60 t $ha^{-1}yr^{-1}$) and mountainous ecosystem (20.03 t $ha^{-1}yr^{-1}$) was maximum in the annual based cropping systems.

- The rate of CO_2 mitigation potential in the valley ecosystem was maximum (7.81 t $ha^{-1}yr^{-1}$) in the orchard + cereal - cereal based land use

system situated at altitudinal range of 1900-2200 m a.s.l. Similarly, in the mountainous ecosystem also the rate of CO_2 mitigation potential was found to be maximum (7.98 t $ha^{-1}yr^{-1}$) in the agri-horticulture land use system situated at an altitude of 2000-2300 m a.s.l.

- In the valley ecosystem maximum carbon density (90.88 t ha^{-1}) was recorded in orchard + cereal – cereal land use system at the elevation range of 1300-1600 m a.s.l. Whereas, in the mountainous ecosystem, maximum carbon density (393.29 t ha^{-1}) was recorded in the forest based land use system situated at the altitudinal range of 2000-2300 m a.s.l.

- Fruit based land use systems viz., orchard+ cereal-cereal, orchard + cereal -vegetable, orchard + vegetable - vegetable and pure orchard displayed 6-7 times more soil carbon density then pure agriculture based land use systems.

- In the valley ecosystem, orchard + vegetable – vegetable land use system situated at 1600-1900 m a.s.l. displayed net profit of Rs. 10, 23,430 $ha^{-1}yr^{-1}$. Whereas, in the mountainous ecosystem agri-horticulture land use system situated at 1700-2000 m a.s.l. displayed net profit of Rs. 9, 69, 194 $ha^{-1}yr^{-1}$.

- Benefit - cost ratio in Kullu valley, was maximum (3.3) in pure fruit tree based land use system situated at 1600-1900 m a.s.l. Whereas, the maximum benefit-cost ratio (6.31) in the mountainous ecosystem was recorded in silvi-pasture land use system situated at 2000-2300 m a.s.l.

- Total benefits (net profit+carbon credits) in valley ecosystem were maximum in orchard + vegetable - vegetable based cropping system at all the four altitudinal gradient levels. Similarly, in the mountainous ecosystem also, fruit based agri-horticulture system displayed maximum total benefits at all the altitudinal gradients, excepting at 1400-1700 m a.s.l., in which horticulture land use system yielded minimum benefits.

- On the basis of above, we can conclude that in the valley ecosystem, fruit based land use systems viz., orchard + cereal - cereal, orchard + cereal -

vegetable, orchard + vegetable - vegetable and pure orchard are not only biological productive but have more carbon density, CO_2 mitigation potential, net profit, higher benefit-cost and total benefits than field crops and/or vegetable based cropping systems hence need to be promoted. Whereas, in the mountainous ecosystems the forest and silvi-pasture system are store house of carbon in both soil and plant, which need to be conserved for environmental protections. Whereas, from the carbon mitigation potential and economic point of view agri-horticulture systems, need to be promoted over the traditional field crops based land use system for realising better monetary return and environmental benefits.

Chapter-7

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ABSTRACT

The present investigations entitled "Bio-economic appraisal and carbon sequestration potential of different land use systems in temperate north-western Himalayas" were carried out through two independent experiments in valley and mountainous ecosystem of Kullu district (31°58′00″ N latitude and 77°06′4″ E longitude) of Himachal Pradesh during 2008-2009. These experiments were laid out in Randomized Block Design (Factorial). In the valley ecosystem, seven land use systems selected were: cereal-cereal, cereal-vegetable, vegetable-vegetable, orchard + cereal-cereal, orchard + cereal-vegetable, orchard + vegetable-vegetable and pure orchard and four altitudinal gradients viz., 1000-1300 m, 1300-1600 m, 1600-1900 m and 1900-2200 m a.s.l. whereas, for conducting an experiments in mountainous ecosystem, four altitudinal ranges having an altitudinal ranges of more than 1100-2300 m a.s.l. were selected as replicates. Each ranges was then further divided into four altitudinal gradients viz., 1100-1400 m, 1400-1700 m, 1700-2000 m and 2000-2300 m a.s.l. In each altitudinal range, five land use systems viz., agriculture, agri-horticuture, horticulture, silvi-pasture and forests were selected. The plot size in each land use system was 50 m x 10 m. Existing biomass production, carbon density, carbon sequestration potential CO_2 mitigation and total benefits of each land use systems were evaluated. The results have revealed that different land use systems have significant influence on the production of above ground biomass, below ground biomass as well as total biomass, carbon stock and CO_2 mitigation potential in both experiments. Maximum above ground biomass (75.64 t ha^{-1}), below ground (23.60 t ha^{-1}) and total biomass (99.23 t ha^{-1}) was accumulated in the orchard + cereal-cereal land use system. Whereas, the maximum above ground biomass (336.4 t ha^{-1}), below ground biomass (67.90 t ha^{-1}) and total biomass (404.35 t ha^{-1}) in mountainous ecosystem of Kullu district was recorded in forest land use system. Total biomass production of different land use systems in valley ecosystem followed the order: orchard + creal-cereal > orchard + cereal-vegetable > orchard + vegetable-vegetable > pure orchard > cereal-cereal > cereal-vegetable > vegetable-vegetable. Whereas, in mountainous ecosystem the trend was : forest > silvi-pasture > agri-horticulture > horticulture > agriculture. Similar trends were also seen in respect of biomass carbon density and CO_2 mitigation potential of different land use systems. In the valley ecosystem an altitudinal range of 1300-1600 m a.s.l. showed the maximum biomass production (63.05 t ha^{-1}). Whereas, in the mountainous ecosystem it was maximum (18.11 t ha^{-1}) at the higher elevation range i.e., 2000-2300 m a.s.l. Rate of biomass production in both valley (22.60 t ha^{-1} yr^{-1}) and mountainous ecosystem (20.03 t ha^{-1} yr^{-1}) was maximum in the annual based cropping systems. The rate of CO_2 mitigation potential in the valley ecosystem was maximum (7.81 t ha^{-1} yr^{-1}) in the orchard + cereal-cereal land use system situated at altitudinal range of 1900-2200 m a.s.l. Similarly, in the mountainous ecosystem also the rate of CO_2 mitigation potential was found to be maximum (7.98 t ha^{-1} yr^{-1}) in the agri-horticuture land use system situated at an altitude of 2000-2300 m a.s.l. In the valley ecosystem maximum carbon density (90.88 t ha^{-1}) was recorded in orchard + cereal-cereal land use system at the elevation range of 1300 -1600 m a.s.l. Whereas, in the mountainous ecosystem, maximum carbon density (393.29 t ha^{-1}) was recorded in the forest based land use system situated at the altitudinal range of 2000-2300 m a.s.l. In the valley ecosystem, orchard + vegetable-vegetable land use system situated at 1600-1900 m a.s.l. displayed net profit of Rs 10,23,430 ha^{-1} yr^{-1}. Whereas, in the mountainous ecosystem agri-horticulture land use system situated at 1700-2000 m a.s.l. displayed net profit of Rs. 9,69,194 ha^{-1} yr^{-1}. Total benefits (net profit + carbon credits) in the valley ecosystem were maximum in orchard + vegetable-vegetable based cropping system at all the four altitudinal gradients. Similarly, in the mountainous ecosystem also, fruit based agri-horticulture system displayed maximum total benefits at all the altitudinal gradients.

The findings evinced that in the valley ecosystem fruit based land use systems and pure orchard are not only biological productive but have more carbon density, CO_2 mitigation potential, net profit, higher benefit cost and total benefits than field crops and/or vegetable based cropping systems hence need to be promoted. Whereas, in the mountainous ecosystems the forest and silvi-pasture system are store house of carbon in both soil and plants, which need to be conserved for environmental protections. Whereas, from the CO_2 mitigation potential and economic point of view agri-horticulture systems, needs to be promoted over the traditional field crops based land use systems for realizing both monetary return as well as environmental benefits.

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APPENDIX I

Metrological data for the month of April, 2008 to March, 2009.

Months	Temperature (^{o}C)		Relative humidity (%)		Total rainfall (mm)	Sunshine (hrs)
	Maximum	Minimum	Morning	Evening		
April, 2008	27.54	10.80	87.20	29.00	13.88	7.92
May	29.83	14.15	85.00	49.50	13.30	7.13
June	30.95	20.33	86.75	64.25	20.50	6.45
July	31.12	21.60	88.60	57.80	24.04	6.08
August	28.58	20.00	90.75	64.50	54.43	5.08
September	28.18	15.10	90.50	51.00	50.10	7.93
October	26.74	9.32	91.00	41.40	5.08	7.98
November	23.08	2.58	93.25	31.25	2.90	7.13
December	19.75	3.73	90.25	36.50	9.85	5.63
January, 2009	17.88	3.52	89.20	41.40	3.76	4.64
February	21.20	5.65	84.50	33.00	9.10	6.48
March	23.05	6.23	86.00	32.50	9.85	6.10

Source: Metrological observatory, Department of Agronomy, Agricultural Research and Extension Centre (CSKHPKV) Bajaura, Kullu (H.P.)

APPENDIX II

ANOVA table for biomass, C and CO_2 production potential in the valley ecosystem of Kullu districts (H.P.)

Source of variation	df	Mean sum of square								
		Above ground biomass (t ha^{-1})	Below ground biomass (t ha^{-1})	Total biomass (t ha^{-1})	Above ground biomass carbon (t ha^{-1})	Below ground biomass carbon (t ha^{-1})	Total biomass carbon (t ha^{-1})	Above ground biomass (CO_2)sequestration (t ha^{-1})	Below ground biomass (CO_2 sequestration) (t ha^{-1})	Total biomass (CO_2) Sequestration (t ha^{-1})
Land use system (L)	**6**	1.2880E+04	1104.5	2.1552E+04	3219.8	282.43	5387.9	4.3331E+04	3809.4	6.9358E+04
Altitudinal range (A)	**3**	246.96	22.480	422.56	61.751	3.5719	105.92	828.29	47.328	1305.3
Replication (R)	**2**	2.5740E-01	2.3244E-01	9.2241E-01	6.5197E-02	6.1130E-01	2.3619E-01	7.0266E-01	7.8131	78.801
LxA	**18**	17.165	3.9037	34.782	4.2969	1.5620	8.6889	58.876	21.007	228.06
LxAxR	**54**	3.0702	2.8424E-01	4.8787	7.6787E-01	3.6830E-01	1.2194	10.342	4.9711	89.765

APPENDIX III

ANOVA table for the rate of biomass production, C and CO_2 mitigation potential in the valley ecosystem of Kullu districts (H.P.)

Source of variation	df	Mean sum of square								
		Rate of biomass production (t $ha^{-1}yr^{-1}$)	Rate of biomass removal (t $ha^{-1}yr^{-1}$)	Rate of biomass retention (t $ha^{-1}yr^{-1}$)	Rate of biomass carbon production (t $ha^{-1}yr^{-1}$)	Rate of biomass carbon removal (t $ha^{-1}yr^{-1}$)	Rate of biomass Carbon mitigation (t $ha^{-1}yr^{-1}$)	Rate of biomass CO_2 production (t $ha^{-1}yr^{-1}$))	Rate of biomass CO_2 removal (t $ha^{-1}yr^{-1}$)	Rate of biomass CO_2 mitigation (t $ha^{-1}yr^{-1}$)
Land use system (L)	**6**	407.38	416.62	32.064	101.54	105.19	8.1689	1378.6	1414.2	109.49
Altitudinal range (A)	**3**	380.04	269.48	13.685	94.758	68.051	2.7533	1284.9	904.00	36.746
Replication (R)	**2**	1.2915E-02	6.0269E-01	1.1672E-01	1.4756E-01	2.5666E-02	6.9925E-04	4.4557	7.7724E-01	1.7023E-02
LxA	**18**	26.789	18.130	7.7938E-01	6.7652	4.4575	1.8138E-01	90.739	60.856	2.4598
LxAxR	**54**	3.1507E-01	4.7971E-01	1.2022E-01	1.5555E-01	9.5709E-02	3.9938E-03	1.7956	1.3571	6.3582E-02

APPENDIX IV

ANOVA table for different parameter of soil in the valley ecosystem of Kullu districts (H.P.)

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)	**6**	5.4687E-02	1.2189E-02	18.179	2.9053E+04
Soil depth (L)	**1**	2.5505	2.3118E-01	1003.6	2.2912E+05
Altitudinal range (A)	**3**	3.9286E-01	2.0709E-01	80.019	2.0569E+04
Replication (R)	**2**	2.2776E-02	1.3325E-02	4.5687	5852.4
TxL	**6**	8.4274E-03	5.7755E-03	4.2754	1119.4
TxA	**18**	7.5785E-03	6.3177E-03	5.9389	2431.5
AxL	**3**	5.1372E-02	2.7589E-02	39.709	1407.4
TxAxL	**18**	3.1411E-03	6.6892E-03	2.4090	2464.2
TxAxLxR	**110**	5.7643E-03	4.9473E-03	3.4661	2071.1

APPENDIX V

ANOVA table for Biomass, C and CO_2 production potential in the mountainous ecosystem of Kullu districts (H.P.)

Source of variation	df	Mean sum of square								
		Above ground biomass (t $ha^{-1)}$	Below ground biomass (t $ha^{-1)}$	Total biomass (t $ha^{-1)}$	Above ground biomass carbon (t $ha^{-1)}$	Below ground biomass carbon (t $ha^{-1)}$	Total biomass carbon (t $ha^{-1)}$	Above ground biomass (CO_2)sequestration (t $ha^{-1)}$	Below ground biomass (CO_2 sequestration) (t $ha^{-1)}$	Total biomass (CO_2) Sequestration (t $ha^{-1)}$
Land use system (L)	**4**	1.9109E+05	6495.7	2.6524E+05	4.7534E+04	1621.6	6.6339E+04	6.3867E+05	2.1843E+04	9.0061E+05
Altitudinal range (A)	**3**	6798.0	230.76	8262.9	1006.7	58.397	2071.9	1.9335E+04	787.06	2.9159E+04
Replication (R)	**2**	452.65	6.2622	300.62	184.30	1.6709	75.185	768.73	22.602	806.07
LxA	**12**	5688.3	234.52	8195.4	1511.6	58.376	2054.4	1.9053E+04	786.19	2.8936E+04
LxAxR	**38**	195.37	3.2808	119.10	67.198	8.1409E-01	29.777	277.79	10.956	289.07

APPENDIX VI

ANOVA for the rate of biomass production, C and CO_2 mitigation potential in the mountainous ecosystem of Kullu districts (H.P.)

Source of variation	df	Mean sum of square								
		Rate of biomass production (t $ha^{-1}yr^{-1}$)	Rate of biomass removal (t $ha^{-1}yr^{-1}$)	Rate of biomass retention (t $ha^{-1}yr^{-1}$)	Rate of biomass carbon production (t $ha^{-1}yr^{-1}$)	Rate of biomass carbon removal (t $ha^{-1}yr^{-1}$)	Rate of biomass Carbon mitigation (t $ha^{-1}yr^{-1}$)	Rate of biomass CO_2 production (t $ha^{-1}yr^{-1}$))	Rate of biomass CO_2 removal (t $ha^{-1}yr^{-1}$)	Rate of biomass CO_2 mitigation (t $ha^{-1}yr^{-1}$)
Land use system (L)	**4**	639.57	625.19	10.372	153.10	161.41	2.6179	2152.2	2129.4	35.267
Altitudinal range (A)	**3**	104.24	62.199	2.5895	22.116	18.652	6.4761E-01	351.10	278.38	8.7169
Replication (R)	**2**	9.0027E-02	1.5777	1.3014E-02	7.3322E-01	1.4630E-02	3.6650E-03	2.9966E-01	7.6110E-01	4.3807E-02
LxA	**12**	56.268	51.184	1.3496	13.911	10.494	3.3543E-01	189.43	137.04	4.5428
LxAxR	**38**	1.7664E-01	1.1052	2.5752E-02	7.3745E-01	2.6203E-02	6.2650E-03	5.9472E-01	1.9464	8.4615E-02

APPENDIX VII

ANOVA table for different parameter of soil in the mountainous ecosystem of Kullu districts (H.P.)

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)	**4**	13.850	2.8688E-01	4396.5	6.3890E+04
Soil depth (L)	**1**	3.4847	2.1735E-02	1402.0	1.9153E+05
Altitudinal range (A)	**3**	5.3434E-01	1.7010E-01	69.563	3.0550E+04
Replication (R)	**2**	2.6754E-02	3.6252E-03	7.6385	822.83
TxL	**4**	1.0739E-01	6.8027E-04	17.097	1042.6
TxA	**12**	2.3895E-02	1.3020E-02	15.066	9642.7
AxL	**3**	8.6919E-02	1.5375E-03	27.962	489.39
TxAxL	**12**	2.2823E-02	8.9309E-04	12.991	555.09
TxAxLxR	**78**	7.9325E-03	2.4494E-03	3.7756	1511.8

APPENDIX VIII

Inventory of forest trees (forest/fruit) and agricultural crops identified in the valley and mountainous ecosystems in kullu districts (H.P.)

Common name/ English name	Scientific name
Forest trees	
Chir	*Pinus roxburghii*
Deodar	*Cedrus deodara*
Fir	*Abies pindrow*
Kail	*Pinus wallichiana*
Spruce	*Picea smithiana*
Fruit trees	
Apple	*Malus domestica*
Plum	*Prunus domestica*
Pomegranate	*Punica granatum*
Peach	*Prunus persica*
Pear	*Prunus cummenis*
Agriculture crops	
Brinzal	*Solanum melongena*
Cabbage	*Brassica botrytis*
Cauliflower	*Brassica capitata*
Garlic	*Allium sativum*
Maize	*Zea mays*
Pea	*Pisum sativam*
Tomato	*Lycopersion esculantum*
Wheat	*Triticum astivum*

APPENDIX IX

Root: shoot ratio of different agricultural crops

Crops name	R:S	Reference
Allium sativum	-	-
Brassica botrytis	0.48	Calculated as per standard method
Brassica capitata	0.50	Calculated as per standard method
Lycopersion esculantum	0.36	Jaja & Odoemena, 2004
Pisum sativam	0.55	McPhee, 2005
Solanum melongena	0.35	Baynelo-Jimenez *et al*., 2002
Triticum astivum	0.30	Kanchikerimath & Singh, 2001
Zea mays	0.50	Kanchikerimath & Singh, 2001
Malus domestica	0.33	Calculated as per standard method
Prunus domestica	0.35	Calculated as per standard method

APPENDIX X

Specific gravity of different forest trees

Tree name	Specific gravity
Abies pindrow	0.37
Cedrus deodara	0.46
Picea smithiana	0.38
Pinus roxburghii	0.47
Pinus wallichiana	0.357

APPENDIX XI

Local cost of agricultural inputs and outputs in valley and mountainous ecosystem of Kullu districts of Himachal Pradesh

Sr. No.	Particulars	Rate (Rs)
	Input	
1.	Labour cost	
	a) Labour charges around year 2008-2009	120
	b) Bullock labour (per day)	350
	c) Ploughing by tractor (per hour)	250
2.	Seed cost (per kg)	
	a) cabbage	25000
	b) cauliflower	25000
	c) garlic	40
	d) Maize	25
	e) pea	60
	f) tomato	30000
	g) Wheat	30
3.	Manure and fertilizers (per quintal)	
	a) FYM	50
	b) Urea	700
	c) NPK 12:32:16	720
	d) Cain	800
4.	Fungicides & Pesticides	
	a) Formalin (5 litre)	250
	b) Dithane M-45 (500 g)	160
	c) Bavestin (100 g)	55
	d) Blytox- 50 (500 g)	150
	e) Metasystox (1 litre)	425
	f) Nuvon (100 ml)	65
5.	Land rent for agriculture (Rs $ha^{-1}yr^{-1}$)	37500
	Output	
1.	Agriculture (per quintal)	
	a) Wheat grain	1000
	b) Wheat straw	450
	c) Maize corn	800
	d) Maize stower	200
	e) Garlic	2500
	f) Tomato	1200
	g) Pea (pods)	4500
	h) Cauliflower	800
	i) Cabbage	600
2.	Fruits (per quintal)	
	a) Apple	2500
	b) Plum	2500
3.	Pastures (per quintal)	
	a) Grass	300
	b) Leaf fodder	150
4.	I. Wood (per cubic ft)	
	a) *Abies pindrow*	450
	b) *Cedrus deodara*	1450
	c) *Picea smithiana*	450
	d) *Pinus roxburghii*	350
	e) *Pinus wallichiana*	700
	II. Fuel wood (per quintal)	450

1. Cost of cultivation for annual crops:

APPENDIX XII

1.1 Plowing and land preparation -

Crops	Cost for using bullocks (Rs/ 800m^2)	Cost for labour (Manday)	Cost Rs/ 800m^2	Cost Rs/ha
Wheat	500	2x120	740	9250
Maize	500	2x120	740	9250
Cauliflower	1000	4x120	1480	18500
Cabbage	1000	4x120	1480	18500
Pea	1000	4x120	1480	18500
Tomato	1000	4x120	1480	18500
Garlic	1000	4x120	1480	18500

*Local wage rates prevailing in the area (2008-09 market prices)

APPENDIX XIII

1.2 Seeds for sowing

Cost item	Seed rate/ha	Price Rs/kg	Rs/ha
Wheat	100 kg	30	3000
Maize	60 Kg	28	1680
Cauliflower	750 g	2000	1500
Cabbage	750 g	2200	1500
Pea	100 kg	60	6000
Tomato	0.125 kg	40000	5000
Garlic	50 kg	80	4000

*Values calculated at 2008-09 market prices

APPENDIX XIV

1.3 Irrigation

Crop	No of irrigation	Labour (Man day)	Cost Rs/800m2	Rs/ha
Wheat	0	0	0	0
Maize	0	0	0	0
Cauliflower	5	3	600	7500
Cabbage	6	3	720	9000
Pea	2	3	360	4500
Tomato	6	6	720	9000
Garlic	3	4	360	4500

* Local wage rates prevailing in the area (2008-09 market prices)

APPENDIX XV

1.4 Pesticides

Crop	Cost Rs/ 800m^2	Rs/ha
Wheat	600	7500
Maize	500	7000
Cauliflower	1200	7000
Cabbage	1200	7000
Pea	1200	15000
Tomato	1400	17500
Garlic	600	7500

*Values calculated at 2008-09 market prices

APPENDIX XVI

1.5 Fertilizer supplied to annual crops

Fertilizer type	Unit	Price (Rs)	Per ha required	Total price (Rs/ha)
FYM	kg	0.5	750q	37500
CAN	kg	10	375kg	3750
SSP	kg	5	500kg	2500
MoP	kg	6	375kg	2250
NPK-complex	kg	5.4	1250kg	6750

*Values calculated at 2008-09 market prices

APPENDIX XVII

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

Crop	Fertilizer	Quantity/ha	Price Rs
Wheat	NPK-complex	625 kg	3375
	FYM	250 q	12500
		Sub total	15875
Maize	FYM	250 q	12500
Cauliflower	FYM	250 q	12500
	CAN	400 Kg	4250
	SSP	600 Kg	2400
	MOP	90 Kg	450
	12:32:16	150 Kg	12500
Cabbage	FYM	250 q	12500
	CAN	400 Kg	4250
	SSP	600 Kg	2400
	MOP	90 Kg	450
	12:32:16	150 Kg	12500
Pea	CAN	375 kg	3750
	SSP	500 kg	2500
	MoP	375 kg	2250
	FYM	250 q	12500
		Sub total	21000
Tomato	NPK-complex	625 kg	3375
	FYM	125q	6250
		Sub total	9625
Garlic	FYM	280 kg	13000
	CAN	500 kg	4000
	SSP	475 kg	2000
	MOP	120 kg	600
	N	120 kg	900

*Values calculated at 2008-09 market prices

APPENDIX XVIII

Fertilizer supplied to apple trees

Fertilizer type	Per tree	For 278 trees/ha	Total price Rupees
FYM	30 kg	8340 kg	4170
CAN	3 kg	834 kg	8340
SSP	2 kg	556 kg	2780
MoP	2 kg	556 kg	3336
Tracel	0.5 kg/biga	6.25 kg	266

*Values calculated at 2008-09 market prices

APPENDIX XIX

Fertilizer supplied to plum trees

Fertilizer type	Per tree	For 278 trees/ha	Total price Rupees
FYM	30 kg	8340 kg	4170
CAN	2 kg	556 kg	4448
SSP	2 kg	556 kg	2780
MoP	1 kg	278 kg	1400
Tracel	0.5kg/biga	6.25 kg	266

*Values calculated at 2008-09 market prices

APPENDIX XX

1.6 Weeding/Agronomic practices

Crop	Number of weeding	Man days	Cost Rs/800m^2	Rs/ha
Wheat	1	3	360	4500
Maize	1	3	360	4500
Cauliflower	3	6	720	9000
Cabbage	3	6	720	9000
Pea	2	6	720	9000
Tomato	3	6	720	9000
Garlic	3	3	720	9000

* Local wage rates prevailing in the area (2008-09 market prices)

APPENDIX XXI

1.7 Harvesting

Crop	Man days	Cost Rs/800m^2	Rs/ha
Wheat	6	720	9000
Maize	5	600	8200
Cauliflower	6	720	9000
Cabbage	6	720	9000
Pea	10	1200	15000
Tomato	9	1080	13500
Garlic	10	1200	15000

* Local wage rates prevailing in the area (2008-09 market prices)

APPENDIX XXII

1.8 Grading and packing

Crop	Man days	Cost Rs/800m^2	Rs/ha
Wheat	2	240	3000
Maize	2	240	3000
Cauliflower	3	360	4500
Cabbage	3	360	4500
Pea	6	720	9000
Tomato	7	840	10500
Garlic	5	720	9000

* Local wage rates prevailing in the area (2008-09 market prices)

APPENDIX XXIII

1.9 Transportation to nearest market

Crop	Three-wheeler carring capacity	Cost (Rs) for three-wheeler	Average produce q/ha	Transport cost (Rs/ha) produce
Wheat	3 q	100	29	966
Maize	5 q	100	25	500
Cauliflower	5 q	250	225	11500
Cabbage	5 q	250	250	11500
Pea	7.5 q	250	96	3200
Tomato	7.5 q	500	736	49066
Garlic	1.5 q	100	45	1500

*Values calculated at 2008-09 market prices

APPENDIX-XXIV

Cost of cultivation of plum and Apple orchard

Orchard	**Plum (278 trees)**	**Apple (278 trees)**
Cost items	**Expenses(Rs)**	**Expenses in Rs/ha**
Basin Preparation	5000	5560
Fertilization and Its Application	8340	35000
Plant protection measures	9000	19460
Irrigation	2000	2000
Pruning	6000	6000
Picking, Grading, Packing	35000	50040
Miscellaneous	2000	5000
Transportation charges	25000	60000
Sub Total	92340	158060
Land Rent	37500	37500
Management (5%)	4617	7903
Interest (5%)	4617	7903
Risk (5%)	1846	3131.2
Total	140290	214525.2

APPENDIX-XXV

Scheduled rate of work and human charges in Kullu Forest Division (H.P.)

Forest	Rs. $ha^{-1}yr^{-1}$
Staff charges	371
Establishment cost	18000
Labour charges	10000
Surrogate value of land	5000
Fire, fencing, climber control and natural regeneration	100

APPENDIX XXVI

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

Forest Species name	Volume equation (Anonymous, 1996)
Pinus roxburghii	$Log_e v = 2.435237 + 2.560689 \log_{ed}$ (R^2=0.9477)
Cedrus deodara	$V = 0.167174 - 1.735312 \times D + 12.039017 \times D^2$ (R^2= 0.2664)
Abies pindrow	$V = 0.293884 - 3.441808 \times D + 15.922114 \times D^2$ (R^2= 0.5539)
Pinus wallichiana	$V = 0.251311 - 2.683081 \times D + 13.484565 \times D^2$ (R^2= 0.4238)
Picea smithiana	$V = 0.293884 - 3.441808 \times D + 15.922114 \times D^2$ (R^2= 0.5539)
Fruit tree species	
Malus domestica	$Y = 1.052 \times X^{1.076}$ (R^2= 0.823)
Prunus domestica	$Y = 0.008 X^2 + 1.860 X - 0.754$ (R^2 = 0.894)
Y = Dry biomass of secondary branches **X = Diameter in meter(m)**	

APPENDIX XXVII

Felling, conversion and transportation rate (upto road side depot) for different forest tree species in Kullu district (H.P.)

Sr. No.	Name of forest/lot No.	Forest division	Standing volume		Felling rate	Conversion rate	MC rate (manual carriage rate)	Ropring rate	Aproximate rate upto Road side depot/m^3
			Spp.	Volume					
1.	Majhuban	Kullu	Fir	7646.13					
	2/2005-08		BL	6072.600					
			Total	13418.730	7.41	474.80	1467.63	214.03	2163.87
			P/F Wood			52.88	654.34	131.36	838.58
2.	Khornugh	Kullu	Fir	6996.21					
	7/2005-08		BL	1901.10					
	2/35		Total	8897.31	6.60	442.98	1468.96	418.29	2336.83
			P/F Wood			49.53	611.14	252.93	913.60
3.	Shang	Parbati	Deo	470.700					
	3/2006-08		Kail	2163.800					
	2/29		Fir	2842.92					
			Chil	12.400					
			BL	519.400					
			Total	5009.220	9.900	509.82	2170.16	258.84	2948.72
			P/F Wood		-	59.82	947.230	151.52	1158.57
4.	Dudhikhol	Parbati	Fir	3978.970					
	5/2006-08		BL	550.940					
	R/2		Total	4529.910	11.00	523.88	1488.38	541.44	2562.70
			P/F Wood		-	54.27	421.88	294.690	770.84
5.	Shilagahar	Parbati	Kail	343.60					
	1/2007-09		Fir	2264.00					
	2/8		BIL	418.14					
			Total	3425.74	14.840	726.74	2043.070	343.300	3122.41
			P/F wood		-	72.99	860.970	184.37	1118.33

Reference: DFO, Wild Life Kullu (HP)

APPENDIX XXVIII

Economics of different land use systems at 1000-1300 m a.s.l. in valley ecosystem

Treatment/Crop name	Av. Yield (q/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 $ha^{-1}yr^{-1}$)
T_1 (cereal-cereal)						
Wheat	39	70410	10	48180	1.46	22220
Maize	45	52350	8	47230	1.1	5120
Total		122760	-	95410	1.28	27350
T_2 (cereal-vegetable)						
Wheat	40.5	72100	10	48180	1.49	23920
cabbage	265	159000	6	94080	1.69	64920
Total		231100		142260	1.62	88840
T_3 (vegetable-vegetable)						
cauliflower	275	220000	8	94080	2.34	125920
cabbage	290	174000	6	96172	1.85	77828
Total		394000	-	190252	2.07	203748
T_4 (orchard+ cereal-cereal)						
Wheat	27.5	56800	10	34970	1.62	21830
Maize	32.46	40408	8	35627	1.13	4781
Plum	139	347500	25	115290	3.01	232210
Total		444708		185887	2.39	258821
T_5 (orchard+ cereal-vegetable)						
Wheat	27	40500	10	34970	1.16	5530
Cauliflower	128	102400	8	61502	1.66	40898
Plum	145	362500	25	115290	3.14	249910
Total		505400		211762	2.39	293638
T_6 (orchard+ vegetable-vegetable)						
Cauliflower	130	104000	8	61502	1.69	42498
Cabbage	140	84000	6	63246	1.32	20754
Plum	140	350000	25	115290	3.04	234710
Total		538000		240038	2.24	297920
T_7 (Pure orchard)						
Plum	162	405000	25	140290	2.88	264710

APPENDIX XXIX

Economics of different land use systems at 1300-1600 m a.s.l. in valley ecosystem

Treatment/Crop name	Av. Yield (q/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 $ha^{-1}yr^{-1}$)
T_1 (cereal-cereal						
Wheat	37	72225	10	48180	1.49	24045
Maize	42	50940	8	47230	1.07	3710
Total		123165		95410	1.29	27755
T_2 (cereal-vegetable)						
Wheat	38	72900	10	48180	1.51	24720
Tomato	354	424800	12	242540	1.75	182260
Total		497700		290720	1.71	206980
T_3 (vegetable-vegetable)						
Pea	85	425000	50	222544	1.9	202456
Tomato	368	441600	12	242540	1.82	199060
Total		866600		465084	1.86	401516
T_4 (orchard+ cereal-cereal)						
Wheat	26.8	55200	10	34970	1.57	20230
Maize	32.4	39880	8	35627	1.12	4253
Apple	338	743600	22	254525	2.92	24483
Total		838680		325122	2.58	513558
T_5 (orchard+ cereal-vegetable)						
Wheat	27	55400	10	34970	1.58	20430
Tomato	210	252000	12	135524	1.85	116476
Apple	345	759000	22	254525	2.98	504475
Total		1066400		425019	2.51	641381
T_6 (orchard+ vegetable-vegetable)						
Pea	58	290000	50	125526	2.31	164473
Tomato	265	318000	12	135524	2.34	182476
Apple	335	737000	22	254525	2.89	522475
Total		1345000		515575	2.6	829424
T_7 (Pure orchard)						
Apple	365	803000	22	254497	3.15	548503

APPENDIX XXX

Economics of different land use systems at 1600-1900 m a.s.l. in valley ecosystem

Treatment/Crop name	Av. Yield (q/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 $ha^{-1}yr^{-1}$)
T_1 (cereal-cereal						
Wheat	32	63400	10	48180	1.31	15220
Maize	39	47900	8	47230	1.02	670
Total		111300		95410	1.16	15890
T_2 (cereal-vegetable)						
Wheat	34	66500	10	48180	1.38	18320
Tomato	348	417600	12	242540	1.72	175060
Total		484100		290720	1.67	193380
T_3 (vegetable-vegetable)						
Pea	80	400000	50	222544	1.79	177456
Tomato	370	444000	12	242540	1.83	201460
Total		844000		465084	1.81	378916
T_4 (orchard+ cereal-cereal)						
Wheat	24.2	52300	10	34970	1.49	17330
Maize	32	39600	8	35627	1.11	3973
Apple	378	945000	25	314520	3.01	630480
Total		1036900		385117	2.69	651783
T_5 (orchard+ cereal-vegetable)						
Wheat	21.5	46500	10	34970	1.33	11530
Tomato	260	312000	12	135524	2.3	176476
Apple	385	962500	25	314520	3.06	647980
Total		1321000		485014	2.72	835986
T_6 (orchard+ vegetable-vegetable)						
Pea	60	300000	50	125526	2.38	174474
Tomato	270	324000	12	135524	2.39	188476
Apple	390	975000	25	314520	3.09	660480
Total		1599000		575570	2.77	1023430
T_7 (Pure orchard)						
Apple	415	1037500	25	314520	3.3	722980

APPENDIX XXXI

Economics of different land use systems at 1900-2200 m a.s.l. in valley ecosystem

Treatment/Crop name	Av. Yield (q/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 $ha^{-1}yr^{-1}$)
T_1 (cereal-cereal						
Wheat	9	24870	10	32902	0.75	-8032
Maize	12	19320	8	33870	0.57	-14550
Total		44190		66772	0.66	-22582
T_2 (cereal-vegetable)						
Garlic	190	475000	25	291110	1.63	183890
Maize	12	19320	8	32875	0.58	-13555
Total		494320		323985	1.52	170335
T_3 (vegetable-vegetable)						
Garlic	210	525000	25	291110	1.8	233890
T_4 (orchard+ cereal-cereal)						
Wheat	6	16500	10	27172	0.6	-10672
Maize	10	14200	8	27844	0.5	-13644
Apple	405	1012500	25	352546	2.87	659954
Total		1043200		407562	2.56	635638
T_5 (orchard+ cereal-vegetable)						
Garlic	140	350000	25	189221	1.85	160778.5
Maize	11	16400	8	27844	0.59	-11444
Apple	402	1005000	25	352546	2.85	652454
Total		1371400		569611	2.41	801789
T_6 (orchard+ vegetable-vegetable)						
Garlic	148	370000	25	189221	1.95	180779
Apple	412	1030000	25	352546	2.92	677454
Total		1400000		541767	2.58	858233
T_7 (Pure orchard)						
Apple	428	1062500	25	364800	2.92	697700

APPENDIX XXXII

Economics of different land use systems at 1100-1400 m a.s.l. in the hill ecosystem of Kullu district (H.P.)

Treatment/Crop name	Av. Yield (q/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 $ha^{-1}yr^{-1}$)
T_1 (agriculture)						
Wheat	38	73000	10	48180	1.52	24820
Maize	42	50600	8	47230	1.07	3370
Total		123600		95410	1.29	28170
T_2 (agri-horticulture)						
Wheat	23	53000	10	34970	1.51	18030
Maize	32	39600	8	35620	1.11	3980
Plum	167	417500	25	140290	2.97	277210
Total		510100		210880	2.42	299220
T_3 (horticulture)						
Plum	172	430000	25	140290	3.06	289710
T_4 (silvi-pasture)						
Grasses (q)	45	13500	-	-	-	-
Trees(per cubic meter)	2.74	33756	-	-	-	-
Total	-	47256	-	16802	2.81	30454
T_5 (forest)						
Trees per cubic meter	8.23	101393	-	27464	3.69	73928

Selling price of wood (per cubic fit) given in the appendix XI

APPENDIX XXXIII

Economics of different land use systems at 1400-1700 m a.s.l. in hill ecosystem of Kullu district (H.P.)

Treatment/Crop name	Av. Yield (q/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 $ha^{-1}yr^{-1}$)
T_1 (agriculture)						
Wheat	38	70500	10	48180	1.45	22320
Maize	42	49200	8	47230	1.04	1970
Total		119700		95410	1.25	24290
T_2 (agri-horticulture)						
Wheat	24	50000	10	34970	1.43	15030
Maize	32	40000	8	35620	1.12	4380
Apple	412	1030000	25	254800	4.02	775200
Total		1120000		325390	3.44	794610
T_3 (horticulture)						
Apple	434	1085000	25	254800	4.25	830200
T_4 (silvi-pasture)						
Grasses (q)	42	12600	-	-	-	-
Trees(per cubic meter)	2.80	51004	-	-	-	-
Total	-	63604	-	18660	3.52	45544
T_5 (forest)						
Trees (per cubic meter)	7.89	161425		29530	5.46	131894

Selling price of wood (per cubic fit) given in the appendix XI

APPENDIX XXXIV

Economics of different land use systems at 1700-2000 m a.s.l. in hill ecosystem of Kullu district (H.P.)

Treatment/Crop name	Av. Yield (q/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 $ha^{-1}yr^{-1}$)
T_1 (agriculture)						
Pea	72	360000	50	222544	1.62	137456
Maize	32	39600	8	32450	1.22	7150
Total		399600		254994	1.56	144606
T_2 (agri-horticulture)						
Pea	61	305000	50	125526	2.42	179474
Maize	23	32400	8	30180	1.07	2220
Apple	423	1057500	25	270000	3.91	787500
Total		1394900		425706	3.27	969194
T_3 (horticulture)						
Apple	442	1105000	25	312500	3.51	792500
T_4 (silvi-pasture)						
Grasses (q)	32	9600	-	18560	-	-
Trees(per cubic meter)	2.54	106837	-		-	-
Total		116437	-	18560	6.27	97877
T_5 (forest)						
Trees (per cubic meter)	5.71	177742	-	32470	5.47	145272

Selling price of wood (per cubic fit) given in the appendix XI

APPENDIX XXXV

Economics of different land use systems at 2000-2300 m a.s.l. in hill ecosystem of Kullu district (H.P.)

Treatment/Crop name	Av. Yield (q/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 $ha^{-1}yr^{-1}$)
T_1 (agriculture)						
Garlic	178	445000	25	291110	1.52	153890
Maize	12.5	19600	8	30180	0.65	-10580
Total		464600		321290	1.45	143310
T_2 (agri-horticulture)						
Garlic	127	317500	25	189221	1.68	128279
Maize	9	15200	8	24265	0.62	-9065
Apple	423	1057500	25	312500	3.38	745000
Total		1390200		525986	2.64	864214
T_3 (horticulture)						
Apple	438	1095000	25	320000	3.42	775000
T_4 (silvi-pasture)						
Grasses (q)	25	7500	-	-	-	-
Trees(per cubic meter)	2.36	120454	-	-	-	-
Total	-	127954	-	20260	6.31	107694
T_5 (forest)						
Trees(per cubic meter)	5.64	210833	-	38255	5.51	172578

Selling price of wood (per cubic fit) given in the appendix XI

Appendix XXXVI

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

	dbh (cm)									
	10	20	30	40	50	60	70	80	90	100
Hardwood										
Stem	54	68	74	77	79	80	81	82	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 XXXVII

Wood yield of different forest tree species (per cubic feet per year)

Forest species	Altitudinal ranges	Yield per cubic ft per year	Total cost of wood per cubic ft	Cost of wood per cubic ft
Pinus roxburghii	1100-1400 m a.s.l.	289.93	101475	350
Pinus roxburghii	1400-1700 m a.s.l.	280.89	98312	350
Pinus wallichiana	1400-1700 m a.s.l.	277.90	193059	700
Pinus wallichiana	1700-2000 m a.s.l.	227.39	159174	700
Cedrus deodara	1700-2000 m a.s.l.	148.19	214878	1450
Cedrus deodara	2000-2300 m a.s.l.	146.02	211816	1450
Abies pindrow & Piecia smithiana	2000-2300 m a.s.l.	142.20	64000	450

*One cubic meter = 35.2 cubic feet

APPENDIX XXXVIII

Rate of pruned wood removal (q $ha^{-1}yr^{-1}$) from the fruit tree based agroforestry systems in both valley and mountainous ecosystem of Kullu district (H.P.)

Altitudinal ranges	Fruit tree species	Pruned (dry) branches (q $ha^{-1}yr^{-1}$)	Rate of pruned branches (Rs. q^{-1})	Total return from pruned wood
1000-1300 m a.s.l. (Valley ecosystem)	Plum Apple	12.5 9.2	200 200	2500 1840
1100-1400 m a.s.l. (Mountainous ecosystem)	Plum Apple	11.8 7.2	200 200	2360 1440
1300-1600 m a.s.l. (Valley ecosystem)	Apple	8.9	200	1780
1400-1700 m a.s.l. (Mountainous ecosystem)	Apple	9.2	200	1840
1600-1900 m a.s.l. (Valley ecosystem)	Apple	11.6	200	2320
1700-2000 ma.s.l. (Mountainous ecosystem)	Apple	9.6	200	1920
1900-2200 m a.s.l. (Valley ecosystem)	Apple	7.8	200	1560
2000-2300 m a.s.l. (Mountainous ecosystem)	Apple	6.9	200	1380

URRICULUM VITAE

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