

STRUCTURE AND FUNCTION OF AGROFORESTRY SYSTEMS IN DRY TEMPERATE REGIONS OF NORTH WESTERN HIMALAYAS

Thesis

by

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(F-2012-02-D)**

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CERTIFICATE-I

This is to certify that the thesis entitled, “**Structure and function of agroforestry systems in dry temperate regions of north western Himalayas**” submitted in partial fulfilment of the requirements for the award of degree of **DOCTOR OF PHILOSOPHY (FORESTRY) AGROFORESTRY** to Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) is a record of bonafide research work carried out by **Mr. Anand Salve (F-2012-02-D)** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

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

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CERTIFICATE-II

This is to certify that the thesis entitled, "**Structure and function of agroforestry systems in dry temperate regions of north western Himalayas**" submitted by **Mr. Anand Salve (F-2012-02-D)** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) in partial fulfilment of the requirements for the award of degree of **DOCTOR OF PHILOSOPHY (FORESTRY) AGROFORESTRY** has been approved by the Student's Advisory Committee after an oral examination of the same in collaboration with the External Examiner.

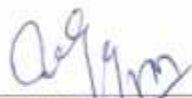


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ABBREVIATIONS USED

%	Per cent
AF	Agroforestry
AFS	Agroforestry systems
AH	Agrihorticulture system
AHS	Agrihortisilviculture system
AS	Agrisilviculture system
ANPP	Above Ground Net Primary Productivity
approx	Approximately
B:C	Benefit-Cost ratio
BCR	Benefit-Cost ratio
BA	Basal area
BD	Bulk density
BEF	Biomass expansion factor
C	Carbon
CD	Critical difference
CEC	Cation exchange capacity
CSP	Carbon sequestration potential
cm	Centimeter
CO ₂	Carbon dioxide
C ha ⁻¹ yr ⁻¹	Carbon per hectare per year
D	Diameter
DDMA	District disaster management authority
dbh	Diameter at breast height
et al	And others
etc	et cetera
FAO	Food and Agriculture Organization
FFID	Forth forest inventory data
FSI	Forest survey of india
g	gram
g m ⁻² yr ⁻¹	Gram per square meter per year
Gt	Giga tonne
H	Height
H'	Shannon Weiner Index

ha	Hectare (10,000 m ²)
HG	Home garden
IPCC	Intergovernmental Panel on Climate Change
IVI	Importance Value Index
IRR	Internal rate of returns
ISFR	India state of Forest report
Km	Kilometer
Km ²	Square kilometer
Kg m ⁻²	Kilogram square meter
Kg ha ⁻¹	Kilogram per hectare
Kg ha ⁻¹ Yr ⁻¹	Kilogram per hectare per year
LER	Land equivalent ratio
m	Meter
m a.s.l	Meter above sea level
M ha	Million hectare
m ²	Square meter
meq	Milliequivalent
Mg	Magnesium
mg	Milligram
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
MAI	Mean annual increment
N	Nitrogen
NPV	Net present value
°C	Degree Celsius
OC	Organic carbon
P	Phosphorus
Pg	Pentagram
Pg C	Pentagram carbon
pH	Puissanc d' hydrogen
ppm	Part per million
q ha ⁻¹	Quintal per hectare
Rs	Rupees
RBS	Randomized branch sampling
SA	Sensitivity analysis
SDI	Simpson's diversity index
SEm	Standard error mean

SOC	Soil Organic Carbon
Spp	Species
TBD	Total biomass density
T DM ha ⁻¹ yr ⁻¹	Total dry matter production per hectare per year
t ha ⁻¹	Tonne per hectare
t ha ⁻¹ yr ⁻¹	Tonne per hectare per year
t c ha ⁻¹	Tonne Carbon per hectare
t C ha ⁻¹ yr ⁻¹	Tonne Carbon per hectare per year
US\$	United State's dollar
\$	Dollar
V	Volume
vis-a-vis	In relation to
viz.	In other words
VOB	Volume over bark
WD	Wood density
yr	Year
gcm ⁻³	Gram per centimeter cube
Kg cm ⁻²	Kilogram per square centimeter
Kg m ⁻²	Kilogram per square meter
Mg C ha ⁻¹ yr ⁻¹	Mega gram carbon per hectare per year
Rs. ha ⁻¹ yr ⁻¹	Rupees per hectare per year
t c ha ⁻¹	Tonne Carbon per hectare
C ha ⁻¹	Carbon per hectare
g Kg ⁻¹	Gram per kilogram
Mg C ha ⁻¹	Mega gram carbon per hectare
Mg ha ⁻¹	Mega gram per hectare
Mg ha ⁻¹ yr ⁻¹	Mega gram per hectare per year
Pg c yr ⁻¹	Pentagram carbon per year

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Chapter-1

INTRODUCTION

Agroforestry may be defined as an efficient and integrated land use management system by raising of certain agricultural crops, forest tree species and or animals simultaneously or sequentially on the same unit of land with appropriate management practices which result in overall increase in the production under a particular set of climatic and edaphic conditions and socioeconomic status of local people (King, 1969). The total forest growing stock in the country is estimated to be 5,768 million cum comprising 4,195 million cum inside forest areas and 1,573 million cum outside recorded forest area (ISFR, 2015).

The rapid increase in human population has put tremendous pressure on forest resources creating environmental crisis, which probably may increase in magnitude in the predictable future. The adoption of improved/efficient agroforestry systems is one of the alternative means to counter this ongoing process of resource exploitation and environmental degradation. This approach has recently received a lot of support nationally and internationally as noted in a number of articles and tree domestication programmes. The evidences from around the world indicate that intensive high input monoculture frequently suffers an ecological crash, destroying farmer's livelihoods and market opportunities.

North-western Himalayan region is spread between 28°43'-37°05' N latitude and 72°40'-81°02' E longitude covering an approximate area of 33 million ha. The major natural resources of western Himalayas are water, forests, floral and faunal biodiversity. Agroforestry land use, covering 20 percent of the total geographical area of the Indian Himalaya, is distributed as patches in the matrix of forests covering 52 percent area. Hence, land development planning in the region needs to be based on an integrated consideration of agroforestry and forestry systems rather than considering the two systems as independent or alternative land uses as number of studies on Himalayan agroforestry systems are available (Toky *et al.* 1989b).

Agroforestry is a common practice in the mid hill situation of the Himalaya. Various fodder, fuelwood and timber trees are deliberately retained on the bunds of agriculture fields where species composition varies depending on land holding and basic requirements of the

farmers (Toky *et al.*, 1989a). Cultivation of agricultural crops along with fruit trees (agri-horticulture) is an exclusive and unique practice in the Himalayan region (Bijalwan, 2012). Fruit trees are planted and/or retained by the farmers as associate crops on agricultural fields. Himachal Pradesh is one of the ideal locations for apple cultivation, covering the districts of Shimla, Sirmour, Kullu, Mandi, Chamba and Kinnaur considering the vast production of apple orchards. The much-awaited delicious variety of apples from Himachal Pradesh's Kalpa (Kinnaur district) where horticulture is considered as a major livelihood source, most of all the households are involved in horticulture activity. The major horticulture produce in this area is apple (Bera, 2015). This system mainly focuses on higher income per unit area. Well-maintained and established orchards bring better returns than field crops from the same piece of land. The farmer can practice intercropping during the early stages of the fruit trees. The system is helpful in generating more employment especially during the off-season when the crops are not cultivated.

Agroforestry also contributes to biodiversity conservation through: (i) the provision of supplementary habitats for species that tolerate lower levels of disturbance, (ii) conservation of remnant native species and their gene pools, (iii) erosion control and water recharge thereby preventing the degradation and loss of surrounding habitat, (iv) buffering the pressure on deforestation of the surrounding natural habitat, and v) provision of corridors and stepping stones for persistence and movement of area-sensitive floral and faunal species through linking fragmented habitats in the landscape (Nyhus and Tilson, 2004). Agroforestry systems are therefore in compliance with the convention of biological diversity and successfully make trade-offs between sustainable biodiversity conservation, resource utilization and human needs. Because of multipurpose activity of agroforestry, it is complex in structure and involves a high degree of biodiversity (Torquebiau *et al.*, 2002). It is essential that detail survey of traditional agroforestry systems is required to assess the present situation.

Leaf litter decomposition is a fundamental process of ecosystem functioning which is closely related to nutrient supply for plant growth. In lower and mid hills of western Himalayas, most of the soils are infertile and therefore incapable of supporting sustainable production without external inputs (Nair *et al.*, 2008). Integration of trees in these soils adds nutrients through litter fall and improves physico-chemical properties. In a soil-plant system, plant nutrients are in a state of continuous and dynamic transfer. Plants take up nutrients from

the soil and use them for their metabolic activities. These nutrients are returned back to the soil either naturally as litter falls in unmanaged systems, deliberately as pruning in some agro-forestry systems or through root senescence in both managed and unmanaged systems. These plant parts are decomposed as a result of microbial activities and the nutrients held in them are released into the soil. These nutrients then become available for plant uptake again

The term nutrient cycling, as used in most agroforestry discussions, refers to the continuous transfer of nutrients that are already present within a soil-plant system, such as a farmer's field. Nutrient cycling occurs to varying degrees in all land-use systems (Roswall, 1980; Jordan, 1985). Nutrients that are taken up are either stored within the plant or used in the production of new biomass. Some of these nutrients are subsequently returned to the soil through litter fall, root turnover, crown drip and stem flow. Agroforestry and other tree-based systems are commonly credited with more efficient nutrient cycling (and, in turn, a greater potential to improve soil fertility) than many other systems because of the presence of woody perennials in the system and their suggested beneficial effects on the soil. These woody perennials have, theoretically, more extensive and deeper root systems than herbaceous plants and thus have a potential to capture and recycle a larger amount of nutrients. Their litter contribution to the soil's surface is probably also greater than that of herbaceous plants. (Nair, 1993).

The Kinnaur district is one of the twelve administrative districts of Himachal Pradesh. This district is given the special status of tribal district as schedule 5 area under the constitution of India. The district came into existence on 1st May 1960. Kinnaur district has a mountainous topography, ranging in altitude from 1,600 m to 6,816 m, having steep valleys carved by streams and rivulets having their origin in the glaciated ridges (DDMA, 2012). In recent times, the farmer's of Kinnaur districts of Himachal Pradesh, which falls in the dry temperate Himalaya, have developed their own agroforestry systems integrating fruits, vegetables and field crops. These newly developed agroforestry systems need to be tested for their biological productivity, environmental suitability and economic sustainability vis-à-vis other land use systems of the region. Hitherto, no elaborative study has been carried to test these systems for above mentioned considerations, Therefore, the present study entitled "Structure and function of agroforestry systems in dry temperate regions of north western Himalayas" was undertaken to test these land uses on these ground. The specific objectives of the study are as follows;

Objectives:

- ❖ To study the species composition including trees, crops and weeds;
- ❖ To estimate the biomass and productivity of different species and the system as a whole;
- ❖ To study the pattern of biomass distribution in different compositions;
- ❖ To study nutrient cycling behavior in different types of agroforestry systems;
- ❖ Economic evaluation of agroforestry systems.

Chapter-2

REVIEW OF LITERATURE

Agroforestry is a common practice in the high hills of Himalaya. Cultivation of agricultural crops along with fruit trees (agri-horticulture) is an exclusive and unique practice in the Himalayan region. Fruit trees are planted and/or retained by the farmers as associate crops on agricultural fields. Agroforestry, the practice of growing trees with agricultural crops, has been identified as an important strategy for conservation and development because it can generate additional sources of income, diversify food crops and protect soil. It is commonly supposed that tree-root systems intercept, absorb, and recycle nutrients in the soil that would otherwise be lost through leaching, thereby making a more closed nutrient cycle. The pertinent literature on the soil nutrient enrichment, plant diversity and economic return of different land use systems has been reviewed under the following heading;

2.1 Species Composition

2.2 Biomass Production

2.3 Carbon Storage in Trees and Soil

2.4 Biomass Distribution

2.5 Nutrient Cycling

2.6 Economic Evaluation

2.1 SPECIES COMPOSITION

The North-West Himalaya has long been recognized as one of the distinct floristic regions in India (Hooker, 1906; Mani, 1974). Owing to varied topography, wide altitudinal ranges and unique geographical location, this region harbours rich flora and exhibits affinities with the Mediterranean, Siberian, Tibetan and Indo-Malayan regions. Paleobotanical evidences indicate that many of the woody elements in the flora of Himalayan region owe their origin from the tropical wet evergreen climate of the Indian peninsula (Vishnu-Mittre, 1972).

Kaur and Sharma (2014) studied the distribution pattern, diversity and phytosociology of tree species in Ramgarh Block, Samba, Jammu and Kashmir. Data were collected through sample plot surveys. A total of thirty sample plots of one hectare size (100 × 100m) each

were selected in agriculture fields. A total of 17 tree species were encountered in agricultural fields with *Zizyphus mauritiana*, *Mangifera indica*, *Melia azadirachta*, *Dalbergia sissoo*, etc. The dominant tree species, *Mangifera indica* was the most dense tree species with density value of 1.9 tree ha⁻¹ followed by *Melia azadirachta* having density of 1.1 tree ha⁻¹. *Bauhinia purpurea* was the least dense species (0.03 tree ha⁻¹). The highest basal area in case of tree species was obtained for *Zizyphus mauritiana* (5.13 m² ha⁻¹) followed by *Ficus religiosa* (2.94m²ha⁻¹). The value of Shannon Weiner index was found to be 2.41 for trees in agriculture fields.

Bijalwan(2014) studied the tree vegetation for the structural characterization, diversity of plant communities and composition under alternation of tree species in traditional agri-silvi-horticulture (ASH) system along altitudinal ranges (1000 to 1500m, 1500 to 2000m and 2000 to 2500m asl) and aspects (northern and southern) in two districts (Tehri Garhwal and Uttarkashi) of Garhwal Himalaya, India. The highest tree density was recorded in 1000-1500m (northern aspect), while the lowest was recorded in 2000-2500m elevation (northern aspects). *Grewia optiva*, *Melia azedarach* in the lower elevation and *Quercus leucotrichophora* at higher elevation were recorded dominant species among forest tree species while *Malus domestica* and *Prunus armeniaca* were noticed dominant species among fruit tree species. Higher number of tree species and individuals in northern aspect with lower elevation compared to southern aspect with higher elevation.

Jiofack *et al.*, (2013) studied 26 sampling plots of 100 × 40 m in cocoa based agroforests in the Mbam and Inoubou division, Centre region of Cameroon. They found 1642 plants species, grouped into 59 species, 41 genera and 25 families. *Moraceae*, *Sterculiaceae*, *Rutaceae*, *Mimosaceae*, *Bignoniaceae*, *Euphorbiaceae*, *Anacardiaceae* and *Arecaceae* appears as dominant families and the common genera were *Albizia*, *Citrus* and *Ficus* representing four species each. The average tree density calculated was 172.166 stems ha⁻¹. In terms of species richness and diversity, the Shannon index found was 4.63 and 0.042 was the Simpson index, while the Pielou Equitability was 0.46, highlighting the diversity as well as the stability of these types of agro-vegetations. These cocoa plantations are also well diversified with the presence of many associated fruits trees species. The most frequent exotic tree species was *Mangifera indica* in all sampling plots.

Singh *et al.*, (2012) studied plant community and the present status of soil in natural forest, home garden as well as agroforestry and shifting cultivation. Plant community

attributes were determined for different land use systems. The results showed that the importance value index (IVI) was the highest for natural forest, and then for agroforestry system, home garden while shifting cultivation indicated the least value of IVI.

Tynsong and Tiwari (2011) studied the woody species diversity and community characteristics of natural forests and arecanut agroforests of south Meghalaya, Northeast India. A total of 117 tree species (≥ 5 cm dbh) belonging to 98 genera were identified in the natural forests and 83 tree species, belonging to 62 genera were identified in the arecanut agroforests. In natural forests, *Lauraceae* (18 species), *Euphorbiaceae* (16 species) and *Fagaceae* (11 species) were the dominant families. In the case of arecanut agroforests, *Euphorbiaceae* (16 species), *Lauraceae* (14 species) and *Moraceae* (11 species) were the dominant families. Arecanut agroforests are less diverse and less dense than the natural forests. In arecanut agroforests, the density of economically important species was significantly higher indicating deliberate promotion of such species.

Yadava and Singh (2010) studied the community structure and floristic diversity of tree stratum of deciduous forest in biosphere reserve. Density and basal area of trees were observed in forest plots ranged from 240 (degraded forest) to 1270 stems ha^{-1} (regeneration forest) and 23.65 (regeneration forest) to 37.57 (dense forest plot) $\text{m}^2 \text{ha}^{-1}$, respectively. Diversities in forest plots were 1.46 to 2.24 (Shannon index), 0.61 to 0.83 (equitability), 2.95 to 6.06 (species richness), 0.41 to 0.53 (concentration of dominance) and 4.05-12.8 (Beta diversity). The beta diversity was highest in forest plot. Forest represents the gradient in diversity and composition as high, medium, poor.

A study carried out by Hussain *et al.*, (2010) to assess the phytosociology and structural characteristics of central Karakoram National Park (CKNP) of Pakistan, in which *Picea smithiana* and *Pinus wallichiana* formed a community at two sites, associated with *Juniperus excelsa*. The pine tree species were distributed as pure stands in different sites with higher density and basal area. In pure stands, *Juniperus excelsa* attained lowest density with highest basal area.

Rana and Gairola (2009) studied the effect of altitudinal variation on structure and composition of the vegetation in natural Himalaya forests of Parshuram Kund area in Lohit district of Arunachal Pradesh. Three altitudinal zones viz., upper zone (550-850 m amsl), middle zone (500-700 m a.s.l) and lower zone (350-450 m amsl) showed variation in species

composition. At upper and middle altitude *Musa nagensium* was the dominant shrub species. At lower altitude *Piper peepuloides* was the dominant shrub species. In grasses at upper altitude, *Imperata cylindrica* was the dominant herb species followed by *Equisetum* spp. At lower altitude *Bidens pilosa* was the dominant herb.

In Kumaon forest of Central Himalaya (India), a total of 19 tree communities and 17 groundvegetation communities were noted (Hussain *et al.*, 2008). The distribution of tree speciesindicated influence of altitudinal gradient as well as of canopy cover and shrub diversity. Along the altitude of Indian Central Himalaya, the geographic and climatic conditions change sharply and, so the plant species. More number of species exists at low altitude to mid altitude corresponding to tropical/subtropical belt due to overlapping of climatic conditions but with further increase in altitude it decrease consistently (Kharkwal *et al.*, 2005).

Lanker (2007) studied the edapho-ecological characteristics of yew in Kotgarh, Chopal and Theog Forest Divisions of Himachal Pradesh and observed the dominance of *Picea smithiana* in Baggi forest as compared to other sites. Similarly, Ali (2007) conducted phytosociology study in Kullu Forest Division and observed the dominance of *Picea smithiana* in Sarsai forest and Sojha forest with IVI values of 120.11 and 74.60, respectively. Mahajan (2010) while working on chir pine forests of Solan district reported *Pinus roxburghii* as the dominant species in all the periodic blocks. The frequency of chir was 100 percent in themixed forest, with maximum value among all the tree species under different periodic blocks.

Gupta (1996) conducted phytosociology and biomass studies of fir-spruce forests at Narkanda and Chhachpur forests and found that *Cedrus deodara* had maximum IVI value of 48.26 and 78.70 in Chhachpur and Narkanda forests, respectively. The IVI value for *Abiespindrow* increased with the increase in elevation in both localities. Deodar tree parameters viz., DBH, basal area, height, age, volume, MAI and other attributes like tree, shrub and herb densities were comparatively higher at lower than upper altitudes (Kaushal *et al.*, 1996). Similarly, in an investigation on structural aspects of *Taxus baccata* found in fir kharsu-oak forests, Shamet *et al.*, (1999) observed higher relative density (14.7), relative frequency (16.22), and relative basal area (3.0) in fir forest followed by kharsu-oak and deodar forests.

2.2 BIOMASS PRODUCTION

Chauhan *et al.*, (2015) assessed the six years poplar plantations for productivity, carbon storage and economics in comparison to sole cropping. Wheat grain yield was significantly higher in control plots (4.55 t ha^{-1}) than boundary plantation (3.28 t ha^{-1}) and block plantation (2.03 t ha^{-1}). Similar trend was recorded for straw yield (6.61 t ha^{-1} in control plots, 4.83 t ha^{-1} in boundary plantation and 3.5 t ha^{-1} in block plantation). The boundary plantation produced higher DBH (24.23 cm) than the block plantation (19.71 cm). The crown spread was same for similar plant height. The total tree biomass was higher with block plantation (96.31 t ha^{-1}) than boundary plantation (30.14 t ha^{-1}) but per tree biomass was more in boundary plantation than block plantation. The total carbon storage was higher in block planting method (55.43 t ha^{-1}) than in boundary plantation (32.70 t ha^{-1}) and lowest total carbon storage in sole cropping system (31.20 t ha^{-1}). The economic benefits were also higher in block plantation than boundary and sole cropping of rice-wheat (B: C ratio of 3.30, 1.90 and 1.61, respectively).

Abaoli (2014) studied the dry weight of fine root biomass of *Juniperus procera* and *Grevillea robusta* tree of 15 year from Gera indigenous Agroforestry, Jimma zone, southwest Ethiopia. A total of 20 trees were selected from all direction and a center by systematic random sampling method. Both species were scatter planted on the maize field. Circle was made around each tree at 1 m and 1.5m for inner and outer circle. Three coring points were made at each horizontal distance. He observed the *Grevillea robusta*: 1.78 ± 0.97 , 1.89 ± 0.95 , 1.95 ± 0.93 and $1.77 \pm 0.91 \text{ gm}$ at 1m, and 0.92 ± 0.03 , 0.93 ± 0.04 , 0.80 ± 0.01 and $0.78 \pm 0.02 \text{ gm}$ at 1.5m, and for *Juniperus procera*, 2.65 ± 0.09 , 2.58 ± 0.10 , 2.45 ± 0.28 , and $2.32 \pm 0.58 \text{ gm}$ at 1m, while it showed 1.98 ± 0.87 , 1.88 ± 0.67 , 1.78 ± 0.77 and $1.51 \pm 0.87 \text{ gm}$ at 1.5m distance for all the soil depth. The fine root biomass density is higher at the upper most of the soil depth and closer to the tree bole, and decreases as soil depth and distance from the tree bole increases for both tree species. The mean dry weight fine root biomass recorded for *Juniperus procera* tree was higher than *Grevillea robusta* tree for both 1 m and 1.5m distance.

Verma and Kapoor (2013) conducted a studied on floristic diversity along an altitudinal gradient at Kinnaur district of Himachal Pradesh. They reported 142 plant species belonging to 49 families and 105 genera. The prominent plant families of these species were: Asteraceae, Polygonaceae, Ranunculaceae and Rosaceae. The number of shrub and herb species decreased as elevation increased. The distribution of species at different elevation

was contiguous. *Populus nigra* was the dominant tree species at 3000-3500 m asl and *Ephedra gerardiana* was dominant at 3000 to 4000 m asl.

The assessment of biomass production in different tree based systems of central Himalayan Tarai region was carried out by Kanime *et al.*,(2013). They reported that highest above (9.48 Mg ha⁻¹) and belowground (16.90 Mg ha⁻¹) biomass was in *Dalbergia sissoo* plantation. Whereas, lowest above (1.23 Mg ha⁻¹) and belowground (0.30 Mg ha⁻¹) biomass was in *Populus deltoides* boundary plantation and *P. salicina*, respectively.

Tamang *et al.*,(2012) developed biomass equations for windbreak grown cadaghi (*Corymbia torelliana*) tree to estimate biomass in various aged windbreaks in south Florida. Trees were selected for destructive sampling based on diameter at breast height (DBH) distribution from five windbreaks. Crown biomass was estimated using randomized branch sampling (RBS) and trunk biomass by taking disks every 1.5 m along the stem. Separate nonlinear equations were developed for crown, trunk and whole tree biomass estimation using DBH and height as predictors. Results indicated that DBH alone was sufficient to predict aboveground biomass, but including height in the models gave better results. Average oven-dry whole tree biomass ranged between 6 and 935 kg for 2- and 20-year-old windbreaks. Oven-dry whole tree biomass per/100 m windbreak length in the same windbreaks ranged between 166 and 26,605 kg.

Kumar *et al.*,(2011) conducted a study to estimate the biomass and net primary productivity of different aged group *Butea monosperma* forest ecosystems in western India and found that the tree biomass increased with age of forest stand. The tree biomass increased with age from 183.7 to 298.3 t ha⁻¹.

Fang *et al.*,(2010) compared the effects of three poplar intercropping designs (configuration A: 250 trees ha⁻¹; configuration B: 167 trees ha⁻¹ and configuration C: 94 trees ha⁻¹) and two intercropping systems (wheat–corn cropping system and wheat–soybean cropping system) on biomass production and C stocks in poplar intercropping systems. A significant difference in C- concentration was observed among the poplar biomass components investigated ($P \leq 0.05$), with the highest value in stem-wood and the lowest in fine roots, ranging from 459.9 to 526.7 g kg⁻¹. There was also a significant difference in C concentration among the different crop components ($P \leq 0.05$), and the highest concentration was observed in the corn ear. The total poplar biomass increased with increasing tree density,

ranging from 8.77 to 15.12 t ha⁻¹, while annual biomass production among the crops ranged from 4.69 to 16.58 t ha⁻¹ in the three configurations and total C stock, reaching 16.7 t C ha⁻¹ for the wheat–soybean cropping system and 18.9 t C ha⁻¹ for the wheat–corn cropping system.

Dossa *et al.*, (2014) studied the carbon and nutrient stocks in shade versus open grown coffee systems and found 140 Mg ha⁻¹ and 32 Mg ha⁻¹ in the coffee–*Albizia* association, and 29.7 Mg ha⁻¹ and 18.7 Mg ha⁻¹ in the open-grown system above- and belowground biomass. *Albizia* trees contributed 87% of total aboveground biomass and 55% of total root biomass in the shaded coffee system. Study conducted by Razakamanarivo *et al.* (2012) on 9 *Eucalyptus robusta* stands (47–87 years of plantation age, 3–5 years of coppice-shoot age) and the stand biomass ranged from 102 to 130 Mg ha⁻¹ with more than 77% contained in the belowground biomass components. The highest biomass of belowground was contributed by the stump (51%) followed by coarse root (42%).

Minj (2008) conducted a study in low and mid hills of Himachal Pradesh and reported that maximum mean aboveground biomass (188.60 t ha⁻¹), belowground biomass (49.04 t ha⁻¹) and total biomass (237.70 t ha⁻¹) was accumulated in pure poplar plantation, followed by agri-silviculture, silvi-pasture, pure agriculture, and pure grassland systems, respectively. 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.

Swami and Puri (2005) studied tree based land use systems which makes a valuable contribution to carbon sequestration and improve productivity, nutrient cycling within the systems. They recorded 14.1 Mg ha⁻¹ total stand biomass in 5 years agri-silviculture system. Plantations accounted 35% higher biomass than agri-silviculture system. The leaves, stem, branches and roots contributed 4.1, 65.2, 10.0 and 20.7%, respectively to total standing biomass (17.9 Mg ha⁻¹). Trees had 3.5 Mg ha⁻¹ more C and 36 kg ha⁻¹ more N in plantation than agri-silviculture system. C: N ratios for tree components were higher in stem wood (135–142) followed by roots (134–139), branches (123–128) and leaves (20–21). After 5 years, soil organic C increased by 51.2 and 15.1% and N by 38.4 and 9.3% in plantation and agri-silviculture system, respectively.

A comparison of aboveground biomass production of four MPTs in silvopasture system in humid tropics of Kerala by Kumar *et al.*, (1998) reported that there are

considerable variation in biomass production among various MPTs. Highest biomass reported is 183.54 Mg ha⁻¹ in the case of *Acacia auriculiformis* and the 7 lowest value for *Ailanthus triphysa* (19.38 Mg ha⁻¹).

Day (1996) conducted investigation on biomass estimation of *Populus deltoides* under agroforestry systems where he used stratified tree technique for obtaining the stem biomass. He concluded that stem contributed about 76-80 per cent, branch 11-16 per cent and leaves 3-7 per cent in agri-silvicultural system while in silvipastoral system, stem contributed about 61-71 per cent, branch 16-29 per cent and leaves 11-14 per cent. The total above ground biomass differed remarkably both by destructive and non-destructive methods of estimation. In agrisilvicultural system, the total biomass was of the order of 82.7 and 75.0 t ha⁻¹ in destructive and non-destructive method, respectively, while in silvipastoral system, it was found to be 34.2 and 30.6 t ha⁻¹ on destructive and non-destructive method, respectively.

Majumdar (1991) while studying the biomass production patterns in traditional agroforestry systems in western Himalaya, reported that hortisilvipastoral system gave the highest standing biomass (355.5 q ha⁻¹) as compared to hortiagricultural system (301.5 q ha⁻¹) and grassland (63.2 q ha⁻¹). Nayar (1989) assessed the aboveground plant biomass productivity 1.57, 2.25 and 47.8 t ha⁻¹yr⁻¹ on common land, wasteland, grassland and orchard, respectively. Among the agricultural crops *Lycopersicon esculentum* gave the higher productivity of 31.83 t ha⁻¹.

2.3 CARBON STORAGE IN TREES AND SOIL

After converting the volume of wood into biomass, the next step would be to find out the carbon content in the biomass. The carbon content of the different part of the plant has been found to vary to a certain extent. But, in general 50 per cent of the biomass is taken as carbon content for all the carbon estimation (Mac Dicken, 1997).

Animon *et al.*, (1999) studied soil organic carbon content under *Acacia auriculiformis* and *Eucalyptus tereticornis* plantations at three different soil depths viz., 0-10 cm, 10-30 cm, and > 30 cm and found that soil organic carbon content decreased under all the plantations with soil depth. Higher organic carbon content was noticed under *Acacia* soils as compared to *Eucalyptus tereticornis*. Comparatively more organic carbon content under *Acacia* was attributed to higher accumulation of litter and its slow decomposition.

Kaur *et al.*, (2000) analyzed the role of agroforestry systems in improving soil organic matter status on moderately alkaline soils in northern India. They selected land use systems: rice-berseem crop rotation; agrisilvicultural systems of *Acacia*, *Eucalyptus* and *Populus* along with rice-berseem and single tree species plantations for the study. It was observed that maximum build up of organic carbon in soil occurred under *Acacia* based systems followed by *Populus* and *Eucalyptus* based systems. Averaged across the distance from the trees at 0-7.5 cm soil depth, carbon concentrations were found to be higher in the *Acacia* (0.57-0.63% C) and *Populus* based systems (0.41-0.59% C) in comparison to *Eucalyptus* based systems (0.38-0.54%C).

In the context of the global carbon cycle, agroforestry is an important land use system for two primary reasons (Pandey, 2002); one, the tree component in agroforestry systems fixes carbon from the atmosphere and store it until they are cut or die. Secondly, it helps in reducing pressure on forest by supplementing some of the products obtained by natural forests. It is reported that agroforestry systems can sequester 0.2 to 3.1 C t ha⁻¹ yr⁻¹, and they have the potential to sequester 7 Gt of carbon between 1995 to 2050 globally; however, better country-specific assessments are needed to refine this estimate.

Dhand *et al.*, (2003) compared carbon content in some important forest tree species and reported that *Pinus roxburghii* stored maximum carbon 61.11 per cent in wood and 60.72 per cent in leaf, followed by *Pterospermum acerifolium* 56.91 per cent in wood and 41.72 per cent in leaf, *Syzygium cumini* 54.63 per cent in wood and 47.31 per cent in leaf. In *Dendrocalamus strictus* lowest amount of carbon stored in wood 52.25 per cent and leaf 41.72 per cent, respectively.

Zhao and Zhou, (2006) evaluated the forest vegetation carbon storage from the Fourth Forest Inventory Data (FFID) in China using a modified volume-derived method. Results showed that total carbon storage and mean carbon density of forest vegetation in China is 3.8 Pg C (about 1.1% of the global vegetation carbon stock) and 41.32 Mg ha⁻¹, respectively.

Carbon sequestration involves the removal and storage of carbon from the atmosphere in carbon sinks (such as oceans, vegetation, or soils) through physical or biological processes. 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 (Kirby and Potvin, 2007).

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 per cent and 4.73 per cent carbon respectively, compared to the natural forest of *Shorea robusta*. However, agroforestry systems viz., tea garden and agri-horticulture contributed 24.24 per cent and 9.09 per cent 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).

Minj (2008) revealed that in low and mid hills of western Himalaya vegetation reported that mean biomass carbon stock and CO₂ sequestration in zone-I (sub montane low hills) was 2.09 times higher than zone-II (mid hills). Maximum mean total carbon stock (107.00 t ha⁻¹) occurred in pure plantation system of poplar planted at an average density of 1066 trees ha⁻¹. 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 system. It was followed by agrisilviculture in zone-I, silvipastoral in zone-II both zone I & II having poplar as woody perennial.

Ranabhat *et al.*, (2008) analyzed the carbon content in different parts as well as total carbon stock of *Alnus nepalensis* forest in mid hills of Nepal and reported that the mean carbon content in stem, branches, leaves and bark of *Alnus nepalensis* were 40.52 per cent, 33 per cent, 9.56 per cent and 16.4 per cent, respectively. Total biomass carbon sequestered in northern aspect was 30.2 t ha⁻¹, while in southern aspect it was 39.60 t ha⁻¹.

Sanjeev *et al.*, (2009) studied biomass and carbon stocking in different agroforestry tree species (root, stem and leaf) and reported that aboveground biomass and carbon stocking is more as compared to belowground biomass.

Baral *et al.*, (2009) assessed the aboveground carbon stock in five major forest types in Nepal, representing two physiographic regions. Results indicated variation in age of the stand (18-75 years), aboveground carbon stock (34.30-97.86 t ha⁻¹) and rate of carbon sequestration (1.30-3.21 t ha⁻¹ yr⁻¹). The rate of carbon sequestration by different forest types depended on

growing nature of the forest stands. Tropical riverine and *Alnus nepalensis* forest types demonstrated the highest carbon sequestration rates.

Gupta *et al.*, (2009) reported that poplar 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 poplar trees and soil type. The surface and subsurface soil samples from agroforestry and adjoining non agroforestry sites with different years of poplar plantation (1, 3 and 6 years) and varying soil textures (loamy and sandy clay) were analyzed. They found that soil carbon increased from 0.36 per cent in sole crop to 0.66 per cent in agroforestry soils. 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 poplar 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 the subsequent years (1.95-2.63 Mg ha⁻¹ yr⁻¹).

Homegardens are sustainable agroforestry system in the tropics, in Thrissur district, Kerala, India. Depth wise study of soil carbon stock under varying sizes and age class of homegardens (HG) was conducted by (Saha *et al.*,2009). They exhibited that the soil C stock was directly related to plant diversity of homegardens. Homegardens with higher number of plant species, compared to those with lower number of plant species as well as higher species richness and tree density had higher soil carbon, especially in the top 50 cm of soil. Overall, within 1 m profile, soil C content ranged from 101.5 to 127.4 Mg ha⁻¹. Smaller-sized HG (<0.4 ha) had higher tree density and plant-species density and more soil C per unit area (119.3 Mg ha⁻¹) of land than larger-sized ones (>0.4 ha) (108.2 Mg ha⁻¹). Soil C content, especially below 50 cm, was higher in older gardens. The enhanced soil-C storage in species-rich homegardens could have relevance and applications in broader ecological contexts.

Saha *et al.*,(2010) examined soil C storage in homegardens (HGs), natural forest, and single-species stands of coconut (*Cocos nucifera*), rice (*Oryza sativa*)-paddy and rubber (*Hevea brasiliensis*), in Thrissur district, Kerala, India. They observed that total C stock was highest in forests (176.6 Mg ha⁻¹), followed by managed tree based systems, and lowest in rice-paddy field (55.6).

Zhu *et al.*, (2010) estimated C stocks in vegetation, detritus and soil of 22 forest plots along an altitudinal gradient of 700-2000 m to quantify altitudinal changes in carbon storage

of major forest ecosystems in Mt Changbai, Northeast China. Total ecosystem averaged C density 237 t C ha^{-1} (ranging from 112 to 338 t C ha^{-1}) across all the forest stands, of which 153 t C ha^{-1} (52 - 245 t C ha^{-1}) was stored in vegetation biomass, 14 t C ha^{-1} (2.2 - 48 t C ha^{-1}) in forest detritus (including standing dead trees, fallen trees, and floor material), and 70 t C ha^{-1} (35 - 113 t C ha^{-1}) in soil organic matter (1 m depth). Among all the forest types, the lowest vegetation and total C density but the highest soil organic carbon (SOC) density occurred in *Betula ermanii* forest, whereas the highest detritus C density was observed in *Picea* and *Abies* forest. The C density of the three ecosystem components showed distinct altitudinal patterns: with increasing altitude, vegetation C density decreased significantly, detritus C density first increased and then decreased, and SOC density exhibited increasing but insignificant trends.

Yadava (2010) conducted experiment on biomass production and carbon sequestration in different agroforestry systems. He reported that aboveground biomass and carbon stocking was more as compare to belowground biomass and carbon stocking.

Fang *et al.*, (2010) studied the carbon sequestered in poplar based intercropping systems. They compared the effects of three poplar intercropping designs and two intercropping systems (wheat–corn cropping system and wheat-soybean cropping system) on biomass production and C stocks in poplar intercropping systems. The experiment was conducted at Suqian Ecological Demonstration Garden of fast-growing poplar plantations in north western Jiangsu and they observed that C concentration among the poplar biomass components was highest in stem wood and the lowest in fine roots, ranging from 459.9 to 526.7 g kg^{-1} . Overall, total C stock in the poplar intercropping system was affected by configurations and cropping systems. The largest total C stock, reaching 16.7 t ha^{-1} for the wheat-soybean cropping system and 18.9 t C ha^{-1} for the wheat-corn cropping system was observed.

Chavan and Rasal (2011) studied the carbon sequestration in *Eucalyptus* tree in Aurangabad. They observed that sequestered carbon stocked in aboveground and belowground standing biomass of *Eucalyptus* spp. was 254.50 t ha^{-1} and 66.17 t ha^{-1} , respectively while, total sequestered carbon of *Eucalyptus* spp. was 320.67 t ha^{-1} .

Chauhan *et al.*, (2011) assessed the carbon sequestration potential under one to six year block plantation of poplars. The enrichment of the soil organic carbon through litter and roots enhanced in the surface layer of soil (0-15 cm) under poplar blocks as compared to open

fields with wheat crop only. Carbon storage potential in agroforestry system was recorded very high in comparison to sole crop. The carbon storage by poplar plantations in agroforestry has also been studied by Rizvi *et al.*, (2011) for two districts. Contribution of poplar plantations at a rotation period of 7 years to carbon storage was found to be 27-32 t ha⁻¹ in boundary system, whereas it was 66-83 t ha⁻¹ in agrisilviculture system.

Tumwebaze *et al.*, (2012) conducted an investigation to quantify and compare the amount and distribution of soil organic carbon (SOC) under a linear simultaneous agroforestry system with four different tree species treatments at Kifu National Forestry Resources Research Institute in Mukono District, Central Uganda. The treatments included four different species viz., *Grevillea robusta*, *Casuarina equisetifolia*, *Maesopsis eminii*, *Markhamia lutea* and a crop as control treatment in a linear agroforestry system established in 1995. They observed that an agroforestry system has significant potential to increase SOC as compared to the crop only control. There was no significant difference in the amount of SOC under exotic and indigenous tree species. Among the exotic species, *Grevillea robusta* had higher SOC than *Casuarina equisetifolia* across the entire depth sampled. There was significant difference in SOC among the indigenous species, where *Maesopsis eminii* had more SOC than *Markhamia lutea*. Distance from the tree row did not significantly influence SOC concentration under any of the tree species. In selecting a tree species to integrate with crops that will sequester reasonable quantities of carbon as well as boost the performance of the crops, a farmer can either plant an exotic species or an indigenous. They found that the soil under *Grevillea robusta* and *Maesopsis eminii* have the highest potential to store organic carbon compared to soil under other tree species.

Agroforestry can be a good option for sequestering carbon in agricultural and marginal lands for climate change mitigation. Gaur (2012) analyzed the impact of *Populus deltoides* based agroforestry systems on carbon storage in the soil- plant system in relation to site conditions. The soil organic carbon pool in the *Populus deltoides* agroforestry system was greater in agroforestry systems at Kalesar (22.31 to 27.82 Mg C ha⁻¹) than at Salimpur (19.63 to 30.11 Mg C ha⁻¹). The carbon storage in the tree component varied in the range of 18.92 to 71.02 Mg C ha⁻¹ at Kalesar and 14.78 to 56.91 Mg C ha⁻¹ at Salimpur. Carbon pool in wheat crop under *Populus deltoides* agroforestry systems was 3.70-3.53 Mg C ha⁻¹ at Salimpur and 3.84-3.68 Mg C ha⁻¹ at Kalesar. The carbon storage in water stable soil aggregates was directly related to soil organic carbon. The macro aggregates (2 µm-250 µm)

formed 3.38 to 14.88 per cent part of bulk soil at Salimpur and 10.56 to 18.82 per cent at Kalesar; soil aggregate carbon was 0.21 to 1.08 per cent at Salimpur and 0.23 to 1.15 per cent at Kalesar in 0-45 cm soil depths. The silt and clay fractions of soil micro-aggregates ($< 53 \mu\text{m}$) at both the sites protected a large fraction of soil carbon. Illite, Kaolinite and Montmorillonite, Dolomite and Muscovite were the dominant minerals. Agroforestry enhanced carbon storage in soil and the woody biomass and can play an important role in carbon sequestration for soil, improving soil health together with climate change mitigation.

A simulation study for potential carbon sequestration and soil organic carbon of agroforestry was conducted by Ajit *et al.*, (2013) in indo-gangetic plains. They observed that carbon sequestration of existing agroforestry systems has been estimated 0.111, 0.126 and 0.551 $\text{Mg C ha}^{-1} \text{ year}^{-1}$ for Sultanpur, Dinajpur and Ludhiana districts, respectively. Carbon sequestration potential (CSP) of agroforestry system (AFS) increases with increasing tree density per hectare and soil organic carbon in the baseline ranged from 8.13 to 9.12 Mg C ha^{-1} and is expected to increase from 8.63 to 24.51 Mg C ha^{-1} .

Rajput *et al.*, (2015) estimated the biomass, carbon density and carbon dioxide mitigation potential of different land use systems along an altitudinal gradient in valley ecosystem showing variation in biodiversity because of changing climatic conditions. Seven different land use systems/crop rotations viz., cereal–cereal, cereal–vegetable, vegetable–vegetable, orchard + cereal–cereal, orchard + cereal–vegetable, orchard + vegetable–vegetable and pure orchard at four altitudinal gradients viz., 1,000–1,300, 1,300–1,600, 1,600–1,900 and 1,900–2,200 m above mean sea level and approximately 1°C temperature gradient were assessed. The results revealed that different land use systems have significant influence on the production of above ground biomass, below ground biomass, carbon density and carbon mitigation potential. Maximum above ground biomass (75.64 Mg ha^{-1}) and below ground biomass (23.60 Mg ha^{-1}) was accumulated in orchard + cereal–cereal system. Total biomass production of different land use systems in valley ecosystem followed the order of orchard + cereal–cereal $>$ orchard + cereal–vegetable $>$ orchard + vegetable–vegetable $>$ pure orchard $>$ cereal–cereal $>$ cereal–vegetable $>$ vegetable–vegetable. Rate of CO_2 mitigation potential was maximum ($7.81 \text{ Mg ha}^{-1} \text{ yr}^{-1}$) in the orchard + cereal–cereal based land use system situated at an altitudinal range of 1,900–2,200 m. Maximum carbon density (90.88 Mg ha^{-1}) of both soil + plant was also observed in orchard + cereal–cereal based land use systems at 1,300–1,600 m above mean sea level.

Rajput *et al.*, (2017) observed the influence of five different altitudes and prevailing agro ecosystems on biomass and carbon sequestration potential in Kullu district of Himachal Pradesh, India. The study area had five prevailing land uses viz., agriculture, agro-horticulture, horticulture, silvi-pasture, and forest at four elevations representing about 1 °C temperature change. The results showed that maximum total biomass of 404.35 Mg C ha⁻¹ was accumulated by forest land use and followed a decreasing trend in the order as forest > silvi-pasture > agro-horticulture > horticulture > agriculture. The rate of C-sequestration was maximum (2.17 Mg ha⁻¹) in the agro-horticulture at 2000–2300 m a.s.l. This study brings out the potential of different land use systems influenced by varying factors on their C-sequestration potential in western Himalayan elevation gradient, thereby providing useful information for effective management in a climate change mitigation and carbon budget.

2.4 BIOMASS DISTRIBUTION

Vermaet *al.*,(2014) studied the tree root distribution pattern and biomass of seventeen year old trees of *Grewia optiva*, *Morus alba*, *Celtis australis*, *Bauhinia variegata* and *Robinia pseudoacacia* by excavation method. They found *B. variegata* roots penetrated to a maximum depth of 4.78 m, whereas, *M. alba* roots were found down to 1.48 m depth. Lateral spread was minimum in *B. variegata* (1.10 m) and maximum in *R. pseudoacacia* (7.33 m). Maximum root biomass of 6.30 kg was found in *R. pseudoacacia* and minimum (2.43 kg) was found in *M. alba*.

Fortier *et al.*,(2013) compared the coarse root (diameter > 2 mm) and fine root (diameter < 2 mm) biomass, as well as distribution of soil carbon stocks in 3 types of riparian land uses across 4 sites located in farmland of southern Canada. For all land uses most of the root biomass was within the 0–20 cm depth range. Total coarse root biomass, to a 60 cm depth, ranged from 8.8-73.7 t ha⁻¹ in woodlots, 0.6-1.3 t ha⁻¹ in herbaceous buffers, and 9.2-27.3 t ha⁻¹ in *Poplars*. Total fine root biomass ranged from 2.68-8.64 t ha⁻¹ in woodlots, 2.60-3.29 t ha⁻¹ in herbaceous buffers, and 1.86-2.62 t ha⁻¹ in *Poplars*. Total fine root biomass ranged from 2.68-8.64 t ha⁻¹ in woodlots, 2.60-3.29 t ha⁻¹ in herbaceous buffers, and 1.86-2.62 t ha⁻¹ in *Poplars*. Total root biomass was similar or higher in *Poplar* buffers compared to a 27 year-old grey birch forest.

Quinkensteinet *al.*, (2012) investigated the biomass production, C and N allocation patterns in *R. pseudoacacia* stands between shoot, stump, coarse, and fine roots samples were

collected from seedlings and three adjacent plantations and plants that were one, two and twelve years old at Lower Lusatia Germany. Results indicated that the summarized average dry matter production (DM) of the woody plant parts increased with plant age up to 7.45 t DM ha⁻¹ yr⁻¹ with a corresponding shoot increment of up to 4.77 t DM ha⁻¹ yr⁻¹ in the twelve-year-old stands. The shoot to root ratio changed from 0.2 for the one-year-old trees to 2.0 in the twelve-year-old plantation, whereby an average amount of 3.4 t C ha⁻¹ yr⁻¹ and 0.1 t N ha⁻¹ yr⁻¹ was annually bound in the living woody plant parts over the period of twelve years.

Ward *et al.*, (2011) compared early (29-day) seedling growth and root : shoot ratios for annual and perennial medics (*Medicago truncatula* and *M. sativa*), and for annual and perennial wheat (*Triticum aestivum* and *Triticum* × *Agropyron* cross) in south-western Australia. Result shows that annual reached the 6-leaf stage after 29 days and produced more root and shoot biomass than *lucerne* (4-leaf stage after 29 days), but there was no difference in root : shoot ratio or depth of root growth. For wheat, there were no differences in root growth, shoot growth, or root: shoot ratio between the annual and perennial lines (*Zadoks* growth stages 23 and 21, respectively, after 29 days).

The belowground living biomass in trees is assessed using root-to-shoot ratio (Nair, 2011). The lower root: shoot biomass ratio indicated that the species has a tendency of accumulating more above ground biomass for building up canopy and is still in the growing phase (Das and Chaturvedi, 2008). The ratios depends mainly on species (higher in palms than in dicot trees) and ecological regions (higher in cold than in warm climates). Mangroves accumulate large amounts of biomass in their roots, and the above-ground biomass to below-ground biomass ratio of mangrove forests is significantly low compared to that of upland forests (Komiya *et al.*, 2008). The comparison of the data of Hase and Foelster, (1983) and Kraenzel *et al.*, (2003) shows a progressive decrease in root to shoot ratio with increasing plantation age.

2.5 NUTRIENT CYCLING

Panwar and Gupta (2015) studied the litter fall, nutrient return and soil fertility under *Celtis australis* in Himachal Pradesh. The annual leaf-fall recorded in *C. australis* (81.80 g m⁻² yr⁻¹) was maximum followed by miscellaneous litter (60.71 g m⁻² yr⁻¹) and the least was from bark twigs component (3.50 g m⁻² yr⁻¹). Non-leaf litter in the species accounted for 43.98 per

cent to the total litter. The highest litter-fall 34.17 g m^{-2} was recorded in the month of October followed by 24.78 g m^{-2} in November 23.04 g m^{-2} while the least litter fall 2.00 g m^{-2} was observed in the month of February. The annual mean concentration values of nitrogen for leaf, twigs and miscellaneous litter were 1.342, 0.818 and 0.857 per cent respectively. Comparatively low concentrations of N, P, and K in leaf litter were observed during the months from October to December in *C. australis*. Total return of nutrients was in the order of $\text{Ca} > \text{N} > \text{Mg} > \text{K} > \text{P}$ in *C. australis*. The order of nutrient input from different components of litter was leaves > miscellaneous litter > twigs. In general soils under *C. australis* were fertile having good physical and chemical health.

Fontes *et al.*, (2014) compared the internal balances of nutrients and the rates of nutrient cycling across nine cocoa agroforestry systems consisting of various combination of soil types (Latosols and Cambisols), production systems (*Cabruca* and *Erythrina glauca*-shade) and fertilization regimes in southern Bahia, Brazil. Results showed that the mean annual litterfall production ranged from 4.6 to 8.5 Mg ha^{-1} , and the amount of accumulated litter ranged from 7.7 to 16.8 Mg ha^{-1} . The *cocoa-erythrina* system presented a higher capacity to recycle nutrients compared to the *cocoa-cabruca* system, with the *cocoa-erythrina* system having the largest transfer rate of nutrients through litterfall, high values for the decomposition coefficient of litter and the lowest values for the mean residence time of nutrients. The nutritional reserves of litter+cocoa fruit husks, with respect only to the nutrients exported in the seeds, the balance was positive for all nutrients (N, P, K, Ca and Mg) in all agroforestry systems.

Gupta *et al.*, (2010) studied the quantification of litter fall, effect of tree management practices under agri-silviculture system at the research farm of National Research Centre for Agroforestry during 2006-2007. The results showed that leaves formed the major component of the total litter followed by petiole, fruit and bark. Leaves formed 67.7, 67.8, 69.7 and 70.4 per cent of the total litter. Annually, litter production under these systems varied between $6.32 - 26.0 \text{ kg tree}^{-1}$. The total leaves litter contributed maximum to N return and was in the order: leaves > petiole > fruit > bark. Annually, leaves contributed 80.6, 79.9, 80.4 and 78.8 per cent of the total N and 71.7, 71.4, 69.7 and 69.0 per cent of total annual Phosphorus. Petiole added 58.5, 50.3, 57.1 and 53.6 per cent K annually, under *A. procera* un-pruned + fallow, *A. procera* unpruned + cropping, *A. procera* pruned 50 per cent + cropping, and *A. procera* pruned 70 per cent + cropping, respectively.

Murovhi and Materechera (2006) analyzed paired soil samples taken under and beyond *A. erioloba* tree canopies in the North West Province, South Africa to quantify the concentration of nutrients in two local agroforestry practices on cultivated and grazing lands. In both practices, there was a significantly higher ($p < 0.05$) concentration of N, P, Ca, Mg, Zn and Mn in soils collected from under *A. erioloba* canopies compared with those collected beyond the canopies. The nutrient concentrations were consistently higher in soil from trees that were located in grazing land than croplands.

Perez *et al.*, (2006) estimated aboveground net primary productivity (ANPP), nutrient cycling and nutrient use efficiency (NUE) for three 20 year old *Pinus taeda* experimental plantations in the north of the Misiones province, Argentina. ANPP was $34.8 \pm 1.5 \text{ t ha}^{-1} \text{ yr}^{-1}$ and litter fall was $16 \pm 1.1 \text{ t ha}^{-1} \text{ yr}^{-1}$. Mean annual bole increment was 20 per cent higher than the mean for commercial plantations of Misiones and near the upper limit of the range for tropical and subtropical pine plantations. The requirements of N, P, K, Ca and Mg were 298, 15, 63, 70 and 15 $\text{kg ha}^{-1} \text{ yr}^{-1}$, respectively and the uptake was 161, 8, 36, 70 and 15 $\text{kg ha}^{-1} \text{ yr}^{-1}$, respectively.

The results of Lin-Cheng *et al.*, (2005) showed that the concentrations of N, P and K differ significantly among litter fractions and the monthly dynamics of N, P and K elements fractions were also different from each other. The annual nutrient return through litter amounted respectively to 51.275 kg m^{-2} N, 2.794 kg m^{-2} P and 29.416 kg m^{-2} K. The return of nutrients was through leaf litter. Annual N and P return were obviously higher than Chinese fir (*Cunninghamialanceolata*) plantation and other coniferous forest, which benefits the maintenance of long term site productivity in the stand.

Bhowmik *et al.*, (2003) examined the litter fall and nutrient dynamics in soil under 20 year's old Eucalyptus hybrid plantation in North Bilaspur Division, Chhattisgarh. Data revealed that the maximum amount of all the nutrients was accumulated in the stem (bark /wood). The maximum amount of calcium ($253.26 \text{ kg ha}^{-1}$) was accumulated in stem. The leaf litter contributed 70 to 73 per cent, twigs 18 to 19 per cent and bark 9 to 10 per cent to the total litter. Based on the nutrient concentration in the litter, the amount of nutrient elements released annually through decomposition was 43.2 kg ha^{-1} Ca, 36.4 kg ha^{-1} N, 18.1 kg ha^{-1} K, 8 kg ha^{-1} Mg and 2.8 kg ha^{-1} P. Among the nutrients returned to the floor, the highest contribution came from Ca followed by N, K and Mg. The response of available nutrient status of the surface soil showed seasonal variability.

Raizada *et al.*, (2002) determined leaf litter production, nutrient returns, retranslocation patterns and breakdown of confined litter in plantations of six tree species in the Doon Valley (Uttaranchal, India). Leaf litter production values ($t\ ha^{-1}$) followed the order of bamboo *Dendrocalamus strictus* and *Bambusa giganteana* (4.25) > *Eucalyptus* spp. (2.97) > *Bauhinia purpurea* (2.86) > *Grewia optiva* (2.63) > *Melia azedarach* (2.61) > *Morus alba* (2.35). Fractional annual turnover rate varied between elements (N, P, K, Ca and Mg) and species, with N having the highest values (68-92%) and Mg the least (13-62%).

Tian *et al.*, (1996) studied N, Ca and Mg release from leaves of 10 selected plants viz., *Gliricidia sepium*, *Leucaena leucocephala*, *Mucuna pruriens*, *Centrosema pubescens*, *Acacia barteri*, *Dialium guineense*, *Alchornea cordifolia*, *Anthonata macrophylla*, *Cassia siamea* and *Pterocarpus santalinoides*. Addition of leaves from all species significantly increased soil exchangeable Ca and Mg levels. *L. leucocephala*, *G. sepium*, *C. pubescens* and *M. pruriens* showed relatively high Ca and Mg release rates. Calcium release rate was related to N release rate rather than to initial Ca contents.

Bhola (1995) studied the soil enrichment potential of seven nitrogen fixing trees species and observed considerable improvement in soil chemical properties under all species in comparison to adjoining unplanted area. However, overall enrichment was recorded as 15.52-39.52, 8.59-17.98, 15.36 to 39.52- 98.91, 2.09-14.0 and 1.93-9.54 percent for organic carbon, available nitrogen, available phosphorus, available potassium, exchangeable calcium and exchangeable magnesium, respectively.

In alley cropping studies in acid soils, Dalland *et al.*, (1993) observed that *Leucaena leucocephala* and *Flemingia* improved nitrogen, organic carbon, Mg, K, CEC and pH values than control during 2 years and also concluded that *Leucaena* was more beneficial than *Flemingia*. Higher levels of organic carbon in alley cropping improved the soil physical properties viz., decreasing bulk density, increasing porosity and infiltration rate.

Pakrashi (1991) studied the effect of leaf fall of *Albizia lebbek*, *Acacia nilotica*, *Leucaena leucocephala*, *Acacia auriculiformis* and some non-legumes on soil properties and observed that there is a significant increase of all major nutrients in soil (N, P, K, C and Mg) with addition of leaf litter.

Toky *et al.*, (1989b) while studying the agroforestry systems in the mid hills of Himachal Pradesh, reported that in agrihortisilviculture and agrihorticulture system, considerable quantity of nutrients upto N-169, P-14, K- 165, Ca-97 and Mg-65 kg ha⁻¹ was recycled through crop debris and tree leaf litter, while the recycling rate was almost half in agrisilviculture system.

Rezende (1983) reported the nitrogen, phosphorus, potassium and magnesium contents of 3.5 years old *Eucalyptus grandis* and *Eucalyptus saligna*, nutrient utilization efficiency was greater in higher tree density plots and in *Ellcalyptlls grandis* stands. Stem removed a greater proportion of nutrients from the site particularly at higher density. Greater volume and dry matter production were obtained at 5000 trees ha⁻¹ than 1667 trees ha⁻¹.

Gupta *et al.*, (1982) reported that 5 year old tree produced 10 kg of leaf litter and return 35 kg N, 80 kg P, 25 kg K and 15 kg Ca ha⁻¹ yr⁻¹. Hosur *et al.*, (1977) reported that nutrient returned through litter in six tree species of age from 13 - 16 years spaced at 2 × 2m followed the order: Ca > K > N in *D.sissoo* and *A.catechu* ; Ca> N > K in *teak* and *casuarina* and K > Ca > N in *bomboo* and *eucalyptus*. The return of P and Mg were lower in all the cases. While the concentration of Ca, K and N were more than Mg and S in the entire plantation.

2.6 ECONOMIC EVALUATION

Raniet *al.*, (2016) reported that the tree based land use systems are economically viable and more profitable than pure agricultural crops. Highest B:C ratio was recorded in pure *E. tereticornis* plantations (3.30) after 5 years. Simultaneously higher B:C ratio (2.02) was recorded in *P. deltoids* + *T. aestivum* crop based land use system followed by *T. grandis* plantations (2.06), *T. aestivum* + *O. sativa* (1.89), *T. aestivum* + *P. glaucum* + fruit crop (1.72), *B. napus* + fruit crop (1.56) and *B. napus* + *O. sativa* (1.27). *E. tereticornis* and *P. deltoids* based land use systems are economically viable and more profitable than other land use systems in Punjab.

Tahir and Vishwanath (2015) studied the on-farm and off-farm benefits of three types of AFS practiced in Eastern Sudan. The net direct-use value of marketable products across all sites was estimated at 7,346,000.0 SDG (1,335,636.36 US\$) HH/annum. Gum Arabic alone accounted for 38%, followed by sorghum grain and fodder 35%, and cash crops (sesame) 18%. This value would be many times higher if other indirect values (non-marketable)

services such as shade, aesthetic and recreation, environmental protection, biodiversity and carbon sequestration.

Thang *et al.*, (2015) studied the cost-benefit analysis in four agroforestry systems, Star Anise (*Illicium verum*) + tea (IT), bead tree (*Melia azedarach*) + cassava (MC), *Acacia hybrid* + cassava (AC) and *Acacia mangium* + maize (AM) in Vietnam. The results indicated that IT had the highest economic benefit (6,527 US\$ ha⁻¹ y⁻¹), followed by MC (2,905 US\$ ha⁻¹ y⁻¹), AC (1,043 US\$ ha⁻¹ y⁻¹), and AM (870 US\$ ha⁻¹ y⁻¹), respectively.

Affendy *et al.*, (2013) studied the economic viability of *Tectona grandis* sole cropping and intercropping for 20 years planting project at the Boonrich plantation in Lahad Datu, Sabah. The parameter that used to measure the economic viability of the project were net present value (NPV), internal rate of return (IRR), benefit cost ratio (BCR), land equivalent ratio (LER), sensitivity analysis (SA) and payback period. A result shows that NPV of intercropping is RM 27,063.70 (USD 8,841.54), the LER is 1.37, 23.68% of IRR and have a shorter payback period (13 years) compare to the sole cropping. In addition, it also showed a higher yield as the LER is more than one (1.37). Therefore, *T. grandis* intercrop with *S. zalaca* will gain extra benefit and greater output than the sole cropping.

Dhillon and Chauhan (2012) conducted a study on the intercropping of four fruit species (Kinnow, guava, peach and plum at 6 m × 6 m spacing) with poplar trees (G-48 clone). The poplar trees were cultivated alternately between the fruit trees. The study aims to evaluate performance and economic returns of growing onion and garlic under poplar-based multi-storey systems. They reported yield reduction of 25.80 and 10.87 percent in garlic, and 22.14 and 14.22 percent in onion under four- and three-year old. However, the reduction in yield of both crops under poplar trees was less sharp as compared to other agricultural crops under poplar trees. The gross income obtained from different crop combinations ranged from Rs.42185 (US\$917) to Rs.94117 (US\$2 046). The highest net return of Rs. 31835 (US\$692) was obtained from guava + onion + poplar, while the lowest net return was obtained from wheat + rice (traditional crop rotation). The total yield of the multi-storey system was economically profitable. The system also maximized the use of land and nutrients and improved microclimatic conditions.

Chisanga *et al.*, (2013) evaluate the economic analysis of Dry temperate region and reported that agri-horticulture land use system better than other land use system viz.,

agriculture, silvipasture and barren land. Rajput *et al.*, (2014) studied in temperate zone of Himalayas reported agrihorticulture land use system better than other system of the region. Rajput *et al.*, (2014) also studied the valley ecosystem and found orchard + vegetable – vegetable land use system better than other land use system this region. Singh *et al.*, (2016) studied the agroforestry based land use systems of subtropical parts of Himalaya and conclude that agrihorticulture is more profitable than the agrisilviculture, agriculture, silvipastoral, forest and grassland. Among the agroforestry systems, higher B:C ratio was observed for agrihorticulture (3.68) followed by silvipastoral (3.58), agrisilviculture (2.10) and agrihorticulture (1.98), respectively.

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. The implications of the results are discussed in the context of suitability and sustainability of the fruit tree species and their importance in AFS.

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 100kg ha⁻¹. Grewal *et al.*, (1992) reported that agri-silvi-horticulture could provide average net returns of Rs. 17066 ha⁻¹ over a period of 4 years as compared to average net returns of Rs. 7852 from sole cropping. Lal *et al.*, (2004) in an experiment, cultivated blackgram and toria under peach based agroforestry systems, accrued net returns of Rs. 10000 ha⁻¹year⁻¹ and B:C ratio was recorded 1.65.

In a study, Dutt and Thakur (2004) calculated the monetary status of cropping systems, practically for two consecutive years under shiwalic range of 26 outer Himalayas, combining medicinal and aromatic herbs with commercial timber species. Four herbal crops

namely *Ocimum sanctum*, *Spilanthus acmella*, *Tagetes minuta* and *Withania somnifera* were intercropped with six year old plantation of *Populus hybrid* (G-48) having 8 × 3m, 6 × 4m, 5 × 5m and 4 × 6m spacing. Net returns were comparatively more under agroforestry systems combining *Ocimum sanctum* and *Tagetes minuta* with *poplar* at different spacing in comparison to monocropping. However in *Spilanthus*, the net return were higher from sole cropping and in *Withania somnifera* due to high cost of cultivation, the net returns became negative. Among different spacing, 8 × 3m and 6 × 4m spacing excelled over 5 × 5m and 4 × 6m spacing which ensured significantly higher net returns from the combination.

Chauhan (2000) observed average net return of Rs. 25690 ha⁻¹ yr⁻¹ from sole plantation of *Populus deltoids* and Rs.36370 ha⁻¹ yr⁻¹ from Japanese mint, Rs. 39670 ha⁻¹ yr⁻¹ from Palmarosa and Rs.43590 ha⁻¹ yr⁻¹ from lemongrass using poplar based agroforestry system in a period of five years. Shanmughavel and Francis (1999) recorded higher annual net returns (Rs. 13, 300) when pigeon pea was intercropped in 1:1 rows at 3×3m spacing (250 plants ha⁻¹) in comparison to 1:2 rows spaced at 2×2m (500 plants ha⁻¹).

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, 037.00) was the best followed by french bean-turmeric (Rs 39,121.00), potato-onion (Rs, 37,861.00) and tomato-cowpea (Rs 32,797.00) cropping system.

Dyal *et al.*, (1996) evaluated agri-silvi-horticulture system with *Leucaena leucocephala*, *Carrica papaya*, *Citrus aurantifolia* and *Curcuma longa*. They found that mean annual returns was Rs. 17,746 and Rs. 15,092 under agri-silvihorticulture as against Rs. 7,752 and Rs.3,342 ha⁻¹ from agriculture cropping system (maize + black gram/ wheat + mustard/ maize + wheat) under irrigated and rainfed conditions, respectively.

Das *et al.*, (1993) evaluated B:C ratios of sole peach (1.19) and mixed peach-annual crops (1.56) were observed. Another evaluation of economic returns of *Sorghum bicolor* and *Vigna mungo*, cropped with *Psidium guajava* (guava), and alley-cropped with *Leucaena leucocephala* in Andhra Pradesh, India, showed BC ratios ranging from 1.52 for crops with *Leucaena* to 2.16 for crops with guava.

Chapter-3

MATERIALS AND METHODS

The present study entitled “**Structure and function of agroforestry systems in dry temperate regions of north western Himalayas**” was conducted in Kinnaur district of Himachal Pradesh in 2014-2015. The details of the studies, techniques used and methodologies adopted in undertaking these studies are given below:

3.1 SITE DESCRIPTION

3.1.1 Location

North-western Himalayan region is spread between 28°43'-37°05' N latitude and 72°40'-81°02' E longitude covering an approximate area of 33 million ha. Kinnaur is located between 77°45'-79° and 79°00'35" East longitudes and between 31°05'50" and 32°05'15" north altitudes. It is bound by Tibet and Uttarakhand on the east, Shimla district in south-west, Kullu and Lahaul-Spiti district in the north-west. Kinnaur district has a mountainous topography, ranging in altitude from 1,600 m to 6,816 m, having steep valleys carved by streams and rivulets having their origin in the glaciated ridges.

3.1.2 Climatic and edaphic factors

The climate of study area ranges lie in the dry temperate zone which is located in the north-eastern part of Himachal Pradesh. The area is characterized by long winter from October to April and short summer from June to August. Though rains are scanty, precipitation is received mostly in the form of snow during winter. This zone is having distinct type of soils viz., brown, alluvial and grey brown with the composition of sandy loam and clay loam.

3.1.3 Site selection

The present study was carried out in dry temperate regions of Himachal Pradesh. The study area is comprised of region- Pooh, Spilloh and Reckong Peo of Kinnaur district of Himachal Pradesh.

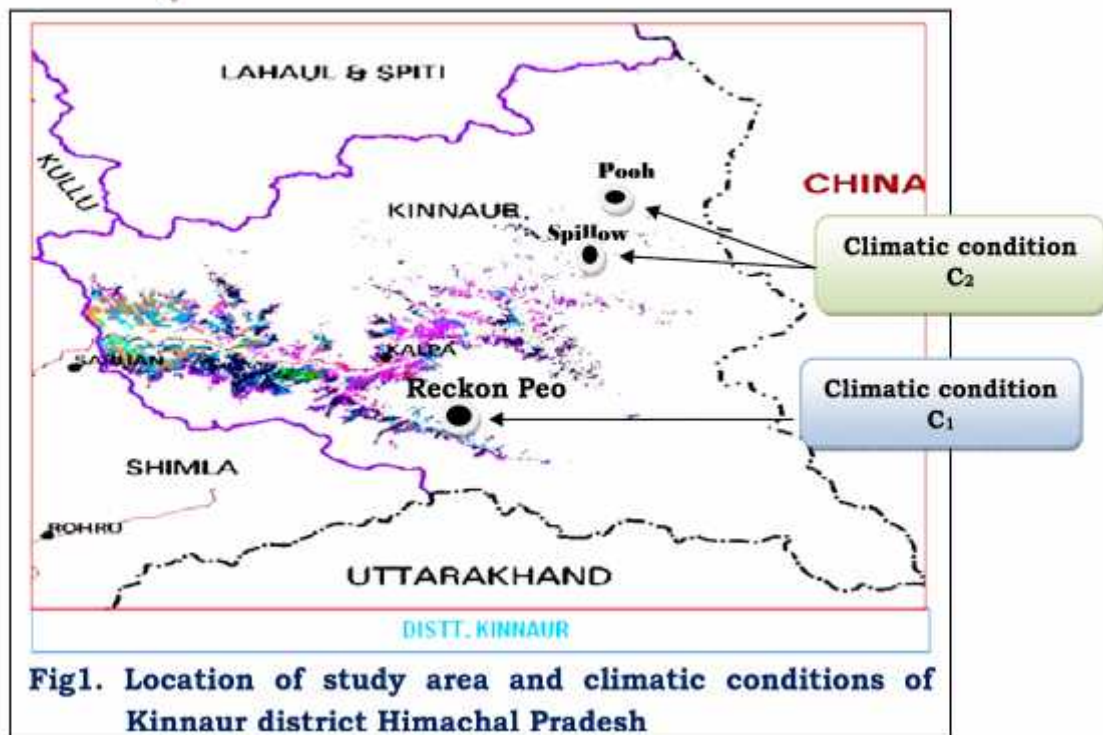
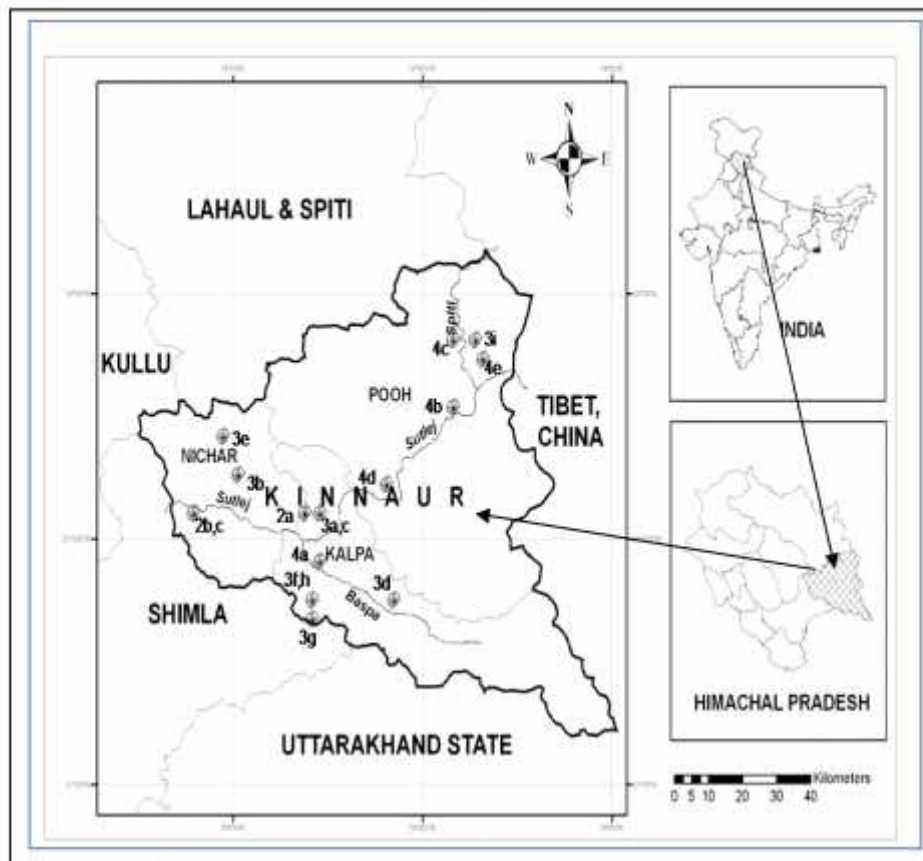
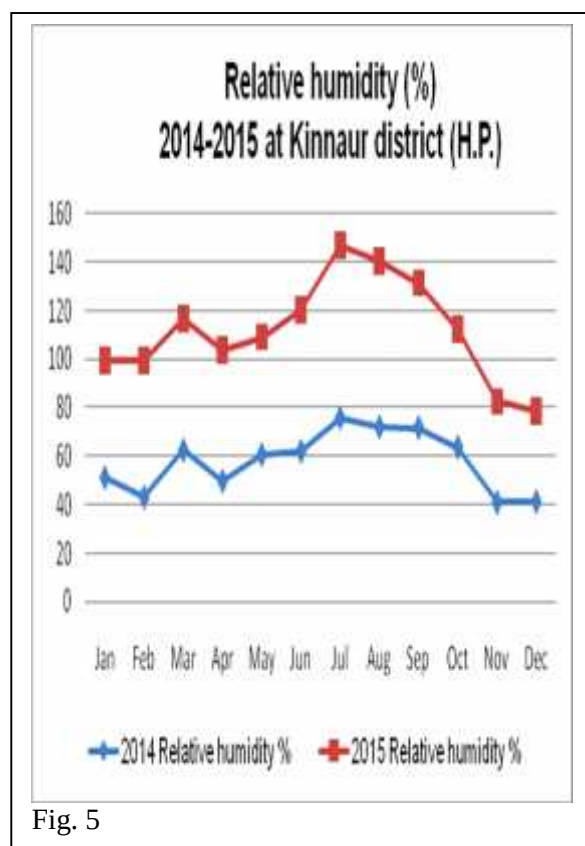
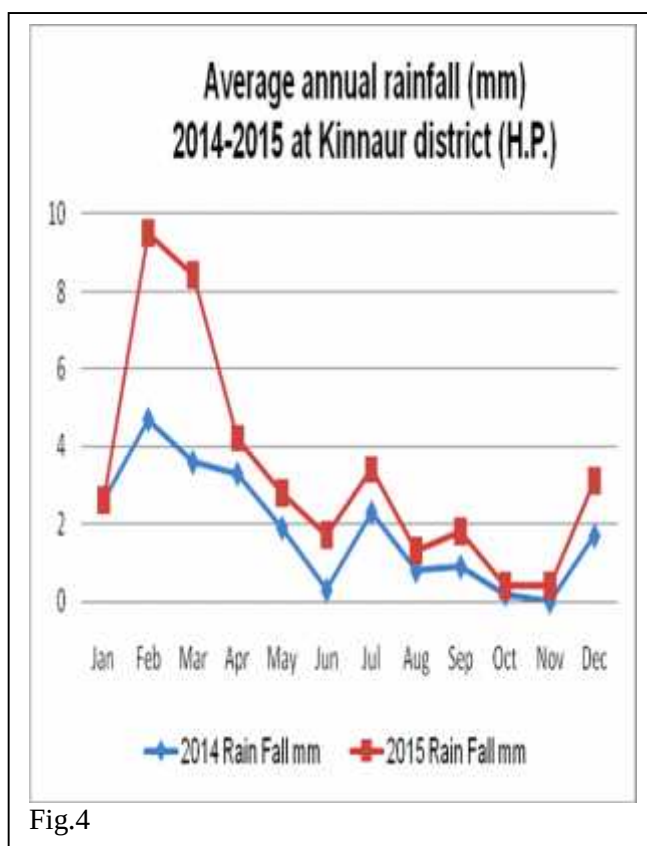
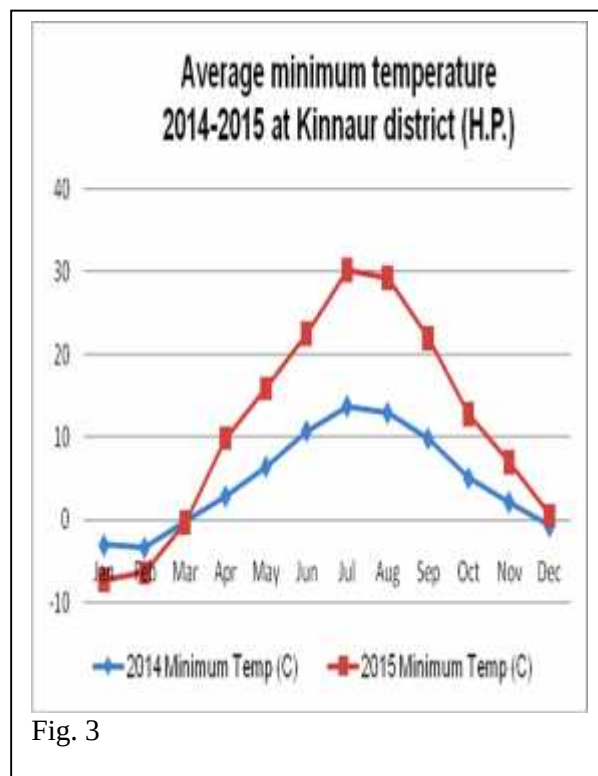
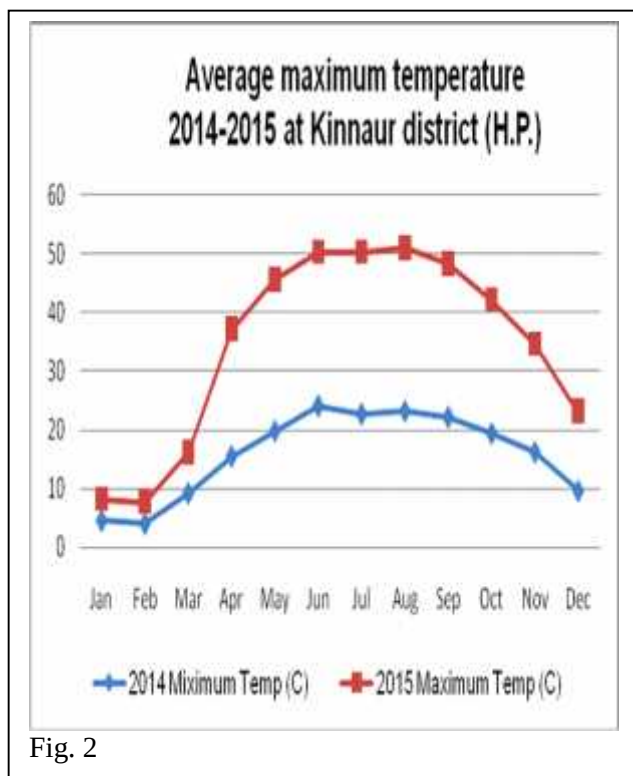


Fig1. Location of study area and climatic conditions of Kinnaur district Himachal Pradesh



Altitudinal range of this zone is about 2350m to 6816m above mean sea level and climate is dry temperate. In this area, rainfall is approximately 682.24 mm. At each site, three agroforestry systems viz., agrihorticulture, agrisilviculture, agrihortisilviculture were identified through extensive survey work in two different climatic conditions, viz., Dry temperate high hills (C₁) and High hills temperate dry and cold (C₂) (Table1).

Table 1: Latitude, longitude and elevation of different study sites of Dry temperate high hills and High hills temperate dry and cold conditions of Himachal Pradesh

Study Sites			
Name of Site/Farmers	Elevation (m)	Latitude	Longitude
Climatic condition C₁-Dry temperate high hills			
Agrihorticulture (T₁)	2197	31°32.660'	078°16.387'
	2136	31°32.565'	078°16.316'
	2057	31°39.405'	078°26.481'
Agrisilviculture (T₂)	2188	31°32.463'	078°16.509'
	2186	31°32.716'	078°16.436'
	2148	31°32.533'	078°16.537'
Agrihortisilviculture (T₃)	2187	31°32.928'	078°16.404'
	2138	31°32.456'	078°16.567'
	2081	31°32.953'	078°16.462'
Climatic condition C₂-High hills temperate dry and cold			
Agrihorticulture (T₁)	2735	31°45.608'	078°35.076'
	2680	31°46.053'	078°35.163'
	2232	31°45.628'	078°34.915'
Agrisilviculture (T₂)	2363	31°39.404'	078°26.482'
	2351	31°39.491'	078°26.533'
	2254	31°39.282'	078°26.487'
Agrihortisilviculture (T₃)	2831	31°46.050'	078°35.247'
	2556	30°49.408'	077°19.062'
	2225	31°39.438'	078°26.571'

3.1.4 Natural vegetation

Portions of Kinnaur are situated high in the Himalayas, where vegetation is sparse and consists primarily of hardy grasses. *Alpine* species such as *Juniper*, *Pine*, *Fir*, *Cypress*, and *Rhododendron* can be found at elevations between 3,500 and 5,000 metres, primarily in Middle Kinnaur. At lower altitudes, temperate-climate trees are found, including *Oak*, *Chestnut*, *Maple*, *Birch*, *Alder*, *Magnolia*, *Apple*, and *Apricot*, etc. The present study was carried out under following five experiments:

3.1.5 Experimental details

EXPERMENT-1: To study the species composition including trees, crops and weeds.

EXPERIMENT-2: To estimate the biomass and productivity of different species and the system as a whole.

EXPERMENT-3: To study the pattern of biomass distribution in different compositions.

EXPERMENT-4: To study nutrient cycling behavior in different types of agroforestry systems.

EXPERMENT-5: Economic evaluation of agroforestry systems.

The treatment details for experiments 1, 2, 3 & 5 are as below:

A. Agroforestry systems

T₁–Agrihorticulture system

T₂–Agrisilviculture system

T₃–Agrihortisilviculture system

B. Climatic condition

C₁ – Dry temperate high hills

C₂ – High hills temperate dry and cold

No. of treatment combinations: $6\{2 \text{ (Climatic condition)} \times 3\text{(Agroforestry systems)}\}$

Design : RBD (Factorial)

Replications : 3

Details of the treatments for experiment 4 are as follows;

A. Agroforestry systems

T₁–Agrihorticulture system

T₂–Agrisilviculture system

T₃–Agrihortisilviculture system

C. Soil depth (D)

D1 0-15 (cm)

D2 15-30 (cm)

Number of treatment: $12- \{2 \text{ (Climatic condition)} \times 3 \text{ (Agroforestry systems)} \times 2 \text{ (Soil depth)}\}$.

Experimental designs: RBD (Factorial)

Replication: Three

Table 2: Experimental details indicating specific tree-crop combinations and their distribution under agroforestry systems of Dry temperate high hills (C₁) climatic condition of Himachal Pradesh

Agroforestry systems	Code	Tree- Crop combination	Plot size (m ²)	Net Cropped Area (ha ⁻¹)	Area under Trees (ha ⁻¹)	No. of tree ha ⁻¹
Climatic condition C₁ -Dry temperate high hills						
Agrihorticulture (T₁)	R ₁	<i>Malus domestica</i> + <i>Diospyros kaki</i> + <i>Pyrus communis</i> + <i>Zea mays</i> + <i>Brassica oleracea</i> + <i>Phaseolus vulgaris</i> + <i>Hordeum vulgare</i>	10 × 10	0.6	0.4	625
	R ₂	<i>Malus domestica</i> + <i>Phaseolus vulgaris</i> + <i>Brassica oleracea</i> + <i>Zea mays</i> + <i>Hordeum vulgare</i> + <i>Beta vulgaris</i>	10 × 10	0.6	0.4	625
	R ₃	<i>Malus domestica</i> + <i>Zea mays</i> + <i>Brassica oleracea</i> + <i>Phaseolus vulgaris</i> + <i>Beta vulgaris</i> + <i>Hordeum vulgare</i>	10 × 10	0.7	0.3	400
Agrisilviculture (T₂)	R ₁	<i>Prunus armeniaca</i> + <i>Celtis australis</i> + <i>Quercus ilex</i> + <i>Salix alba</i> + <i>Populus ciliata</i> + <i>Pinus wallichiana</i> + <i>Pinus gerardiana</i> + <i>Zea mays</i> + <i>Brassica oleracea</i> + <i>Phaseolus vulgaris</i> + <i>Beta vulgaris</i> + <i>Hordeum vulgare</i>	10 × 10	0.8	0.2	420
	R ₂	<i>Quercus ilex</i> + <i>Prunus armeniaca</i> + <i>Celtis australis</i> + <i>Populus ciliata</i> + <i>Cedrus deodara</i> + <i>Pinus gerardiana</i> + <i>Zea mays</i> + <i>Brassica oleracea</i> + <i>Phaseolus vulgaris</i> + <i>Hordeum vulgare</i>	10 × 10	0.8	0.2	400
	R ₃	<i>Prunus armeniaca</i> + <i>Celtis australis</i> + <i>Pinus gerardiana</i> + <i>Quercus ilex</i> + <i>Zea mays</i> + <i>Brassica oleracea</i> + <i>Phaseolus vulgaris</i> + <i>Hordeum vulgare</i>	10 × 10	0.8	0.2	340
Agrihortisilviculture (T₃)	R ₁	<i>Prunus armeniaca</i> + <i>Quercus ilex</i> + <i>Populus ciliata</i> + <i>Pinus gerardiana</i> + <i>Malus domestica</i> + <i>Zea mays</i> + <i>Brassica oleracea</i> + <i>Phaseolus vulgaris</i> + <i>Hordeum vulgare</i>	10 × 10	0.7	0.3	470
	R ₂	<i>Prunus armeniaca</i> + <i>Quercus ilex</i> + <i>Pinus gerardiana</i> + <i>Malus domestica</i> + <i>Ailanthus altissima</i> + <i>Celtis australis</i> + <i>Zea mays</i> + <i>Brassica oleracea</i> + <i>Phaseolus vulgaris</i> + <i>Hordeum vulgare</i>	10 × 10	0.8	0.2	460
	R ₃	<i>Prunus armeniaca</i> + <i>Quercus ilex</i> + <i>Pinus gerardiana</i> + <i>Malus domestica</i> + <i>Celtis australis</i> + <i>Salix alba</i> + <i>Populus ciliate</i> + <i>Zea mays</i> + <i>Brassica oleracea</i> + <i>Phaseolus vulgaris</i> + <i>Hordeum vulgare</i>	10 × 10	0.8	0.2	450

Table 3: Experimental details indicating specific tree-crop combinations and their distribution under agroforestry systems of High hills temperate dry and cold (C₂) climatic condition of Himachal Pradesh

Agroforestry systems	Code	Tree- Crop combination	Plot size (m ²)	Net Cropped Area (ha ⁻¹)	Area under Trees (ha ⁻¹)	No. of trees ha ⁻¹
Climatic condition C₂ - High hills temperate dry and cold						
Agrihorticulture (T₁)	R ₁	<i>Malus domestica</i> + <i>Zea mays</i> + <i>Brassica oleracea</i> + <i>Phaseolus vulgaris</i> + <i>Hordeum vulgare</i> + <i>Capsicum annuum</i>	10 × 10	0.8	0.2	400
	R ₂	<i>Malus domestica</i> + <i>Zea mays</i> + <i>Brassica oleracea</i> + <i>Phaseolus vulgaris</i> + <i>Capsicum annuum</i> + <i>Hordeum vulgare</i>	10 × 10	0.8	0.2	400
	R ₃	<i>Malus domestica</i> + <i>Prunus dulcis</i> + <i>Zea mays</i> + <i>Brassica oleracea</i> + <i>Phaseolus vulgaris</i> + <i>Capsicum annuum</i> + <i>Hordeum vulgare</i>	10 × 10	0.7	0.3	560
Agrisilviculture (T₂)	R ₁	<i>Populus ciliate</i> + <i>Prunus armeniaca</i> + <i>Populus Alba</i> + <i>Celtis australis</i> + <i>Salix alba</i> + <i>Quercus semecarpifolia</i> + <i>Ailanthus altissima</i> + <i>Zea mays</i> + <i>Brassica oleracea</i> + <i>Phaseolus vulgaris</i> + <i>Hordeum vulgare</i>	10 × 10	0.8	0.2	350
	R ₂	<i>Quercus ilex</i> + <i>Ailanthus altissima</i> + <i>Salix alba</i> + <i>Prunus armeniaca</i> + <i>Celtis australis</i> + <i>Rajhma</i> + <i>Zea mays</i> + <i>Brassica oleracea</i> + <i>Phaseolus vulgaris</i> + <i>Hordeum vulgare</i>	10 × 10	0.8	0.2	350
	R ₃	<i>Celtis australis</i> + <i>Prunus armeniaca</i> + <i>Quercus ilex</i> + <i>Salix alba</i> + <i>Quercus semecarpifolia</i> + <i>Zea mays</i> + <i>Brassica oleracea</i> + <i>Phaseolus vulgaris</i> + <i>Hordeum vulgare</i>	10 × 10	0.8	0.2	343
Agrihortisilviculture (T₃)	R ₁	<i>Populus ciliate</i> + <i>Malus domestica</i> + <i>Prunus dulcis</i> + <i>Populus Alba</i> + <i>Morus alba</i> + <i>Phaseolus vulgaris</i> + <i>Zea mays</i> + <i>Brassica oleracea</i> + <i>Capsicum annuum</i> + <i>Hordeum vulgare</i>	10 × 10	0.7	0.3	500
	R ₂	<i>Prunus armeniaca</i> + <i>Malus domestica</i> + <i>Prunus dulcis</i> + <i>Populus alba</i> + <i>Morus Alba</i> + <i>Zea mays</i> + <i>Phaseolus vulgaris</i> + <i>Brassica oleracea</i> + <i>Hordeum vulgare</i> + <i>Beta vulgaris</i>	10 × 10	0.8	0.2	410
	R ₃	<i>Prunus armeniaca</i> + <i>Populus ciliata</i> + <i>Juglans regia</i> + <i>Celtis australis</i> + <i>Malus domestica</i> + <i>Pinus gerardiana</i> + <i>Zea mays</i> + <i>Phaseolus vulgaris</i> + <i>Brassica oleracea</i> + <i>Hordeum vulgare</i> + <i>Solanum lycopersicum</i>	10 × 10	0.8	0.2	420

3.1.6 Observations recorded:

A) Floristic composition

1. Frequency
2. Density
3. Basal area
4. I.V.I.

B) Biomass and productivity assessment

1. **Tree:** Bole, branches, foliage, fruit yield.
2. **Shrubs:** Stem, branches and leaf
3. **Crops:** Roots, shoots and grain yield
4. **Weeds:** Roots and shoots
5. **Leaf litter biomass:** Seasonal collection of leaf litter and dried for litter
Biomass determination
6. **Biomass increment:** Tree and shrubs (after one year)

C) Soil analysis

- Bulk Density
- Pore Space
- Texture Classes
- pH (1:2)
- Organic carbon
- Total Nitrogen (N) %
- K (mg/ 100 g)
- Ca (mg/ 100 g)
- Mg (mg/ 100 g)
- Extractable P (mg/ 100 g)

D) Plant analysis

- Total Nitrogen
- Phosphorus
- Potassium



Plate 1. Overview of Dry temperate high hills (C_1) climatic condition in Kinnaur district Himachal Pradesh



Plate 2. Overview of High hills temperate dry and cold climatic condition (C_2) in Kinnaur district Himachal Pradesh



Plate 3. Agrihorticulture system in Dry temperate high hills (C_1) climatic condition



Plate 4. Agrisilviculture system in Dry temperate high hills (C_1) climatic condition



Plate 5. Agrihortisilviculture system in Dry temperate high hills (C_1) climatic condition



Plate 6. Agrihorticulture system in High hills temperate dry and cold (C_2) climatic condition



Plate 7. Agrisilviculture system in system in High hills temperate dry and cold (C_2) climatic condition



Plate 8. Agrihortisilviculture system in High hills temperate dry and cold (C_2) climatic condition

- Calcium
- Magnesium

E) Amount of nutrient added through litter-fall: Seasonal collection of leaf litter and its analysis for estimation of nutrients.

F) Economic analysis:

- A) Cost of different inputs
- B) Market price of the product
- C) Net returns

Sample plot	:	10 m×10 m
Shrub	:	5 m×5 m
Herb and crops	:	1 m×1 m
Grass	:	0.5 m×0.5 m

3.2. VEGETATION STUDY

Density of trees was calculated by counting them in each agroforestry system in 10 m×10 m plots, which was replicated 10 times. Basal area of each tree was calculated with the help of DBH measured by tree calliper in the sample plot. Shrubs were studied in each agroforestry system by laying out 5 sub plot of size 5 m × 5m. Density of shrubs was calculated by counting plants of different species in each plot. The basal area of shrubs was estimated by cutting plant samples of different species using random stratified sampling method.

Herbaceous vegetation in different agroforestry systems was studied in the growing season (September-October) by harvesting quadrates of size 1m×1m each from every agroforestry system, which was replicated 10 times. Similarly 0.5m × 0.5m quadrate was made for grass in each agroforestry system, which was replicated 10 times. The vegetation from each quadrate was segregated species wise and identified with the help of herbarium by the UHF experts & text books. Important community parameters such as frequency, density, abundance, basal area of all the plant species were worked out by following Mishra (1969) which is given as below:

3.2.1 Basal area

The cross sectional area of shrubs, herbs & trees falling in the recording unit was determined by the formula as:-

$$\text{Basal area} = \pi d^2/4 \quad (\text{where } d = \text{diameter in 'm'})$$

3.2.2 Frequency

It is the indicator of number of samples in which given species occurs, thus express the distribution of various species in community.

$$\text{Frequency \%} = \frac{\text{Number of sample units in which species occurred}}{\text{Number of sampling units studied}} \times 100$$

3.2.3 Density

It represents the population of a species in the community and was calculated by counting number of species in the sample plot / sub-plot / quadrat.

$$\text{Density} = \frac{\text{Number of individuals of the species}}{\text{Total number of quadrats studied}}$$

3.2.4 Importance Value Index (IVI)

For each species in different quadrates relative density, relative basal area and relative frequency were calculated by procedure of Mishra (1969), which is given as below:

$$\text{RD} = \frac{(\text{Density of a species} \times 100)}{\text{Total density of all species in a quadrat}}$$

$$\text{RBA} = \frac{(\text{basal area of a species} \times 100)}{\text{Total basal area of species in a quadrat}}$$

$$\text{RF} = \frac{(\text{Frequency of a species} \times 100)}{\text{Total frequency of species in a quadrat}}$$

The importance value index for each species was worked by using formula given by Curtis and McIntosh (1950)

$$\text{IVI} = \text{Relative density} + \text{relative dominance} + \text{relative frequency}$$

3.3 VEGETATION INDICES

3.3.1 Shannon Weiner Index

Species diversity of each forest was determined by using Shannon Weiner (1963) index as:

$$H' = - \sum \frac{N_i}{N} \times \ln \frac{N_i}{N}$$

Where, H' = Shannon Weiner index

N = Total no. of individuals of all the species

N_i = Total no of individuals of i^{th} species

$\ln$ = Natural log

Shannon Weiner's index is a measure of the amount of information needed to describe every member of the community.

3.3.2 Simpson's Diversity Index (Simpson, 1949)

Simpson's diversity index gives the probability that individuals, selected at random will belong to the species. Simpson's Diversity Index was determined by using Simpson's Diversity (1949) index as:

$$D = \frac{N(N-1)}{2n(n-1)}$$

Where, D = Diversity index;

N = Number of individual of a particular species.

n = Total no. of individuals of all the species

3.4 ABOVE GROUND TREE BIOMASS

3.4.1.1 Volume estimation

The trees falling in the plot ($10 \times 10 \text{ m}^2$) were enumerated. The diameter at breast height (dbh) was measured with the help of tree calliper and height was measured with Ravi's multimeter, consecutively for two years. The trees were painted with colour at the breast height and measurements were recorded very carefully at the same point in both the years. Then volume equation developed for specific tree species and region was used for calculating the volume of the forest trees of the sample plot (Table 4).

3.4.1.2 Stem biomass

To estimate biomass, the entire trees falling in the plot ($10 \times 10 \text{ m}^2$) 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 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 formulae 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

$$g = \pi r^2 = \pi dbh^2/4$$

Where,

r = radius, dbh – diameter at breast height

Table 4: Equations for volume estimation of different woody tree species

Sr. No.	Name of species	Volume equation	References
1.	<i>Pinus roxburghii</i>	$V=0.167095/D^2-2.085944/D+9.929936$	FSI, 1996
2	<i>Cedrus deodara</i>	$V= 0.167174 - 1.735312 \times D + 12.039017 \times D^2$	FSI, 1996
3	<i>Pinus wallichiana</i>	$V= 0.251311 - 2.683081 \times D + 13.484565 \times D^2$	FSI, 1996
4.	<i>Toona ciliata</i>	$V=-0.12483+0.284996 \times D^2 \times H$	FSI, 1996
5.	<i>Populus deltoides</i>	$V=0.193297-2.267002 \times D+10.679492 \times D^2$	FSI, 1996
6	<i>Malus domestica</i>	$Y = 1.052 \times X^{1.076} \quad (R^2 = 0.823)$ Y = Dry biomass of secondary branches X = Diameter in cm	Rajput (2010)
7.	<i>Morus alba</i>	$V=0.167174-1.735312 \times D+12.039017 \times D^2$	FSI, 1996
8	<i>Quercus semecarpifolia</i>	$V/D^2 = 0.0988/D^2 - 1.5547/ D + 10.1631$	FSI, 1996

3.4.1.3: Biomass estimation

The aboveground biomass of woody trees was estimated by using expansion factors and specific gravity, which were developed for estimation of aboveground biomass of trees by non-destructive method.

$$\text{Aboveground biomass density (t ha}^{-1}\text{)} = \text{VOB} \times \text{WD} \times \text{BEF}$$

Where,

VOB = Volume over bark

WD = Volume-weighted average wood density (1 gm of oven-dry biomass per m³ green volume)

BEF = Biomass expansion factor

3.4.1.4: Biomass expansion factor (BEF)

The ratio of total aboveground oven-dry biomass density of trees with a minimum dbh of 10 cm or more to the oven-dry biomass density of the inventoried volume. Some expansion factors developed for various tree species are given in the Table 5.

Table 5: Biomass expansion factor for volume estimation of different woody tree species

Sr. No.	Name of species	Expansion factor	References
1.	<i>Pinus roxburghii</i>	1.91	Rajput (2016)
2.	<i>Cedrus deodara</i>	1.40	Rajput (2016)
3.	<i>Toona ciliata</i>	1.40	Rajput (2016)
4.	<i>Populus deltoides</i>	1.58	Kaul and Sharma (1983)
5.	<i>Morus serrata</i>	1.40	Calculate in lab

3.4.1.5: Specific gravity

Specific gravity values for biomass estimation of different trees were used from the available literature (Table 6). Wherever 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).

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

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 $\times$ volume

Table 6: Average specific gravity of stem wood of different woody tree species

Sr. No.	Name of species	Specific gravity	References
1.	<i>Ailanthus altissima</i>	0.400	Sheikh (1993)
2.	<i>Cedrus deodara</i>	0.468	Rajput (2016)
3.	<i>Celtis australis</i>	0.550	Gupta <i>et al.</i> , (2016)
4.	<i>Diospyros kaki</i>	0.640	Calculate in lab
5.	<i>Juglans regia</i>	0.610	Sheikh (1993)
6.	<i>Malus domestica</i>	0.640	Rajput (2016)
7.	<i>Morus alba</i>	0.603	IPCC (2003)
8.	<i>Pinus gerardiana</i>	0.580	Sheikh (1993)
9.	<i>Pinus wallichiana</i>	0.357	Rajput (2010)
10.	<i>Populus Spp</i>	0.400	Kaul and Sharma (1983)
12.	<i>Prunus armeniaca</i>	0.673	Rajput. (2016)
13.	<i>Prunus dulcis</i>	0.530	Calculate in lab
14.	<i>Pyrus communis</i>	0.642	Rajput.(2016)
15.	<i>Quercus Spp</i>	0.720	Kumar (1989)
16.	<i>Selx alba</i>	0.480	Wani <i>et.al.</i> ,(2014)

3.4.1.3 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. Following formula (Chidumaya 1990) was used to determine the dry weight of branches.

$$Bdwi = Btwi/1 + Mcbd$$

Where,

Bdwi - oven dry weight of branch

Btwi - Fresh/green weight of branches

Mcbdi - Moisture content of branch on dry weight basis

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

$$Bbt = n_1bw_1 + n_2bw_2 + n_3bw_3 - \sum n_i bwi$$

Where,

Bbt - Branch biomass (fresh/dry) per tree

Ni - Number of branches in the ith branch group

Bwi - average weight of branch of ith group

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

3.4.1.4: Leaf biomass

Leaves from the branches were removed, weighed and oven dried separately to a constant weight at $60 \pm 5^\circ\text{C}$ (Chidumaya, 1990). Leaf biomass of the forest tree species was estimated using the table given by Jenkins *et al.*, (2003) 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.

3.4.1.5: Crown Width

The crown width was measured in two directions (North-South and East-West) and average was calculated as suggested by Assmann (1970), Chaturvedi and Khanna (1982).

$$CW = \frac{D_1 + D_2}{2}$$

Where:

CW – Crown width (m)

D₁ –Crown diameter measurement in East-West direction (m)

D₂ –Crown diameter measurement in North-South direction (m).

3.4.2.1: Tree biomass

The total tree biomass was the sum of stem biomass, branch biomass and leaf biomass.

3.4.2.2: Fruit tree biomass

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

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

Where,

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

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.

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

The volume of the main stem was calculated with the help of quarter girth formula.

3.4.2.3: Fruit tree root biomass

In fruit trees, the trees uprooted by the farmers during their orchard replacement time (Dec.-Jan.) 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 and developed shoot-root ratio.

3.4.2.4: Above ground biomass of crop and herbs

Ten plots of 1 m×1 m were used for estimation of crop biomass. All crops and herbs biomass occurring within the borders of quadrat were cut at ground level and collected

samples were weighed, sub sampled and oven dried at $60\pm 5^{\circ}\text{C}$ to a constant weight. The crop biomass was converted into carbon by multiplying with a factor of 0.5 (IPCC default value).

3.4.2.5: Litter biomass

To quantify standing floor mass, standing floor litter were randomly collected at five points using a 1m x 1m quadrat size. All the standing floor litter inside the quadrat was collected and oven dried at $60\pm 5^{\circ}\text{C}$ weighed. To convert to litter biomass to carbon, the biomass value was multiplied by a default value of 0.370 (Smith and Heath, 2001).

3.5: BELOW GROUND TREE BIOMASS

3.5.1: Below ground biomass

Below ground biomass of trees was calculated by using the guidelines of IPCC (1996) and Cairns *et al.*, (1997). Belowground biomass of trees was calculated by multiplying aboveground biomass with a factor of root: shoot ratio of particular tree (Table 7). The data pertaining to root: shoot ratio of trees are shown below:

$$\text{Belowground biomass} = \text{aboveground biomass} \times \text{Root: shoot ratio}$$

3.5.2: Below ground biomass of crops and herbs

Below ground biomass of crops and grasses was calculated by multiplying aboveground 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.

$$\text{Below ground biomass} = \text{aboveground biomass} \times \text{Root: shoot ratio}$$

3.5.3: Carbon stock

Above and belowground carbon stock in vegetation is determined by vegetation biomass multiply with default value 0.5 (IPCC, 1996).

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

$$\text{Soil carbon stock} = \text{Bulk density} \times \text{Organic carbon (\%)} \times \text{soil depth (cm)}$$

Table 7: Root: Shoot ratio of different woody tree species

Sr. no.	Name of species	Root shoot ratio	References
1.	<i>Ailanthus altissima</i>	0.27	IPCC (2003)
2.	<i>Celtis australis</i>	0.49	Rawat (2016)
3.	<i>Quercus Spp</i>	0.39	IPCC (2003)
4.	<i>Morus alba</i>	0.27	Rajput <i>et al.</i> , (1985)
5.	<i>Malus domestica</i>	0.264	Dimri (2011)
6.	<i>Prunus armeniaca</i>	0.27	IPCC (2003)
7.	<i>Populus deltoids</i>	0.19	Kumar (1998)
8.	<i>Salix alba</i>	0.27	IPCC (2003)

3.5.4: Vegetation nutrient concentration

After determining the biomass, the dried plant samples of all the species were analysed for plant nutrients. Trees parts such as boles, branches, leaves, fruits and roots were analyzed separately. Litter from the tree species were categorised into leaf, woody and miscellaneous parts, was also analyzed separately.

In the case of tree+crop situation, besides plant samples of different compartments of trees, the aboveground biomass of crops, shrubs, grasses, weeds, litter, and below ground biomass were also analysed for nutrient concentration. Plant samples were ground to a powder and passed through a 0.5-mm sieve, and digested in triacid mixture (HNO₃, HClO₄ and H₂SO₄ in the ratio of 10:4:1) and analysed for P, K, and Ca. For estimation of total N, plant samples were digested with concentrated H₂SO₄ and catalyst (CuSO₄ + K₂SO₄). From the digested sample an aliquot of 10 ml was distilled with alkali in steam distillation unit and ammonia liberated was collected in boric acid (5 ml) which was titrated against N/10 H₂SO₄. (AOAC, 1990).

The concentration of other nutrients was determined by following standard procedures as given below. The mean nutrient concentrations were corrected to oven-dry weight basis. The standing state of nutrients (g m⁻²) was computed from mean biomass values of different compartments and the corresponding nutrient concentration percentage.

Nutrients	Procedure	References
P	Van Molybdate yellow spectrophotometer and flame photometer	Jackson (1973)
K		Jackson (1973)
Ca	Versenate titration	Jackson (1973)
Total N	Modified Kjeldahl method	Jeldahl (1983)

The nutrient contents of shrubs, weeds and grass species in the agroforestry systems were also determined following the methods described above.

3.5.5: Nutrient Uptake by vegetation

Nutrient uptake by vegetation was calculated by the following formula

$$\text{Nutrient uptake} = \frac{\text{Nutrient concentration \%} \times \text{dry matter (Kg ha}^{-1}\text{)}}{100}$$

The sum of the uptake of nutrients in the two compartments (above- and below-ground) yielded total uptake in the plants.

3.5.6: Nutrient carried away from the system

The nutrient content removed from the agroforestry system was estimated by multiplying the quantity of dry matter of these components with their respective mean nutrient concentrations. The quantities of nutrients recycled in the system through crop and weed residues after the crop harvest were estimated by multiplying the quantity of the dry matter of these components with their respective mean concentration of the nutrients.

The biomass of the crop (edible and non- edible parts) and weeds removed at harvest was measured by subtracting the residues of crop and weeds left in the field (biomass recycled) after the harvest from the biomass of crop and weeds just before harvest.

3.5.7: Fractional annual turnover of each element

For soil and vegetation compartments, the fractional annual turnover of each element was calculated by dividing the weight that left the compartment by the weight held in that compartment and expressed as percentage following Reiners and Reiners (1970).

$$\text{Annual turnover of nutrients in soil compartment} = \frac{\text{Annual uptake of nutrients by the vegetation}}{\text{Total amount of nutrients in the soil pool}} \times 100$$

$$\text{Annual turnover of nutrients in vegetation compartment} = \frac{\text{Nutrients lost from the standing biomass}}{\text{Total amount stored in the vegetation pool}} \times 100$$

3.6 SOIL ANALYSIS

3.6.1 Collection and preparation of samples

Soil samples were collected at two different depths (0-15 & 15-30 cm) from each agroforestry system and climatic conditions by using post hole and screw auger. Composite samples from all land uses were obtained from 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 physical and chemical attributes of soils were determined by standard methods given below (Table 8).

Table 8: Soil physical and chemical analysis: methods and instruments used

Sr. No.	Parameters	Methods Employed	Instrument/ap paratus used
1	Soil Texture	Hydrometer method by George John Bouyocos 1927	Hydrometer method
2	Bulk density (g/cc)	Method for disturbed soil-the weight of oven dried soil filled in Pycnometer by gently tapping divided by its volume.	Pycnometer
3	Partical density (g/cc)	Method for disturbed soil-solids (g) divided by weight of Pycnometer filled with water +wt. Soil solids – wt. of Pycnometer filled with soil	Pycnometer
4	Pore space (%)	100% - % solid space	-----
5	pH	1:2 soil water suspension (Jackson, 1973)	pH meter
6	Organic Carbon (%)	Wet Combustion method (Walkley and black, 1934)	-----
7	Total Nitrogen (kg ha ⁻¹)	Kjeldahl, J. (1883)	Kjeldahl distillation unit
8	Extractable Phosphorus (kg ha ⁻¹)	Bray, RH & Kurtz, LT 1945	Spectrtronnlic 20 D ⁺
9	Available Potassium (kg ha ⁻¹)	Neutral 1 N ammonium acetate solution method (Merwin and Peach, 1951)	Flame photometer
10	Exchangeable Calcium (mg ka ⁻¹)	Neutral 1 N ammonium acetate solution method	Flame photometer
11	Exchangeable Magnesium (mg ka ⁻¹)	Neutral 1 N ammonium acetate solution method	-----

3.7 ECONOMIC YIELD

3.7.1 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 CIII - CIV.

3.7.2 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 CIII - CIV).

3.7.3 Net returns

Net returns were taken on marketing, land value and production costs (variable cost) are given Appendix CIII – CIV.

3.7 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

RESULTS AND DISCUSSION

The results obtained from the present investigation entitled “**Structure and function of agroforestry systems in dry temperate regions of north western Himalayas**” conducted at different sites lying in the dry temperate parts of district Kinnaur of Himachal Pradesh are presented and discussed in this chapter. The area was first stratified into two climatic condition viz., dry temperate high hills (C₁) and High hills temperate dry and cold (C₂) climatic conditions. In each climatic condition, three agroforestry systems viz., Agri-horticulture system, Agri-silviculture system and Agri-horti-silviculture were selected in such a manner that they represented entire condition of the zone. The details of the findings of the present investigations are described in this chapter under the following major heads and sub heads.

4.1. Phytosociology of plant species in different agroforestry systems

4.1.1 Phytosociology of herbage

4.1.2 Phytosociology of shrubs

4.1.3 Phytosociology of trees

4.1.4 Phytosociology of grass

4.2. Vegetation indices

4.3. Biomass production of different agroforestry systems

4.3.1. Aboveground biomass

4.3.2. Belowground biomass

4.3.3. Total biomass (Above and belowground)

4.3.4. Carbon inventory

4.3.5. Biomass increment in trees and shrubs

4.4 Nutrient cycling in different agroforestry systems

4.4.1. Nutrient stock in different components

4.4.2. Nutrient available in 0-30cm soil layer

4.4.3. Density of elements in ecosystem

4.4.4. Nutrient uptake by different components

4.4.5. Nutrient concentration in different components

4.4.6. Nutrient addition in soil

4.4.7. Nutrient removal from the system

4.4.8. Nutrient turnover in the system

4.5. Soil physico-chemical properties

4.6. Economic analysis

4.1. PHYTOSOCIOLOGY ANALYSIS OF DIFFERENT AGROFORESTRY SYSTEMS

4.1.1. Phytosociology of herbage

4.1.1.1. Herbage density (tillers m⁻²)

Growing trees along the edges in the agricultural field is an age-old practice in the Indian Himalaya. There are a variety of multipurpose tree species grown and managed for subsistence requirement of local communities (Maikhuri *et al.*, 2000) such as fuelwood, timber, fruits and raw materials. Singh (1975) reported that each species play a definite role and possess its structural and functional individualism in the community. As such it is necessary to study numerical abundance and spatial distribution of all the species in understanding the community organization. The most important aspect of the agroforestry and forestry systems is lessening the anthropogenic pressure on natural forests (Nautiyal & Negi 1994, Rao & Maikhuri 1996).

The phytosociology of the herbage, shrub and tree layer in the present context has been dealt under density. Data in Table 8 shows that density of herbage including agricultural crops under different land use systems ranged from 13.001 to 15.465 (tillers m⁻²). Higher total density was displayed by Dry temperate high hills (C₁) climatic condition than the High hills temperate dry and cold (C₂) climatic condition.

Data in Table 9 shows that agroforestry systems viz., agrisilviculture and AHS system displayed higher herbage density at C₂ climatic condition than C₁ climatic conditions. At C₁ maximum total herbage density was displayed by AH system (15.465 tillers m⁻²) followed by AS system (14.133 tillers m⁻²) and AHS system (13.065 tillers m⁻²). Under C₂ climatic condition, AS system (14.566 tillers m⁻²) showed higher herbage total density followed by the AHS (14.502 tillers m⁻²) and AH systems (13.001 tillers m⁻²), respectively. More or less similar density was observed by Gupta *et al.*, (2015), Hailu (2017) in their investigations.

Table 9. Effect of agroforestry systems and climatic conditions on density (tillers m⁻²) of herbage under Dry temperate conditions of north western Himalaya

Sr. No.	Herb species	Agrihorticulture system		Agrisilviculture system		Agrihortisilviculture system	
		C ₁	C ₂	C ₁	C ₂	C ₁	C ₂
1	<i>Achyranthes aspera</i>	-	-	-	0.233	-	-
2	<i>Aconitum heterophyllum</i>	-	0.200	-	-	-	-
3	<i>Ageratum conyzoides</i>	0.633	-	0.067	0.200	0.064	0.500
4	<i>Ajuga parviflora</i>	0.533	-	0.233	0.100	0.433	0.733
5	<i>Ameranthus caudatus</i>	-	-	0.065	-	-	-
6	<i>Amerantus spinosus</i>	0.200	0.300	0.300	0.600	-	0.333
7	<i>Anaphalis arvensis</i>	-	-	0.333	-	0.200	0.067
8	<i>Anaphalis nepalensis</i>	-	-	0.167	-	-	-
9	<i>Arebidopsis thaliana</i>	-	-	-	-	0.233	0.033
10	<i>Arisaema flavum</i>	0.167	-	0.200	-	0.200	-
11	<i>Asparagus adscendens</i>	-	-	0.067	0.267	-	-
12	<i>Asparagus filicinus</i>	-	0.167	-	-	-	-
13	<i>Aster albescens</i>	-	-	0.100	-	-	-
14	<i>Beta vulgaris</i>	3.233	-	1.733	-	-	2.067
15	<i>Brassica oleracea</i>	2.000	2.100	2.133	2.267	2.367	2.000
16	<i>Bupleurum candollii</i>	-	-	-	0.233	-	-
17	<i>Cannabis staiva</i>	0.400	0.233	-	-	0.333	0.067
18	<i>Capsicum annuum</i>	-	1.467	-	-	-	0.533
19	<i>Carum carvi</i>	-	0.200	0.300	0.500	0.433	-
20	<i>Chinopodium album</i>	0.933	0.533	0.433	0.200	0.467	0.133
21	<i>Cleome viscosa</i>	-	-	-	-	-	0.167
22	<i>Conyza stricta</i>	-	-	0.133	-	-	-
23	<i>Cynoglossum wallichii</i>	-	-	0.167	0.500	0.133	-
24	<i>Epipactis veratrifolia</i>	--	0.400	-	0.233	-	0.300

Sr. No.	Herb species	Agrihorticulture system		Agrisilviculture system		Agrihortisilviculture system	
		C ₁	C ₂	C ₁	C ₂	C ₁	C ₂
25	<i>Erigeron multiaulis</i>	0.333	-	-	-	0.133	0.100
26	<i>Fagopyrum cymosum</i>	0.400	0.300	-	-	0.133	-
27	<i>Fumaria indica</i>	-	-	-	0.067	-	-
28	<i>Gallinsoga parviflora</i>	0.833	0.167	0.233	0.833	0.633	-
29	<i>Gentiana argentea</i>	-	-	-	0.233	-	0.067
30	<i>Geranium sibiricum</i>	-	-	-	-	-	0.267
31	<i>Halenia elliptica</i>	-	0.200	-	-	-	-
32	<i>Impatiens brachycentra</i>	-	-	-	-	0.167	-
33	<i>Impatiens roylei</i>	-	0.200	-	-	-	-
34	<i>Impomea eriocarpa</i>	0.200	-	-	0.067	0.133	-
35	<i>Lactuca dissecta</i>	0.300	0.467	0.067	0.467	0.200	0.367
36	<i>Lapidium apetalum</i>	-	-	-	0.067	-	-
37	<i>Lappula barbata</i>	-	-	-	-	0.167	-
38	<i>Lathyrus emodi</i>	-	0.200	0.500	-	-	-
39	<i>Leucas lanata Benth.</i>	-	-	0.267	-	0.167	-
40	<i>Lithospermum arvense</i>	-	-	-	-	-	0.267
41	<i>Malva neglecta</i>	0.167	0.167	0.133	0.200	0.200	-
42	<i>Malva rutondifolia</i>	0.233	-	-	-	0.233	0.167
43	<i>Malva verticillata</i>	-	-	0.133	-	-	-
44	<i>Mentha longifolia</i>	-	-	0.100	-	0.133	-
45	<i>Morina longifolia</i>	0.133	-	-	0.233	-	-
46	<i>Morina persica</i>	-	0.200	-	-	-	-
47	<i>Myriactis nepalensis</i>	0.167	-	-	-	0.167	-
48	<i>Myrsine africana</i>	-	-	-	0.033	-	-
49	<i>Nepeta erecta</i>	-	0.133	-	-	-	0.267
50	<i>Oreorchis indica</i>	-	0.200	-	-	-	-
51	<i>Parnassia laxmanii</i>	-	-	-	0.133	-	-

Sr. No.	Herb species	Agrihorticulture system		Agrisilviculture system		Agrihortisilviculture system	
		C ₁	C ₂	C ₁	C ₂	C ₁	C ₂
52	<i>Parochetus communis</i>	-	-	0.300	-	-	-
53	<i>Phaseolus vulgaris</i>	2.400	2.533	2.367	3.167	2.567	3.133
54	<i>Physochlaena praealta</i>	-	-	0.200	-	0.100	-
55	<i>Prunella vulgaris</i>	-	-	0.067	-	0.133	-
56	<i>Raninculus arvensis</i>	-	-	-	-	0.133	-
57	<i>Raphanus raphanistrum</i>	-	-	-	0.033	-	-
58	<i>Rumex nepalensis</i>	-	0.233	-	-	-	-
59	<i>Salsola collina</i>	-	-	-	0.233	-	-
60	<i>Salvia lanata</i>	0.133	0.167	-	0.133	-	-
61	<i>Silene vulgaris</i>	-	-	-	-	-	0.100
62	<i>Sisymbrium officinale</i>	-	-	0.067	-	-	-
63	<i>Solanum lycopersicum</i>	-	-	-	-	-	0.867
64	<i>Spergularia marina</i>	-	0.167	-	-	-	-
65	<i>Strobilanthes alatus</i>	-	0.133	-	-	-	-
66	<i>Thalictrum foliosum</i>	-	0.167	0.633	-	0.600	-
67	<i>Trifolium repens</i>	0.267	0.167	-	0.267	0.300	0.467
68	<i>Urtica parviflora</i>	-	-	0.133	-	0.167	-
69	<i>Valeriana hardwickii</i>	-	-	0.067	-	-	-
70	<i>Verbascum thapsus</i>	-	-	-	0.267	-	-
71	<i>Veronica persica</i>	-	-	-	0.100	-	-
72	<i>Veronica serpyllifolia</i>	-	-	-	-	-	0.167
73	<i>Vicia bakeri</i>	-	-	0.133	0.233	-	-
74	<i>Xanthium strumarium</i>	-	-	0.133	-	-	-
75	<i>Zea mays</i>	1.800	1.600	2.167	2.467	1.733	1.333
	Total	15.465	13.001	14.133	14.566	13.065	14.502

In AH systems at C₁ climatic condition, agricultural crops, namely *Beta vulgaris* (3.233 tiller m⁻²) followed by *Phaseolus vulgaris* (2.400 tiller m⁻²) was the predominant crops. In weeds the maximum density was displayed by *Chinopodium album* (0.933 tiller m⁻²). While, minimum density was displayed by *Salvia lanata* (0.133 tiller m⁻²). In AS system at C₁ climatic condition, the maximum density was recorded in *Phaseolus vulgaris* (2.367 tiller m⁻²), whereas minimum density in agriculture crops was displayed by *Beta vulgaris* (1.733 tiller m⁻²). In weeds, maximum density was found for *Lathyrus emodi* (0.500 tiller m⁻²) while, minimum density was recorded for *Ameranthus caudatus* (0.065 tiller m⁻²). In AHS system, among agriculture crops, the maximum density was reported by *Phaseolus vulgaris* (2.567 tiller m⁻²), while least density was shows by *Zea mays* (1.733 tiller m⁻²). Among weeds, the maximum density was reported by *Thalictrum foliosum* (1.733 tiller m⁻²) whereas, least value of weed density was reported by *Ageratum conyzoides* (0.064 tiller m⁻²).

At High hills temperate dry and cold (C₂) climatic condition, maximum density under agriculture crop in AH system, *Phaseolus vulgaris* (2.533 tiller m⁻²) reported maximum density while, minimum density was displayed by *Capsicum annum* (1.467 tiller m⁻²). In weeds maximum density was recorded by *Carum carvi* (0.533 tiller m⁻²), whereas minimum density was displayed by *Nepeta erecta* (0.133 tiller m⁻²). In AS system, the maximum density was displayed by *Phaseolus vulgaris* (3.167 tiller m⁻²) and minimum density was recorded by *Brassica oleracea* (2.267 tiller m⁻²) under agriculture crops. Among weeds, the higher density was recorded by *Gallinsoga parviflora* (0.833 tiller m⁻²) and minimum weed density was displayed by *Raphanus raphanistrum* and *Myrsine Africana* (0.033 tiller m⁻²), each displayed identical values. Similarly, in AHS system *Phaseolus vulgaris* (3.133 tiller m⁻²) was dominant species under agriculture crops and minimum density was reported by *Capsicum annum* (0.533 tiller m⁻²). Under weeds, *Ajuga parviflora* (0.733 tiller m⁻²) reported maximum density, whereas minimum density was found in *Arebidopsis thaliana* (0.033 tiller m⁻²).

4.1.1.2. Herbage Basal area (cm² m⁻²)

Herbage basal area under different land use systems, ranged between 16.121 to 20.343 cm² m⁻². Table 10 shows that AS system and AHS system displayed higher herbage total basal area at C₁ climatic condition than C₂ climatic condition. At C₁ climatic condition, the maximum (20.343 cm² m⁻²) herbage total basal area was recorded in AS systems followed by AHS system (19.536 cm² m⁻²) and AH systems (16.121 cm² m⁻²). Similarly at C₂ climatic

condition the maximum total basal area was recorded in AS systems ($18.886 \text{ cm}^2 \text{ m}^{-2}$) followed by AH systems ($16.155 \text{ cm}^2 \text{ m}^{-2}$) and AHS system ($15.319 \text{ cm}^2 \text{ m}^{-2}$), respectively. Among all weed species, *Prunella vulgaris* in AS system exhibited minimum ($0.003 \text{ cm}^2 \text{ m}^{-2}$) basal area. Among agriculture crops, *Zea mays* accounted for higher ($10.112 \text{ cm}^2 \text{ m}^{-2}$) herbage basal area among all agricultural crops in AS system.

At C_1 climatic condition under AH system, among agriculture crops the maximum basal area was showed by *Brassica oleracea* ($9.099 \text{ cm}^2 \text{ m}^{-2}$) in AH system. Whereas, minimum basal area was occupied by *Beta vulgaris* ($0.177 \text{ cm}^2 \text{ m}^{-2}$). In weeds, maximum basal area was displayed by *Ajuga parviflora* ($0.146 \text{ cm}^2 \text{ m}^{-2}$) and least basal area was occupied by *Myriactis nepalensis* and *Trifolium repens* ($0.007 \text{ cm}^2 \text{ m}^{-2}$). In AS system at C_1 climatic condition, among all agriculture crops *Zea mays* ($10.112 \text{ cm}^2 \text{ m}^{-2}$) occupied maximum basal area and minimum basal area was occupied by *Beta vulgaris* ($0.401 \text{ cm}^2 \text{ m}^{-2}$). Under weeds, the maximum basal area was occupied by *Thalictrum foliosum* ($0.166 \text{ cm}^2 \text{ m}^{-2}$). *Prunella vulgaris* in AS system, exhibited minimum ($0.003 \text{ cm}^2 \text{ m}^{-2}$) basal area. Under AHS system, among all agriculture crops *Brassica oleracea* ($9.865 \text{ cm}^2 \text{ m}^{-2}$) recorded highest basal area whereas, *Phaseolus vulgaris* ($0.552 \text{ cm}^2 \text{ m}^{-2}$) recorded least basal area. Under weeds *Thalictrum foliosum* ($0.167 \text{ cm}^2 \text{ m}^{-2}$) occupied maximum basal area, while least basal area was reported by *Physochlaena praealta* ($0.004 \text{ cm}^2 \text{ m}^{-2}$), respectively.

In C_2 climatic condition, under AH system, maximum basal area was reported by *Brassica oleracea* ($9.526 \text{ cm}^2 \text{ m}^{-2}$) and least basal area was occupied by *Capsicum annuum* ($0.253 \text{ cm}^2 \text{ m}^{-2}$) while, *Lathyrus emodi* ($0.139 \text{ cm}^2 \text{ m}^{-2}$) reported maximum basal area under weeds. The minimum basal area was found for *Oreorchis indica* and *Trifolium repens* ($0.006 \text{ cm}^2 \text{ m}^{-2}$). In AS system, *Brassica oleracea* reported highest basal area ($10.048 \text{ cm}^2 \text{ m}^{-2}$) and minimum basal area was found for *Phaseolus vulgaris* ($0.403 \text{ cm}^2 \text{ m}^{-2}$).

Under weed species, the maximum basal area was shows by *Amerantus spinosus* ($0.073 \text{ cm}^2 \text{ m}^{-2}$) while, least basal area was found for *Ajuga parviflora* ($0.004 \text{ cm}^2 \text{ m}^{-2}$). In AHS system, the maximum basal area was displayed by *Brassica oleracea* ($7.725 \text{ cm}^2 \text{ m}^{-2}$) and least basal area under agriculture crops was displayed by *Capsicum annuum* ($0.096 \text{ cm}^2 \text{ m}^{-2}$). Among weed species, the highest value of basal area was found for *Ajuga parviflora* ($0.066 \text{ cm}^2 \text{ m}^{-2}$), whereas least basal area was shown by *Erigeron multiaulis* ($0.002 \text{ cm}^2 \text{ m}^{-2}$).

Table 10. Effect of agroforestry systems and climatic condition on basal area (cm² m⁻²) of herbage under dry temperate climatic conditions of north-western Himalaya

Sr. No.	Herb species	Agrihorticulture system		Agrisilviculture system		Agrihortisilviculture system	
		C ₁	C ₂	C ₁	C ₂	C ₁	C ₂
1	<i>Achyranthes aspera</i>	-	-	-	0.011	-	-
2	<i>Aconitum heterophyllum</i>	-	0.009	-	-	-	-
3	<i>Ageratum conyzoides</i>	0.035	-	0.004	0.012	0.005	0.033
4	<i>Ajuga parviflora</i>	0.146	-	0.024	0.004	0.101	0.066
5	<i>Ameranthus caudatus</i>	-	-	0.025	-	-	-
6	<i>Ameranthus spinosus</i>	0.096	0.068	0.129	0.073	-	0.048
7	<i>Anaphalis arvensis</i>	-	-	0.058	-	0.036	0.011
8	<i>Anaphalis nepalensis</i>	-	-	0.025	-	-	-
9	<i>Arebidopsis thaliana</i>	-	-	-	-	0.006	0.003
10	<i>Arisaema flavum</i>	0.061	-	0.028	-	0.035	-
11	<i>Asparagus adscendens</i>	-	-	0.021	0.043	-	-
12	<i>Asparagus filicinus</i>	-	0.026	-	-	-	-
13	<i>Aster albescens</i>	-	-	0.006	-	-	-
14	<i>Beta vulgaris</i>	0.177	-	0.401	-	-	0.110
15	<i>Brassica oleracea</i>	9.099	9.526	8.212	10.048	9.865	7.725
16	<i>Bupleurum candollii</i>	-	-	-	0.008	-	-
17	<i>Cannabis sativa</i>	0.085	0.030	-	-	0.103	0.016
18	<i>Capsicum annuum</i>	-	0.253	-	-	-	0.096
19	<i>Carum carvi</i>	-	0.011	0.024	0.030	0.034	
20	<i>Chinopodium album</i>	0.066	0.038	0.057	0.010	0.034	0.014
21	<i>Cleome viscosa</i>	-	-	-	-	-	0.013
22	<i>Conyza stricta</i>	-	-	0.009	-	-	-
23	<i>Cynoglossum wallichii</i>	-	-	0.042	0.052	0.026	-
24	<i>Epipactis veratrifolia</i>	-	0.014	-	0.010	-	0.018

Sr. No.	Herb species	Agrihorticulture system		Agrisilviculture system		Agrihortisilviculture system	
		C ₁	C ₂	C ₁	C ₂	C ₁	C ₂
25	<i>Erigeron multiaulis</i>	0.044	-	-	-	0.019	0.002
26	<i>Fagopyrum cymosum</i>	0.015	0.047	-	-	0.009	-
27	<i>Fumaria indica</i>	-	-	-	0.010	-	-
28	<i>Gallinsoga parviflora</i>	0.133	0.011	0.025	0.063	0.055	-
29	<i>Gentiana argentea</i>	-	-	-	0.025	-	0.007
30	<i>Geranium sibiricum</i>	-	-	-	-	-	0.034
31	<i>Halenia elliptica</i>	-	0.020	-	-	-	-
32	<i>Impatiens brachycentra</i>	-	-	-	-	0.019	-
33	<i>Impatiens roylei</i>	-	0.028	-	-	-	-
34	<i>Impomea eriocarpa</i>	0.020	-	-	0.007	0.019	-
35	<i>Lactuca dissecta</i>	0.017	0.020	0.004	0.022	0.010	0.027
36	<i>Lapidium apetalum</i>	-	-	-	0.006	-	-
37	<i>Lappula barbata</i>	-	-	-	-	0.025	-
38	<i>Lathyrus emodi</i>	-	0.139	0.045	-	-	-
39	<i>Leucas lanata Benth.</i>	-	-	0.044	-	0.028	-
40	<i>Lithospermum arvense</i>	-	-	-	-	-	0.016
41	<i>Malva neglecta</i>	0.025	0.032	0.023	0.027	0.028	-
42	<i>Malva rutondifolia</i>	0.009	-	-	-	0.012	0.025
43	<i>Malva verticillata</i>	-	-	0.021	-	-	-
44	<i>Mentha longifolia</i>	-	-	0.040	-	0.041	-
45	<i>Morina longifolia</i>	0.047	-	-	0.021	-	-
46	<i>Morina persica</i>	-	0.011	-	-	-	-
47	<i>Myriactis nepalensis</i>	0.007	-	-	0.011	0.008	-
48	<i>Myrsine africana</i>	-	-	-	-	-	-
49	<i>Nepeta erecta</i>	-	0.010	-	-	-	0.034
50	<i>Oreorchis indica</i>	-	0.006	-	-	-	-
51	<i>Parnassia laxmanii</i>	-	-	-	0.006	-	-

Sr. No.	Herb species	Agrihorticulture system		Agrisilviculture system		Agrihortisilviculture system	
		C ₁	C ₂	C ₁	C ₂	C ₁	C ₂
52	<i>Parochetus communis</i>	-	-	0.019	-	-	-
53	<i>Phaseolus vulgaris</i>	0.538	0.391	0.685	0.403	0.552	0.417
54	<i>Physochlaena praealta</i>	-	-	0.010	-	0.004	-
55	<i>Prunella vulgaris</i>	-	-	0.003	-	0.008	-
56	<i>Ranunculus arvensis</i>	-	-	-	-	0.011	-
57	<i>Raphanus raphanistrum</i>	-	-	-	0.005	-	-
58	<i>Rumex nepalensis</i>	-	0.008	-	-	-	-
59	<i>Salsola collina</i>	-	-	-	0.013	-	-
60	<i>Salvia lanata</i>	0.029	0.023	-	0.016	-	-
61	<i>Silene vulgaris</i>	-	-	-	-	-	0.007
62	<i>Sisymbrium officinale</i>	-	-	0.006	-	-	-
63	<i>Solanum lycopersicum</i>	-	-	-	-	-	1.544
64	<i>Spergularia marina</i>	-	0.023	-	-	-	-
65	<i>Strobilanthes alatus</i>	-	0.034	-	-	-	-
66	<i>Thalictrum foliosum</i>	-	0.019	0.166	-	0.167	-
67	<i>Trifolium repens</i>	0.007	0.006	-	0.013	0.015	0.021
68	<i>Urtica parviflora</i>	-	-	0.013	-	0.014	-
69	<i>Valeriana hardwickii</i>	-	-	0.008	-	-	-
70	<i>Verbascum thapsus</i>	-	-	-	0.044	-	-
71	<i>Veronica persica</i>	-	-	-	0.007	-	-
72	<i>Veronica serpyllifolia</i>	-	-	-	-	-	0.015
73	<i>Vicia bakeri</i>	-	-	0.015	0.026	-	-
74	<i>Xanthium strumarium</i>	-	-	0.039	-	-	-
75	<i>Zea mays</i>	5.465	5.352	10.112	7.860	8.247	5.017
		16.121	16.155	20.343	18.886	19.536	15.319

4.1.1.3 Herbage importance value index (IVI)

It is quite clear from the data presented in Table 11 that agrihorticulture system situated in C₁ climatic condition, the maximum and minimum IVI was shown by *Brassica oleracea* (79.89) and *Beta vulgaris* (21.03) among all agriculture crops whereas in weeds, the maximum IVI was displayed by *Gallinsoga paruiiflora* (17.38) and least IVI was engaged by *Salvia lanata* (2.72). In AS system under (C₁) climatic condition, *Zea mays* (73.95) displayed maximum IVI while, minimum IVI was reported by *Beta vulgaris* (14.01) among all agriculture crops. In weeds, the maximum IVI was recorded by *Thalictrum foliosum* (12.83) while, *Ageratum conyzoides* in AS system, exhibited minimum (1.23) IVI. Under AHS system, among all agriculture crops *Brassica oleracea* (79.07) displayed highest IVI whereas, *Phaseolus vulgaris* (30.36) recorded least value of IVI. Under weeds, *Thalictrum foliosum* (11.32) showed maximum IVI and minimum IVI was shown by *Ageratum conyzoides* (1.39), respectively.

Under C₂ climatic condition, the maximum IVI was reported by *Brassica oleracea* (85.24) and least value of IVI was shows by *Capsicum annuum* (19.64) while, in weeds, *Chinopodium album* (9.97) reported maximum IVI index. Minimum IVI was found in *Nepeta erecta* (3.40) under AH system. In AS system, *Brassica oleracea* reported highest IVI (79.09) and minimum IVI was found in *Phaseolus vulgaris* (34.19). Among weed species, maximum IVI was reported by *Gallinsoga paruiiflora* (13.65) while, least IVI was found in *Raphanus raphanistrum* (1.13). In AHS system, the maximum IVI was displayed by *Brassica oleracea* (73.14) and least IVI under agriculture crops was displayed by *Capsicum annuum* (6.42). Among the weed species, the highest value of IVI was recorded in *Ajuga parviflora* (14.76), whereas least value of IVI was reported by *Erigeron multiaulis* and *Arebidopsis thaliana* (1.11), each displayed identical values.

4.1.2. Phytosociology of shrubs

4.1.2.1. Shrub basal area (m² ha⁻¹), density (plant ha⁻¹) and IVI at dry temperate high hills (C₁) climatic condition

The data presented in the Table 12 shows that at Dry temperate high hills climatic conditions, maximum shrub total density was recorded in AH system (1573.33 plant ha⁻¹), which was followed by AS system (853.33 plant ha⁻¹) and AHS system (800.00 plant ha⁻¹), respectively.

Table 11. Effect of agroforestry systems and climatic conditions on herbage IVI of under Dry temperate conditions of north western Himalaya

Sr. No.	Herb species	Agrihorticulture system		Agrisilviculture system		Agrihortisilviculture system	
		C ₁	C ₂	C ₁	C ₂	C ₁	C ₂
1	<i>Achyranthes aspera</i>	-	-	-	3.86	-	-
2	<i>Aconitum heterophyllum</i>	-	3.71	-	-	-	-
3	<i>Ageratum conyzoides</i>	11.97	-	1.23	3.25	1.39	13.14
4	<i>Ajuga parviflora</i>	9.95	-	6.74	2.47	9.02	14.76
5	<i>Ameranthus caudatus</i>	-	-	2.75	-	-	-
6	<i>Amerantus spinosus</i>	3.59	7.18	6.43	10.66	-	9.46
7	<i>Anaphalis arvensis</i>	-	-	7.90	-	3.75	2.25
8	<i>Anaphalis nepalensis</i>	-	-	3.24	-	-	-
9	<i>Arebidopsis thaliana</i>	-	-	-	-	4.85	1.11
10	<i>Arisaema flavum</i>	3.90	-	4.90	-	4.26	-
11	<i>Asparagus adscendens</i>	-	-	1.69	4.26	-	-
12	<i>Asparagus filicinus</i>	-	3.72	-	-	-	-
13	<i>Aster albescens</i>	-	-	1.72	-	-	-
14	<i>Beta vulgaris</i>	21.03	-	14.01	-	-	14.93
15	<i>Brassica oleracea</i>	79.89	85.24	66.22	79.09	79.07	73.14
16	<i>Bupleurum candollii</i>	-	-	-	3.85	-	-
17	<i>Cannabis sativa</i>	7.66	6.56	-	-	6.48	1.45
18	<i>Capsicum annuum</i>	-	19.64	-	-	-	6.42
19	<i>Carum carvi</i>	-	3.73	4.66	7.93	8.75	-
20	<i>Chinopodium album</i>	13.45	9.97	6.02	3.63	7.34	2.79
21	<i>Cleome viscosa</i>	-	-	-	-	-	4.66
22	<i>Conyza stricta</i>	-	-	2.89	-	-	-
23	<i>Cynoglossum wallichii</i>	-	-	3.66	8.04	2.86	-
24	<i>Epipactis veratrifolia</i>	-	7.81	-	4.34	-	5.65

Sr. No.	Herb species	Agrihorticulture system		Agrisilviculture system		Agrihortisilviculture system	
		C ₁	C ₂	C ₁	C ₂	C ₁	C ₂
25	<i>Erigeron multiaulis</i>	7.93	-	-	-	3.67	1.11
26	<i>Fagopyrum cymosum</i>	5.76	7.19	-	-	2.62	-
27	<i>Fumaria indica</i>	-	-	-	1.40	-	-
28	<i>Gallinsoga paruiflora</i>	17.38	3.63	3.09	13.65	9.88	-
29	<i>Gentiana argentea</i>	-	-	-	3.86	-	2.24
30	<i>Geranium sibiricum</i>	-	-	-	-	-	6.31
31	<i>Halenia elliptica</i>	-	3.95	-	-	-	-
32	<i>Impatiens brachycentra</i>	-	-	-	-	4.38	-
33	<i>Impatiens roylei</i>	-	4.00	-	-	-	-
34	<i>Impomea eriocarpa</i>	4.11	-	-	2.24	2.67	-
35	<i>Lactuca dissecta</i>	7.34	8.09	2.89	7.66	5.84	8.69
36	<i>Lapidium apetalum</i>	-	-	-	1.38	-	-
37	<i>Lappula barbata</i>	-	-	-	-	3.43	-
38	<i>Lathyrus emodi</i>	-	4.69	10.07	-	-	-
39	<i>Leucas lanata Benth.</i>	-	-	4.19	-	2.97	-
40	<i>Lithospermum arvense</i>	-	-	-	-	-	6.39
41	<i>Malva neglecta</i>	3.72	3.81	2.52	3.66	4.22	-
42	<i>Malva rutondifolia</i>	4.88	-	-	-	4.96	3.95
43	<i>Malva verticillata</i>	-	-	3.34	-	-	-
44	<i>Mentha longifolia</i>	-	-	2.41	-	2.79	-
45	<i>Morina longifolia</i>	3.57	-	-	3.84	-	-
46	<i>Morina persica</i>	-	3.73	-	-	-	-
47	<i>Myriactis nepalensis</i>	-	-	-	-	3.34	-
48	<i>Myrsine africana</i>	3.17	-	-	1.16	-	-
49	<i>Nepeta erecta</i>	-	3.40	-	-	-	6.24
50	<i>Oreorchis indica</i>	-	3.70	-	-	-	-
51	<i>Parnassia laxmanii</i>	-	-	-	2.72	-	-

Sr. No.	Herb species	Agrihorticulture system		Agrisilviculture system		Agrihortisilviculture system	
		C ₁	C ₂	C ₁	C ₂	C ₁	C ₂
52	<i>Parochetus communis</i>	-	-	3.43	-	-	-
53	<i>Phaseolus vulgaris</i>	28.31	31.01	28.37	34.19	30.36	32.59
54	<i>Physochlaena praealta</i>	-	-	4.31	-	2.35	-
55	<i>Prunella vulgaris</i>	-	-	2.31	-	2.61	-
56	<i>Raninculus arvensis</i>	-	-	-	-	3.09	-
57	<i>Raphanus raphanistrum</i>	-	-	-	1.13	-	-
58	<i>Rumex nepalensis</i>	-	3.95	-	-	-	-
59	<i>Salsola collina</i>	-	-	-	3.88	-	-
60	<i>Salvia lanata</i>	2.72	3.70	-	3.63	-	-
61	<i>Silene vulgaris</i>	-	-	-	-	-	2.48
62	<i>Sisymbrium officinale</i>	-	-	1.45	-	-	-
63	<i>Solanum lycopersicum</i>	-	-	-	-	-	18.36
64	<i>Spergularia marina</i>	-	3.70	-	-	-	-
65	<i>Strobilanthes alatus</i>	-	3.55	-	-	-	-
66	<i>Thalictrum foliosum</i>	-	3.55	12.83	-	11.32	-
67	<i>Trifolium repens</i>	4.85	3.45	-	4.10	5.43	10.41
68	<i>Urtica parviflora</i>	-	-	2.91	-	2.89	-
69	<i>Valeriana hardwickii</i>	-	-	2.34	-	-	-
70	<i>Verbascum thapsus</i>	-	-	-	5.06	-	-
71	<i>Veronica persica</i>	-	-	-	2.49	-	-
72	<i>Veronica serpyllifolia</i>	-	-	-	-	-	3.81
73	<i>Vicia bakeri</i>	-	-	2.48	3.87	-	-
74	<i>Xanthium strumarium</i>	-	-	3.05	-	-	-
75	<i>Zea mays</i>	54.83	53.36	73.95	68.70	63.44	47.66
		300.00	300.00	300.00	300.00	300.00	300.00

AH system under C₁ climatic conditions, maximum density is illustrated by *Artemisia vulgaris* (426.67 plant ha⁻¹), whereas minimum density was displayed by *Lonicera quinquelocularis* (26.67 plant ha⁻¹). The AS system, *Artemisia vulgaris* (373.33 plant ha⁻¹) showed maximum density while, minimum density was reported by *Berberis aristata*, *Caranga brevispina*, *Lonicera quinquelocularis* and *Rosa webbaiana* (26.67 plant ha⁻¹).

It is quite clear from the data presented in Table 12 that the maximum total basal area of shrubs was found in AS system (0.367 m² ha⁻¹) followed by AH system (0.354 m² ha⁻¹). The least value of basal area of shrubs was displayed by AHS system (0.187 m² ha⁻¹).

In AH system, the maximum basal area was shown by *Artemisia vulgaris* (0.099 m² ha⁻¹), while minimum basal area was displayed by *Lonicera quinquelocularis* (0.003 m² ha⁻¹). In AS system the maximum basal area was reported by *Arctium lappa* (0.192 m² ha⁻¹) and minimum basal area was displayed by *Caranga brevispina* (0.006 m² ha⁻¹). Similarly, under AHS system the maximum basal area was reported by *Artemisia vulgaris* (0.041 m² ha⁻¹) and minimum basal area was displayed by *Rubus purpureus* (0.006 m² ha⁻¹).

It is crystal clear from the data presented in Table 12 that the maximum IVI of shrubs was reported for *Artemisia vulgaris* (87.39), whereas minimum IVI was displayed by *Lonicera quinquelocularis* (6.48) in AH system. Under AS system, the maximum IVI was reported by *Artemisia vulgaris* (86.14), while, minimum IVI was engaged by *Caranga brevispina* (7.96). Similarly under AHS system, the maximum IVI was reported by *Artemisia vulgaris* (75.59) and minimum IVI was displayed by *Plectranthus rugosus* (12.63).

4.1.2.2. Shrub basal area (m² ha⁻¹), density (plant ha⁻¹) and IVI at high hills temperate dry and cold (C₂) climatic condition

The data given in Table 13 reveals that the maximum shrub total density was recorded by AH system (706.67 plant ha⁻¹), followed by AHS system (666.67 plant ha⁻¹) and AS system (506.67 plant ha⁻¹) under C₂ climatic condition. The maximum density was demonstrated by *Artemisia vulgaris* (133.33 plant ha⁻¹) in AH system and AS systems each displaying identical values.

In AH system, the minimum density was demonstrated by *Rosa webbaiana*, *Juniperus prostrata* and *Syringa emodi* (26.67 plant ha⁻¹). Within AS system at C₂ climatic condition, the minimum density was reported by *Abelia triflora*, *Juniperus prostrate*, *Lonicera quinquelocularis*, *Rhus semialata* (26.67 plant ha⁻¹).

Table 12. Density (plants ha⁻¹), basal area (m² ha⁻¹) and IVI of shrubs under different agroforestry systems in Dry temperate high hills climatic conditions (C₁) of Kinnaur district in H.P.

Sr. No.	Shrub species	Climatic condition (C ₁)								
		Agrihorticulture system			Agrisilviculture system			Agrihortisilviculture system		
		Density (plants ha ⁻¹)	BA (m ² ha ⁻¹)	IVI	Density (plants ha ⁻¹)	BA (m ² ha ⁻¹)	IVI	Density (plants ha ⁻¹)	BA (m ² ha ⁻¹)	IVI
1	<i>Abelia triflora</i>	160.00	0.043	31.93	53.33	0.020	28.08	106.67	0.023	36.03
2	<i>Arctium lappa</i>	80.00	0.018	18.63	106.67	0.192	59.45	-	-	-
3	<i>Artemisia maritima</i>	266.67	0.040	28.09	-	-	-	-	-	-
4	<i>Artemisia vulgaris</i>	426.67	0.099	87.39	373.33	0.063	86.14	266.67	0.041	75.59
5	<i>Berberis aristata</i>	-	-	-	26.67	0.008	13.71	53.33	0.027	30.20
6	<i>Berberis lycium</i>	80.00	0.041	31.71	-	-	-	-	-	-
7	<i>Caranga brevispina</i>	53.33	0.016	15.78	26.67	0.006	7.96	-	-	-
8	<i>Colutea nepalensis</i>	-	-	-	-	-	-	80.00	0.018	43.31
9	<i>Daphne oleoides</i>	133.33	0.028	19.49	53.33	0.010	10.88	133.33	0.038	41.28
10	<i>Lonicera quinquelocularis</i>	26.67	0.003	6.48	26.67	0.007	12.74	-	-	-
11	<i>Plectranthus rugosus</i>	-	-	-	53.33	0.013	24.93	26.67	0.008	12.63
12	<i>Rhus semialata</i>	133.33	0.022	17.87	-	-	-	-	-	-
13	<i>Rosa webbaiana</i>	-	-	-	26.67	0.010	14.00	80.00	0.026	34.02
14	<i>Rubus purpureus</i>	-	-	-	-	-	-	53.33	0.006	26.94
15	<i>Syringa emodi</i>	106.67	0.013	14.39	-	-	-	-	-	-
16	<i>Woodfordia fruticosa</i>	106.67	0.032	28.24	106.67	0.037	42.11	-	-	-
17	<i>Zanthoxylum armatum</i>	-	-	-	-	-	-	-	-	-
		1573.33	0.354	300.00	853.33	0.367	300.00	800.000	0.187	300.00

Table 13. Density (plants ha⁻¹), basal area (m² ha⁻¹) and IVI of shrubs in different agroforestry systems at High hills temperate dry and cold climatic condition (C₂) in Kinnaur district of H.P.

Sr. No.	Shrub species	Climatic condition (C ₂)								
		Agrihorticulture system			Agrisilviculture system			Agrihortisilviculture system		
		Density (plants ha ⁻¹)	BA (m ² ha ⁻¹)	IVI	Density (plants ha ⁻¹)	BA (m ² ha ⁻¹)	IVI	Density (plants ha ⁻¹)	BA (m ² ha ⁻¹)	IVI
1	<i>Abelia triflora</i>	-	-	-	26.67	0.079	24.47	-	-	-
2	<i>Arctium lappa</i>	100.00	0.014	36.60	-	-	-	133.33	0.023	46.98
3	<i>Artemisia vulgaris</i>	133.33	0.027	37.67	133.33	0.019	53.06	53.33	0.006	13.26
4	<i>Caranga brevispina</i>	-	-	-	53.33	0.006	22.66	-	-	-
5	<i>Daphne oleoides</i>	100.00	0.014	30.45	-	-	-	-	-	-
6	<i>Desmodium tiliaefoli</i>	53.33	0.017	26.64	106.67	0.031	52.31	-	-	-
7	<i>Ephedra gerardiana</i>	80.00	0.011	30.47	-	-	-	133.33	0.050	35.96
8	<i>Indigofera gerardiana</i>	53.33	0.011	18.76	-	-	-	-	-	-
9	<i>Juniperus prostrata</i>	26.67	2.872	42.70	26.67	0.408	42.25	26.67	0.619	39.29
10	<i>Lonicera quinquelocularis</i>	-	-	-	26.67	0.113	29.86	-	-	-
11	<i>Rhus semialata</i>	-	-	-	26.67	0.010	13.85	53.33	0.007	26.51
12	<i>Rosa webbaiana</i>	26.67	0.034	24.21	53.33	0.018	35.40	80.00	0.026	35.23
13	<i>Syringa emodi</i>	26.67	0.002	11.92	-	-	-	80.00	0.018	32.74
14	<i>Woodfordia fruticosa</i>	53.33	0.010	21.04	53.33	0.007	26.11	80.00	0.035	48.24
15	<i>Zanthoxylum armatum</i>	53.33	0.009	19.55	-	-	-	26.67	0.034	21.78
		706.67	3.021	300.00	506.67	0.691	300.00	666.67	0.818	300.00

Shrub species in AHS system, *Arctium lappa* and *Ephedra gerardiana* (133.33 plant ha⁻¹) displayed maximum density whereas, minimum density was reported by *Juniperus prostrata* and *Zanthoxylum armatum* (26.67 plant ha⁻¹).

The data presented in Table 13 clearly shows that the maximum total basal area of shrubs was found in AH system (3.021 m² ha⁻¹), followed by AHS system (0.818 m² ha⁻¹), while the minimum basal area of shrubs was occupied by AS system (0.691 m² ha⁻¹) in C₂ climatic condition. Under AH system, the maximum basal area was reported by *Juniperus prostrata* (2.872 m² ha⁻¹) while minimum basal area was engaged by *Syringa emodi* (0.002 m² ha⁻¹). In AS system the maximum basal area was reported by *Juniperus prostrata* (0.408 m² ha⁻¹) whereas, minimum basal area was displayed by *Caranga brevispina* (0.006 m² ha⁻¹). Similarly under AHS system, the maximum basal area was reported by *Juniperus prostrata* (0.619 m² ha⁻¹) while, minimum basal area was displayed by *Artemisia vulgaris* (0.006 m² ha⁻¹).

It is crystal clear from the data presented in Table 13 that the maximum IVI of shrubs in C₂ climatic condition, was reported by *Juniperus prostrata* (42.70) in AH system, whereas minimum IVI was displayed by *Syringa emodi* (11.92). Under AS system, the maximum IVI was reported by *Artemisia vulgaris* (53.06) while, minimum IVI was engaged by *Rhus semialata* (13.85). Similarly under AHS system the maximum IVI was reported by *Woodfordia fruticosa* (48.24) and minimum IVI was displayed by *Artemisia vulgaris* (13.26). Similar results have also been reported previously by Dar and Sundarapandian (2016) in their study at seven temperate forest types of Western Himalaya.

Juniperus was observed at the altitude of 2,700 to 3,000m, mainly in the agroforestry and forest systems (Rawat and Everson 2012). The results of the present study clearly indicated that density, basal area and IVI of *J. prostrata* were higher in the agroforestry system. This might have been due to the fact that, at lower altitude farmer's have maintained *Juniperus prostrata* along the margins of terraced crop field. A longer growth period, better climatic conditions and higher soil moisture might have also been reasons for the greater basal area of *Juniperus prostrata* at C₂ climatic conditions.

4.1.3. Phytosociology of trees

4.1.3.1. Tree density (tree ha⁻¹), basal area (m² ha⁻¹) and IVI at dry temperate high hills (C₁) climatic condition

The tree density, basal area and IVI data of Dry temperate high hills climatic conditions given in Table 14 reveals that the maximum tree total density was found in AH

system (513.33 tree ha⁻¹) followed by AHS system (393.33 tree ha⁻¹). Minimum density was observed in AS system (243.33 tree ha⁻¹). At this climatic condition, the maximum density was demonstrated by *Malus domestica* (503.33 tree ha⁻¹) in AH system and minimum in AHS system (206.67 tree ha⁻¹). The minimum density was shown by *Diospyros kaki* (3.33 tree ha⁻¹) in AH system. Under AHS system, the minimum density was reported for *Salix alba* (6.67 tree ha⁻¹). Among all trees under AS system *Celtis australis* (60.00 tree ha⁻¹) displayed maximum density whereas, minimum density was reported by *Cedrus deodara* and *Pinus wallichiana* (3.33 tree ha⁻¹), each displaying identical values.

The data presented in Table 14 clearly shows that the maximum total basal area of trees was found in AH system (13.204 m² ha⁻¹) which was closely followed by AHS system (10.322 m² ha⁻¹), while the least amount of basal area of trees was occupied by AS system (9.594 m² ha⁻¹). Under AH system, the maximum basal area was reported by *Malus domestica* (12.858 m² ha⁻¹) while, minimum basal area was occupied by *Diospyros kaki* (0.097 m² ha⁻¹). In AS system, the maximum basal area was displayed by *Celtis australis* (2.469 m² ha⁻¹) whereas, minimum basal area was displayed by *Pinus wallichiana* (0.096 m² ha⁻¹). Similarly, under AHS system the maximum basal area was reported by *Malus domestica* (3.888 m² ha⁻¹) while minimum basal area was occupied by *Salix alba* (0.218 m² ha⁻¹).

The data presented in Table 14 reveals that the maximum IVI was occupied by *Malus domestica* in AH system (287.58) and AHS system (125.25) while the least IVI value was for by *Diospyros kaki* (4.01) in AH system. Under AHS system, the minimum IVI was reported by *Salix alba* (5.86). In AS system, the maximum IVI was displayed by *Celtis australis* (76.00) whereas, minimum IVI was displayed by *Pinus wallichiana* (3.52).

4.1.3.2. Tree density (tree ha⁻¹), basal area (m² ha⁻¹) and IVI at high hills temperate dry and cold (C₂) climatic condition

The data given in Table 15 shows that among all the agroforestry system, highest tree total density was found in AH system (530.00 tree ha⁻¹), which was closely followed by AHS system (430.00 tree ha⁻¹). Minimum density was found in AS system (260.00 tree ha⁻¹). At this climatic condition, the maximum density was demonstrated by *Malus domestica* (486.67 tree ha⁻¹) in AH system and minimum in AHS system (230.00 tree ha⁻¹). Among tree species minimum density was shown by *Prunus dulcis* (43.33 tree ha⁻¹) in AH system. Under AHS system, the minimum density was reported for

Table 14. Density (trees ha⁻¹), basal area (m² ha⁻¹) and IVI of trees of different agroforestry systems of Dry temperate high hills climatic condition (C₁) in Kinnaur district of H. P.

Sr. No.	Trees	Climatic condition (C ₁)								
		Agrihorticulture system			Agrisilviculture system			Agrihortisilviculture system		
		D	BA	IVI	D	BA	IVI	D	BA	IVI
1	<i>Ailanthus altissima</i>	-	-	-	-	-	-	20.00	0.682	17.80
2	<i>Cedrus deodara</i>	-	-	-	3.33	0.180	4.76	-	-	-
3	<i>Celtis australis</i>	-	-	-	60.00	2.469	76.00	16.67	0.547	15.06
4	<i>Diospyros kaki</i>	3.33	0.097	4.01	-	-	-	-	-	-
5	<i>Malus domestica</i>	503.33	12.858	287.58	-	-	-	206.67	3.888	125.25
6	<i>Pinus gerardiana</i>	-	-	-	36.67	1.358	42.62	40.00	1.307	37.57
7	<i>Pinus wallichiana</i>	-	-	-	3.33	0.096	3.52	-	-	-
8	<i>Populus ciliata</i>	-	-	-	30.00	1.113	34.71	26.67	1.103	27.60
9	<i>Prunus armeniaca</i>	-	-	-	50.00	2.107	64.08	40.00	1.329	37.41
10	<i>Pyrus communis</i>	6.67	0.248	8.42	-	-	-	-	-	-
11	<i>Quercus ilex</i>	-	-	-	53.33	2.058	67.06	36.67	1.248	33.44
12	<i>Salix alba</i>	-	-	-	6.67	0.213	7.25	6.67	0.218	5.86
		513.33	13.204	300.00	243.33	9.594	300.00	393.33	10.322	300.00

Table 15. Density (trees ha⁻¹), basal area (m² ha⁻¹) and IVI of trees in different agroforestry systems undre High hills temperate dry and cold climatic condition (C₂) in Kinnaur district of H. P.

Sr. No.	Trees	Climatic condition (C ₂)								
		Agrihorticulture system			Agrisilviculture system			Agrihortisilviculture system		
		D	BA	IVI	D	BA	IVI	D	BA	IVI
1	<i>Ailanthus altissima</i>	-	-	-	26.67	1.299	29.90	-	-	-
2	<i>Celtis australis</i>	-	-	-	40.00	1.704	47.68	10.00	0.369	10.09
3	<i>Juglans regia</i>	-	-	-	-	-	-	6.67	0.212	6.44
4	<i>Malus domestica</i>	486.67	9.777	269.25	-	-		230.00	6.288	134.32
5	<i>Morus alba</i>	-	-	-	-	-	-	20.00	0.989	17.80
6	<i>Pinus gerardiana</i>	-	-	-	-	-	-	6.67	0.264	6.88
7	<i>Populus alba</i>	-	-	-	-	-	-	40.00	1.707	30.67
8	<i>Populus ciliata</i>	-	-	-	20.00	0.837	24.23	26.67	1.094	22.19
9	<i>Prunus armeniaca</i>	-	-	-	53.33	2.234	62.97	23.33	0.845	21.65
10	<i>Prunus dulcis</i>	43.33	0.765	30.75	-	-	-	66.67	2.640	49.98
11	<i>Quercus ilex</i>	-	-	-	23.33	0.984	26.29	-	-	-
12	<i>Quercus semecarpifolia</i>	-	-	-	60.00	2.553	68.75	-	-	-
13	<i>Salix alba</i>	-	-	-	36.67	1.572	40.18	-	-	-
		530.00	10.542	300.00	260.00	11.185	300.00	430.00	14.408	300.00

Juglans regia and *Pinus gerardiana* ($6.67 \text{ tree ha}^{-1}$), each displaying identical values. Among tree species under AS system, *Quercus semecarpifolia* ($60.00 \text{ tree ha}^{-1}$) displayed maximum density whereas, minimum density was reported for *Populus ciliata* ($20.00 \text{ tree ha}^{-1}$).

The data presented in Table 15 clearly shows that the maximum total basal area of trees was found in AHS system ($14.408 \text{ m}^2 \text{ ha}^{-1}$), which was followed by AS system ($11.185 \text{ m}^2 \text{ ha}^{-1}$), while the least value of total basal area of trees was in AH system ($10.542 \text{ m}^2 \text{ ha}^{-1}$). Under AH system, the maximum basal area was reported by *Malus domestica* ($9.777 \text{ m}^2 \text{ ha}^{-1}$) while, minimum basal area was occupied by *Prunus dulcis* ($0.765 \text{ m}^2 \text{ ha}^{-1}$). In AS system, the maximum basal area was found in *Quercus ilex* ($2.553 \text{ m}^2 \text{ ha}^{-1}$) whereas, minimum basal area was displayed by *Populus ciliata* ($0.837 \text{ m}^2 \text{ ha}^{-1}$). Similarly under AHS system, the maximum basal area was reported by *Malus domestica* ($6.288 \text{ m}^2 \text{ ha}^{-1}$), while minimum basal area was occupied by *Juglans regia* ($0.212 \text{ m}^2 \text{ ha}^{-1}$).

Celtis is a truly multipurpose tree grown for fodder, fuel, timber and various other uses in or around agricultural fields in rainfed agriculture and plays a vital role in socioeconomic structure of hill people by supplying highly palatable, nutritious and tannin-free green fodder particularly during the period of scarcity of green fodder to livestock (Yadav and Bisht, 2013). It can also survive on shallow, gravelly and rocky sites. It grows well along stream banks, on sloping hillsides and on clay loam soil with sufficient moisture (Luna, 1996). Due to above multipurpose qualities, *Celtis australis* tree shows maximum density, basal area and IVI in AS systems under C_1 climatic condition. Thakur *et al.*, (2004), found maximum density ($200 \text{ trees ha}^{-1}$) of *Celtis australis* in AS systems of western Himalayas during the study of three agroforestry systems (AS, SP, HSP), which is more comparable with present study.

It is evident from the Table 15 that the maximum IVI of *Malus domestica* was in AH (269.25) and AHS systems (134.32), while the least value of IVI was occupied by *Prunus dulcis* (30.75) in AH system. Under AHS system, the minimum IVI was reported by *Juglans regia* (6.44). The apple tree (*Malus domestica*) is dominating in the agri-horticulture and agrihortisilviculture system of this region that revealed the social as well as economical desire for this important species. Similar observation was also recorded by Bijalwan (2012) and Vishvakarma *et al.*, (1998) under their investigations.

Under AS system, the maximum IVI was displayed by *Quercus ilex* (68.75) whereas, minimum IVI was displayed by *Populus ciliata* (24.23).

Quercus is commonly known as oak. Oak (*Quercus* spp.) is the dominant, climax tree species of the temperate forests of the Indian Himalayan region, Troup (1921). *Quercus* is distributed between 1000-3500 m elevations either in abundance or somewhat narrowly from the north eastern to the westernmost part of the Himalayas. It grows naturally in the western Himalaya, Jazib and Rather (2012) and site factors as well as climatic factors are responsible for the maximum basal area of *Q. semecarpifolia* in AS system. Singh and Rawat (2012) also found that the *Q. semecarpifolia* (178 trees ha⁻¹) had a maximum density in the southern fringe of Kedarnath Wildlife Sanctuary, Chamoli-Rudraprayag district in Western Himalaya.

4.1.4 Phytosociology of grasses

4.1.4.1. Grass density (tiller m⁻²), basal area (cm² m²) and IVI at dry temperate high hills (C₁) climatic condition

The grass density, basal area and IVI data is presented in Table 16. The maximum grass total density under Dry temperate high hills climatic condition (C₁) was found in AS system (88.800 tiller m⁻²), which was followed by AH system (76.000 tiller m⁻²) whereas, minimum density was observed in AHS system (75.333 tiller m⁻²).

At this climatic condition, the maximum density was demonstrated by *Hordeum vulgare* amongst all agroforestry system. The maximum density of *Hordeum vulgare* was found in AS system (37.867 tiller m⁻²) followed by AHS system (32.800 tiller m⁻²) and AH systems (24.933 tiller m⁻²). The minimum density was shown by *Heteropogon contortus* (0.800 tiller m⁻²) in AH system. In AS system, the minimum density was reported for *Eragrostis nigra* (1.067 tiller m⁻²). Among all grasses under AHS system, *Cymbopogon martinii* and *Trisetum spicatum* (0.933 tiller m⁻²) displayed minimum density.

The data cited in Table 16 clearly demonstrated that the maximum total basal area of grasses was found in AH system (8.570 cm² m²), which was followed by AHS system (0.288 cm² m²), while the minimum value of total basal area of grasses was occupied by AS system (0.253 cm² m²). Under AH system, the maximum basal area was reported by *Hordeum vulgare* (3.215 cm² m²) while, minimum basal area was occupied by *Heteropogon contortus* (0.006 cm² m²). In AS system and AHS system the maximum basal area was displayed by *Hordeum vulgare* i.e. 0.075 cm² m² and 0.067 cm² m² respectively. In AS system, the minimum basal area was reported for *Avena aspera* (0.004 cm² m²). Under AHS system the minimum basal area was displayed by *Setaria glauca* (0.008 cm² m²).

Table 16. Density (tiller m⁻²), basal area (cm² m²) and IVI of grasses in agroforestry systems at dry temperate high hills climatic condition (C₁) in Kinnaur district of H. P.

Sr. No.	Grass species	Climatic condition (C ₁)								
		Agrihorticulture system			Agrisilviculture system			Agrihortisilviculture system		
		D	BA	IVI	D	BA	IVI	D	BA	IVI
1	<i>Agropyron longearistatum</i>	3.200	-	-	-	-	-	-	-	-
2	<i>Agrostis alba</i>	-	0.189	13.368	3.200	0.010	10.803	6.400	0.026	25.523
3	<i>Avena aspera</i>	1.333	0.236	4.452	1.867	0.004	6.972	-	-	-
4	<i>Avena fatua</i>	2.133	1.182	9.203	-	-	-	6.000	0.026	27.135
5	<i>Bromus asper</i>	2.800	0.518	9.258	4.133	0.011	12.129	4.000	0.031	24.630
6	<i>Cymbopogon martinii</i>	-	-	-	-	-	-	0.933	0.023	14.367
7	<i>Cynodon dactylon</i>	21.600	1.476	78.394	11.467	0.036	42.117	8.533	0.021	26.342
8	<i>Eragrostis nigra</i>	1.867	0.012	11.211	1.067	0.007	5.650	-	-	-
9	<i>Erianthus fulvus</i>	2.667	1.134	13.383	-	-	-	3.867	0.021	19.400
10	<i>Festuca valesiaca</i>	-	-	-	1.733	0.011	9.239	1.600	0.009	8.592
11	<i>Heteropogon contortus</i>	0.800	0.006	5.423	2.400	0.010	10.493	3.867	0.012	14.000
12	<i>Hordeum vulgare</i>	24.933	3.215	93.663	37.867	0.075	103.793	32.800	0.067	95.820
13	<i>Panicum plicatum</i>	-	-	-	3.067	0.011	14.275	-	-	-
14	<i>Poa pratensis</i>	-	-	-	11.067	0.033	38.029	3.333	0.015	15.372
15	<i>Pollinia mollis</i>	4.133	0.012	16.069	2.800	0.011	10.573	-	-	-
16	<i>Setaria glauca</i>	-	-	-	-	-	-	1.867	0.008	9.173
17	<i>Stipa sibirica</i>	5.600	0.574	22.689	6.000	0.024	25.820	1.200	0.018	11.160
18	<i>Themeda anathera</i>	3.467	0.008	13.557	2.133	0.010	10.107	-	-	-
19	<i>Trisetum spicatum</i>	1.467	0.009	9.330	-	-	-	0.933	0.011	8.487
		76.000	8.570	300.000	88.800	0.253	300.000	75.333	0.288	300.000

Under all grasses presents in Dry temperate high hills climatic condition, the maximum IVI was represented by *Hordeum vulgare* in AS system (103.793), which was followed by AHS system (95.820) and AH system (93.663), respectively. Whereas minimum IVI was displayed by *Avena aspera* (4.452) in AH system. In AS system the least value of IVI was shown by *Eragrostis nigra* (5.650). Similarly, the least value of IVI under AHS system was observed in *Trisetum spicatum* (8.487).

4.1.5.2. Grass density (tiller m⁻²), basal area (cm² m²) and IVI at high hills temperate dry and cold (C₂) climatic condition

The data presented in Table 17 reveal that the maximum grass total density at high hills temperate dry and cold (C₂) climatic condition was found in AH system (79.200 tiller m⁻²), which was followed by AS system (68.400 tiller m⁻²). While, least total density was observed in AHS system (56.800 tiller m⁻²). The maximum density of *Hordeum vulgare* was found in AS system (35.467 tiller m⁻²), which was followed by AH system (32.667 tiller m⁻²) and AHS systems (32.533 tiller m⁻²). The minimum density was occupied by *Saccharum filifolium* (0.267 tiller m⁻²) in AH system. The minimum density was reported by *Agropyron longearistatum* and *Stipa sibirica* (0.533 tiller m⁻²) each displayed identical values. Among all grasses in AHS system, *Avena aspera* (0.533 tiller m⁻²) displayed minimum density.

Table 17 demonstrated that the maximum total basal area of grasses was found in AHS system (0.720 cm² m²), which was closely followed by AS system (0.540 cm² m²). The minimum value of total basal area of grasses was found in AH system (0.234 cm² m²). Under AH system, the maximum basal area was reported by *Hordeum vulgare* (0.069 cm² m²), while, minimum basal area was displayed by *Pollinia mollis* and *Saccharum filifolium* (0.004 cm² m²) each displayed identical values. In AS system, maximum basal area was displayed by *Cynodon dactylon* (0.128 cm² m²) while, minimum basal area under greases was displayed by *Phleum alpinum* (0.009 cm² m²). In AHS system, the highest basal area was shown by *Heteropogon contortus* (0.193 cm² m²) whereas, least basal area was demonstrated by *Avena aspera* (0.005 cm² m²).

Under all grasses presented at C₂ climatic condition, the maximum IVI was represented by *Hordeum vulgare* in AS system (103.113) followed by AH system (101.677) and AHS system (96.449). The minimum IVI was displayed by *Saccharum filifolium* (3.940) in agrihorticulture system. At agrisilviculture system the least value of IVI was represented by *Stipa sibirica* (3.796). Similarly, the least value of IVI under agrihortisilviculture system was reported by *Avena aspera* (3.508). In the high altitude areas of the western Himalaya,

Table 17. Density (tiller m⁻²), basal area (cm² m²) and IVI of grasses in agroforestry systems under High hills temperate dry and cold climatic condition (C₂) in Kinnaur district of H.P.

Sr. No.	Grass species	Climatic condition (C ₂)								
		Agrihorticulture system			Agrisilviculture system			Agrihortisilviculture system		
		D	BA	IVI	D	BA	IVI	D	BA	IVI
1	<i>Agropyron longearistatum</i>	-	-	-	0.533	0.018	15.187	-	-	-
2	<i>Agrostis alba</i>	-	-	-	3.067	0.085	20.150	1.200	0.027	10.258
3	<i>Apluda mutica</i>	2.667	0.010	10.560	2.533	0.046	15.972	1.867	0.047	16.778
4	<i>Avena aspera</i>	-	-	-	-	-	-	0.533	0.005	3.508
5	<i>Avena fatua</i>	5.200	0.014	17.936	-	-	-	-	-	-
6	<i>Bromus arvensis</i>	5.733	0.022	27.462	-	-	-	1.067	0.020	7.806
7	<i>Bromus asper</i>	3.200	0.012	14.404	1.200	0.022	9.386	-	-	-
8	<i>Cymbopogon martinii</i>	-	-	-	-	-	-	0.667	0.033	10.432
9	<i>Cynodon dactylon</i>	7.467	0.023	29.677	13.333	0.128	48.451	4.933	0.031	16.729
10	<i>Erianthus fulvus</i>	-	-	-	-	-	-	0.933	0.031	9.388
11	<i>Festuca gigantea</i>	3.600	0.016	15.820	1.467	0.024	10.113	3.067	0.056	19.745
12	<i>Festuca valesiaca</i>	3.333	0.014	17.930	-	-	-	1.200	0.043	11.416
13	<i>Heteropogon contortus</i>	4.000	0.013	15.035	2.133	0.012	15.383	2.667	0.193	46.539
14	<i>Hordeum vulgare</i>	32.667	0.069	101.677	35.467	0.074	103.113	32.533	0.065	96.449
15	<i>Panicum plicatum</i>	2.400	0.008	9.813	1.733	0.010	11.503	-	-	-
16	<i>Phleum alpinum</i>	1.600	0.005	6.880	2.000	0.009	11.777	2.000	0.052	15.623
17	<i>Pollinia mollis</i>	1.333	0.004	6.088	1.200	0.044	15.548	1.600	0.064	16.579
18	<i>Saccharum filifolium</i>	0.267	0.004	3.940	-	-	-	-	-	-
19	<i>Setaria glauca</i>	-	-	-	1.733	0.010	7.718	1.600	0.034	10.608
20	<i>Setaria pumila</i>	-	-	-	1.467	0.045	11.902	-	-	-
21	<i>Stipa sibirica</i>	-	-	-	0.533	0.013	3.796	-	-	-
22	<i>Themeda anathera</i>	5.733	0.020	22.779	-	-	-	-	-	-
23	<i>Trisetum spicatum</i>	-	-	-	-	-	-	0.933	0.017	8.142
		79.200	0.234	300.00	68.400	0.540	300.00	56.800	0.720	300.00

barley is generally a crop of marginal, low input drought stressed environments. The landraces grown in these areas are favored by farmers for their quality, both as grain and straw. Manjunatha *et al.*, (2007). It might be due to above reasons *Hordeum vulgare* shows maximum density basal area and IVI in all agroforestry systems. Parihaar *et al.*, (2015) also found that *Hordeum vulgare* was dominant crop of winter season in indigenous agroforestry system in Kumaun Himalaya, India. Similar results were also reported by Guleria *et al.*, (1999); Dutt and Gupta (2005).

Study also revealed that highest density of herbs (15.465 tiller m²), shrubs (1573.33 plant ha⁻¹) and trees (513.33 trees ha⁻¹) was found in AH system at climatic condition C₁ which may be due to continuous use of fertilizers. In climatic condition, C₂ the maximum density of shrubs (706.67 plant ha⁻¹), grasses (79.200 tiller m⁻²) was found in AH system, whereas, maximum herbage density (14.566 tiller m⁻²) and basal area (18.886 cm² m²) was recorded in AS system, which may be due to the minimum disturbance of human population for fuel wood, fodder, and animals for grazing. The minimum density and species richness of shrubs in high disturbance stand is possibly due to collection of fuel wood, fodder and grazing pressure (Uniyal *et al.*, 2010). Similar observations have also been made previously by other workers, such as Kumar and Jeet (2005), Bhuyan *et al.*, (2003) and Mishra *et al.*, (2004).

4.2. VEGETATION INDICES

Vegetation indices Shannon Weiner Index (H') and Simpson's Diversity Indices are calculated for two of the climatic conditions are being presented in table 18 respectively.

4.2.1. Shannon Weiner index (H')

The Table 18 shows that maximum value (2.26) of Shannon Weiner Index (H') was displayed by AS systems, which was significantly higher than AH land use system. The AS system (2.26) and AHS systems (2.21) remained statistically at par with one other. The effect of climatic conditions and agroforestry systems on Shannon Weiner Index H', was found to be non-significant. The diversity of these agroforestry systems are comparable with the diversity indices of agroforestry and non-agroforestry systems reported by different workers (Sharma *et al.*, 2006, Toky *et al.*, 1989, Singh & Singh 1991). In Thar desert Tiwari *et al.*, (1999) reported that Shannon-Weiner Index values ranges from 0.41 to 2.31, under natural silvopastoral system.

4.2.2. Simpson's Diversity Index (SDI)

Data in Table 18 reveals that maximum Simpson diversity Index of vegetation shows that effect land use systems and their interaction significantly influenced on SDI.

Table 18. Shannon Weiner index and Simpson's Diversity Index for different land use systems, climatic conditions and their interaction effects of Kinnaur district of H.P.

Agroforestry systems (T)	Shannon Weiner index	Simpson's Diversity Index
T₁ (AH)	1.80	0.22
T₂ (AS)	2.26	0.16
T₃ (AHS)	2.21	0.15
SEm±	0.05	0.01
C.D_{0.05}	0.14	0.04
Climatic conditions (C)		
C₁	2.04	0.19
C₂	2.15	0.16
SEm±	0.04	0.01
C.D_{0.05}	NS	0.03
Agroforestry systems (T) × Climatic conditions (C)		
T₁ × C₁	1.75	0.22
T₂ × C₁	2.23	0.18
T₃ × C₁	2.13	0.17
T₁ × C₂	1.84	0.21
T₂ × C₂	2.30	0.14
T₃ × C₂	2.30	0.13
SEm±	0.06	0.02
C.D_{0.05}	NS	NS

Simpson's diversity index values for agroforestry systems ranged between 0.15-0.22. The Simpson diversity Index for the home garden of Kerala varied from 0.44 to 0.86 (Kumar *et al.*, 1994), which is quite higher than the present study. The maximum value of SDI was recorded in AH systems (0.22), which was found to be significantly higher than both AS system (0.16) and AHS system (0.15). However, the effect of climatic conditions on SDI was found to be non-significant. Whereas values in C₁ exceeded significantly over C₂ climatic condition. The interaction effects of land use systems and climatic conditions on SDI value were found to be non-significant. The diversity indices for trees are within the ranged reported in other studies in Himalayan areas (Saxena and Singh 1982; Adhikari *et al.*, 1991).

4.3. BIOMASS PRODUCTION OF DIFFERENT AGROFORESTRY SYSTEMS

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

A perusal of the data presented in the Table 19 reveals that the aboveground biomass is significantly influenced due to agroforestry systems, climatic conditions and their interactions effect (Appendix-III).

Table 19. Effect of agroforestry systems, climatic conditions and their interaction on different pools of biomass (t ha^{-1}) in Kinnaur district Himachal Pradesh

Agroforestry systems (T)	Above ground biomass (t ha^{-1})	Below ground biomass (t ha^{-1})	Total biomass (t ha^{-1})	Litter biomass (t ha^{-1})
T₁ (AH)	66.76	14.91	81.70	0.54
T₂ (AS)	97.31	28.88	126.19	0.61
T₃ (AHS)	90.15	22.26	112.40	0.58
SEm$\pm$	2.09	0.80	2.81	0.02
C.D_{0.05}	6.67	2.56	8.98	0.05
Climatic conditions(C)				
C₁	85.73	22.55	108.28	0.56
C₂	83.75	21.48	105.24	0.59
SEm$\pm$	2.96	1.13	3.98	0.01
C.D_{0.05}	NS	NS	NS	NS
Agroforestry systems (T) $\times$ Climatic conditions (C)				
T₁ $\times$ C₁	72.98	16.56	89.54	0.52
T₂ $\times$ C₁	98.74	28.72	127.46	0.58
T₃ $\times$ C₁	85.47	22.36	107.83	0.58
T₁ $\times$ C₂	60.54	13.26	73.85	0.55
T₂ $\times$ C₂	95.88	29.03	124.91	0.64
T₃ $\times$ C₂	94.82	22.16	116.97	0.58
SEm$\pm$	1.71	0.65	2.30	0.02
C.D_{0.05}	9.44	NS	12.70	NS

Total above ground biomass production was found to be significantly higher in AS system (97.31 t ha^{-1}) than AHS system (90.15 t ha^{-1}) and AH system (66.76 t ha^{-1}). Whereas, the effect of climatic condition on the above ground biomass production was found to be non-significant.

In the interaction effect between agroforestry system and climatic condition it was found that in the AH and AS systems the above ground biomass declined from C₁ to C₂.

However, in the AHS system the trend was just reverse. In the interaction effect maximum value (98.74 t ha⁻¹) of the above ground biomass was in the agrisilviculture system situated at the Dry temperate high hills climatic conditions, which remained statistically identical to the treatment combinations of T₂C₂, T₃C₂ only.

4.3.2. Below ground biomass (t ha⁻¹)

The data in Table 19 reveals that the total belowground biomass followed the same trend as that of aboveground biomass. Highest total belowground biomass (28.88 t ha⁻¹) was found in AS system, which, was found to be significantly differed from AHS systems (22.26 t ha⁻¹) and AH system (14.91 t ha⁻¹). The interaction effect between agroforestry systems and climatic conditions was found to be non-significant on below ground biomass production. The maximum value of total below ground biomass was recorded in treatment combination T₂C₂ (29.03 t ha⁻¹) followed by T₂C₁ (28.72 t ha⁻¹).

Irrespective of agroforestry system the mean total below ground biomass declined from climatic condition Dry temperate high hills (C₁) climatic condition (22.55 t ha⁻¹) to High hills temperate dry and cold C₂ climatic condition (21.48 t ha⁻¹).

4.3.3. Total biomass production (t ha⁻¹) (above +belowground)

Data presented in Table 19 evinced that the total biomass production was significantly influenced by agroforestry systems and interaction effects of agroforestry systems and climatic conditions (Appendix-II).

The data in Table 19 revealed that the agroforestry systems were found to have significant effect on total biomass production. Irrespective of climatic conditions the maximum value of mean total biomass (126.19 t ha⁻¹) was depicted in AS system which, was found to be significantly differ to AHS system (112.40 t ha⁻¹) and AH system (81.70 t ha⁻¹).

In the interaction between agroforestry system and climatic conditions total biomass declined from the climatic condition C₁ to climatic condition C₂ in T₁ and T₂ but improved in T₃. The interaction between agroforestry systems and climatic condition was found to be significant. The maximum value of total biomass production was observed in treatment combination T₂C₁ (127.46 t ha⁻¹) which was found to be significantly than all treatment combinations except T₂C₂ and T₃C₂.

The biomass in an agroforestry system depends on a number of factors including the growth habit of the species, site quality, age, management practices and the interaction between trees and understory crops (Graham *et al.*, 1992; Jana *et al.*, 2009; Kanime *et al.*, 2013). Variability in productivity of agroforestry system as recorded in our case is also in consonance with the observations of Albrecht and Kandji (2003).

The above results have indicated that biomass component viz; above ground biomass, below ground biomass and total biomass produced by particular land use system is influenced by the age of the components-annual or perennial, type of crop, structure of the system, nature and number of woody components *etc.* Such observations have also been reported by different authors from time to time (Nayak 1996, Deshmukh 1998 and Sehgal, 1999).

4.3.4. Litter biomass production (t ha^{-1})

Data pertaining to the effect of agroforestry systems, climatic conditions and their interaction on litter biomass have been presented in Table 19. (Appendix-III)

The total litter biomass production was significantly influenced due to agroforestry systems, climatic conditions and two way interactions between agroforestry systems and climatic conditions. Among different agroforestry systems, the maximum total litter biomass (0.61 t ha^{-1}) was accumulated in AS system (0.61 t ha^{-1}) to over AHS system (0.58 t ha^{-1}) and AH system (0.54 t ha^{-1}). The effect of climatic conditions and interaction between agroforestry systems and climatic conditions was non-significant on litter biomass production.

In present study litter biomass production was higher in C_2 climatic condition than C_1 climatic condition which may be due to more stressful conditions of C_2 climatic conditions. The production of litter depends primarily on the site productivity but environment and other factors such as temperature, water and nutrient availability also play their role (Jorgensen *et al.*, 1975).

4.3.4. Carbon inventory

Data pertaining to the effect of agroforestry systems, climatic conditions and their interaction on carbon content in vegetation, leaf litter and soil has been presented in Table 20.

Table 20. Effect of agroforestry systems, climatic conditions and their interaction effects on different components of carbon inventory (C t ha⁻¹)

Agroforestry systems (T)	Vegetation (C t ha⁻¹)	Soil (C t ha⁻¹)	Leaf litter (C t ha⁻¹)	Total (C t ha⁻¹)
T₁ (AH)	40.85	56.34	0.39	97.58
T₂ (AS)	63.09	52.06	0.45	115.60
T₃ (AHS)	56.20	58.75	0.42	115.37
SEm±	1.41	1.09	0.004	1.02
C.D_{0.05}	4.49	3.48	0.01	3.25
Climatic conditions(C)				
C₁	54.14	58.68	0.40	113.22
C₂	52.62	52.75	0.44	105.82
SEm±	1.15	0.89	0.004	0.83
C.D_{0.05}	NS	2.84	0.01	2.65
Agroforestry systems (T) × Climatic conditions (C)				
T₁ × C₁	44.77	58.28	0.36	103.41
T₂ × C₁	63.73	54.02	0.44	118.18
T₃ × C₁	53.92	63.75	0.40	118.07
T₁ × C₂	36.92	54.40	0.43	91.76
T₂ × C₂	62.45	50.11	0.46	113.02
T₃ × C₂	58.49	53.74	0.45	112.67
SEm±	1.99	1.54	0.01	1.44
C.D_{0.05}	6.35	NS	0.02	NS

4.3.4.1. Vegetation carbon

It is evident from the data presented in Table 20 that the maximum value of carbon density was observed in the AS system (63.09 C t ha⁻¹), which differed significantly with the AHS system (56.20 C t ha⁻¹) and AH system (40.85 C t ha⁻¹). The effect of climatic conditions was non-significant on vegetation carbon content.

The interaction between agroforestry systems and climatic conditions showed significant influence on carbon density in vegetation. The maximum value of vegetation carbon was observed in treatment combination T₂C₁ (63.73 C t ha⁻¹) whereas, minimum carbon under vegetation was reflected by treatment combination of T₁C₂ (36.92 C t ha⁻¹) which was found to be higher than the all other treatment combinations.

4.3.4.2 Soil carbon

The data in Table 20 reveals that the value of soil carbon (0-30 cm depth) was significantly influenced due to climatic conditions and agroforestry systems. The maximum carbon density in soil was recorded in AHS system ($58.75 \text{ C t ha}^{-1}$), which was found to be significantly higher than AH system only. Irrespective of climatic conditions the soil carbon density decreased from climatic condition C_1 to climatic condition C_2 . The effect of interaction between agroforestry systems and climatic conditions was found to be non-significant. The climatic condition C_1 proved superior to C_2 .

4.3.4.3 Leaf litter carbon

Leaf litter carbon content data is presented in Table 20 which shows that the maximum carbon density under leaf litter was found in AS system (0.45 C t ha^{-1}) which, was significantly higher than AHS system (0.42 C t ha^{-1}) but differed statistically to AH system (0.39 C t ha^{-1}).

The climatic conditions was found to be significantly influenced to the litter carbon density the maximum amount of carbon density was found in C_2 climatic condition which was significantly higher than C_1 climatic condition. The interaction between climatic conditions and agroforestry systems was found to be significant effect on litter carbon density. The maximum carbon content in litter was recorded in treatment combinations of T_2C_2 (0.46 C t ha^{-1}), which was found to be significantly higher than the treatment combinations of T_1C_1 (0.36 C t ha^{-1}).

4.3.4.4 Total carbon content

The data in Table 20 revealed that the total carbon content was significantly influenced by the agroforestry systems and climatic conditions. The maximum carbon content was found in AS system ($115.60 \text{ C t ha}^{-1}$) which was significantly at par with AHS system ($115.37 \text{ C t ha}^{-1}$) whereas minimum total carbon content was observed in AH system (97.58).

The maximum carbon density was observed in C_1 climatic condition ($113.22 \text{ C t ha}^{-1}$), which was found to be significantly higher than the C_2 climatic condition ($105.82 \text{ C t ha}^{-1}$). The interaction effect between agroforestry systems and climatic conditions non-significantly influenced the total carbon content.

In the present study, it was found that carbon density- vegetation, soil, leaf litter and total carbon density varied with agroforestry systems. This variability in the carbon density of different land use system might be due to variation in age, structure, functional components and their number intensity of management. Albrecht and Kandji (2003) also found that amount of carbon sequestered in agroforestry, largely depend on the agroforestry system, the structure, and function of agroforestry systems which to a great extent, are determined by environmental and socioeconomic factors. Also, tree species and system management can influence carbon storage in agroforestry systems.

The biomass and carbon storage capacity in calculated in present study is higher than the density value reported for different agroforestry systems viz., subtropical (Sing 2014) and temperate (Rajput *et al.*, 2017). This variation can be attributed to the prevailing climatic conditions- temperature, rainfall pattern and sandy texture of soil.

Gupta *et al.*, (2017) also concluded that Silvi-pasture system shows higher above ground (118.8 t ha^{-1}) and total biomass production (143.29 t ha^{-1}), whereas agri-silviculture recorded highest below-ground biomass (24.58 t ha^{-1}). Silvi-pasture recorded highest total vegetation carbon density (71.63 t ha^{-1}), in Kinnaur and Lahaul-Spiti, and parts of Chamba. High hills dry temperate /Alpine zone (zone IV).

4.3.5. Biomass increment in trees and shrubs after one year

4.3.5.1. Tree biomass increment after one year under different agroforestry systems at different climatic conditions

It is evident from the data presented in Table 21 that the biomass increment in tree components significantly influenced due to agroforestry system effect. Data shows that the maximum biomass increment in tree was observed in AH system (1.69 t ha^{-1}) which was found to be significantly higher than the AS (1.36 t ha^{-1}) and AHS systems (1.24 t ha^{-1}).

The effect of interaction between climatic conditions and agroforestry systems was found to be significant. The maximum value of tree biomass increment was found in treatment combination of T_1C_2 (1.81 t ha^{-1}) which was found to be significantly higher than the all other than treatment combinations.

In present study it was seen that tree biomass increments is more in agrihorticulture system, such may be due to intensity of the management. The intensity of management in

agrihorticulture is quite high. This system is supported with the application of fertilizers and plant protection measure. `

Table 21. Effect of agroforestry systems, climatic condition and their interaction on the rate of biomass production (t ha⁻¹y⁻¹) in Kinnaur district Himachal Pradesh

Agroforestry systems (T)	Tree biomass increment	Shrubs biomass increment
T ₁ (AH)	1.69	0.29
T ₂ (AS)	1.36	0.22
T ₃ (AHS)	1.24	0.19
SEm±	0.02	0.06
C.D _{0.05}	0.05	NS
Climatic conditions(C)		
C ₁	1.45	0.28
C ₂	1.41	0.19
SEm±	0.01	0.05
C.D _{0.05}	NS	NS
Agroforestry systems (T) × Climatic conditions (C)		
T ₁ × C ₁	1.58	0.39
T ₂ × C ₁	1.55	0.27
T ₃ × C ₁	1.21	0.17
T ₁ × C ₂	1.81	0.20
T ₂ × C ₂	1.16	0.17
T ₃ × C ₂	1.27	0.22
SEm±	0.02	0.08
C.D _{0.05}	0.08	NS

4.3.5.2. Shrub biomass increment after one year (t ha⁻¹) under different agroforestry systems at different climatic conditions

Data presented in Table 21 reveals that the biomass increment in shrubs components under each agroforestry systems. Data illustrated in the Table 21 shows that the non-significant but maximum biomass increment of shrub was observed in AH system (0.29 t ha⁻¹) which was relatively higher than the AS system (0.22 t ha⁻¹), while least value of biomass increment in shrub was observed in AHS system (0.19 t ha⁻¹). Climatic conditions and interaction between agroforestry and climatic conditions was also found to be non-significant.

4.4. NUTRIENT CYCLING IN DIFFERENT LAND USES SYSTEMS

4.4.1 Nutrient stock in Trees

4.4.1.1. Trees stem nutrient stock in different agroforestry systems (Kg ha⁻¹) under different climatic conditions

The nutrient stock in tree stem is given in Table 22 which shows that stem N, K and Ca stock is significantly influenced by the agroforestry systems. The maximum nitrogen and

potassium stock in tree stem was recorded in AS system ($158.03 \text{ Kg ha}^{-1}$), which was significantly higher than AH and AHS systems.

Irrespective of the climatic conditions, the maximum stem nitrogen stock was reported by C_2 climatic condition ($127.50 \text{ Kg ha}^{-1}$) which was found to be significantly higher than the C_1 climatic condition ($112.91 \text{ Kg ha}^{-1}$). The interaction between agroforestry systems and climatic conditions was found to be significant on nitrogen stock under tree stem. The significantly higher value of N stock in tree stem was found in treatment combination T_2C_1 .

Table 22 reveals that stem phosphorus P stock was non-significantly influenced by the effect of agroforestry systems and climatic conditions. The phosphorus content in tree stem was significantly influenced by the interaction between agroforestry systems and climatic conditions. The maximum value of tree stem phosphorus stock was found in treatment combination of T_3C_1 (17.32 Kg ha^{-1}), which was found to be significantly higher than the all other treatment combinations.

Data in Table 22 shows that the stem potassium K stock was not significantly influenced due to the climatic conditions and interaction between agroforestry systems and climatic conditions but the agroforestry systems significantly influenced K content under tree stem. The maximum value ($286.68 \text{ Kg ha}^{-1}$) of K content was recorded in AS system, which was found to be significantly higher than AH and AHS systems.

Table 22 shows that the significant effects of agroforestry systems were observed on calcium stock under tree stem. The maximum stem calcium Ca stock was found in AH system ($258.73 \text{ Kg ha}^{-1}$) which significantly differed with AHS system ($164.34 \text{ Kg ha}^{-1}$) only. The average effects of climatic conditions and interaction between agroforestry systems and climatic conditions were found to be non-significant on tree stem stock.

4.4.1.2. Tree branch nutrient stock in different agroforestry systems (Kg ha^{-1}) under different climatic conditions

It is evident from the data presented in Table 22 that the nutrient (N, P, K and Ca) stock in branch was significantly influenced due to agroforestry systems. Results displayed that the higher branch nitrogen N stock followed the trend: AHS > AS > AH. Interaction between agroforestry systems and climatic conditions was found to be significant on nitrogen stock of tree branches. The maximum nitrogen stock was observed in treatment combination T_3C_1 (2.38 Kg ha^{-1}).

Table 22. Effect of agroforestry systems, climatic conditions and their interaction with nutrient stocks (Kg ha⁻¹) under different components of trees

Agroforestry systems (T)	Nutrient stock in different part of trees (Kg ha ⁻¹)																			
	Tree stem				Tree branch				Tree leaf				Tree root				Tree fruits			
	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
T ₁ (AH)	107.21	10.72	235.82	258.73	1.26	0.79	2.41	1.59	12.31	1.61	9.65	8.33	66.24	14.93	68.67	47.99	83.05	15.22	105.53	80.15
T ₂ (AS)	158.03	8.96	286.68	237.88	1.90	1.45	3.65	2.96	7.46	1.61	7.37	6.82	148.68	52.71	221.04	133.92	82.70	22.20	136.84	120.90
T ₃ (AHS)	104.39	14.01	225.55	164.34	2.15	1.70	5.35	2.41	12.50	1.79	13.18	10.25	104.59	27.09	138.99	144.85	162.24	27.13	187.84	173.22
SEm±	2.40	1.37	8.00	21.45	0.13	0.18	0.64	0.21	0.54	0.16	0.39	0.29	7.38	5.69	13.58	12.71	24.45	2.92	15.63	15.99
C.D _{0.05}	7.65	NS	25.54	68.45	0.42	0.56	2.04	0.68	1.73	NS	1.25	0.92	23.56	18.17	43.35	40.57	NS	9.33	49.88	51.03
Climatic conditions(C)																				
C ₁	118.92	11.04	254.50	212.21	1.87	1.63	3.37	2.78	10.82	1.83	10.65	8.20	101.84	32.95	154.09	117.37	110.51	23.31	154.28	132.46
C ₂	127.50	11.42	244.20	228.43	1.83	0.99	3.88	1.86	10.70	1.52	9.48	8.73	111.17	30.21	131.71	100.47	108.15	19.73	132.53	117.05
SEm±	1.96	1.12	6.53	17.51	0.11	0.14	0.52	0.18	0.44	0.13	0.32	0.24	6.03	4.65	11.09	10.38	19.96	2.39	12.76	13.05
C.D _{0.05}	6.25	NS	NS	NS	NS	0.46	NS	0.56	NS	NS	1.02	NS	NS	NS	NS	NS	NS	NS	NS	NS
Agroforestry systems (T) × Climatic conditions (C)																				
T ₁ × C ₁	104.90	7.25	247.88	253.00	1.26	1.20	2.56	1.45	12.10	1.41	10.84	8.92	41.67	14.37	87.92	40.42	87.39	14.54	112.30	76.91
T ₂ × C ₁	145.85	8.54	281.18	215.79	1.97	1.68	3.23	3.74	6.93	2.04	7.35	6.11	155.46	55.00	203.21	150.50	130.27	35.08	202.05	183.87
T ₃ × C ₁	106.01	17.32	234.43	167.84	2.38	2.02	5.41	3.16	13.43	2.04	13.77	9.56	108.39	29.50	171.14	161.19	113.86	20.29	148.49	136.60
T ₁ × C ₂	109.51	14.19	223.76	264.46	1.43	0.38	2.26	1.73	12.53	1.82	8.47	7.73	90.81	15.50	49.42	55.56	78.70	15.89	98.76	83.40
T ₂ × C ₂	170.21	9.37	292.17	259.98	2.35	1.21	4.08	2.18	8.00	1.18	7.39	7.54	141.90	50.43	238.87	117.34	35.12	9.32	71.63	57.93
T ₃ × C ₂	102.78	10.70	216.66	160.85	1.70	1.38	5.30	1.67	11.57	1.54	12.59	10.93	100.80	24.69	106.83	128.51	210.62	33.98	227.20	209.84
SEm±	3.39	1.94	11.32	30.33	0.19	0.25	0.90	0.30	0.77	0.22	0.55	0.41	10.44	8.05	19.21	17.98	34.58	4.13	22.10	22.61
C.D _{0.05}	10.82	6.18	NS	NS	0.60	NS	NS	0.97	NS	0.72	NS	1.30	33.31	NS	NS	NS	NS	13.19	70.54	72.17

The data in Table 22 revealed that the maximum value of P stock in tree branch was found in AHS system (1.70 Kg ha^{-1}), which was found to be significantly higher than all other agroforestry systems. The phosphorus stock in tree branch was follows the trend: AHS > AS > AH. Significantly higher value of P stock was found in C₁ climatic condition.

Table 22 showed that higher branch potassium K stock was found in AHS system (5.35 Kg ha^{-1}) which significantly higher than AS (3.65 Kg ha^{-1}) and AH systems (2.41 Kg ha^{-1}). The potassium content in tree branch was significantly influenced by the agroforestry systems, whereas climatic conditions and interaction between agroforestry systems and climatic conditions were not significantly influenced potassium stock in tree branch.

A perusal of the data presented in Table 22 reveals that the maximum value of calcium stock in tree branch was found in AS system (2.96 Kg ha^{-1}) which was found to be significantly higher than the AH system only (1.59 Kg ha^{-1}).

The calcium stock in tree branch was significantly higher in C₂ climatic condition (2.96 Kg ha^{-1}) which was found to be significantly higher than the C₁ climatic condition (1.86 Kg ha^{-1}). The calcium content in tree branch was significantly influenced by interaction between agroforestry systems and climatic conditions; the maximum value of calcium stock in tree branch was found in treatment combination of T₂C₁ (3.74 Kg ha^{-1}) which was significantly higher than all other treatment combinations excepting T₃C₁.

4.4.1.3. Tree leaf nutrient stock in different agroforestry systems (Kg ha^{-1}) under different climatic conditions

Data cited in Table 22 show that the agroforestry systems had significant influence on N, K and Ca stock in tree leaves. The higher amount of N, K and Ca nutrients was found in AHS system and lowest in AS system only.

The climatic conditions were significantly influenced the potassium (K) stock only. The higher value of potassium K stock (10.65 Kg ha^{-1}) in tree leaf was found in C₁ climatic condition.

The effect of interaction between agroforestry systems and climatic conditions significantly influenced the phosphorus and calcium stock in tree leaf only. The maximum value of Ca was recorded in treatment combination of T₃C₂ (10.93 Kg ha^{-1}) whereas, maximum amount of P was recorded in T₃C₁ and T₂C₁ (2.04 Kg ha^{-1}) treatment combinations.

4.4.1.4. Tree root nutrient stock in different agroforestry systems (Kg ha⁻¹) under different climatic conditions

It is clear from the data in Table 22 that the nutrient N,P and K stock in tree root was higher in AS system, which differed significantly with AHS and AH systems. Whereas, maximum value of Ca stock (144.85 Kg ha⁻¹) was recorded in AHS system. The interaction between agroforestry systems and climatic conditions was found to have non-significant effect on tree root nutrient stock. The climatic conditions did not significantly influence the nutrient stock in tree roots. The maximum level of P, K and Ca was recorded in C₁ climatic conditions whereas, higher value of N stock in tree roots was observed in C₂ climatic condition.

According to Table 22 tree root potassium Ca stock was higher in AHS system (144.85 Kg ha⁻¹) which was significantly higher than AS system (133.92 Kg ha⁻¹) and AH system (47.99 Kg ha⁻¹).

Interaction between agroforestry systems and climatic condition did not significantly influenced to the P, K and Ca stock in tree root nutrient stock. Only nitrogen N stock was significantly influenced due to the interaction between agroforestry systems and climatic conditions. The Maximum level of N stock in tree roots was found in treatment combination T₂C₁ (155.46 Kg ha⁻¹) which was found to be significantly higher than all other treatment combinations except T₂C₂.

4.4.1.5. Tree fruit nutrient stock in different agroforestry systems (Kg ha⁻¹) under different climatic conditions

The data presented in the Table 22 reveals that the effect of agroforestry systems, climatic conditions and their interaction effects on nitrogen stock in tree fruits were found to be non-significant.

The data in the Table 22 reveals that the agroforestry systems had a significant effect on fruit P, K and Ca stock. The maximum fruit phosphorus P stock was recorded in agrihortisilviculture system (27.13 Kg ha⁻¹) which differed statistically from AH systems (15.22 Kg ha⁻¹) only. Similarly, the maximum stock of K and Ca was recorded in AHS system, which was found to be significantly higher than all other agroforestry systems.

Though non-significant but higher N, P, K and Ca stock in fruits was noticed in Dry temperate high hills (C_1) climatic conditions than C_2 climatic conditions. The interaction between agroforestry systems and climatic conditions on P, K and Ca stock in tree fruits was found to have significant effect. The maximum fruit phosphorus stock was reported by treatment combination T_2C_1 , whereas maximum K and Ca stock was found in treatment combination T_3C_2 .

4.4.1.2. Nutrient stock in shrubs

4.4.1.2.1. Shrubs stem nutrient stock ($Kg\ ha^{-1}$)

The stock of the N, P, K and Ca in the different components of the shrubs, stem branch, leaf and roots is depicted in the Table 23.

It is evident from the data presented in the Table 23 that the agroforestry systems, climatic conditions and interaction between them did not influence significantly the N, P K and Ca stock in shrub stem. Non-significant but higher N was found in AS system while maximum P, K and Ca was observed in AHS system.

Similar to the agroforestry systems, the nutrient stock of N, P, K and Ca was found to be non-significantly influenced due to climatic conditions. The higher values of all nutrients (N, P, K and Ca) in the shrub stem were observed in the C_2 climatic condition over C_1 climatic conditions.

Interaction effect between the agroforestry systems and climatic conditions exerted non-significant influence on the stock of the N, P, K and Ca under shrub stem. In general, the nutrient stock of the N, P, K and Ca declined as moved from C_2 climatic condition to C_1 climatic conditions. Non-significant but higher values of P and Ca stock in shrub stem were recorded in treatment combination T_3C_1 while, maximum K stock was observed in T_3C_2 and maximum stock of treatment combustion T_2C_1 and T_2C_2 ($0.64\ Kg\ ha^{-1}$).

4.4.1.2.2. Shrub branch nutrient stock ($Kg\ ha^{-1}$)

The N, P, K and Ca stock in the branches were not found to be non-significantly influenced due to agroforestry systems. Though, the values of these nutrients were higher under the AHS followed by AS system and AH system (Table 23).

The stock of P, K and Ca was found to be non-significantly higher under the Dry temperate high hills (C₁) climatic conditions than the High hills temperate dry and cold (C₂) climatic conditions while the trend for N was opposite.

The interaction between the agroforestry systems and climatic conditions failed to exercise significant influence on the nutrient stock of N, P and Ca under shrub branches. Interaction between agroforestry systems and climatic conditions was found to have significantly influence on K stock in shrub branches. The maximum level of K stock on shrub branches was recorded in treatment combination of T₃C₁ (1.55 Kg ha⁻¹) which was found to be significantly higher than T₁C₁ and T₂C₂.

4.4.1.2.3. Shrub leaf nutrient stock (Kg ha⁻¹)

The stock of the N, P, Ca and K in the shrub leaf was non-significantly influenced due to the effect of the agroforestry systems. Non significant but higher values of N, P and Ca stock in shrub leaf were found in AH system while maximum K stock in shrub leaf was found in AS system (Table 23).

The N in the leaf of the shrubs was found to be significantly influenced due to their climatic conditions. Significantly higher stock of the N was found in the leaves of the shrubs growing under C₂ climatic conditions than C₁ climatic conditions.

Interaction effect between the agroforestry systems and climatic conditions exercised a significant influence on the N and K stock of the shrub leaves. The stock of the N enhanced as are moved from C₁ climatic condition to C₂ climatic condition whereas, in the K trend was not consistent one.

4.4.1.2.4. Shrub root nutrient stock (Kg ha⁻¹)

It is evident from the data in Table 23 that the levels of the N, P, K and Ca was higher in the shrub roots growing under the AS system than the AH system followed by AHS system. However, the agroforestry systems had significant effect on K and Ca stock only.

The effect of the climatic conditions exercised significant influence on the K stock of the shrub roots. The significant higher K stock was found under C₁ climatic condition over C₂ climatic condition.

Table 23. Effect of agroforestry systems, climatic conditions and their interaction on nutrient stocks (Kg ha⁻¹) in different parts of shrubs

Agroforestry systems	Nutrient stock in different part of shrubs (kg ha ⁻¹)															
	Shrub stem				Shrub branch				Shrub leaf				Shrub root			
	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
T₁ (AH)	0.25	0.10	0.58	0.75	0.32	0.10	0.66	0.67	0.88	0.18	1.37	1.92	0.53	0.17	0.56	1.12
T₂ (AS)	0.64	0.15	1.06	1.19	0.63	0.11	1.02	1.15	0.84	0.14	1.49	1.59	0.88	0.19	2.41	2.17
T₃ (AHS)	0.48	0.19	1.17	1.40	0.69	0.15	1.25	1.44	0.73	0.17	1.22	1.45	0.77	0.18	1.22	1.47
SEm±	0.10	0.03	0.17	0.23	0.12	0.03	0.16	0.27	0.09	0.03	0.17	0.22	0.09	0.03	0.01	0.19
C.D_{0.05}	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.04	0.62
Climatic conditions(C)																
C₁	0.38	0.14	0.85	1.03	0.50	0.13	1.14	1.15	0.60	0.13	1.17	1.49	0.74	0.19	1.80	1.73
C₂	0.53	0.16	1.03	1.20	0.59	0.10	0.81	1.02	1.03	0.20	1.55	1.81	0.72	0.17	0.99	1.44
SEm±	0.09	0.02	0.14	0.19	0.10	0.02	0.13	0.22	0.07	0.02	0.14	0.18	0.08	0.03	0.01	0.16
C.D_{0.05}	NS	NS	NS	NS	NS	NS	NS	NS	0.23	NS	NS	NS	NS	NS	0.03	NS
Agroforestry systems (T) × Climatic conditions (C)																
T₁ × C₁	0.12	0.07	0.37	0.42	0.23	0.10	0.43	0.50	0.40	0.10	0.72	1.30	0.48	0.12	0.83	0.95
T₂ × C₁	0.64	0.14	1.14	1.18	0.71	0.14	1.44	1.58	0.78	0.13	1.58	1.54	0.93	0.21	3.09	2.55
T₃ × C₁	0.39	0.20	1.04	1.48	0.57	0.15	1.55	1.39	0.64	0.17	1.22	1.63	0.81	0.22	1.49	1.70
T₁ × C₂	0.39	0.13	0.79	1.09	0.41	0.09	0.89	0.85	1.37	0.27	2.02	2.54	0.58	0.22	0.29	1.29
T₂ × C₂	0.64	0.16	0.99	1.21	0.55	0.07	0.59	0.72	0.89	0.15	1.41	1.63	0.84	0.16	1.72	1.79
T₃ × C₂	0.57	0.18	1.31	1.32	0.80	0.15	0.95	1.50	0.81	0.17	1.21	1.27	0.74	0.14	0.95	1.25
SEm±	0.15	0.04	0.24	0.33	0.17	0.04	0.23	0.38	0.13	0.04	0.25	0.31	0.13	0.05	0.02	0.27
C.D_{0.05}	NS	NS	NS	NS	NS	NS	0.72	NS	0.40	NS	0.79	NS	NS	NS	0.05	NS

The interaction between the agroforestry systems and climatic conditions exercised a significant influence on the K stock of the shrub roots. Maximum and minimum value of the K stock was recorded in the treatment combinations of T_2C_1 and T_1C_2 whereas minimum level of K stock was found in treatment combination T_1C_2 .

4.4.1.3. Total nutrient stock (Kg ha^{-1}) in tree and shrubs at different agroforestry systems (Kg ha^{-1}) under different climatic conditions

The total stock of N, P, K and Ca in trees and shrubs is displayed in Table 24.

4.4.1.3.1. Total nutrient stock in trees (Kg ha^{-1})

It is clear from the data presented in Table 24 that total stock of N, K and P were significantly influenced by the agroforestry systems. The maximum amount of N, P and K was found in AS system which was found to be significantly higher than AHS system and AH system. Non-significant but higher total stock of Ca was found in AS system. Irrespective of climatic conditions, maximum amount of K stock ($577.25 \text{ Kg ha}^{-1}$) in trees was found in C_1 climatic condition which was found to be significantly higher than C_2 climatic condition. Climatic conditions did not significantly influenced N, P and Ca stock in trees.

Interaction between agroforestry systems and climatic conditions did not significantly influenced to the N, P K and Ca stock in tree components. Non significant but higher N, P, K and Ca stock was recorded in treatment combination T_2C_1 .

4.4.1.3.2. Total nutrient stock in shrubs (Kg ha^{-1})

Data in Table 24 reveals that the agroforestry systems significantly influenced total stock of P and K stock in shrubs. The maximum total stock of P and K in shrubs was observed in AS system which was significantly higher than AH systems only. Climatic conditions were non-significantly influence the total stock of N, K and Ca in shrubs whereas the total stock of P was significantly influenced due to climatic conditions. The significantly higher total stock P in shrubs was found in C_2 climatic condition over C_1 climatic condition.

Interaction between agroforestry systems and climatic conditions did not influence the total stock of N, P, K and Ca in shrubs. Non-significant but highest stock of N, K and Ca in shrubs was recorded in treatment combination T_2C_1 whereas, maximum value of P stock in shrubs was found in treatment combination T_2C_2 .

Table 24. Effect of agroforestry systems, climatic conditions and their interaction on total nutrient stock (Kg ha⁻¹) in tree and shrubs

Agroforestry systems	Total nutrient stock (Kg ha ⁻¹) (trees and shrubs)							
	Trees total nutrient stock (Kg ha ⁻¹)				Shrubs total nutrient stock (Kg ha ⁻¹)			
	N	P	K	Ca	N	P	K	Ca
T₁ (AH)	270.15	43.28	422.09	396.79	1.99	0.55	3.17	4.47
T₂ (AS)	399.03	86.93	655.57	502.48	2.99	1.85	5.98	6.10
T₃ (AHS)	385.77	71.73	570.91	495.07	2.67	1.71	4.85	5.76
SEm±	26.26	5.70	20.01	36.67	0.40	0.34	0.62	0.70
C.D_{0.05}	83.81	18.19	63.85	NS	NS	1.08	1.96	NS
Climatic conditions(C)								
C₁	343.96	70.76	577.25	473.02	2.32	0.58	4.96	5.40
C₂	359.35	63.87	521.79	456.54	2.78	2.16	4.37	5.48
SEm±	21.44	4.65	16.33	29.94	0.33	0.28	0.50	0.57
C.D_{0.05}	NS	NS	52.14	NS	NS	0.88	NS	NS
Agroforestry systems (T) × Climatic conditions (C)								
T₁ × C₁	247.32	38.77	461.50	380.70	1.23	0.39	2.35	3.17
T₂ × C₁	440.48	102.34	697.00	560.01	3.06	0.63	7.24	6.85
T₃ × C₁	344.07	71.16	573.24	478.35	2.41	0.73	5.29	6.19
T₁ × C₂	292.98	47.79	382.67	412.87	2.75	0.71	3.99	5.77
T₂ × C₂	357.58	71.52	614.14	444.96	2.93	3.08	4.71	5.35
T₃ × C₂	427.47	72.29	568.57	511.79	2.92	2.70	4.42	5.33
SEm±	37.14	8.06	28.29	51.86	0.57	0.48	0.87	0.99
C.D_{0.05}	NS	NS	NS	NS	NS	NS	NS	NS

In present study tree nutrient stock in the branch, leaf and fruits were found to be maximum in AHS system situated in C₁ climatic condition, which may be due to maximum use of FYM, nutrients availability in the soil, better microclimatic conditions and the maximum addition of nutrients through weed debris and crop debris. The total nutrient of N, P, K, and Ca stock in trees was maximum in AS system which may be results of maximum standing biomass in this compartment. Removal of harvestable biomass (Fruits and Vegetables) was less in AS system than the AH and AHS system. Similarly stock of nutrients in vegetation were also reported by Tokey *et al.*, (1989b) in traditional agroforestry system under north western Himalayas and Rawat and Singh (1988) Oak Forests in Central Himalaya.

4.4.2. Nutrient available (Kg ha⁻¹) in soil layer (0-30 cm) depth under different agroforestry systems at different climatic conditions

Total nutrient stock of N, P, K and Ca as recorded in 0-30 cm soil layer is displayed in Table 25.

It is evident from the data presented in the Table 25 that P and Ca stock of the agroforestry systems was significantly influenced due to agroforestry systems. Maximum P stock (316.52 Kg ha⁻¹) of 0-30 cm soil layer is recorded in agrisilviculture system, which was found to be significantly higher than P stock of agrihorticulture system whereas, Ca stock was found to be maximum in AH system (2163.95 Kg ha⁻¹) which was found to be significantly higher than AS and AHS systems.

The stock of the P, K and Ca was found to be significantly higher in the soils of the Dry temperate high hills (C₁) climatic condition over the High hills temperate dry and cold climatic condition (C₂).

Interaction between the agroforestry systems and climatic conditions significantly influenced the P and Ca contents of the soil.

The P stock of the T₁ and T₂ land use system declined from climatic condition C₁ to climatic condition C₂, whereas the trend was just reserves for T₃, in case of Ca stock. The level of Ca declined significantly in T₁ and T₂ while value moving from the C₁ climatic condition to C₂ climatic condition, whereas the level of the T₃ enhanced non-significantly.

Table 25. Effect of agroforestry systems, climatic conditions and their interaction on availability of the nutrients (Kg ha⁻¹) in 0-30 cm soil depth

Agroforestry systems (T)	Total stock in 0-30 cm soil depth (Kg ha ⁻¹)			
	N	P	K	Ca
T ₁ (AH)	7397.05	313.16	483.78	2163.95
T ₂ (AS)	6056.73	316.52	503.44	2068.52
T ₃ (AHS)	5689.20	303.54	469.12	2051.07
SEm±	820.62	3.02	26.47	23.54
C.D _{0.05}	NS	9.65	NS	75.12
Climatic conditions(C)				
C ₁	7204.98	320.88	542.36	2184.78
C ₂	5557.00	301.27	428.53	2004.25
SEm±	670.04	2.47	21.61	19.22
C.D _{0.05}	NS	7.88	68.98	61.34
Agroforestry systems (T) × Climatic conditions (C)				
T ₁ × C ₁	8146.10	340.57	518.16	2383.41
T ₂ × C ₁	7034.95	341.77	566.79	2122.14
T ₃ × C ₁	6433.90	280.30	542.13	2048.78
T ₁ × C ₂	6648.00	285.75	449.40	1944.49
T ₂ × C ₂	5078.50	291.27	440.09	2014.90
T ₃ × C ₂	4944.50	326.78	396.11	2053.36
SEm±	1160.54	4.28	37.43	33.28
C.D _{0.05}	NS	13.65	NS	106.24

4.4.3. Effect of agroforestry systems, climatic conditions and their interaction on total density (soil + vegetation) of nutrients available in ecosystem (Kg ha⁻¹)

The total density of the nutrients N, P, K and Ca recorded by adding the (0-30 cm layer) plus vegetations is depicted in the Table 26.

It is evident from the Table 26 that the total density of the N is not significantly influenced due to effect of the agroforestry systems, climatic conditions and interaction effect between them. The total density of the P significantly influenced due to the average effect of the agroforestry systems, climatic conditions and the interaction effect between them. The density of the P (414.36 Kg ha⁻¹) was found to be significantly higher in the agrisilviculture system, which was found to be significantly higher than both AH and AHS systems.

In the climatic conditions, total density of P was found to be significantly higher in Dry temperate high hills (C₁) climatic condition than High hills temperate dry and cold (C₂) climatic condition. In the interaction effect between the agroforestry systems and climatic condition was found to be significant, it was observed that in T₁ and T₂ the total density of the P decline from C₁ to C₂, whereas in T₃ the trend was just reverse.

Table 26. Effect of agroforestry systems, climatic conditions and their interaction on total density of elements in different agro ecosystems (Kg ha⁻¹) of Kinnaur district Himachal Pradesh

Agroforestry systems (T)	Total density of elements in ecosystem (Kg ha ⁻¹)			
	N	P	K	Ca
T ₁ (AH)	7739.21	367.69	1274.33	2638.16
T ₂ (AS)	6534.77	414.36	1269.19	2644.08
T ₃ (AHS)	6140.35	384.12	1137.29	2611.95
SEm±	824.09	7.11	26.17	41.62
C.D _{0.05}	NS	22.70	83.53	NS
Climatic conditions(C)				
C ₁	7622.90	403.47	1227.19	2726.61
C ₂	5986.66	373.98	1226.68	2536.18
SEm±	672.87	5.81	21.37	33.98
C.D _{0.05}	NS	18.54	68.20	108.46
Agroforestry systems (T) × Climatic conditions (C)				
T ₁ × C ₁	8465.29	390.82	1081.67	2831.94
T ₂ × C ₁	7559.75	457.68	1389.36	2756.07
T ₃ × C ₁	6843.65	361.90	1210.55	2591.82
T ₁ × C ₂	7013.13	344.57	1467.00	2444.39
T ₂ × C ₂	5509.79	371.04	1149.02	2532.09
T ₃ × C ₂	5437.05	406.34	1064.03	2632.07
SEm±	1165.44	10.06	37.01	58.85
C.D _{0.05}	NS	32.10	118.12	187.85

Similar to P, the total density of the K was also found to be significantly influenced due to the average effect of the agroforestry systems and interaction effect between agroforestry system and climatic conditions. The total density of the K was significantly higher in the agrihorticulture T₁, which was found to be significantly higher than T₃ and T₂. In the interaction effect, the total density of the K enhanced in T₁ from C₁ to C₂ whereas in T₂ and T₃ the trend was just reverses.

The total density of the Ca was found to be significantly influenced due to the climatic conditions and interaction effect between agroforestry systems and climatic conditions. C₁ climatic conditions displayed significantly higher Ca density than C₂ climatic condition. In T₁ and T₂ the level of the Ca declined, whereas in T₃ the trend was reverse. Significantly higher value of Ca was found in treatment combination T₁C₁.

In present study maximum nutrient density was recorded climatic condition C₁ it might be due to the maximum accumulation of biomass in climatic condition C₁. There were quite variations in nutrient availability at 0-30 cm soil depth, which may be due to soil texture, active slope gradient and management practices of agroforestry system. Changes in soil chemical properties were found to be different as soils, climates, and cropping systems differed is also suggested by Hartemink (2005) Total density of elements in different agro-ecosystems of the present study is more compatible with other workers Tokey *et al.*, (1989b) and Lodhiyal *et al.*, (2002).

4.4.4. Nutrient uptake

4.4.4.1. Tree nutrient uptake ($\text{Kg ha}^{-1} \text{ yr}^{-1}$)

The nutrient uptake by different components of the trees *i. e.* tree stem, tree branch, tree leaf, tree roots and tree fruits is being presented in the Table 27.

4.4.4.1.1 Nutrient uptake by tree stems ($\text{Kg ha}^{-1} \text{ yr}^{-1}$)

It is evident from the data presented in the Table 27 that uptake rate of the N, K and Ca were found to be significantly higher under the agrihorticulture system, whereas the climatic conditions failed to exercise any significant influence on the uptake of the N, P, K and Ca. Interaction effect of the agroforestry system and climatic conditions significantly influenced the uptake of N, K and Ca of the tree stem.

4.4.4.1.2. Nutrient uptake by tree branch ($\text{Kg ha}^{-1} \text{ yr}^{-1}$)

Nutrient uptake of the N and Ca was found to be significantly influence due to the average effect of the agroforestry system (Table27). The contents of both the element was found to be significantly higher in the agrisilviculture system. In the average effect of the climatic conditions, the Ca was found to be significantly higher in high hills temperate dry C_1 climatic condition than C_2 climatic condition whereas, the interaction effect failed to influence the N, P, K and Ca content significantly.

4.4.4.1.3. Nutrient uptake by tree leaf ($\text{Kg ha}^{-1} \text{ yr}^{-1}$)

The uptake of N, K and ca was found to be significantly influenced due to the average effect of the agroforestry system (Table27). These elements displayed their maximum value in agrisilviculture system. In the average effect of the climatic conditions, N, K as well as Ca uptake was found to be significantly higher in the C_2 climatic conditions than C_1 climatic condition. The uptake of the N, K and Ca was found to be significantly influenced due to the interaction of climatic conditions and agroforestry systems.

4.4.4.1.4. Nutrient uptake by tree root ($\text{Kg ha}^{-1} \text{ yr}^{-1}$)

Data in the Table 27 shows that the nutrient uptake of K and Ca was found to be significantly influenced due to the average effect of the agroforestry system, which was found to be maximum in T_2 than T_1 . Irrespective of the agroforestry system, K content was found to be maximum in the C_2 climatic condition than C_1 climatic condition. Interaction effect between agroforestry systems and climatic conditions significantly influenced the K and Ca uptake rate.

Table 27. Effect of agroforestry systems, climatic conditions and their interaction on nutrient uptake (Kg ha⁻¹ yr⁻¹) by different parts of tree in dry temperate regions of north western Himalaya

Agroforestry systems (T)	Nutrient uptake by different parts of tree (Kg ha ⁻¹ yr ⁻¹)																			
	Tree stem				Tree branch				Tree leaf				Tree root				Tree fruits			
	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
T₁ (AH)	2.63	0.56	5.60	6.58	0.24	0.53	1.12	0.31	0.92	0.19	0.72	0.62	2.33	0.63	1.80	1.45	25.14	4.21	32.17	23.39
T₂ (AS)	2.32	0.14	4.57	3.83	0.38	0.26	0.59	0.56	1.35	0.28	1.39	1.21	4.02	1.23	3.90	3.83	17.95	3.65	27.37	23.21
T₃ (AHS)	0.96	0.56	1.86	1.46	0.19	0.15	0.49	0.23	1.21	0.17	1.26	1.03	2.37	0.72	2.81	3.71	22.71	5.47	29.44	26.32
SEm±	0.38	0.30	0.92	0.89	0.04	0.12	0.40	0.03	0.04	0.04	0.02	0.04	0.73	0.19	0.03	0.66	2.61	0.38	3.14	2.76
C.D_{0.05}	1.20	NS	2.94	2.85	0.14	NS	NS	0.10	0.14	NS	0.07	0.13	NS	NS	0.10	2.11	NS	1.22	NS	NS
Climatic conditions(C)																				
C₁	1.52	0.32	3.40	3.00	0.29	0.39	0.98	0.46	0.92	0.20	0.89	0.65	3.21	1.04	2.75	3.70	22.68	4.27	30.41	23.87
C₂	2.42	0.52	4.62	4.92	0.25	0.24	0.48	0.27	1.39	0.23	1.35	1.26	2.60	0.68	2.92	2.29	21.18	4.62	28.91	24.74
SEm±	0.31	0.24	0.75	0.73	0.04	0.10	0.33	0.03	0.04	0.04	0.02	0.03	0.60	0.15	0.03	0.54	2.13	0.31	2.57	2.25
C.D_{0.05}	NS	NS	NS	NS	NS	NS	NS	0.08	0.11	NS	0.06	0.10	NS	NS	0.08	NS	NS	NS	NS	NS
Agroforestry systems (T) × Climatic conditions (C)																				
T₁ × C₁	1.12	0.62	2.73	3.35	0.34	0.69	2.01	0.44	0.89	0.25	0.79	0.65	1.16	0.65	1.45	0.86	31.35	4.91	40.28	26.09
T₂ × C₁	2.38	0.16	5.33	3.97	0.35	0.31	0.46	0.67	0.79	0.22	0.79	0.56	4.85	1.30	2.50	4.43	20.56	5.03	31.75	27.91
T₃ × C₁	1.05	0.19	2.14	1.67	0.19	0.16	0.48	0.27	1.10	0.14	1.09	0.74	3.62	1.16	4.31	5.81	16.14	2.87	19.21	17.61
T₁ × C₂	4.13	0.50	8.47	9.81	0.15	0.37	0.23	0.18	0.96	0.14	0.65	0.59	3.50	0.60	2.16	2.04	18.94	3.51	24.07	20.70
T₂ × C₂	2.26	0.11	3.81	3.69	0.41	0.20	0.73	0.44	1.91	0.33	1.99	1.87	3.19	1.16	5.29	3.23	15.33	2.27	22.98	18.51
T₃ × C₂	0.87	0.94	1.58	1.25	0.19	0.14	0.49	0.19	1.31	0.20	1.42	1.32	1.11	0.28	1.31	1.61	29.27	8.07	39.67	35.02
SEm±	0.53	0.42	1.30	1.26	0.06	0.17	0.56	0.04	0.06	0.06	0.03	0.06	1.03	0.26	0.04	0.93	3.68	0.54	4.44	3.90
C.D_{0.05}	1.69	NS	4.16	4.03	NS	NS	NS	NS	0.20	NS	0.10	0.18	NS	NS	0.14	2.98	11.76	1.73	14.18	12.46

4.4.4.1.5. Nutrient uptake by tree fruit ($\text{Kg ha}^{-1} \text{yr}^{-1}$)

It is evident from the data on the Table 28 that P uptake rate was found to be maximum in AHS system followed by AH and AS systems whereas, average effect of the climatic condition failed to significantly influence the N, P K and Ca content. Interaction effect also significantly influenced the N, P, Ca and K contents.

4.4.4.2. Nutrient uptake by agriculture crops $\text{Kg ha}^{-1} \text{yr}^{-1}$)

Nutrient uptake of the N, P, K and Ca by the part of agriculture crop is being depicted in the Table 28.

4.4.4.2.1. Nutrient uptake by agriculture crop shoots ($\text{Kg ha}^{-1} \text{yr}^{-1}$)

The nutrient uptake of N, P, K and Ca was not found to be significantly influenced due to agroforestry system whereas, in the average effect of the climatic condition conditions, only Ca was found to be significantly influenced (Table 28). Ca uptake by the agriculture crop shoots was found to be higher in the High hills temperate dry (C_1) climatic condition than C_2 climatic condition. Interaction effect between agroforestry systems and climatic conditions failed to exert any significant influence.

4.4.4.2.2. Nutrient uptake by agriculture crop roots ($\text{Kg ha}^{-1} \text{yr}^{-1}$)

It is quite clear from the data in Table 28 that the N, P and K were found to be significantly influenced due to agroforestry system effect. N, P, and K uptake was found to be significantly higher in AHS, AS (both P and K), respectively. In the average effect of the climatic, uptake of the P was significantly higher in C_1 climatic condition than C_2 climatic condition, whereas, K and Ca uptake was higher in C_2 climatic condition than C_1 climatic condition. Interaction between agroforestry system and climatic condition significantly influenced the N, P, K and Ca uptake.

4.4.4.2.3. Nutrient uptake by agriculture crop grain/fruits ($\text{Kg ha}^{-1} \text{yr}^{-1}$)

It is evident from the data presented in the Table 28 that the uptake of N, P, K and Ca was significantly influenced due to the average effect of the agroforestry systems. The uptake rate of the N was maximum in AS system followed by AH and AHS system, respectively whereas, the uptake rate of P and Ca was maximum in AH system followed by AS and AHS systems. The uptake rate of the K followed the trend. $AS > AH > AHS$.

Table 28. Effect of agroforestry systems, climatic conditions and their interaction on nutrient uptake (Kg ha⁻¹ yr⁻¹) by different parts of agriculture crop in dry temperate climatic conditions of north western Himalaya

Agroforestry systems (T)	Nutrient uptake by different part of agriculture crops (Kg ha ⁻¹ yr ⁻¹)											
	Agriculture crop shoots				Agriculture crop roots				Agriculture crop fruits/gains			
	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
T₁ (AH)	11.02	1.45	15.13	9.30	1.03	0.20	1.41	0.84	38.73	6.67	56.61	35.15
T₂ (AS)	11.46	1.51	14.25	9.42	0.95	0.27	1.70	0.72	47.27	5.70	62.87	26.46
T₃ (AHS)	10.56	1.29	14.69	9.23	1.20	0.13	1.04	0.72	33.83	4.02	48.59	23.05
SEm±	0.46	0.11	0.46	0.45	0.04	0.01	0.05	0.05	1.53	0.56	1.31	1.64
C.D_{0.05}	NS	NS	NS	NS	0.11	0.04	0.16	NS	4.88	1.78	4.19	5.22
Climatic conditions(C)												
C₁	11.56	1.30	15.02	10.27	1.03	0.18	1.50	0.84	41.44	7.33	59.86	28.51
C₂	10.47	1.53	14.36	8.36	1.09	0.22	1.27	0.68	38.45	3.61	52.19	27.93
SEm±	0.38	0.09	0.38	0.37	0.03	0.01	0.04	0.04	1.25	0.46	1.07	1.34
C.D_{0.05}	NS	NS	NS	1.18	NS	0.03	0.13	0.12	NS	1.46	3.42	NS
Agroforestry systems (T) × Climatic conditions (C)												
T₁ × C₁	12.05	1.35	15.92	11.22	1.06	0.24	1.35	0.99	40.42	7.97	59.32	32.92
T₂ × C₁	12.15	1.37	14.67	9.97	1.00	0.15	1.96	0.86	51.94	8.58	71.80	28.58
T₃ × C₁	10.48	1.18	14.47	9.63	1.04	0.15	1.19	0.67	31.97	5.42	48.45	24.04
T₁ × C₂	9.99	1.55	14.34	7.37	1.00	0.15	1.48	0.69	37.03	5.37	53.90	37.38
T₂ × C₂	10.78	1.64	13.84	8.86	0.91	0.39	1.43	0.58	42.61	2.82	53.94	24.34
T₃ × C₂	10.64	1.40	14.91	8.84	1.36	0.11	0.89	0.76	35.70	2.62	48.74	22.07
SEm±	0.65	0.16	0.65	0.64	0.05	0.02	0.07	0.07	2.16	0.79	1.86	2.31
C.D_{0.05}	NS	NS	NS	NS	0.16	0.06	0.22	0.21	6.90	NS	5.93	NS

Irrespective of the agroforestry systems, under climatic conditions, the uptake of N, P < K and Ca was maximum under C₁ climatic condition than C₂ climatic condition. However, their effect was significant for P and K only. In the interaction effect only the uptake of the N and K was found to be significantly influenced.

4.4.4.3. Nutrient uptake by weeds and grasses (Kg ha⁻¹ yr⁻¹)

The nutrient uptake by different components of the weeds and grasses was displayed in the Table 29.

4.4.4.3.1. Nutrient uptake by weed shoots (Kg ha⁻¹yr⁻¹)

It is evident from the data presented in the Table 29 that nutrient uptake of the N, P K and Ca was found to be significantly influenced due to the agroforestry systems, climatic conditions and interaction effect between them.

4.4.4.3.2. Nutrient uptake by weed roots (Kg ha⁻¹yr⁻¹)

It is crystal clear from the data presented in the Table 29 that the only uptake of P was found to be significantly influenced due to the average and interaction effect. P uptake was maximum in the AH followed by AS and AHS system. Irrespective of the AS system, C₁ climatic conditions displayed significantly higher uptake of P than C₂ climatic condition.

Interaction effect between agroforestry systems and climatic condition did not depict any consistent trend.

4.4.4.3.3. Nutrient uptake by grass shoots in different agroforestry systems (Kg ha⁻¹yr⁻¹)

Data in Table 29 shows that only uptake of the N was found to be significantly influenced due to the average effect and interaction effect. In the agroforestry systems, uptake rate of N were maximum in AH system followed by AHS and AS system. Irrespective of the AS system, C₁ climatic conditions displayed higher uptake of N than C₂ climatic condition.

In the interaction effect, the uptake rate of the N declined from C₁ climatic condition to C₂ climatic condition under all the agroforestry systems.

Table 29. Effect of agroforestry systems, climatic conditions and their interaction on nutrient uptake (Kg ha⁻¹ yr⁻¹) by different part of weeds and grasses under dry temperate region of north western Himalaya

Agroforestry systems (T)	Nutrient uptake by different part of weed and grasses (Kg ha ⁻¹ yr ⁻¹)															
	Weed shoots				Weed roots				Grass shoots				Grass roots			
	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
T₁ (AH)	2.84	0.46	5.50	5.46	0.64	0.16	1.42	1.23	14.07	1.85	17.93	20.56	3.77	0.68	5.78	6.53
T₂ (AS)	3.22	0.73	6.10	5.67	0.69	0.14	1.53	1.20	9.96	1.69	15.07	20.32	4.57	0.65	5.47	6.64
T₃ (AHS)	2.46	0.44	3.93	3.93	0.49	0.11	0.91	0.85	10.61	1.66	17.62	17.26	3.59	0.51	5.63	5.01
SEm±	0.50	0.14	1.16	1.31	0.13	0.001	0.31	0.19	0.13	0.22	2.36	0.91	0.59	0.03	0.12	0.29
C.D_{0.05}	NS	NS	NS	NS	NS	0.004	NS	NS	0.42	NS	NS	NS	NS	0.09	NS	0.92
Climatic conditions(C)																
C₁	2.77	0.66	5.42	4.81	0.64	0.14	1.45	1.12	13.39	1.73	18.05	18.36	3.67	0.65	5.79	5.84
C₂	2.90	0.42	4.93	5.23	0.57	0.13	1.12	1.06	9.70	1.73	15.70	20.39	4.28	0.58	5.45	6.28
SEm±	0.41	0.11	0.95	1.07	0.11	0.001	0.26	0.15	0.11	0.18	1.93	0.75	0.48	0.02	0.10	0.24
C.D_{0.05}	NS	NS	NS	NS	NS	0.003	NS	NS	0.34	NS	NS	NS	NS	NS	0.32	NS
Agroforestry systems (T) × Climatic conditions (C)																
T₁ × C₁	1.96	0.40	4.69	4.00	0.65	0.18	1.44	1.13	14.69	1.79	18.91	20.35	3.92	0.67	5.86	6.23
T₂ × C₁	3.76	1.08	7.36	6.20	0.76	0.12	1.91	1.42	11.66	1.64	20.63	20.03	4.20	0.69	5.54	6.88
T₃ × C₁	2.59	0.50	4.20	4.24	0.51	0.11	1.00	0.82	13.81	1.76	14.61	14.70	2.88	0.58	5.97	4.40
T₁ × C₂	3.71	0.52	6.30	6.92	0.62	0.13	1.39	1.32	13.44	1.91	16.95	20.76	3.61	0.68	5.69	6.82
T₂ × C₂	2.67	0.37	4.83	5.14	0.62	0.15	1.15	0.97	8.26	1.73	9.51	20.60	4.94	0.61	5.39	6.39
T₃ × C₂	2.32	0.38	3.66	3.62	0.46	0.11	0.81	0.88	7.40	1.55	20.63	19.81	4.29	0.44	5.28	5.62
SEm±	0.71	0.20	1.64	1.86	0.19	0.002	0.44	0.27	0.19	0.32	3.34	1.29	0.83	0.04	0.17	0.41
C.D_{0.05}	NS	NS	NS	NS	NS	0.006	NS	NS	0.60	NS	NS	NS	NS	NS	NS	NS

4.4.4.3.4. Nutrient uptake by grass roots ($\text{Kg ha}^{-1}\text{yr}^{-1}$)

It is evident from the data in the Table 30 that both P and Ca nutrients uptake by the roots of the grasses was significantly higher under the AH and AS systems over AHS system. In the effect of climatic conditions, the C_1 displayed significantly higher value over C_2 climatic condition for K and uptake only. Interaction effect between the agroforestry system and the climatic condition could not exercise any significant influence on the uptake of any of the nutrients under investigation.

4.4.4.4. Nutrient uptake by shrubs ($\text{Kg ha}^{-1}\text{yr}^{-1}$)

The nutrient uptake by the different components of the shrubs – stem, branch, leaf and roots is being presented in the Table 30.

4.4.4.4.1. Nutrient uptake by shrubs stems ($\text{Kg ha}^{-1}\text{yr}^{-1}$)

It is crystal clear from the data presented in the Table 31 that agroforestry system as well as interaction effect between agroforestry systems and climatic conditions failed to exercise significant influence on the uptake rate of any of the nutrients under investigations.

Irrespective of the agroforestry system, C_2 climatic conditions dimpled significantly higher uptake of all the nutrients – N, P, K and Ca than C_1 climatic condition.

4.4.4.4.2. Nutrient uptake by shrub branches ($\text{Kg ha}^{-1}\text{yr}^{-1}$)

It is evident from the data in the Table 30 that in the average effect of the agroforestry system, only Ca uptake rate was significantly influenced. Both AS and AHS systems displayed significantly higher uptake of Ca than AH system.

Irrespective of the agroforestry system nutrient uptake of all the investigated elements were found to be significantly higher in C_2 climatic condition than C_1 climatic condition whereas, the interaction effect failed to exercise any significant influence on the uptake rate of any of the elements.

4.4.4.4.3. Nutrient uptake by shrubs leaf ($\text{Kg ha}^{-1}\text{yr}^{-1}$)

Data demonstrated in the Table 30 shows that only P content of shrub leaf could be influenced due to agroforestry systems only. It was found to be significantly higher in AH system than AS or AHS system. Uptake rate of the nutrient- N, P, K and Ca was significantly

Table 30. Effect of agroforestry systems, climatic conditions and their interaction on nutrient uptake (Kg ha⁻¹ yr⁻¹) by different parts of shrubs under dry temperate regions of north western Himalaya

Agroforestry systems (T)	Nutrient uptake by different part of shrubs (Kg ha ⁻¹ yr ⁻¹)															
	Shrub stem				Shrub branch				Shrub leaf				Shrub root			
	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
T ₁ (AH)	0.20	0.07	0.38	0.50	0.24	0.05	0.38	0.34	0.50	0.10	0.74	0.99	0.34	0.13	0.76	0.79
T ₂ (AS)	0.21	0.05	0.42	0.41	0.31	0.06	0.51	0.60	0.31	0.05	0.59	0.67	0.19	0.14	0.47	0.46
T ₃ (AHS)	0.16	0.07	0.35	0.45	0.24	0.04	0.35	0.60	0.21	0.05	0.38	0.47	0.24	0.05	0.41	0.50
SEm±	0.03	0.04	0.08	0.10	0.07	0.02	0.11	0.04	0.08	0.01	0.11	0.15	0.03	0.06	0.05	0.06
C.D _{0.05}	NS	NS	NS	NS	NS	NS	NS	0.13	NS	0.04	NS	NS	0.08	NS	0.15	0.20
Climatic conditions(C)																
C ₁	0.09	0.03	0.21	0.24	0.12	0.03	0.25	0.27	0.16	0.04	0.31	0.43	0.18	0.12	0.43	0.45
C ₂	0.29	0.10	0.56	0.66	0.40	0.07	0.57	0.75	0.52	0.10	0.83	0.99	0.33	0.09	0.66	0.71
SEm±	0.03	0.03	0.07	0.08	0.06	0.01	0.09	0.03	0.06	0.01	0.09	0.12	0.02	0.05	0.04	0.05
C.D _{0.05}	0.09	0.04	0.21	0.26	0.18	0.04	0.29	0.11	0.20	0.03	0.29	0.40	0.07	NS	0.12	0.16
Agroforestry systems (T) × Climatic conditions (C)																
T ₁ × C ₁	0.04	0.02	0.13	0.14	0.08	0.02	0.15	0.17	0.13	0.03	0.24	0.42	0.17	0.06	0.36	0.41
T ₂ × C ₁	0.15	0.03	0.27	0.27	0.17	0.03	0.34	0.37	0.23	0.04	0.46	0.53	0.21	0.25	0.63	0.58
T ₃ × C ₁	0.08	0.04	0.22	0.31	0.12	0.03	0.27	0.28	0.12	0.03	0.24	0.34	0.17	0.05	0.30	0.36
T ₁ × C ₂	0.37	0.12	0.63	0.85	0.40	0.08	0.62	0.51	0.87	0.16	1.25	1.55	0.51	0.20	1.16	1.16
T ₂ × C ₂	0.26	0.07	0.57	0.54	0.44	0.09	0.68	0.83	0.39	0.06	0.73	0.82	0.16	0.03	0.30	0.34
T ₃ × C ₂	0.23	0.10	0.48	0.58	0.36	0.05	0.42	0.92	0.30	0.06	0.52	0.60	0.31	0.06	0.53	0.64
SEm±	0.05	0.06	0.11	0.14	0.10	0.02	0.16	0.06	0.11	0.02	0.16	0.21	0.04	0.08	0.06	0.09
C.D _{0.05}	NS	NS	NS	NS	NS	NS	NS	NS	0.35	0.05	NS	NS	0.11	NS	0.21	0.28

higher in C₂ climatic condition than C₁ climatic condition. In the interaction effect, only the uptake rate of the N and P was significantly influenced due to interaction effect.

4.4.4.4. Nutrient uptake by shrubs root (Kg ha⁻¹yr⁻¹)

It is evident from the data in the Table 30 that N, K and Ca uptake rate by shrub roots was significantly higher in the agrihorticulture system than AS and AHs system.

Irrespective of the agroforestry system, the uptake rate of N, K and Ca was significantly higher in C₂ climatic condition than C₁ climatic condition. Interaction effect between agroforestry systems and climatic conditions significantly influenced the uptake rate of the N, K and Ca. was significantly higher in C₂ climatic condition than C₁ climatic condition. Interaction effect between agroforestry systems and climatic conditions significantly influenced the uptake rate of the N, K and Ca.

4.4.4.5. Total nutrient uptake by trees and shrubs (Kg ha⁻¹ yr⁻¹)

Total nutrient uptake of N, P, K and Ca by trees and shrubs is being demonstrated in Table 31.

4.4.4.5.1. Total nutrient uptake rate by trees (Kg ha⁻¹ yr⁻¹)

It is evident from the data in the Table 31 that none of the nutrients- N, P, K and Ca uptake rate was significantly influenced due to agroforestry systems effect. Similarly, climatic conditions failed to influence the overall nutrient uptake rate of any of the nutrients. In the interaction effect, only the level of the K was found to be significantly influenced due to the interaction effect. The level of K declined in T₁ and T₂ from C₁ to C₂ climatic condition whereas in T₃ the trend was reverses.

4.4.4.5.2. Total nutrient uptake rate by shrubs (Kg ha⁻¹ yr⁻¹)

None of the nutrient- N, P, Ca and K uptake rate was significantly influenced due to average effect of the agroforestry systems (Table32). Irrespective of the agroforestry system, N and Ca uptake were significantly higher in C₂ climatic condition than C₁ climatic condition. Interaction between agroforestry systems and climatic conditions significantly influenced the uptake rate of N, K and Ca.

Almost similar nutrient uptake by tree and shrubs were observed in both climatic conditions. The variation in tree nutrient uptake may be due to age, root: shoot ratio,

composition of components, applied management practices under different agroforestry systems and revealing temperature. Temperature can also stimulate nutrient transportation in soils and nutrient uptake by roots Hobbie *et al.*, (2002). Due to long dry cold climatic conditions a quite variation was observed in tree nutrient uptake both climatic conditions but the variation was found to be non-significant. Marschner (1990) and Lambers *et al.*, (1998) also found that nutrient uptake by seedlings in the 9 °C treatment was probably reduced as a result of the low activity of root nutrient transport.

4.4.4.6. Total nutrient uptake by agriculture crops, weeds and grasses (Kg ha⁻¹ yr⁻¹)

Total nutrient uptake rate of agriculture crops, weeds and grasses have been depicted in the Table 32.

4.4.4.6.1. Total nutrient uptake by agriculture crops (Kg ha⁻¹ yr⁻¹)

It is evinced from the data in the Table 32 that agrisilviculture T₂ system displayed maximum uptake of N and K followed by AH and AHS systems whereas, P and Ca were found to be maximum in T₁ which was found to be significantly higher than T₃ only.

Irrespective of the agroforestry systems, agroforestry total uptake rate of the N, P and K was maximum in C₁ climatic condition than in comparison to C₂ climatic condition.

Interaction effect between agroforestry system and climatic condition exercised significant influence on the uptake rate of N and K.

Due to cold dry climatic condition, nutrients availability decreases at low temperature and moisture content because of reduced root activity, low rates of dissolution and diffusion of nutrients results reduction in nutrient uptake by crop in C₂ climatic condition. As nutrient uptake is a function of nutrient content and biomass production of the crops, the increase in nutrient availability resulted in significant increase in nutrient uptake by crops as seen in the present study. Growth and nutrient uptake is affected by soil temperature. Soil temperature may influence the physico-chemical and biological processes which affect nutrient availability in soils, and in turn affect plant nutrient uptake (Hussain and Maqsood 2011).

4.4.4.6.2. Total nutrient uptake by weeds (Kg ha⁻¹ yr⁻¹)

It is evident from the data presented in the Table 32 that total nutrient uptake rate of N, P, K and Ca were not found to be significantly influenced due to agroforestry system, climatic conditions and interaction effect between them.

Table 31. Effect of agroforestry systems, climatic conditions and their interaction on total nutrient uptake (Kg ha⁻¹ yr⁻¹) by tree and shrubs under dry temperate climatic conditions of north western Himalaya

Agroforestry systems (T)	Total nutrient uptake by trees and shrubs (Kg ha ⁻¹ yr ⁻¹)							
	Trees nutrient uptake (Kg ha ⁻¹ yr ⁻¹)				Shrubs nutrient uptake (Kg ha ⁻¹ yr ⁻¹)			
	N	P	K	Ca	N	P	K	Ca
T₁ (AH)	31.23	6.15	41.42	32.36	1.28	0.34	2.27	2.61
T₂ (AS)	25.45	5.63	37.82	32.64	1.01	0.30	1.99	2.14
T₃ (AHS)	27.33	7.51	35.86	32.75	0.85	0.22	1.49	2.02
SEm±	2.89	39.02	3.17	3.11	0.15	0.07	0.24	0.22
C.D_{0.05}	NS	NS	NS	NS	NS	NS	NS	NS
Climatic conditions(C)								
C₁	28.63	6.23	38.44	31.68	0.56	0.21	1.20	1.40
C₂	27.38	6.64	38.29	33.49	1.54	0.36	2.63	3.11
SEm±	2.36	31.86	2.59	2.54	0.12	0.06	0.20	0.18
C.D_{0.05}	NS	NS	NS	NS	0.39	NS	0.63	0.57
Agroforestry systems (T) × Climatic conditions (C)								
T₁ × C₁	34.85	7.13	47.26	31.40	0.42	0.13	0.88	1.15
T₂ × C₁	28.93	7.03	40.83	37.54	0.76	0.36	1.71	1.75
T₃ × C₁	22.11	4.52	27.24	26.10	0.50	0.16	1.03	1.30
T₁ × C₂	27.61	5.18	35.57	33.31	2.15	0.55	3.67	4.07
T₂ × C₂	21.98	4.23	34.81	27.75	1.25	0.25	2.28	2.53
T₃ × C₂	32.55	10.50	44.47	39.39	1.21	0.27	1.96	2.74
SEm±	4.09	55.18	4.49	4.40	0.21	0.11	0.34	0.31
C.D_{0.05}	NS	NS	14.32	NS	0.67	NS	1.09	0.99

Table 32. Effect of agroforestry systems, climatic conditions and their interaction on total nutrient uptake (Kg ha⁻¹ yr⁻¹) by agriculture crop, weeds and grasses at different agroforestry systems under different climatic conditions

Agroforestry Systems (T)	Total nutrient uptake by agriculture crop, weeds and grass (Kg ha ⁻¹ yr ⁻¹)											
	Agriculture crops total nutrient uptake				Weeds total nutrient uptake				Grass total nutrient uptake			
	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
T₁ (AH)	50.77	8.32	73.16	45.29	3.47	0.62	6.91	6.69	17.83	2.53	23.70	27.08
T₂ (AS)	59.69	7.48	78.82	36.60	3.91	0.86	7.62	6.87	14.52	2.33	20.53	26.95
T₃ (AHS)	45.59	5.44	64.33	33.00	2.94	0.55	4.84	4.78	14.19	2.16	23.25	22.26
SEm±	1.53	0.47	1.53	1.50	0.62	0.14	1.46	1.44	0.64	0.21	2.41	1.12
C.D_{0.05}	4.89	1.51	4.89	4.78	NS	NS	NS	NS	2.03	NS	NS	3.57
Climatic conditions(C)												
C₁	54.04	8.81	76.38	39.63	3.41	0.80	6.87	5.94	17.05	2.37	23.84	24.20
C₂	50.00	5.35	67.83	36.96	3.47	0.56	6.05	6.28	13.98	2.31	21.15	26.67
SEm±	1.25	0.39	1.25	1.22	0.51	0.11	1.19	1.17	0.52	0.17	1.97	0.91
C.D_{0.05}	3.99	1.23	3.99	NS	NS	NS	NS	NS	1.65	NS	NS	NS
Agroforestry systems (T) × Climatic conditions (C)												
T₁ × C₁	53.53	9.57	76.59	45.13	2.61	0.58	6.13	5.13	18.61	2.46	24.77	26.58
T₂ × C₁	65.09	10.11	88.43	39.41	4.52	1.20	9.27	7.63	15.85	2.32	26.17	26.91
T₃ × C₁	43.49	6.75	64.11	34.34	3.10	0.61	5.20	5.06	16.68	2.33	20.58	19.10
T₁ × C₂	48.02	7.07	69.73	45.44	4.33	0.65	7.69	8.24	17.05	2.59	22.63	27.58
T₂ × C₂	54.29	4.85	69.21	33.78	3.30	0.52	5.98	6.10	13.20	2.34	14.89	26.99
T₃ × C₂	47.70	4.14	64.54	31.66	2.77	0.50	4.47	4.50	11.69	1.99	25.91	25.43
SEm±	2.17	0.67	2.17	2.12	0.88	0.20	2.06	2.03	0.90	0.30	3.41	1.58
C.D_{0.05}	6.92	NS	6.92	NS	NS	NS	NS	NS	NS	NS	NS	NS

4.4.4.6.3. Total nutrient uptake by grasses ($\text{Kg ha}^{-1} \text{ yr}^{-1}$)

It is evident from the data presented in the Table 32 that N and Ca uptake rate was significantly influenced by agroforestry systems. Both of these nutrients displayed their maximum value in AH system followed by AS and AHS system, respectively.

Irrespective of agroforestry systems, climatic conditions significantly influenced the total uptake rate of N by the grasses. C_1 climatic conditions displayed significantly higher values of N than C_2 climatic condition. Interaction effect between the agroforestry system and climatic condition failed to exercise any significant influence. Variation in nutrient uptake by grass was mainly due to management practices, composition of components and competition for space light as well as the nutrient.

4.4.4.6.4. Total nutrient stock in vegetation (Kg ha^{-1}) and total uptake ($\text{Kg ha}^{-1}\text{yr}^{-1}$) by vegetation (Tree+Crop+Weeds+Grass).

Data cited in Table 33 shows total stock in vegetation and total uptake by whole vegetation under different agroforestry system at Kinnaur district Himachal Pradesh.

4.4.4.6.4.1. Total nutrient stock in vegetation (Kg ha^{-1})

It is clear from the data presented in Table 33 that the total stock of N, P and K nutrient in vegetation significantly influenced by agroforestry system except Ca. The maximum stock of N, P and K was significantly higher in AH system followed by AHS system whereas minimum stock was found in AS system.

The climatic condition was found to significant influence on total stock of K under vegetation only. The maximum value of K stock ($684.48 \text{ Kg ha}^{-1}$) was found in C_1 climatic condition which was significantly than C_2 climatic condition.

The interaction between agroforestry systems and climatic conditions was found to be non-significantly influenced the total nutrient stock under whole vegetation in agroforestry systems. Non-significant but maximum values of N, P, K and Ca were found in treatment combination of T_2C_1 .

Table 33. Effect of agroforestry systems, climatic condition and their interaction on total nutrient stock in vegetation (Kg ha⁻¹) and total nutrient uptake (Kg ha⁻¹yr⁻¹) by vegetation in different agroforestry systems at dry temperate climatic conditions of north western Himalaya (Tree+Crop+Weeds+Grass)

Agroforestry systems (T)	Total nutrient stock in vegetation (Kg ha ⁻¹)				Total nutrient uptake by vegetation (Kg ha ⁻¹ yr ⁻¹)			
	N	P	K	Ca	N	P	K	Ca
T ₁ (AH)	344.21	55.20	529.03	480.32	104.58	17.96	147.46	114.03
T ₂ (AS)	480.14	99.45	768.52	579.00	104.58	16.60	146.78	105.88
T ₃ (AHS)	451.16	81.59	668.18	560.87	90.90	15.88	129.77	94.81
SEm±	25.92	5.50	20.16	36.88	3.70	0.58	4.08	3.49
C.D _{0.05}	82.72	17.55	64.35	NS	11.82	NS	13.03	11.13
Climatic conditions(C)								
C ₁	415.12	82.71	684.48	548.12	102.04	18.34	141.91	107.21
C ₂	435.21	74.78	626.01	532.01	98.00	15.29	140.76	102.60
SEm±	21.16	4.49	16.46	30.11	3.02	0.47	3.33	2.85
C.D _{0.05}	NS	NS	52.54	NS	NS	1.51	NS	NS
Agroforestry systems (T) × Climatic conditions (C)								
T ₁ × C ₁	321.67	51.42	569.66	463.54	108.38	19.71	153.93	112.20
T ₂ × C ₁	522.48	116.06	816.96	640.87	108.65	20.47	155.24	114.67
T ₃ × C ₁	401.22	80.65	666.81	539.94	89.09	14.83	116.56	94.77
T ₁ × C ₂	366.75	58.97	488.41	497.11	100.78	16.20	140.98	115.86
T ₂ × C ₂	437.79	82.84	720.08	517.12	100.52	12.72	138.31	97.09
T ₃ × C ₂	501.09	82.52	669.54	581.81	92.71	16.93	142.99	94.85
SEm±	36.65	7.78	28.51	52.16	5.24	0.82	5.77	4.93
C.D _{0.05}	NS	NS	NS	NS	NS	2.62	18.42	NS

4.4.4.6.4.2. Total nutrient uptake by vegetation (Kg ha⁻¹yr⁻¹) (Tree + Crop + Weeds + Grass)

Data in Table 33 shows that the agroforestry systems that the total uptake of N, K and Ca by whole vegetation significantly influenced due to the agroforestry systems. The maximum uptake of was found in AH and AS systems, whereas, maximum stock of K and Ca was found in AH system, which was found to be significantly higher than all other agroforestry systems.

Irrespective of climatic conditions the P uptake was found to be significantly higher in C₁ climatic condition than C₂ climatic condition. Interaction effect displayed that interaction between agroforestry systems and climatic conditions significantly influenced the total uptake of P and Ca. The total uptakes of these elements were found to be significantly higher in the treatment combination T₂C₁.

Results of present study is more comparable with other researchers Lodhiyal *et al.*, (1995b) and Singh and Singh (1992).

4.4.5. Concentration percentage (dry weight basis) of various components

Nutrient concentration of different components of the trees is presented in the Table 34.

4.4.5.1. Trees stem nutrient concentration percentage (dry weight basis)

It is evident from the data presented in the Table 34 that the concentration of the N, P, K and Ca in the tree stem is significantly influenced due to the agroforestry systems. The content of N was found to be significantly higher in AH (0.23%) than AHS and AS system whereas the content of P was maximum in AH and AHS. The concentration of K and Ca was found to be significantly higher in AH than AS and AHS systems.

Irrespective of the agroforestry systems, the K (0.73%) concentration was found to be significantly higher in dry temperate high hills (C_1) climatic condition than High hills temperate dry and cold (C_2) climatic condition.

Interaction effect between agroforestry systems and climatic conditions significantly influenced the concentration of the N and K. The concentration of N was maximum in T_1C_2 and that of K in T_1C_1 .

4.4.5.2. Tree branch nutrient concentration percentage (dry weight basis)

In the average effect of the agroforestry systems, the concentration of the N, K and Ca were significantly influenced due to the effects of the agroforestry systems. Maximum N concentration was found in AS system (0.25%) which was significantly higher than AH and AHS whereas, the concentration of K in tree branch was significantly highest in the AH system which however remained statistically higher than AS and AHS system. The Ca concentration was maximum in AS (0.47%) system which remained statistically at par with AH system only (Table 34).

Irrespective of the agroforestry system, climatic conditions significantly influenced the concentration of the N, K and Ca. The concentration of the nutrients – N, K and Ca was found to be significantly higher in the tree branches of the dry temperate high hills (C_1) than high hills temperate dry and cold condition (C_2).

Table 34. Effect of agroforestry systems, climatic conditions and their interaction on tree nutrient concentration % (dry weight basis) under dry temperate climatic conditions of north western Himalaya

Agroforestry systems (T)	Nutrient concentration % (dry weight basis)																			
	Tree stem (%)				Tree branch (%)				Tree leaf (%)				Tree root (%)				Tree fruits (%)			
	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
T ₁ (AH)	0.23	0.03	0.93	0.70	0.22	0.13	0.47	0.27	1.77	0.24	1.44	1.24	0.48	0.12	0.56	0.36	1.72	0.39	2.31	2.08
T ₂ (AS)	0.21	0.01	0.36	0.34	0.25	0.15	0.42	0.33	1.21	0.29	1.27	1.17	0.57	0.18	0.63	0.44	0.98	0.22	1.48	1.30
T ₃ (AHS)	0.18	0.03	0.42	0.30	0.17	0.14	0.34	0.20	1.32	0.22	1.48	1.21	0.55	0.14	0.66	0.63	1.11	0.22	1.32	1.25
SEm±	0.01	0.003	0.03	0.11	0.004	0.02	0.01	0.02	0.01	0.02	0.05	0.05	0.01	0.02	0.01	0.05	0.02	0.03	0.18	0.20
C.D _{0.05}	0.02	0.01	0.08	0.33	0.01	NS	0.02	0.07	0.04	0.05	0.17	NS	0.02	NS	0.02	0.17	0.05	0.11	0.59	0.62
Climatic conditions(C)																				
C ₁	0.20	0.02	0.73	0.46	0.23	0.18	0.49	0.32	1.35	0.27	1.46	1.14	0.46	0.15	0.65	0.47	1.09	0.25	1.43	1.36
C ₂	0.21	0.02	0.41	0.43	0.19	0.09	0.33	0.21	1.51	0.23	1.32	1.27	0.61	0.14	0.58	0.48	1.45	0.30	1.97	1.72
SEm±	0.004	0.003	0.02	0.09	0.003	0.02	0.01	0.02	0.01	0.01	0.04	0.04	0.004	0.02	0.01	0.04	0.012	0.03	0.15	0.16
C.D _{0.05}	NS	NS	0.07	NS	0.01	NS	0.02	0.06	0.03	0.04	0.14	0.14	0.01	NS	0.02	NS	0.04	NS	0.48	NS
Agroforestry systems (T) × Climatic conditions (C)																				
T ₁ × C ₁	0.21	0.02	1.34	0.77	0.21	0.19	0.61	0.27	1.67	0.21	1.60	1.33	0.22	0.11	0.70	0.22	1.21	0.27	1.44	1.46
T ₂ × C ₁	0.20	0.01	0.36	0.30	0.30	0.21	0.49	0.46	1.10	0.36	1.25	1.04	0.6	0.19	0.42	0.48	1.09	0.29	1.71	1.60
T ₃ × C ₁	0.19	0.03	0.48	0.32	0.18	0.15	0.36	0.23	1.28	0.23	1.53	1.04	0.55	0.15	0.83	0.71	0.96	0.18	1.15	1.03
T ₁ × C ₂	0.25	0.03	0.52	0.62	0.22	0.06	0.32	0.27	1.86	0.26	1.27	1.15	0.74	0.13	0.41	0.50	2.23	0.51	3.18	2.70
T ₂ × C ₂	0.21	0.01	0.36	0.38	0.20	0.10	0.35	0.19	1.32	0.21	1.28	1.29	0.54	0.17	0.83	0.40	0.87	0.15	1.25	1.00
T ₃ × C ₂	0.17	0.02	0.36	0.28	0.15	0.12	0.32	0.16	1.36	0.21	1.42	1.38	0.54	0.12	0.49	0.55	1.25	0.25	1.49	1.46
SEm±	0.01	0.005	0.04	0.15	0.005	0.03	0.01	0.03	0.02	0.02	0.07	0.07	0.01	0.03	0.01	0.07	0.02	0.05	0.26	0.28
C.D _{0.05}	0.02	NS	0.11	NS	0.02	NS	0.03	0.10	0.06	0.07	NS	0.24	0.02	NS	0.03	0.24	0.07	0.15	0.83	0.88

Interaction effect between agroforestry systems and climatic condition exercised significant influence on the N, K and Ca concentrations. The maximum level of N and Ca was found in treatment combination T₂C₁ while maximum level of K was found in T₁C₁.

4.4.5.3. Tree leaf nutrient concentration percentage (dry weight basis)

The data in Table 34 evinced that the concentration of the nutrients N, P and K in leaves was significantly influenced due to the agroforestry systems. The leaves of the N was maximum in the AH system while P content was exceeded significant in the AHS system than AS and AH system.

Irrespective of the agroforestry system, the concentration of the nutrients- N, P K and Ca were significantly influenced due to climatic conditions. The concentration of N and Ca were significantly more in C₂ climatic condition, the maximum content of P and K was recorded higher in C₁ climatic condition than C₂ climatic condition.

The interaction between the agroforestry system and climatic condition showed that N, P and Ca concentration was significantly influenced where different nutrients recorded their maximum concentration in different treatment combinations.

From the above investigation it is clear that nitrogen concentration in leaf of tree is higher at high hills temperate dry and cold (C₂) climatic condition than dry temperate high hills (C₁) climatic condition this elevational increase of nitrogen content per unit leaf area appears to be largely attributable to increases in leaf thickness which corresponds to reduced specific leaf area (SLA). This confirms observations by Korner, Bannister & Mark (1986) in the mountains of New Zealand.

4.4.5.4. Tree root nutrient concentration percentage (dry weight basis)

The concentration of N, K and Ca were found to be significantly influenced due to effect of agroforestry systems and interaction between agroforestry systems and climatic conditions (Table 34). The maximum concentration of K and Ca was found in AHS system while maximum level of N was found in AS system. The climatic condition significantly influenced the tree root N and K concentration only. The maximum level of N was found in C₂ climatic condition while maximum level of K was recorded in C₁ climatic condition.

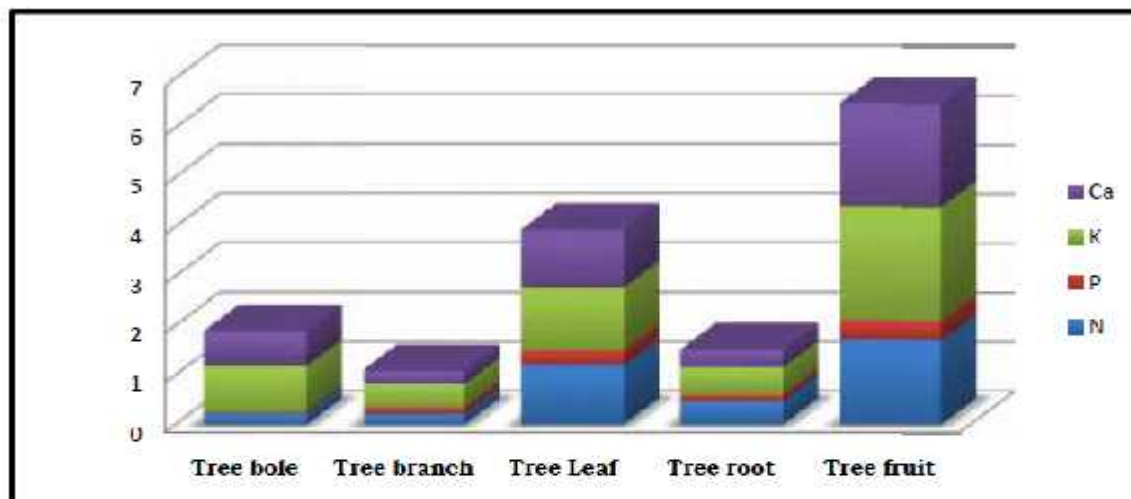


Fig.6. Nutrient concentration (%) in different tree parts of agrihorticulture system

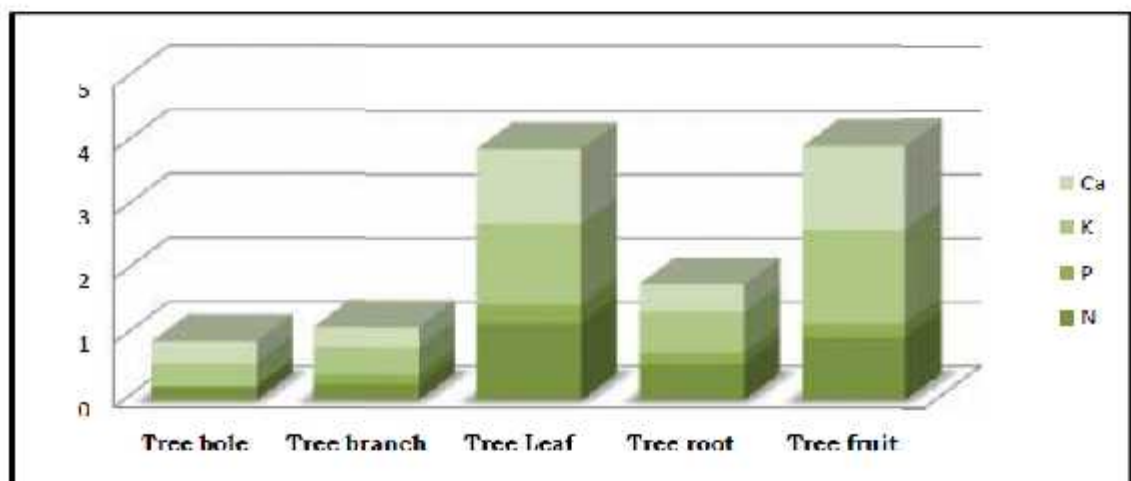


Fig.7. Nutrient concentration (%) in different tree parts of agrisilviculture system

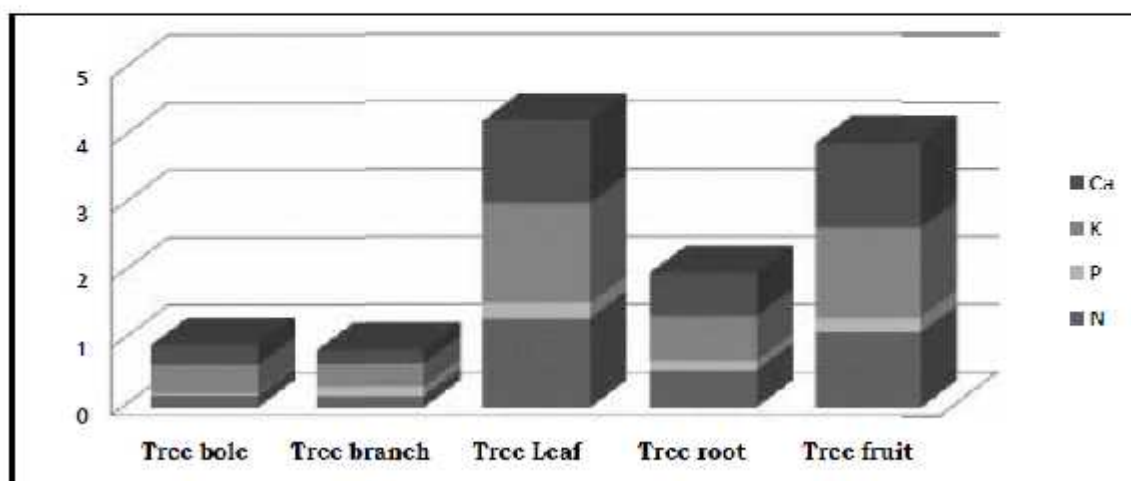


Fig.8. Nutrient concentration (%) in different tree parts of agrihortisilviculture system

4.4.5.5. Tree fruit nutrient concentration percentage (dry weight basis)

The data presented in Table 34 shows that N, P K and Ca concentration in fruits was significantly influenced due to agroforestry systems. The concentration of all of these elements was found to be significantly higher in AH system in comparison of AS and AHS systems.

The climatic conditions significantly influenced the K and Ca contents, though the concentration of all the nutrients N, P, K and Ca exceeded distinctly in C₂ than C₁ climatic condition.

Interaction effect between the agroforestry systems and climatic conditions significantly influenced the nutrient concentrations. Maximum level of the N, K and Ca were found in the treatment combination of T₁C₂ while maximum level of P was observed in T₂C₁ which was found to be significantly higher than all other treatment combinations.

4.4.5.6. Shrub nutrient concentration percentage (dry weight basis)

Data in respect of the nutrient concentration of the different compartment of shrubs is being presented in Table 35.

4.4.5.6.1. Shrub nutrient concentration in shrub stem

It is evident from the data in the table 35 that N and Ca content were significantly influenced due to agroforestry systems. Both of these elements displayed their maximum level in the agrisilviculture system followed by AHS and AH, respectively in descending order.

In the average effect of the climatic conditions, the nutrient concentrations in the stem of the shrubs were found to be significantly influenced. N, P and Ca were significantly higher in C₂ climatic condition than C₁ climatic condition whereas, K was found to be significantly higher in C₁ over C₂ climatic condition.

Interaction effect between the agroforestry system and climatic conditions significantly influenced the concentration of P, K and Ca. In short branch P, K and Ca did not reveal any significant differences due to agroforestry systems, climatic conditions and their interaction. N expressed significantly executing climatic conditions where C₂ exceeded significantly than C₁ climatic conditions.

Table 35. Effect of agroforestry systems, climatic conditions and their interaction on nutrient concentration % (dry weight basis) of shrubs under dry temperate climatic conditions of north western Himalaya

Agroforestry systems (T)	Nutrient concentration % (dry weight basis) of shrubs															
	Shrub stem (%)				Shrub branch (%)				Shrub leaf (%)				Shrub root (%)			
	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
T₁ (AH)	0.54	0.24	1.44	1.69	1.14	0.24	1.69	2.37	1.35	0.28	2.12	3.24	1.34	0.36	2.77	3.07
T₂ (AS)	1.12	0.26	1.85	2.15	1.21	0.20	1.99	1.98	1.78	0.27	3.00	3.15	1.09	0.21	2.77	2.65
T₃ (AHS)	0.65	0.27	1.72	2.02	1.02	0.20	1.71	1.92	1.19	0.28	2.13	2.52	1.21	0.27	2.12	2.45
SEm±	0.05	0.01	0.01	0.11	0.13	0.96	0.21	0.25	0.20	0.02	0.30	0.18	0.09	0.02	0.22	0.14
C.D_{0.05}	0.15	NS	NS	0.36	NS	NS	NS	NS	NS	NS	NS	0.56	NS	0.08	NS	0.45
Climatic conditions(C)																
C₁	0.60	0.24	1.90	1.78	0.95	0.21	1.72	2.08	1.33	0.26	2.42	3.05	1.26	0.29	2.94	3.03
C₂	0.93	0.27	1.44	2.13	1.29	0.21	1.87	2.10	1.54	0.28	2.41	2.89	1.16	0.27	2.16	2.41
SEm±	0.04	0.01	0.01	0.09	0.11	0.78	0.17	0.21	0.16	0.02	0.24	0.14	0.07	0.02	0.18	0.11
C.D_{0.05}	0.12	0.03	0.03	0.29	0.34	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.58	0.36
Agroforestry systems (T) × Climatic conditions (C)																
T₁ × C₁	0.31	0.20	1.70	1.38	1.04	0.20	1.46	2.23	1.06	0.23	1.92	3.48	1.52	0.32	2.99	3.51
T₂ × C₁	1.01	0.21	2.24	1.74	0.96	0.21	1.80	2.06	1.90	0.29	3.28	3.09	1.20	0.25	3.65	3.19
T₃ × C₁	0.49	0.30	1.75	2.21	0.85	0.22	1.89	1.94	1.04	0.27	2.05	2.57	1.07	0.30	2.19	2.39
T₁ × C₂	0.77	0.27	1.18	2.00	1.23	0.27	1.92	2.51	1.63	0.32	2.32	3.00	1.16	0.40	2.54	2.63
T₂ × C₂	1.23	0.31	1.45	2.55	1.46	0.19	2.18	1.89	1.65	0.25	2.72	3.20	0.97	0.17	1.89	2.10
T₃ × C₂	0.80	0.24	1.69	1.83	1.19	0.18	1.52	1.89	1.33	0.28	2.20	2.46	1.34	0.24	2.05	2.50
SEm±	0.06	0.02	0.02	0.16	0.19	1.35	0.30	0.36	0.28	0.03	0.42	0.25	0.13	0.03	0.32	0.20
C.D_{0.05}	NS	0.06	0.06	0.51	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.63

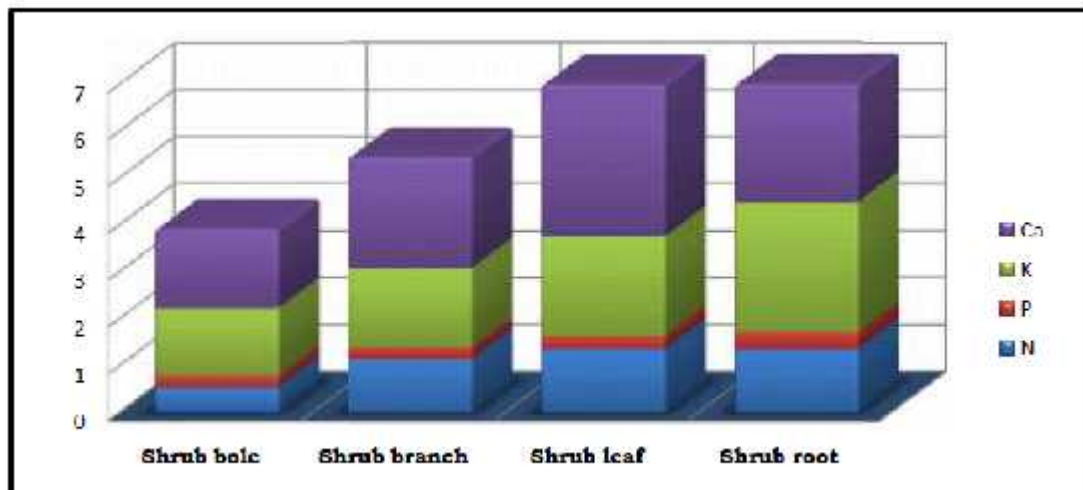


Fig.9. Nutrient concentration (%) in different shrub parts of agrihorticulture system

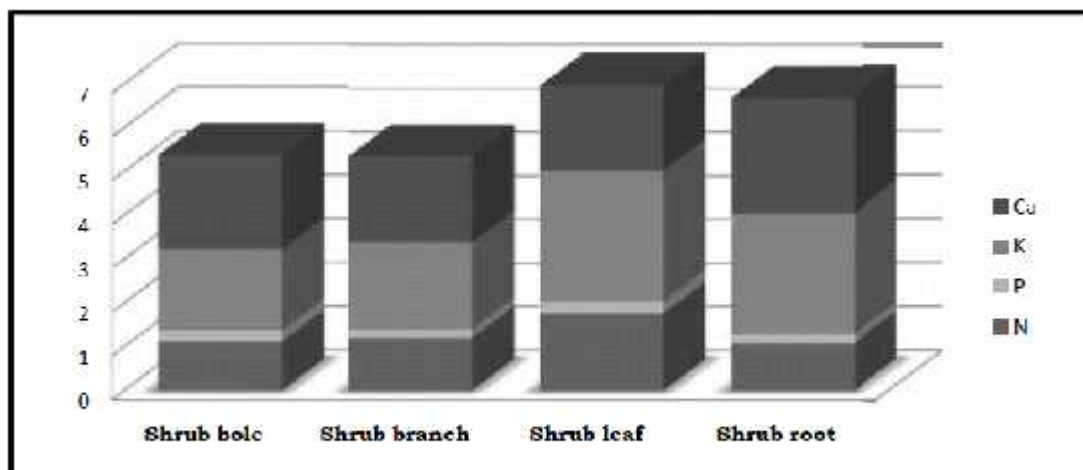


Fig.10. Nutrient concentration (%) in different shrub parts of agrisilviculture system

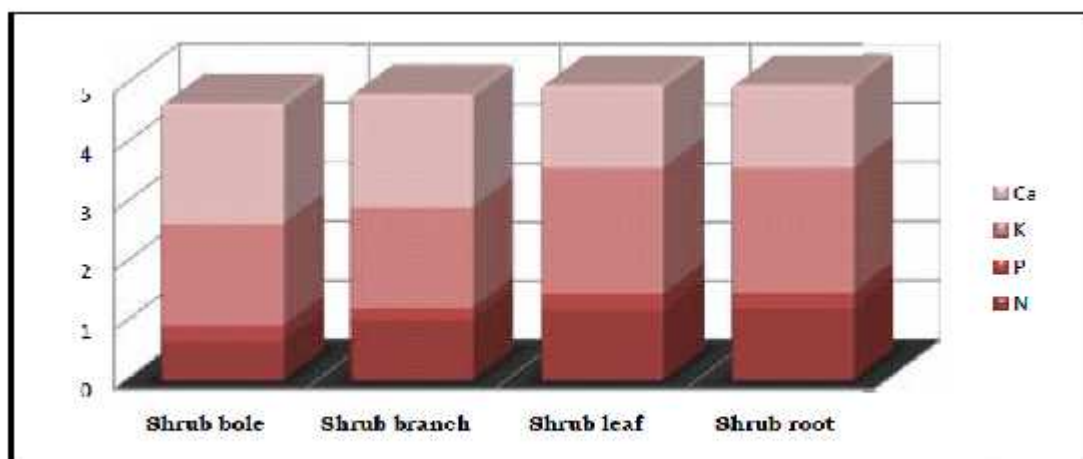


Fig.11. Nutrient concentration (%) in different shrub parts of agrihortisilviculture system

4.4.5.6.2. Shrub leaves nutrient concentration percentage (dry weight basis)

The data presented in Table 35 reveals that Ca concentration in shrubs leaves was significantly influenced due to agroforestry system. Ca concentration of shrubs leaves was found to be significantly highest in the agrihorticulture system than in AHS and AS systems. The effect of agroforestry systems on the nutrient concentration of other elements as well as effect of climatic condition and agroforestry system and climatic conditions interaction effect on all of them was found to be non-significant.

4.4.5.6.3. Shrub root nutrient concentration percentage (dry weight basis)

It is crystal clear from the data in the Table 35 that concentration of the shrub root nutrients P and Ca were found to be significantly superior in AH system compared to other land use systems. The treatments of AS and AHS were found to remain statistically at par with one another.

Irrespective of the agroforestry systems, K and Ca concentration were found to be significantly higher in C₁ climatic condition than C₂ climatic condition. The effect of climatic condition on the N and P concentration was found to be non-significant.

The interaction effect between the agroforestry system and climatic conditions significantly influenced the Ca contents only. In T₁ and T₂, the Ca content declined from C₁ climatic condition to C₂ climatic condition whereas, in T₃ the trend was just reverse.

The shrub nutrient concentration values are quite higher than the values reported by Garkoti (1996). He studied the nutrient dynamics in high altitudes shrubs of Central Hmalaya which may be due to conditions use of fertilizer and improved soil physical and chemical properties.

4.4.5.7. Agriculture crop nutrient concentration percentage (dry weight basis)

The nutrient concentration in the different components of the agricultural crop is being presented in the Table 36.

4.4.5.7.1. Agriculture crop shoots nutrient concentration percentage (dry weight basis)

It is evident from the data presented in the Table 36 that K and Ca concentration were highest in the agricultural crops shoots raised under agrihorticulture systems; K content in

AHS system remained statistically at par with AH system. However, for Ca its concentration in AHS system remained significantly higher than AS and AH systems.

Irrespective of the agroforestry systems, climatic conditions significantly influenced the concentration of N, P and K which were found to be significantly higher in C₂ climatic condition than C₁ climatic condition. Interaction between agroforestry systems and climatic condition failed to exercise significantly influence on any the nutrients.

4.4.5.7.2. Agriculture crop root nutrient concentration percentage (dry weight basis) in different agroforestry systems

Data in the Table 36 demonstrated that the N, P and K concentration of the agricultural crop roots were significantly influenced due to the influence of the agroforestry systems. N concentration was maximum in the roots of agricultural crop found in the AHS systems whereas, P and K concentration of the agricultural crops roots was found to be maximum in the crop raised under the agrisilviculture system, which was found to be significantly higher than all other land use systems.

In the average effect of the climatic conditions only the level of the P (0.39 %) was significantly higher in the roots of agricultural crop growing in the High hills temperate dry and cold climatic conditions (C₂) than Dry temperate high hills climatic conditions (C₁).

Interaction between agroforestry system and climatic conditions demonstrated significant influence on the P and K concentration. The concentration of P was found to be maximum in the treatment combination of T₂C₂ system whereas K concentration was observed to be highest in T₂C₁ treatment combination.

4.4.5.7.3. Agriculture crop grains/fruits nutrient concentration percentage (dry weight basis)

It is quite evident from the Table 36 that P and Ca concentration in the fruits/grains were significantly influenced due to average effect of the agroforestry system. Both P and Ca displayed their maximum values in the agrihorticulture land use system, which was found to be significantly higher than other land use systems. The N and K concentration in crop grain did not reflect statistical difference.

Table 36. Effect of agroforestry systems, climatic conditions and their interaction on agriculture crop nutrient concentration % (dry weight basis) under dry temperate climatic conditions of north western Himalaya

Agroforestry systems (T)	Nutrient concentration % (dry weight basis)											
	Agriculture crop shoots (%)				Agriculture crop roots (%)				Agriculture crop fruits/gains (%)			
	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
T ₁ (AH)	2.38	0.34	3.41	1.98	1.85	0.34	2.50	1.45	2.34	0.41	3.47	2.07
T ₂ (AS)	2.43	0.36	3.21	2.17	1.71	0.47	3.06	1.23	2.56	0.30	3.39	1.45
T ₃ (AHS)	2.63	0.30	3.63	2.41	2.32	0.25	2.05	1.45	2.49	0.29	3.46	1.73
SEm±	0.08	0.02	0.10	0.08	0.10	0.02	0.09	0.08	0.08	0.03	0.09	0.07
C.D _{0.05}	NS	NS	0.31	0.24	0.30	0.06	0.28	NS	NS	0.10	NS	0.22
Climatic conditions(C)												
C ₁	2.35	0.26	3.22	2.27	1.88	0.31	2.64	1.46	2.52	0.45	3.70	1.78
C ₂	2.61	0.41	3.61	2.09	2.03	0.39	2.43	1.29	2.40	0.22	3.17	1.72
SEm±	0.07	0.02	0.08	0.06	0.08	0.02	0.07	0.07	0.07	0.02	0.07	0.06
C.D _{0.05}	0.21	0.06	0.25	NS	NS	0.05	NS	NS	NS	0.08	0.24	NS
Agroforestry systems (T) × Climatic conditions (C)												
T ₁ × C ₁	2.26	0.26	3.19	2.16	1.83	0.38	2.20	1.61	2.56	0.49	3.75	2.01
T ₂ × C ₁	2.17	0.26	2.91	2.13	1.70	0.26	3.37	1.36	2.68	0.45	3.70	1.49
T ₃ × C ₁	2.61	0.26	3.57	2.53	2.11	0.28	2.34	1.42	2.33	0.40	3.66	1.83
T ₁ × C ₂	2.50	0.42	3.64	1.80	1.86	0.29	2.79	1.29	2.11	0.32	3.18	2.13
T ₂ × C ₂	2.69	0.46	3.50	2.20	1.71	0.67	2.75	1.10	2.44	0.15	3.08	1.41
T ₃ × C ₂	2.64	0.34	3.68	2.28	2.52	0.21	1.75	1.47	2.64	0.18	3.25	1.62
SEm±	0.11	0.03	0.14	0.11	0.13	0.03	0.12	0.12	0.11	0.04	0.13	0.10
C.D _{0.05}	NS	NS	NS	NS	NS	0.09	0.39	NS	0.36	NS	NS	NS

In the average effect of the climatic conditions both P and K were found to be significantly higher under C₁ climatic condition than C₂ climatic condition.

Interaction effect between agroforestry systems and climatic conditions depicted that only N concentration was found to be significantly influenced due to their effects. In the T₁ and T₂ agroforestry system the value declined from C₁ to C₂ whereas, in the T₃ the trend was reverse but non-significant.

4.4.5.8. Weeds and grasses nutrient concentration percentage (dry weight basis)

Nutrient concentration in weeds and grasses has been presented in the Table 37.

4.4.5.8.1. Weeds shoot nutrient concentration percentage (dry weight basis)

It is evident from the data presented in the Table 37 that only N and K concentration in weed shoots were significantly influenced due to agroforestry system. Maximum N and K concentration in weed shoots were recorded in the AH systems, which was followed by AS and AHS systems respectively.

Irrespective of the agroforestry systems, N and Ca concentration was significantly higher in the weed shoots growing under C₂ climatic conditions than C₁ climatic conditions.

Interaction effect between agroforestry system and climatic conditions displayed that only N concentration in weed shoots was significantly influenced due to it. The N concentration under T₁ and T₃ enhanced from C₁ to C₂ while in T₂ the trend was just opposite.

4.4.5.8.2. Weed roots nutrient concentration percentage (dry weight basis)

It is clear from the data presented in the Table 37 that agroforestry systems significantly influenced the K and Ca content of the roots of weeds. Maximum concentration of K and Ca was recorded in the agrihorticulture system, which was followed by agrisilviculture and agrihortisilviculture systems.

Irrespective of the climatic conditions failed to significantly influence the concentration of the nutrients of weed roots. In the interaction between agroforestry systems and climatic conditions effect only Ca concentration was found to significantly influence. The concentration of Ca increased in T₁ and T₃ from C₁ climatic condition to C₂ climatic condition, whereas, in T₂ the trend was reverse.

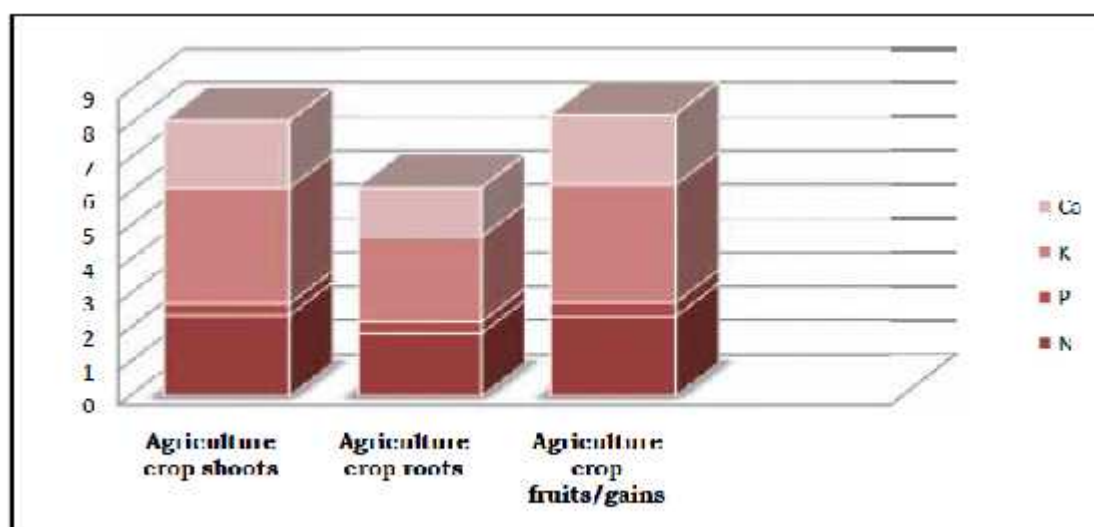


Fig.12. Nutrient concentration (%) in different agriculture crop parts of agrihorticulture system

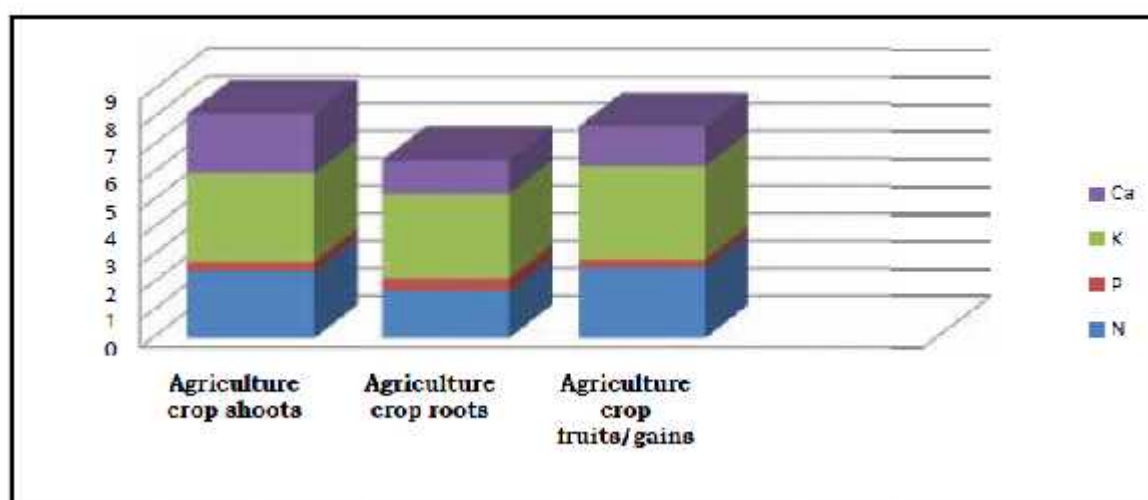


Fig.13. Nutrient concentration (%) in different agriculture crop parts of agrisilviculture system

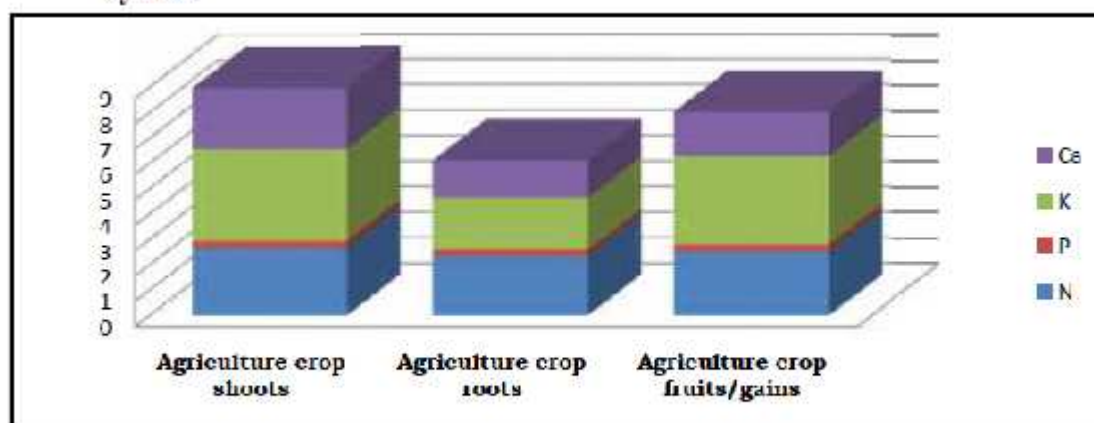


Fig.14. Nutrient concentration (%) in different agriculture crop parts of agrihortisilviculture system

Table 37. Effect of agroforestry systems, climatic conditions and their interaction on nutrient concentration percentage (dry weight basis) of grass and weeds under dry temperate climatic conditions of north western Himalaya

Agroforestry systems (T)	Nutrient concentration percentage (dry weight basis) of grass and weeds															
	Weed shoots (%)				Weed roots (%)				Grass shoots (%)				Grass roots (%)			
	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
T₁ (AH)	1.60	0.26	3.09	2.82	1.21	0.37	2.66	2.49	1.13	0.16	1.35	1.65	1.01	0.18	1.49	1.76
T₂ (AS)	1.39	0.36	2.60	2.27	0.98	0.27	2.21	1.87	1.15	0.19	1.39	2.39	1.53	0.23	1.76	2.19
T₃ (AHS)	1.35	0.25	2.24	2.12	1.06	0.25	1.94	1.86	1.26	0.21	2.10	2.28	1.52	0.25	2.68	2.36
SEm±	0.06	0.08	0.20	0.23	0.07	0.06	0.18	0.08	0.12	0.02	0.01	0.28	0.01	0.03	0.27	0.26
C.D_{0.05}	0.20	NS	0.64	NS	NS	NS	0.57	0.25	NS	NS	0.03	NS	0.05	NS	0.87	NS
Climatic conditions(C)																
C₁	1.30	0.34	2.52	2.07	1.04	0.32	2.33	1.98	1.10	0.14	1.37	1.50	1.04	0.19	1.71	1.65
C₂	1.59	0.24	2.76	2.73	1.13	0.27	2.21	2.16	1.26	0.22	1.86	2.71	1.66	0.25	2.24	2.56
SEm±	0.05	0.07	0.16	0.19	0.06	0.05	0.15	0.07	0.10	0.02	0.01	0.23	0.01	0.03	0.22	0.21
C.D_{0.05}	0.16	NS	NS	0.61	NS	NS	NS	NS	NS	0.06	0.03	0.73	0.04	NS	NS	0.68
Agroforestry systems (T) × Climatic conditions (C)																
T₁ × C₁	1.29	0.26	2.92	2.51	1.17	0.48	2.46	2.25	1.25	0.16	1.46	1.75	1.01	0.18	1.47	1.62
T₂ × C₁	1.46	0.53	2.77	1.89	0.96	0.29	2.62	2.13	0.86	0.11	1.49	1.48	1.16	0.18	1.44	1.74
T₃ × C₁	1.16	0.23	1.88	1.82	0.98	0.20	1.90	1.57	1.18	0.16	1.15	1.26	0.95	0.20	2.21	1.58
T₁ × C₂	1.91	0.26	3.26	3.12	1.25	0.26	2.86	2.72	1.00	0.15	1.23	1.54	1.00	0.18	1.51	1.90
T₂ × C₂	1.32	0.19	2.42	2.65	1.00	0.25	1.80	1.61	1.44	0.26	1.29	3.30	1.90	0.27	2.08	2.64
T₃ × C₂	1.53	0.27	2.59	2.41	1.14	0.30	1.98	2.14	1.33	0.25	3.05	3.30	2.09	0.29	3.14	3.13
SEm±	0.09	0.12	0.28	0.33	0.10	0.08	0.25	0.11	0.18	0.03	0.01	0.40	0.02	0.05	0.38	0.37
C.D_{0.05}	0.28	NS	NS	NS	NS	NS	NS	0.36	NS	NS	0.05	1.27	0.07	NS	NS	NS

4.4.5.8.3. Grass shoots nutrient concentration percentage (dry weight basis)

Data in the Table 37 indicated that only the K was found to be significantly influenced due to the effect of the agroforestry systems. Maximum K (2.10 %) concentration was found in the AHS system followed by AS and AH system respectively.

In the average effect of the climatic conditions, P, K and Ca concentration was found to be significantly higher in C₂ climatic condition than C₁ climatic condition. The interaction between agroforestry systems and climatic conditions effect between exercised significant influence on the K and Ca concentration of grass shoots in T₁ the concentration of K and Ca declined from C₁ climatic condition to C₂ climatic condition and in T₂ and T₃ the trend was just reversed.

4.4.5.8.4. Grass roots nutrient concentration percentage (dry weight basis)

It is evident from the Table 37 that the N and K concentration was found to be influenced significantly due to agroforestry system. Nitrogen concentration were found to be significantly higher in the AS system, which proved maximum to AH system only whereas, K concentration was observed to be maximum in the agrihortisilviculture system which differed significantly from both T₁ and T₂.

The climatic conditions significantly influenced the N and Ca concentration only. Both of these nutrients displayed significantly higher value in the C₂ climatic condition than C₁ climatic condition.

Interaction effect between agroforestry systems and climatic conditions significantly influenced the N concentration only. In T₁ the concentration of the N declined whereas, in T₂ and T₃ their values enhanced significantly while moving from C₁ to C₂.

4.4.5.9. Litter fall, crop debris and weed debris nutrient concentration percentage (dry weight basis)

The nutrient concentration in the litter fall, crop debris and weed debris is tabulated in the Table 38.

4.4.5.9.1. Litter fall nutrient concentration percentage (dry weight basis)

It is evident from the data in the Table 38 that only Ca concentration was found to be significantly influenced due to the average effect of the agroforestry systems. Ca was found to be maximum in the AHS system which was found to be significantly higher than AH and AS system.

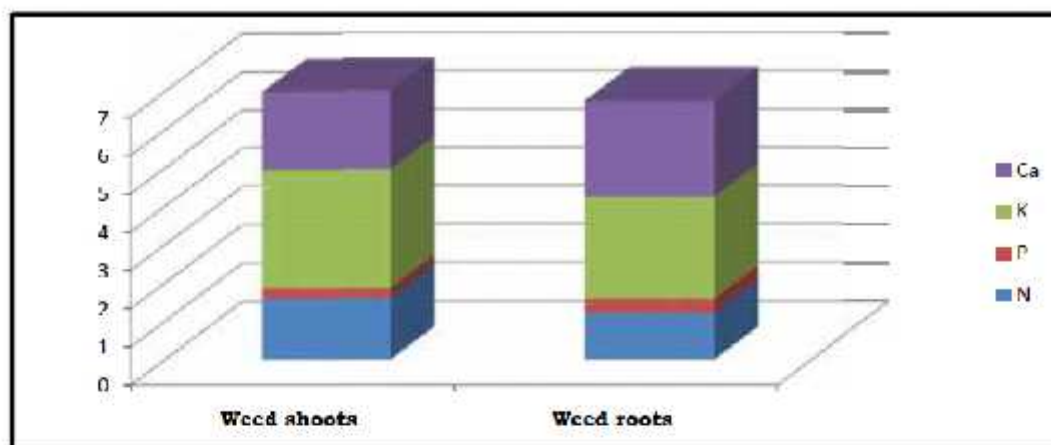


Fig.15. Nutrient concentration (%) in different weed parts of agrihorticulture system

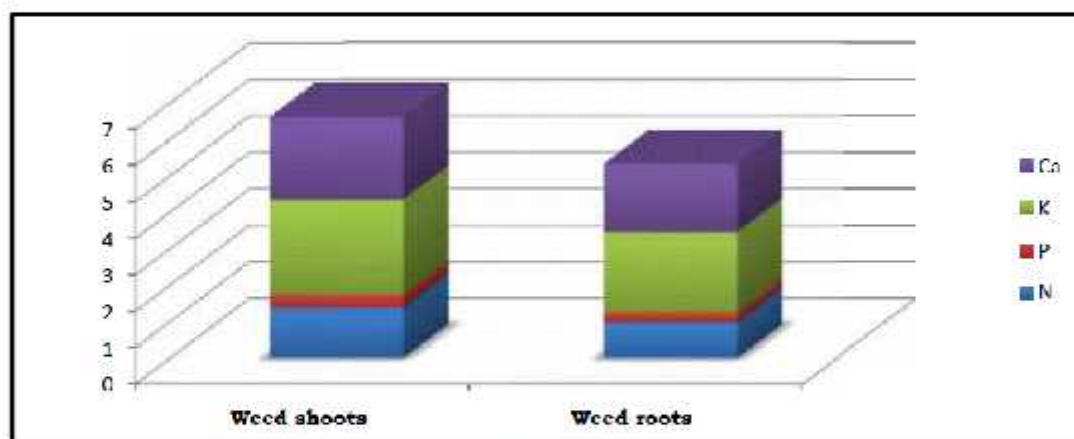


Fig.16. Nutrient concentration (%) in different weed parts of agrisilviculture system

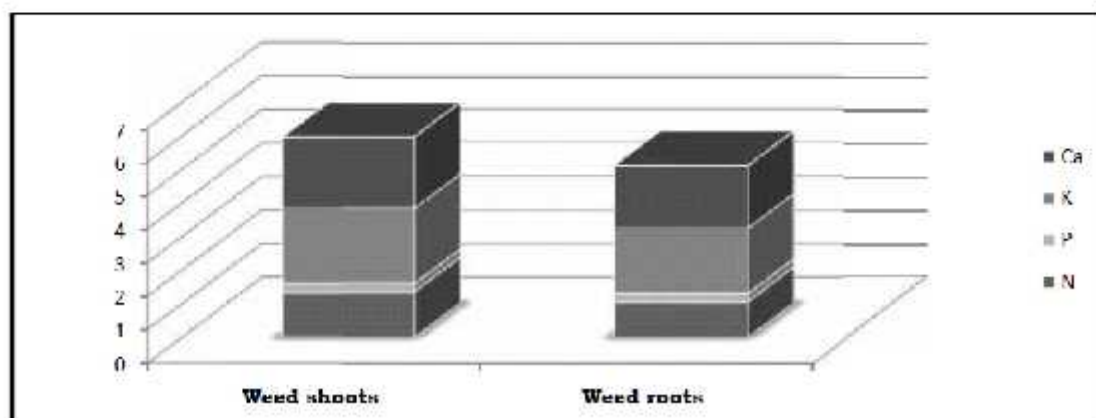


Fig.17. Nutrient concentration (%) in different weed parts of agrihortisilviculture system

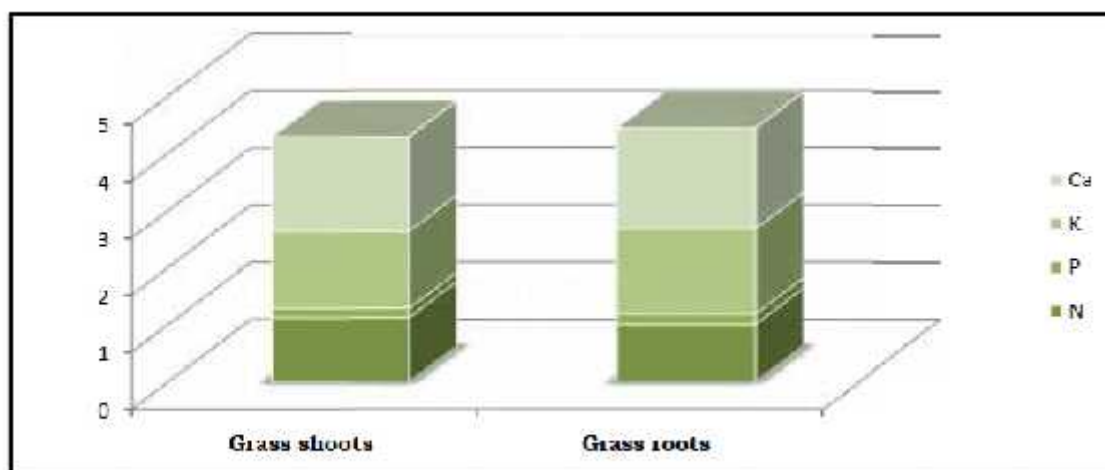


Fig.18. Nutrient concentration (%) in different grass parts of agrihorticulture system

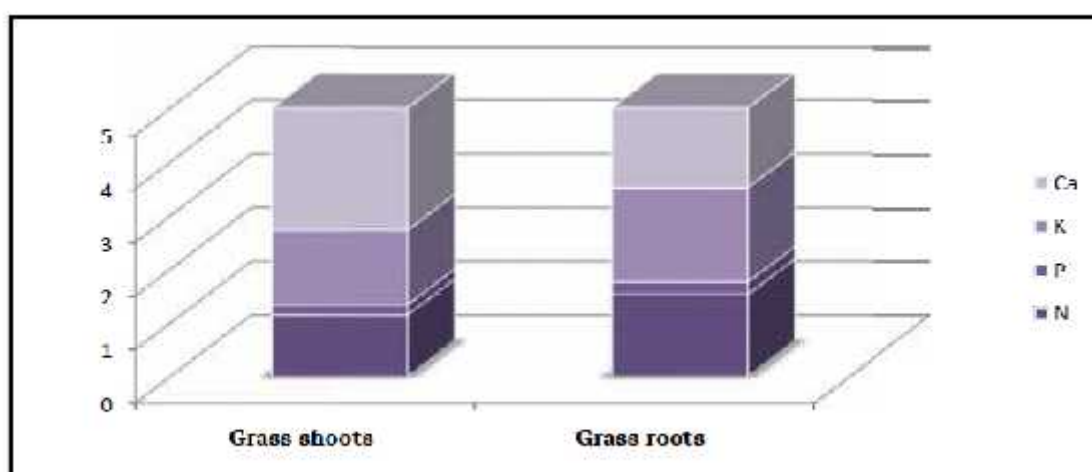


Fig.19. Nutrient concentration (%) in different grass parts of agrisilviculture system

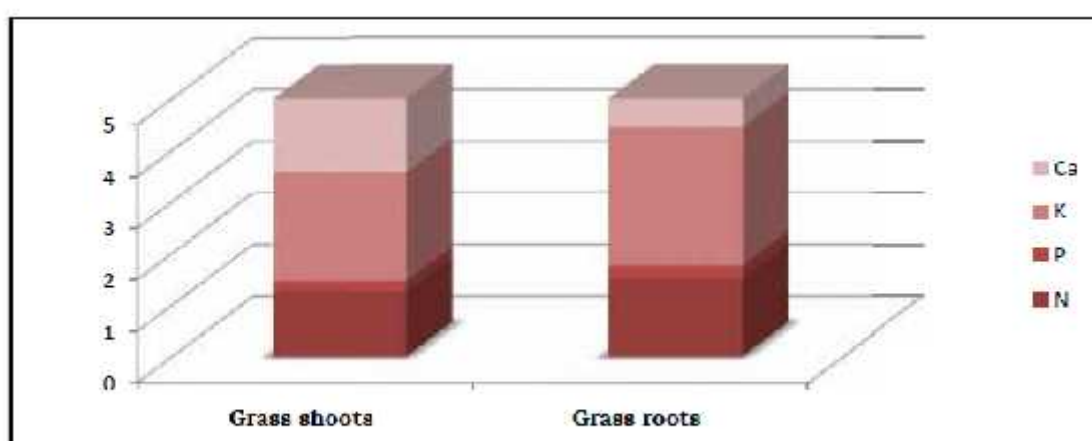


Fig.20. Nutrient concentration (%) in different grass parts of agrihortisilviculture system

Table 38. Effect of agroforestry systems, climatic conditions and their interaction on litter fall, crop debris and weed debris nutrient concentration percentage (dry weight basis) under dry temperate climatic conditions of north western Himalaya

Agroforestry systems (T)	Nutrient concentration percentage (dry weight basis) of litter fall, crop debris and weed debris											
	Litter fall (%)				Crop debris (%)				Weed debris (%)			
	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
T₁ (AH)	1.14	0.22	1.18	1.05	1.15	0.20	1.13	1.02	1.16	0.18	1.32	1.15
T₂ (AS)	1.11	0.22	1.15	0.92	1.38	0.20	2.01	1.84	1.24	0.22	1.25	1.07
T₃ (AHS)	1.15	0.24	1.21	1.09	1.00	0.16	1.64	1.33	1.09	0.16	1.19	1.04
SEm±	0.02	0.02	0.03	0.01	0.07	0.004	0.11	0.11	0.04	0.01	0.04	0.04
C.D_{0.05}	NS	NS	N/S	0.03	0.21	0.01	0.33	0.35	NS	0.02	NS	NS
Climatic conditions(C)												
C₁	1.17	0.22	1.18	0.99	1.21	0.21	1.63	1.47	1.17	0.19	1.25	1.10
C₂	1.10	0.23	1.18	1.05	1.14	0.16	1.55	1.32	1.15	0.18	1.24	1.06
SEm±	0.02	0.02	0.02	0.01	0.05	0.003	0.09	0.09	0.03	0.01	0.03	0.03
C.D_{0.05}	0.06	NS	NS	0.03	NS	0.01	NS	NS	NS	NS	NS	NS
Agroforestry systems (T) × Climatic conditions (C)												
T₁ × C₁	1.16	0.20	1.21	1.04	1.18	0.21	1.19	1.05	1.15	0.18	1.31	1.14
T₂ × C₁	1.17	0.19	1.15	0.85	1.41	0.24	2.02	1.94	1.26	0.22	1.26	1.10
T₃ × C₁	1.17	0.28	1.17	1.08	1.03	0.17	1.68	1.42	1.10	0.16	1.19	1.06
T₁ × C₂	1.12	0.24	1.15	1.06	1.11	0.19	1.06	0.98	1.17	0.18	1.32	1.15
T₂ × C₂	1.04	0.24	1.14	0.98	1.34	0.16	1.99	1.73	1.21	0.22	1.23	1.03
T₃ × C₂	1.13	0.20	1.24	1.10	0.96	0.14	1.60	1.24	1.08	0.15	1.18	1.01
SEm±	0.03	0.03	0.04	0.01	0.09	0.006	0.15	0.16	0.05	0.01	0.06	0.05
C.D_{0.05}	NS	NS	NS	0.04	NS	0.02	NS	NS	NS	NS	NS	NS

In the average effect of the climatic condition, N concentration was significantly higher in C₁ climatic condition than C₂ climatic condition whereas, for Ca the trend was just reverse.

Interaction effect between agroforestry system and climatic condition showed that out of all elements investigated only Ca was found to be significantly influenced due to it. The concentration of the Ca enhanced in all the agroforestry systems from climatic condition C₁ to climatic condition C₂ but this rate is more marked in the agrisilviculture system than AH or AHS system.

Panwar and Gupta (2015) calculated nitrogen in the leaf litter, twigs, reproductive litter, miscellaneous litter and bark as 2.23, 1.21, 0.91, 1.01 and 0.95 per cent, respectively while phosphorus concentration was maximum (0.139 %) in leaf litter followed by twigs (0.11 %), reproductive litter (0.11 %), bark (0.11 %) and the least was in miscellaneous litter (0.08 %). Potassium concentration was varied from 1.13 per cent in miscellaneous litter to 2.03 per cent in leaf litter. Calcium concentration varied from 1.75 per cent in reproductive litter to 3.12 per cent in bark.

4.4.5.9.2. Crop debris nutrient concentration percentage (dry weight basis)

It is evident from the Table 38 that the concentration of the nutrients- N, P, K and Ca were significantly influenced due to the effect of the agroforestry systems. The concentrations of all of these elements were maximum in crop debris under agrisilviculture system, which was found to be significantly higher than T₁ and T₂ system. Excepting P under T₁ and T₂ which assumed identical values.

In the average effect of the climatic conditions only the P concentration was found to be significantly influenced due to its effect, which was found to be significantly higher in C₁ climatic condition than C₂ climatic condition.

Interaction between agroforestry systems and climatic condition significantly influenced the P content of the crop debris only. Crop debris declined in all the agroforestry system from C₁ to C₂ but this decline is quite marked in the T₂.

4.4.5.9.3. Weed debris nutrient concentration percentage (dry weight basis)

Among all the debris nutrients only P concentration was found to be significantly influenced due to the agroforestry system effect (Table 38). The P concentration attained the maximum value in T₂ which excelled significantly to both T₁ and T₃.

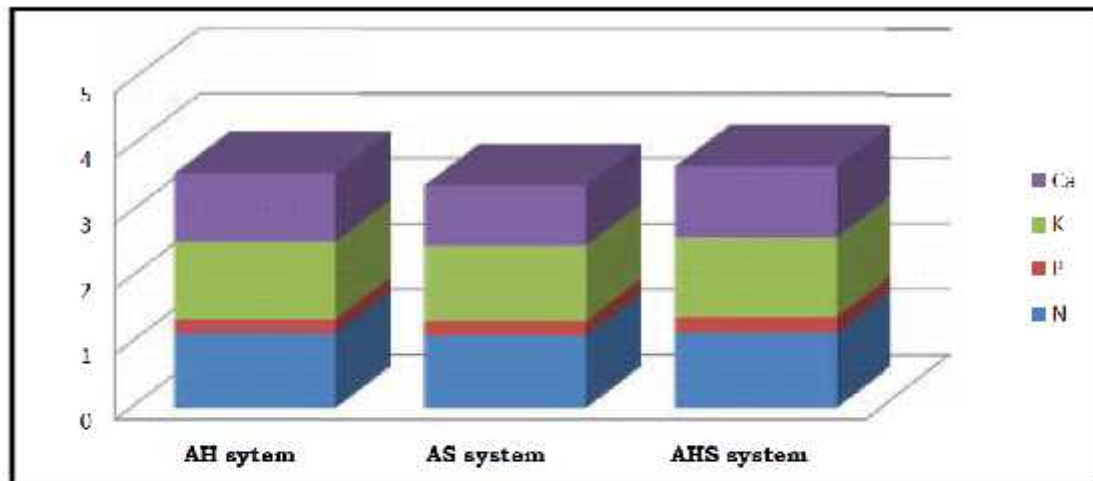


Fig.21. Litter fall nutrient concentration (%) in different agroforestry systems

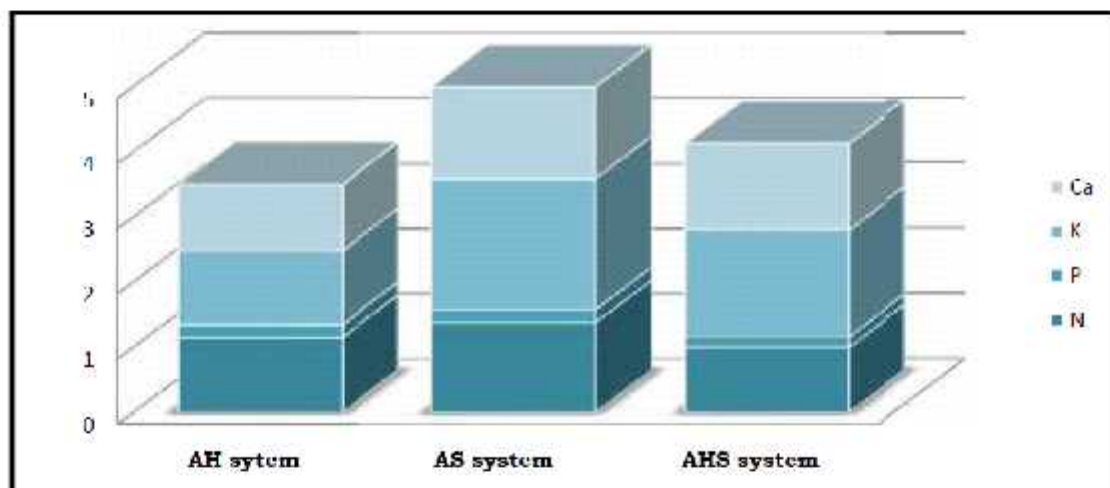


Fig.22. Crop debris nutrient concentration (%) in different agroforestry system

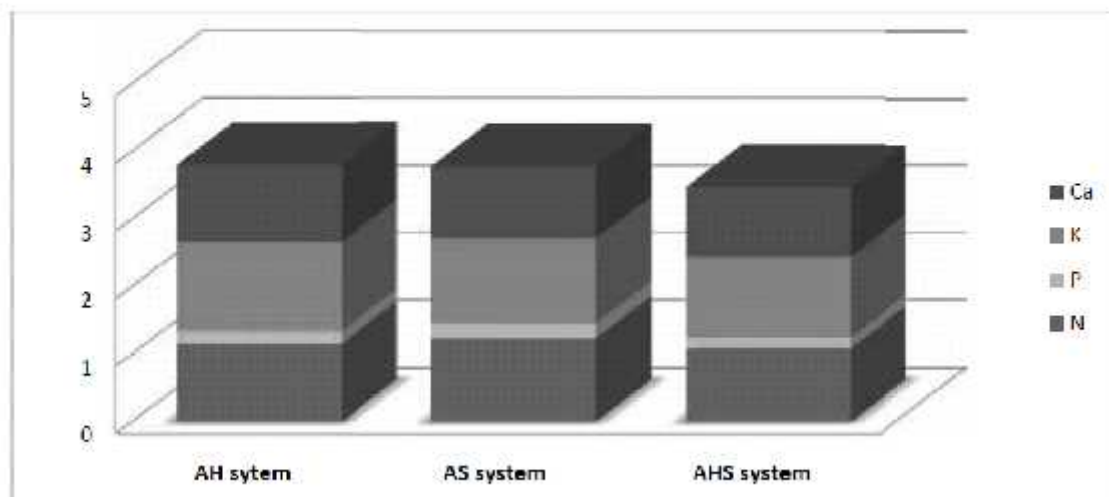


Fig.23. Weed debris nutrient concentration (%) in different agroforestry system

Table 39. Effect of agroforestry systems, climatic conditions and their interaction on nutrients added through litter fall, crop debris and weed debris (Kg ha⁻¹ yr⁻¹) under dry temperate climatic conditions of north western Himalaya

Agroforestry systems (T)	Nutrients add by litter fall, crop debris and weed debris (Kg ha ⁻¹ yr ⁻¹)											
	Litter fall				Crop debris				Weed debris			
	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
T₁ (AH)	6.03	1.28	6.19	5.57	1.74	0.31	1.96	1.85	6.34	0.96	7.20	6.32
T₂ (AS)	6.62	1.31	6.88	5.37	2.10	0.27	3.12	2.87	5.73	1.02	5.76	4.93
T₃ (AHS)	6.81	1.40	6.83	6.13	2.18	0.35	3.54	2.93	6.58	1.01	7.24	6.45
SEm±	0.21	0.16	0.08	0.23	0.10	0.03	0.25	0.27	0.03	0.04	0.05	0.03
C.D_{0.05}	NS	NS	0.26	NS	0.31	NS	0.81	0.87	0.10	NS	0.14	0.10
Climatic conditions(C)												
C₁	6.60	1.27	6.51	5.55	2.04	0.31	2.92	2.67	6.23	1.01	6.70	5.92
C₂	6.36	1.39	6.76	5.83	1.97	0.31	2.82	2.43	6.20	0.98	6.76	5.88
SEm±	0.17	0.13	0.07	0.19	0.08	0.03	0.21	0.22	0.03	0.03	0.04	0.03
C.D_{0.05}	NS	NS	0.21	NS	NS	NS	NS	NS	NS	NS	NS	NS
Agroforestry systems (T) × Climatic conditions (C)												
T₁ × C₁	5.88	1.13	6.02	5.35	1.91	0.32	2.39	2.26	6.39	0.94	7.19	6.35
T₂ × C₁	6.84	1.11	6.74	5.00	2.08	0.27	2.94	2.84	5.72	1.02	5.70	4.97
T₃ × C₁	7.09	1.56	6.77	6.29	2.14	0.34	3.44	2.91	6.58	1.07	7.20	6.43
T₁ × C₂	6.17	1.42	6.37	5.80	1.57	0.29	1.53	1.45	6.29	0.98	7.20	6.28
T₂ × C₂	6.40	1.50	7.03	5.74	2.12	0.26	3.30	2.89	5.75	1.03	5.81	4.89
T₃ × C₂	6.52	1.23	6.89	5.96	2.21	0.36	3.64	2.95	6.57	0.94	7.28	6.48
SEm±	0.30	0.22	0.12	0.32	0.14	0.05	0.36	0.39	0.04	0.06	0.06	0.04
C.D_{0.05}	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

4.4.6. Nutrients addition through biological components of agroforestry systems in soil under different agroforestry systems

4.4.6.1. Nutrients addition through litter fall ($\text{Kg ha}^{-1} \text{ yr}^{-1}$)

It is crystal clear from the data presented in the Table 39 that only K addition was significantly influenced due to agroforestry systems. Maximum addition of K through litter fall was in AS system followed by AHS and AH systems, respectively. Similarly to the agroforestry systems, only K addition was significantly influenced due to climatic conditions. C_2 climatic conditions displayed significantly higher addition of K than C_1 climatic condition. Interaction effect between the agroforestry systems and climatic conditions failed to significantly influence the addition of N, P, K and Ca addition through higher litter fall.

The role of climatic factors in affecting litter mass loss has received much attention in ecological studies. At a global scale, mean annual temperature and actual evapotranspiration were shown to have the strongest influence (Gholz *et al.*, 2000; Liski *et al.*, 2003). In the subalpine regions of Himalaya, leaf litter is reported to be the major contributor (67–81%) in total annual litter production (Rawat *et al.*, 2010).

In C_2 climatic condition decomposition of litter takes more time than the C_1 climatic condition, whereas less amount of nitrogen contribution through leaf litter was related to the minimum concentration of nitrogen in litterfall at the C_2 climatic condition. Microbial activity can also affect decomposition rate. Litter decomposition and subsequent nutrient loss are driven primarily by microbial activity also suggested by Fioretto (2008).

4.4.6.2. Nutrients addition through crop debris ($\text{Kg ha}^{-1} \text{ yr}^{-1}$)

Data in the Table 39 reveals that N, K and Ca additions through crop debris were significantly influenced due to the agroforestry systems. The maximum addition of N, K and Ca through crop debris was added in AHS system followed by AS and AH systems, respectively. The effect of climatic condition and interaction between agroforestry systems and climatic conditions failed to exercise any significant influence on the addition of nutrients.

In above investigation, C_1 climatic condition shows maximum nutrient concentration in crop debris so that the N, K and Ca addition through crop debris was maximum in C_1 climatic condition over the C_2 climatic condition.

Common residue factors include chemical composition, C/N ratio, lignin content, and the size of residue particles (Johnson 2007). Residue C/N ratio is a common indicator of residue quality but is not necessarily an accurate predictor of decomposition rate (Handayanto *et al.*, 1994). Crop species vary in the amount, chemical composition, and structural composition of lignin's (Hofmann *et al.*, 2009). Crop residue decomposition is generally negatively related to residue lignin content (Hatfield *et al.*, 2009) might be due to above crop debris add less amount in the present study.

4.4.6.3. Nutrients addition through weed debris ($\text{Kg ha}^{-1} \text{yr}^{-1}$)

It is evident from the data presented in the Table 39 that the addition of N, K and Ca through weed debris was significantly influenced due to agroforestry systems. Maximum addition of these nutrients was in AHS system followed by AH and AS systems respectively. Addition of N, K and Ca nutrient was not influenced significantly due to climatic condition. Similarly interaction of agroforestry systems, climatic conditions failed to exert significantly influence the nutrient additions through the weed debris. In the above investigations distinct variation was found in nutrient addition through litter fall, weed debris and crop debris which may be due to variation in the biomass added and decomposition rate of these organic materials in the soil.

Other researchers also concluded that the decomposition process is dependent upon many more biological and physical factors than solely the C: N ratio. Microbial activity will be influenced not only by the environment (moisture, heat, soil pH, *etc*) but by the characteristics and management of residue. Residue of large physical size (sunflower and corn stalks) or high lignin and fiber content (flax straw) that is left on the soil surface will resist microbial breakdown and immobilization will occur slowly (Heard and Hay 2006).

4.4.6.4. Amount of nutrients addition through different fertilizers ($\text{Kg ha}^{-1} \text{yr}^{-1}$)

Data presented in the Table 40 evinced that amount of the fertilizer application had significantly influenced the release of N, K and Ca under different agroforestry systems.

Maximum amount ($154.32 \text{ Kg ha}^{-1}$) of N was added in the agrihorticulture system which, however, remained statistically identical to AHS system only. Similar trend was recorded for the release of K and Ca. Although non-significant, the addition of the P also followed the order. $\text{AH} > \text{AHS} > \text{AS}$ system.

The effect of the climatic conditions and interaction effect between agroforestry system and climatic conditions was also found to be non-significant.

From the above study, it can be concluded that a good amount of- N P K and Ca are imparted from the agrihorticulture and agrihortisilviculture systems in the form of fruits and grains/seeds and thus recycling of these nutrients through leaf-litter, crop debris and weed debris is large which make it mandatory to add these nutrients externally to make these systems sustainable.

Table 40. Effect of agroforestry systems, climatic conditions and their interaction with amount of nutrients added by different fertilizers (Kg ha⁻¹ yr⁻¹) in different agroforestry systems under different climatic conditions

Agroforestry systems (T)	Amount of nutrients added through different fertilizers (Kg ha ⁻¹ yr ⁻¹)			
	N	P	K	Ca
T₁ (AH)	154.32	41.29	193.81	25.22
T₂ (AS)	87.52	36.74	94.63	10.35
T₃ (AHS)	128.25	38.01	185.10	20.32
SEm±	10.15	4.79	7.98	4.68
C.D_{0.05}	32.39	NS	25.47	14.93
Climatic conditions(C)				
C₁	111.16	41.28	166.68	16.67
C₂	135.57	36.08	149.01	20.58
SEm±	8.29	3.91	6.52	3.82
C.D_{0.05}	NS	NS	NS	NS
Agroforestry systems (T) × Climatic conditions (C)				
T₁ × C₁	129.55	49.34	194.80	21.93
T₂ × C₁	75.26	29.43	98.36	7.39
T₃ × C₁	128.68	45.07	206.88	20.68
T₁ × C₂	179.09	33.24	192.82	28.50
T₂ × C₂	99.79	44.05	90.89	13.30
T₃ × C₂	127.83	30.95	163.31	19.95
SEm±	14.35	6.77	11.29	6.62
C.D_{0.05}	NS	NS	NS	NS

4.4.6.5. Total amount of nutrients addition through different sources (Kg ha⁻¹ yr⁻¹)

The amount of nutrients added in to the soil through different sources is being depicted in the Table 41.

The data presented in the Table 41 reveals that among all only addition of N and K were significantly influenced due to the effect of agroforestry systems. Maximum addition of these nutrients is in the agrihorticulture systems followed by agrihortisilviculture system and agrisilviculture system respectively. Through non-significant but similar trend was noticed for the P and Ca also.

Irrespective of the agroforestry systems, the addition of nutrients- N, P K and Ca have not been influenced due to the climatic conditions. The effect of interaction between agroforestry systems and climatic conditions on the addition of N, P, K and Ca was found to be non-significant.

The amount of nutrients recycled through tree leaf litter, debris of crops and weeds showed a slight variation in these agroforestry systems. Significant amounts of the nutrients are taken up by trees and agricultural crops and most fruits and grains in these agroforestry systems and thus removed from the system Loss of N, P, K and Ca from this system is compensated through external inputs and application of these nutrients stored in the soil or from debris, litter and weeds. External addition of nitrogen, potassium, phosphorus and calcium through organic and inorganic fertilizers becomes essential to maintain soil fertility for sustaining soil productivity.

Table 41. Effect of agroforestry systems, climatic conditions and their interaction on total amount of nutrients added through different sources (Kg ha⁻¹ yr⁻¹) under dry temperate climatic conditions of north western Himalaya

Agroforestry systems (T)	Amount of nutrients added through different sources (Kg ha ⁻¹ yr ⁻¹)			
	N	P	K	Ca
T₁ (AH)	168.43	43.84	209.16	38.96
T₂ (AS)	101.97	39.33	110.39	23.51
T₃ (AHS)	143.81	40.76	202.70	35.83
SEm±	10.30	4.80	8.03	4.40
C.D_{0.05}	32.88	NS	25.64	NS
Climatic conditions(C)				
C₁	126.04	43.87	182.81	30.81
C₂	150.10	38.75	165.36	34.73
SEm±	8.41	3.92	6.56	3.59
C.D_{0.05}	NS	NS	NS	NS
Agroforestry systems (T) × Climatic conditions (C)				
T₁ × C₁	143.74	51.73	210.40	35.89
T₂ × C₁	89.89	31.83	113.74	20.21
T₃ × C₁	144.48	48.04	224.29	36.32
T₁ × C₂	193.12	35.94	207.92	42.03
T₂ × C₂	114.05	46.84	107.03	26.82
T₃ × C₂	143.14	33.48	181.12	35.33
SEm±	14.57	6.79	11.36	6.23
C.D_{0.05}	NS	NS	NS	NS

The trends of nutrients removal or addition are different from the forest ecosystems where a large quantity of nutrients recycled annually (Fittkau and Klinge, 1973). They estimated that in climax forest of Brazil 7.3 tons of litter ha^{-1} produced in one year recycles 106 Kg of nitrogen and maintained 5 t ha^{-1} soil fertility.

In the present systems, though the quantity recycled through tree leaf fall, debris and cropland weeds is comparable with other studies (Fssbender *et al.*, 1988, Lundre, 1978, Maghembe *et al.*, 1983), the quantity lost through fruits removal seeds/ grain is significantly higher in agrihorticulture and agrihortisilviculture making these system unsustainable until external inputs are added.

4.4.7. Amount of nutrients removal in the system ($\text{Kg ha}^{-1} \text{yr}^{-1}$)

The amount of the nutrients removed from the land under investigation is presented in the Table 42.

Data presented in the Table 42 reveals that only the removal of P was significantly influenced due to agroforestry systems effects. Maximum amount of P was removed from agrihortisilviculture system, which however remained statistically identical to AH system.

Irrespective of the agroforestry systems, the nutrients removals of- N, P, K and Ca under High hills temperate day and cold (C_2) climatic conditions was significantly higher than Dry temperate high hills climatic conditions. Interaction between the climatic conditions and agroforestry systems did not influence the removal of the nutrients.

The Agrisilviculture (AS) system is practiced in high altitude for fuel, fodder and conservation purpose due to limitation of land use for other purpose, nutrient loss is function of dry biomass. The biomass which is removed from the AS system in form of fuel, fodder was less than AH and AHS system. Due to maximum number of fruit trees AH system produce higher amount valuable biomass than AHS system result maximum removal of nutrient from this system. Tokey *et al.*, (1989b) also found similar observation during the study of tradition agroforestry systems in western Himalayas.

Variation in nutrient remove from the agroforestry system in both climatic conditions might be due to reduction in (Crop/Fruits) yield. This is mainly due to competition for the light, water, nutrients, allelopathic effect, and applied management practices.

Table 42. Effect of agroforestry systems, climatic conditions and their interaction on amount of nutrients removal ($\text{Kg ha}^{-1} \text{ yr}^{-1}$) under dry temperate climatic conditions of north western Himalaya

Agroforestry systems (T)	Nutrients removal from agroforestry systems ($\text{Kg ha}^{-1} \text{ yr}^{-1}$)			
	N	P	K	Ca
T₁ (AH)	117.39	27.97	161.56	109.45
T₂ (AS)	101.29	19.84	147.70	93.70
T₃ (AHS)	102.54	28.73	154.92	102.23
SEm$\pm$	5.26	1.59	5.27	5.50
C.D._{0.05}	NS	5.08	NS	NS
Climatic conditions(C)				
C₁	100.01	22.73	139.57	86.06
C₂	114.13	28.29	169.88	117.52
SEm$\pm$	4.30	1.30	4.30	4.49
C.D._{0.05}	13.72	4.15	13.73	14.33
Agroforestry systems (T) $\times$ Climatic conditions (C)				
T₁ $\times$ C₁	106.85	21.67	146.77	91.35
T₂ $\times$ C₁	95.93	19.50	131.60	75.73
T₃ $\times$ C₁	97.26	27.01	140.32	91.11
T₁ $\times$ C₂	127.93	34.26	176.34	127.55
T₂ $\times$ C₂	106.64	20.18	163.80	111.67
T₃ $\times$ C₂	107.82	30.44	169.51	113.34
SEm$\pm$	7.45	2.25	7.45	7.77
C.D._{0.05}	NS	NS	NS	NS

4.4.8. Annual turnover percentage of the nutrients in the soil and vegetation compartments

The fractional annual turnover of the nutrients in the soil and vegetation compartment is being depicted in the Table 43.

The data presented in the Table 43 reveals that fractional annual turnover (%) of in soil pool nutrients- P, K and Ca was significantly influenced due to the agroforestry systems. The percent annual turnover of P, K and Ca was highest under agrihorticulture system followed by agrisilviculture system and agrihortisilviculture system respectively. Irrespective of the agroforestry system, the fractional annual turnover of P and K were found to be significantly higher under C₁ climatic condition than C₂ climatic condition. The interaction of agroforestry systems the climatic conditions significantly influenced the fractional annual nutrient turnover of P, K and Ca.

It is evident from the data presented in the Table 43 that annual nutrient turnover of N, P, K and Ca in the vegetation pool was found to be significantly influenced due to agroforestry systems. The annual turnover of N, P K and Ca was maximum in AH system, followed by AHS and AS system respectively. Irrespective of the agroforestry systems, the annual turnover of the P, K and Ca turnover percentage was found to be significantly influenced due to the climatic conditions. C₂ climatic conditions displayed significantly higher values of the all nutrients annual turnover than C₁ climatic condition. The interaction between agroforestry systems and climatic conditions did not significantly influence the fractional turnover of nutrients in vegetation pool.

Tokey *et al.*, (1989b) evaluated the traditional agroforestry systems of the mid hills of western Himalaya for biomass productivity and nutrient cycling. They concluded that agrihorticulture system was remarkably efficient from points of views of biomass production for fuel, fodder and fruits and nutrient cycling.

Based on the outcomes these studies, various nutrients conserving mechanics have been postulated for tropical climate against high rate of organic matter decomposition and water flux through the system. The living biomass of the system acts as major storage of essential nutrients and releases then slowly to increase the nutrient efficiency of the system.

In the present study we investigated three different types of most prevalent agroforestry systems, viz., agrihorticulture system, agrisilviculture system and agrihortisilviculture system of the major agro-climatic conditions of Kinnaur district of Himachal Pradesh i.e. Dry temperate high hills (C₁) climatic condition and High hills temperate dry and cold (C₂) climatic condition. These systems have come into existence because of the large scale integration of the apple crop in the regions.

Major pathway for recycling of nutrients in these systems, particularly fruits based systems- agrihorticulture, agrihortisilviculture system is through external inputs through manure and organic fertilizers and to some extent through debris of crops and weeds, tree leaf litter *etc.* Environmental addition of nutrients particularly N in the form of snow is also major external source, which has not been taken into consideration while making nutrient balance sheet.

Table 43. Effect of agroforestry systems, climatic condition and their interaction on fractional annual turnover of elements percentage in soil pool and vegetation pool under dry temperate climatic conditions of north western Himalaya

Agroforestry systems (T)	Nutrients annual turnover (%) in soil pool				Nutrients annual turnover (%) in vegetation pool			
	N	P	K	Ca	N	P	K	Ca
T ₁ (AH)	1.43	5.72	31.47	5.34	34.50	51.03	31.25	23.47
T ₂ (AS)	1.86	4.52	19.02	4.48	21.58	22.60	19.74	16.79
T ₃ (AHS)	1.63	4.50	16.22	3.98	23.20	36.21	23.25	18.47
SEm±	0.22	0.23	2.04	0.22	1.42	3.27	1.12	1.25
C.D _{0.05}	NS	0.72	6.50	0.70	4.52	10.44	3.57	3.98
Climatic conditions(C)								
C ₁	1.47	5.71	27.77	4.71	25.28	31.28	21.06	16.76
C ₂	1.80	4.12	16.70	4.49	27.57	41.94	28.43	22.39
SEm±	0.18	0.19	1.66	0.18	1.16	2.67	0.91	1.02
C.D _{0.05}	NS	0.59	5.31	NS	NS	8.53	2.92	3.25
Agroforestry systems (T) × Climatic conditions (C)								
T ₁ × C ₁	1.36	5.84	31.76	4.58	33.78	43.43	26.02	21.43
T ₂ × C ₁	1.69	6.16	29.76	5.35	18.34	17.25	16.10	11.97
T ₃ × C ₁	1.37	5.13	21.79	4.19	23.73	33.17	21.06	16.89
T ₁ × C ₂	1.50	5.60	31.18	6.10	35.22	58.63	36.48	25.50
T ₂ × C ₂	2.02	2.88	8.28	3.60	24.82	27.96	23.38	21.61
T ₃ × C ₂	1.88	3.87	10.64	3.77	22.67	39.24	25.44	20.06
SEm±	0.32	0.32	2.88	0.31	2.00	4.63	1.58	1.76
C.D _{0.05}	NS	1.02	9.20	0.99	NS	NS	NS	NS

A considerable amount of – N, P K and Ca from these systems is depleted because of export of fruits and seeds (*Neozsa* pine) from the area. In present study results shows that maximum amount of nutrients were removed from AH system followed by AHS system in the form of economical yield but after harvesting, recycling of this nutrients by litterfall, crop debris and weed debris.

Highest amount of nutrients- N, P and K were recycled from soil and vegetation and vice-versa in all agroforestry systems due to the fact that diverse types of tree such as timber, fodder and fruit are mixed as together and intercepts each other for utilization for fruits and/or root vegetable crops/grain. The amount of nutrients recycled through litterfall, crop residue and weeds varied significantly influenced by climatic condition. The assumption is supported by (Nye & Greenland, 1960; Jordan, 1972; Toky & Ramakrishnan, 1983a).

C₂ climatic condition shows maximum turnover in soil compartment may be due to cold climatic condition, decomposition takes more time, so that nutrients stay on the floor for longer period. These are nutrients easily available to the standing vegetation, results C₂ climatic condition shows maximum turnover under soil compartment as well as vegetation compartment.

Minimum turnover of nitrogen under soil compartment may be due to nitrogen loss through denitrification (Eyre 2013). Nitrogen available from organic mulches not used by crops is incorporated into active and less active pools of soil organic matter (SOM), while much of the fertilizer nitrogen not used by crops is subject to leaching and denitrification losses.

4.5. PHYSICO-CHEMICAL ANALYSIS OF SOILS

The data for different physical and chemical properties of soils are presented in the Tables 44-45.

4.5.1 Soil texture in Dry temperate high hills climatic conditions

The data presented in Table 44 reveals that all the three samples collected from 0 -15 cm soil depth of the AH land use system displayed silty clay loam texture. Whereas at the sub surface depth (15-30 cm depth) two samples displayed silty clay loam texture and one sample displayed silty clay texture. In the AS system at 0-15 cm as well as 15-30 cm soil depth two samples showed silty clay loam texture and one sample displayed silty clay texture. Whereas in the AHS system the top 0-15 cm soil depth displayed silty clay loam (one sample) two clay loam properties (two samples). But in sub surface soil layer out of the three samples analyzed two sample showed the silty clay properties and one sample have silty clay loam properties.

4.5.2. Soil texture in High hills temperate dry and cold condition.

It is quite evident from the data presented in the Table 45 that the surface soil depth (0-15 cm) have clay loam (two samples) – silt clay (one sample) soil texture whereas, subsurface depth (15-30 cm) displayed silty clay (one sample) –silty clay loam (two sample) properties. Whereas surface layer under the AS system is having clay loam type of the texture the subsurface layer displayed silty clay (two samples)-silty clay loam (one sample) texture. In the AHS system all the samples collected from the surface soil layer displayed clay loam texture whereas, in the subsurface soil depth (15-30 cm) two samples showed silty clay loam texture and one silty clay.

Table 44. Soil texture properties of Dry temperate high hills (C₁) climatic condition at two depths under different agroforestry systems in Kinnaur district Himachal Pradesh

C₁ (Soil depth 0-15 cm)									C₁ (Soil depth 15-30 cm)						
Soil sample	Sand %	Silt %	Clay %	Soil texture	Clay ratio	Sand/Clay ratio	Silt/Clay ratio		Sand %	Silt %	Clay %	Soil texture	Clay ratio	Sand/Clay ratio	Silt/Clay ratio
1	C₁T₁R₁	64.18	6.10	29.72	Silty clay loam	2.36	2.16	0.21	66.06	4.22	29.72	Silty clay loam	2.36	2.22	0.14
2	C₁T₁R₂	70.08	1.98	27.94	Silty clay loam	2.58	2.51	0.07	70.08	1.00	28.92	Silty clay loam	2.46	2.42	0.03
3	C₁T₁R₃	64.48	6.80	28.72	Silty clay loam	2.48	2.25	0.24	68.08	1.80	30.12	Silt clay	2.32	2.26	0.06
4	C₁T₂R₁	70.98	0.30	28.72	Silty clay loam	2.48	2.47	0.01	71.08	0.20	28.72	Silty clay loam	2.48	2.47	0.01
5	C₁T₂R₂	63.78	4.50	31.72	Silt clay	2.15	2.01	0.14	71.28	1.00	27.72	Silty clay loam	2.61	2.57	0.04
6	C₁T₂R₃	61.18	10.00	28.82	Silty clay loam	2.47	2.12	0.35	66.48	3.20	30.32	Silt clay	2.30	2.19	0.11
7	C₁T₃R₁	65.08	5.60	29.32	Silty clay loam	2.41	2.22	0.19	66.28	3.20	30.52	Silt clay	2.28	2.17	0.10
8	C₁T₃R₂	63.08	3.30	33.62	Clay loam	1.97	1.88	0.10	71.18	1.10	27.72	Silty clay loam	2.61	2.57	0.04
9	C₁T₃R₃	62.18	9.60	28.22	Clay loam	2.54	2.20	0.34	66.08	2.60	31.32	Silt clay	2.19	2.11	0.08

Table 45. Soil texture properties in High hills temperate dry and cold (C₂) climatic condition at two depths under different agroforestry systems in Kinnaur district of Himachal Pradesh

C₂ (Soil depth 0-15 cm)									C₂ (Soil depth 15-30 cm)						
Soil sample	Sand %	Silt %	Clay %	Soil texture	Clay ratio	Sand/Clay ratio	Silt/Clay ratio		Sand %	Silt %	Clay %	Soil texture	Clay ratio	Sand/Clay ratio	Silt/Clay ratio
1 C₂T₁R₁	62.18	6.00	31.82	Clay loam	2.14	1.95	0.19		67.28	1.00	31.72	Silt clay	2.15	2.12	0.03
2 C₂T₁R₂	65.78	2.60	31.62	Silt clay	2.16	2.08	0.08		68.48	1.60	29.92	Silty clay loam	2.34	2.29	0.05
3 C₂T₁R₃	61.48	5.30	33.22	Clay loam	2.01	1.85	0.16		68.68	1.40	29.92	Silty clay loam	2.34	2.30	0.05
4 C₂T₂R₁	63.18	1.40	35.42	Clay loam	1.82	1.78	0.04		67.48	1.20	31.32	Silt clay	2.19	2.15	0.04
5 C₂T₂R₂	62.88	5.40	31.72	Clay loam	2.15	1.98	0.17		64.28	3.60	32.12	Silt clay	2.11	2.00	0.11
6 C₂T₂R₃	62.68	7.70	29.62	Silty clay loam	2.38	2.12	0.26		70.18	1.50	28.32	Silty clay loam	2.53	2.48	0.05
7 C₂T₃R₁	64.08	3.10	32.82	Clay loam	2.05	1.95	0.09		66.28	1.60	32.12	Silt clay	2.11	2.06	0.05
8 C₂T₃R₂	58.68	6.50	34.82	Clay loam	1.87	1.69	0.19		70.18	1.50	28.32	Silty clay loam	2.53	2.48	0.05
9 C₂T₃R₃	59.18	6.60	34.22	Clay loam	1.92	1.73	0.19		69.48	1.00	29.52	Silty clay loam	2.39	2.35	0.03

4.5.3. Bulk density, Particle density and Pore space

The average effects of the agroforestry systems, climatic conditions and soil depth on soil physical properties- bulk density, particle density and pore space are being depicted in the Table 46.

It is evident from the data presented in the Table 46 that the bulk density is significantly influenced due to the climatic conditions and soil depth. Though non-significant but higher bulk density was displayed by the AS and AHS land use systems compared to AH system. Irrespective of the agroforestry system and soil depth, the soil under dry temperate high hills displayed significantly higher bulk density (1.38 g cm^{-3}) than high hills temperate dry and cold conditions. In the average effect of soil depth the bulk density enhanced significantly from D_1 to D_2 only.

Table 46. Soil physical properties as influenced by average effect of agroforestry systems, climatic conditions and soil layers in dry temperate regions of north western Himalaya

Agroforestry systems (T)	Bulk density (g cm^{-3})	Particle density (g cm^{-3})	Pore space percent
T₁ (Agrihorticulture)	1.32	2.49	46.99
T₂ (Agrisilviculture)	1.34	2.42	44.88
T₃ (Agrihortisilviculture)	1.34	2.39	42.37
SEm$\pm$	0.01	0.02	0.76
CD_{0.05}	NS	0.05	2.22
Climatic Conditions (C)			
C₁ – Dry temperate high hills	1.38	2.44	43.18
C₂ – High hills temperate dry and cold	1.28	2.42	46.31
SEm$\pm$	0.01	0.01	0.62
CD_{0.05}	0.03	NS	1.81
Soil depth (D)			
D₁ (0-15 cm)	1.20	2.48	48.90
D₂ (15-30 cm)	1.47	2.38	40.60
SEm$\pm$	0.01	0.01	0.62
CD_{0.05}	0.03	0.04	1.81

Data in the Table 46 showed that particle density was significantly influenced due to agroforestry systems. It attained higher value in AH systems that proved significantly better to AS and AHS systems. The average effect of climatic conditions was though non-significant yet higher particle density was displayed by the soil under dry temperate high hills than the high hills temperate dry and cold climatic conditions. Soil depth 0-15cm soil layer displayed significantly higher values than 15-30 cm soil layer.

It is quite evident from the data presented in Table 47 that pore space percent characteristic of the soil was significantly influenced due to the agroforestry systems, climatic conditions and soil depth. The pore space percent under different agroforestry systems followed the trend AH > AS > AHS systems the pore space was higher in dry temperate high hills and soil depth 0-15 cm compared to their respective treatments.

It might be due to continuous use of organic fertilizer, soil texture and variation in soil organic carbon content. Soil organic carbon can improve soil texture, results pore space percent higher at surface soil and decrease with increasing soil depth. In general, the per cent soil porosity decreases with the depth (Singh *et al.*, 2000).

It is evident from the data from the Table 47 that the pore space percent values were significantly influenced due to three way interaction effect between the climatic conditions, agroforestry system and soil depth. The values of pore space percent followed the same trend in C₁ and C₂ climatic conditions with the agroforestry systems and soil depth excepting in the treatment combination of C₂T₃D₁. Maximum pore space percent (55.42) was recorded in C₂T₁D₁ treatment combination which was found to be significantly higher than all other treatment combinations excepting C₂T₂D₁ whereas, minimum pore space values was displayed by the C₁T₃D₂, which assumed identical values in C×T×D interaction revealed no significant effect in pore space per cent.

Table 47. Soil physical properties as influenced by three way interaction effect of agroforestry systems, climatic conditions and soil layers (C × T × D) in dry temperate regions of north western Himalayas

Agroforestry systems (T)	Bulk density (g cm ⁻³)	Particle density(g cm ⁻³)	Pore space (%)
C ₁ × T ₁ × D ₁	1.30	2.59	49.91
C ₁ × T ₁ × D ₂	1.49	2.43	38.72
C ₁ × T ₂ × D ₁	1.28	2.51	49.12
C ₁ × T ₂ × D ₂	1.52	2.37	35.94
C ₁ × T ₃ × D ₁	1.23	2.46	50.75
C ₁ × T ₃ × D ₂	1.50	2.29	34.65
C ₂ × T ₁ × D ₁	1.12	2.51	55.42
C ₂ × T ₁ × D ₂	1.37	2.42	43.91
C ₂ × T ₂ × D ₁	1.13	2.43	53.54
C ₂ × T ₂ × D ₂	1.44	2.35	40.92
C ₂ × T ₃ × D ₁	1.15	2.40	34.65
C ₂ × T ₃ × D ₂	1.15	2.40	49.44
SEm±	0.02	0.03	1.15
CD _{0.05}	NS	NS	4.44

Results shows (Table 47) increasing trend of bulk density with increasing depth. The bulk density values had significantly negative relationship with organic carbon. The assessment is also supported by the work of Sharma *et al.*, (1997). According to him the value of this physical constant (bulk density) generally increases with depths. Which may be due to decreasing trend of organic carbon. Ndungu *et al.*, (2017) also reported similar bulk density in agroforestry systems in mid hills of Himachal Pradesh.

4.5.3. Two way infection effects

It is evident from the data from the Table 48 that bulk density enhanced from D_1 to D_2 in all the agroforestry systems under investigations but this enhancement was more preannounced in AHS system than others.

In the two way interaction effect between depth and climatic conditions on the bulk density it is evidently clear (Table 48) that bulk density enhanced in both climatic conditions with depth but this enhancement is more pronounced in C_2 than at C_1 .

Data in the Table 48 further shows that bulk density declined in all the agroforestry systems from C_1 to C_2 but the reduction was highest in AH land use systems.

The effect of interaction between the agroforestry system and depth indicated that all in the agroforestry system under investigation the pore space percent declined with the depth but this decline is significant in case of the AH and AS system only (Table 48). It interaction seen that the pore space percent declined with depth in both types of climatic conditions under investigation but this decline is more pronounced in C_1 than at C_2 .

It is also clear from the data in Table 48 that pore space percent enhanced from C_1 to C_2 at T_1 and T_2 but in T_3 declined.

Among the agroforestry systems (Table 48), a little variation was observed in respect of bulk density. However, agrisilviculture and agrihortisilviculture system showed higher bulk density than agrihorticulture system. Under climatic condition, the soil of the Dry temperate high hills showed more bulk density than the High hills temperate dry and cold climatic conditions which can be due to the texture of soil and deposition of sediment. In general, the sand (%) of the sample analyzed showed that its proportion is more in the soil of

the high hills temperate dry climatic condition than the high hills temperate dry and cold climatic conditions.

In present study it was observed (Table 48) that the pore space (%) is more in the upper soil profile than the lower one, which can again be ascribed to the continuous deposition of leaf litter on the upper soil layer and its decomposition.

Table 48. Soil physical properties as influenced by two way interaction effect of T × D, D × C and T × C in dry temperate regions of north western Himalaya

Agroforestry systems (T)	Bulk density (g cm ⁻³)	Particle density (g cm ⁻³)	Pore space percent
T ₁ × D ₁	1.21	2.55	52.67
T ₂ × D ₁	1.20	2.47	51.33
T ₃ × D ₁	1.19	2.43	42.70
T ₁ × D ₂	1.43	2.43	41.32
T ₂ × D ₂	1.48	2.36	38.43
T ₃ × D ₂	1.49	2.35	42.05
SEm±	0.015	0.02	1.07
CD _{0.05}	0.04	NS	3.14
D ₁ × C ₁	1.27	2.52	49.93
D ₂ × C ₁	1.50	2.36	36.44
D ₁ × C ₂	1.13	2.45	47.87
D ₂ × C ₂	1.43	2.39	44.76
SEm±	0.01	0.02	0.87
CD _{0.05}	0.04	0.06	2.56
T ₁ × C ₁	1.39	2.51	44.32
T ₂ × C ₁	1.40	2.44	42.53
T ₃ × C ₁	1.36	2.38	42.70
T ₁ × C ₂	1.25	2.46	49.67
T ₂ × C ₂	1.29	2.39	47.23
T ₃ × C ₂	1.32	2.4	42.05
SEm±	0.02	0.02	1.07
CD _{0.05}	0.04	NS	3.14

4.5.5. Chemical characteristics of the soil

Data in the Table 49 reveals that only the organic carbon (%), exchangeable Ca and exhalable Mg were found to be significantly influenced due to the effects of the agroforestry systems. Maximum organic carbon (%) was registered in AHS system which, however, remained statistically to AH system.

Table 49. Soil chemical properties as influenced by average effect of agroforestry systems, climatic conditions and soil depth under dry temperate climatic conditions of north western Himalaya

Agroforestry system (T)	pH (1.2)	Organic carbon %	Total Nitrogen (N) %	Extractable P (mg/100g)	Available K (mg/100g)	Ex. Ca (mg/100g)	Ex. Mg (mg/100g)
T₁ (Agrihorticulture)	7.57	1.24	0.19	0.79	1.26	5.52	4.00
T₂ (Agrisilviculture)	7.59	1.14	0.16	0.81	1.29	5.21	4.30
T₃ (Agrihortisilviculture)	7.62	1.26	0.15	0.79	1.21	5.19	4.06
SEm±	0.06	0.05	0.017	0.01	0.07	0.04	0.09
C.D_{0.05}	NS	0.10	NS	NS	NS	0.10	0.25
Climatic Conditions (C)							
C₁ – Dry temperate high hills	6.97	1.04	0.18	0.78	1.35	5.34	4.18
C₂ – High hills temperate dry and cold	8.21	1.39	0.15	0.81	1.16	5.28	4.05
SEm±	0.05	0.04	0.014	0.01	0.06	0.03	0.07
C.D_{0.05}	0.14	0.08	NS	0.02	0.17	NS	NS
Soil depth (D)							
D₁ (0-15 cm)	7.44	1.46	0.25	0.97	1.69	6.03	4.77
D₂ (15-30 cm)	7.75	0.98	0.09	0.62	0.82	4.58	3.46
SEm±	0.05	0.04	0.014	0.01	0.06	0.03	0.07
CD_{0.05}	0.14	0.08	0.04	0.02	0.17	0.08	0.20

In present study it was seen that the organic carbon percent is more in the agrihortisilviculture systems which may be due to maximum species richness. (Saha *et al.*, 2009) also reported that higher species richness can result in higher SOC contents in agroforestry systems. Organic carbon decreased with the increase in soil depth (Table 49).

Higher amount of soil organic carbon on the surface layer may be due to continuous accumulation of leaf litter on the surface, which keeps on decomposing and thus enriches the surface layer continuously (Nair and Chamuah 1988; Minhas *et al.*, 1997). There was a significant effect noticed between soil depth and total nitrogen percentage. It might be due to steep slope, low decomposition rate and denitrification loss of total N. Similar decreasing trend of total N with increase soil depth was also reported earlier by Bhardwaj *et al.*, (2001).

Exchangeable Ca content were found to be maximum in the AH system, which was found to be statistically higher than the exchangeable Ca contents of AS and AHS systems. The systems of AS and AHS remained statistically identical the Exchangeable Mg content was found to be maximum in the AS system, which was found to be significantly higher than AH and AHS systems. The Mg content of the systems followed the trend AS > AHS > AH.

The data in Table 49 shows that agroforestry systems, climatic conditions and soil depth effect on total N was non-significant. The maximum level of total N was found in AH system situated in C₁ climatic condition at D₁ depth.

The data demonstrated in the Table 49 evinced that pH, organic carbon, extractable P and available K contents were significantly influenced due to the effect of climatic conditions. High hills temperate dry and cold climatic conditions (C₂) demonstrated higher values of the pH, organic carbon (%) and extractable P but available K content was significantly higher at C₁ than C₂. This may be due to more level of organic carbon in C₁ than at C₂. Basumatary and Bordoloi (1992) and Boruah and Nath (1992) also reasoned that a layer of organic matter significantly improves the retention of available K in the soils.

It is crystal clear from the Table 50 that all the chemical characteristic of the soils irrespective of the agroforestry system and climatic conditions were significantly influenced due to the effect of depth. All the chemical characteristic displayed significantly higher values at D₁ (0-15 cm) than D₂ (15-30 cm) excepting pH, which was found to be significantly higher at the surface layer. The impact of agroforestry systems on soil fertility has also been

shown by various workers. Varghese *et al.*, (1978) and Bavappa *et al.*, (1986) also observed higher organic matter content, total nitrogen, phosphorus and potash in the top soil, and improved microbial activities in the agroforestry systems.

The data from two way interaction between agroforestry systems $\times$ soil depth, depth $\times$ climatic condition and agroforestry systems $\times$ climatic conditions on the various studied chemical traits have been presented in Table 50.

It is evident from the Table 50 that two way interaction between agroforestry systems, soil depth exercised significant influence on the extractable P content only. The level of P content declined significantly from D₁ to D₂ in all the agroforestry systems. But this declined was quite marked in AS and AHS system in comparison to T₁.

Two way interactions between climatic conditions and soil depth showed that it significantly influenced the chemical characteristics – pH, organic carbon (%), extractable P and exchangeable Ca contents (Table 50). The values of pH enhanced significantly from D₁ to D₂ but this rate of the enhancement is more pronounced at C₁ than C₂. Contrary to it, the organic carbon percent declined significantly with depth in both the climatic conditions. Ndungu *et al.*, (2017) also found soil organic carbon ranged from 0.83% to 1.75% in surface soil. The cropping system wise trend of soil organic carbon in surface soil was; fruit orchard (1.75%) and agroforestry (1.63%) The sub-surface soil organic carbon was lower compared to surface soil organic carbon in mid hills mountain cropping systems of Himachal Pradesh.

Data in the Table 50 also revealed that the exchangeable P content declined significantly declined from D₁ to D₂ at both the climatic conditions but this declined is quite marked in the C₂ climatic conditions. The level of the exchangeable Ca also declined significantly with the depth but this decline is quite marked in the D₁ to D₂ in the C₁ type of the climatic conditions.

Organic carbon (%), extractable P, exchangeable Ca and exchangeable Mg level were found to be significant influenced due to two way interactions between agroforestry systems and climatic conditions. The level of organic carbon (%) enhanced from C₁ to C₂ in all the studied agroforestry systems. This rate of enhancement was quite marked in T₃ treatment. In the interaction effect between agroforestry system and climatic condition the level of the P declined from C₁ to C₂ in AH and AS system but enhanced significantly in T₃.

Table 50. Soil chemical properties as influenced by two way interaction between agroforestry systems, climatic conditions and soil depth under dry temperate climatic conditions of north western Himalaya

Agroforestry system (T)	pH (1.2)	Organic carbon %	Total Nitrogen (N) %	Extractable P (mg/100g)	avil. K (mg/100g)	Ex. Ca (mg/100g)	Ex. Mg (mg/100g)
T₁ × D₁	7.40	1.47	0.27	0.84	1.73	6.23	4.51
T₂ × D₁	7.45	1.35	0.23	1.04	1.69	5.92	5.00
T₃ × D₁	7.47	1.56	0.24	1.04	1.65	5.96	4.82
T₁ × D₂	7.74	1.02	0.12	0.75	0.80	4.80	3.48
T₂ × D₂	7.73	0.94	0.08	0.58	0.88	4.51	3.60
T₃ × D₂	7.78	0.97	0.06	0.54	0.78	4.42	3.30
SEm±	0.08	0.07	0.024	0.02	0.10	0.05	0.12
CD_{0.05}	NS	NS	NS	0.03	NS	NS	NS
D₁ × C₁	6.72	1.20	0.27	0.91	1.83	6.20	4.84
D₂ × C₁	7.22	0.88	0.09	0.66	0.87	4.47	3.52
D₁ × C₂	8.15	1.72	0.22	1.04	1.55	5.86	4.71
D₂ × C₂	8.27	1.07	0.08	0.58	0.77	4.69	3.40
SEm±	0.07	0.06	0.02	0.01	0.08	0.04	0.10
CD_{0.05}	0.02	0.11	NS	0.03	NS	0.12	NS
T₁ × C₁	6.87	1.04	0.20	0.82	1.28	5.78	3.93
T₂ × C₁	7.02	1.05	0.17	0.83	1.39	5.13	4.27
T₃ × C₁	7.03	1.03	0.17	0.70	1.38	5.10	4.35
T₁ × C₂	8.27	1.44	0.18	0.77	1.25	5.26	4.07
T₂ × C₂	8.17	1.24	0.14	0.79	1.18	5.30	4.33
T₃ × C₂	8.21	1.50	0.14	0.87	1.05	5.28	3.76
SEm±	0.08	0.07	0.02	0.01	0.10	0.05	0.12
CD_{0.05}	NS	0.14	NS	0.03	NS	0.14	0.35

Whereas, in case of exchangeable Ca the level declined in AH system but enhanced in AS and AHS system. The exchangeable Mg contents were also found to be influenced significantly. Jenny (1930); McDaniel and Munn, (1985) also found that organic matter decreasing with increasing temperature as a result of increased decomposition rates, results decrease in organic carbon.

Least value soil pH in C₁ climatic condition may be due to higher decomposition rates. Peculiar reason for the above finding is that faster the decomposition of organic matter leads to more release of organic acid as a results pH decreases. Similar results have been reported in sal (Yadav, 1963), eucalyptus (Saralch, 1994), nitrogen fixing trees (Bhola, 1995).

The three way interaction effect of agroforestry system × climatic conditions × depth (Table 51) reveals that organic carbon (%), extractable P and exchangeable Ca were significantly influenced. The level of the organic carbon (%) and extractable P declined significantly from D₁ to D₂ in all the agroforestry land use system in both types of the climatic conditions. But this decline was more marked in the treatment combination of C₂T₃ from D₁ to D₂. Almost similar type of the trend was also seen for the exchangeable Ca too. Non-significant maximum level of total N was found in D₁ depth under both climatic conditions which was declined from C₁ to C₂ as well as D₁ to D₂ depth.

The extractable phosphorus was not found to be significantly influenced by the agroforestry land use system. It was also observed that more P and K was observed in the High hills temperate dry and cold condition than Dry temperate high hills, which may be due to comparatively lower temperature condition of the former than latter, which leader to slower rate of their leaching. In present study it was also found that upper soil layer had significantly higher amount of P and K on the upper soil layer, which can be due to the higher pruning of their elements from the subsoil by the prevailing agroforestry systems.

The exchangeable Ca and Mg were found to be significantly higher in agrihorticulture and agrisilviculture systems. Higher quantity of exchangeable Ca in the agrihorticulture system can be due to the application of the higher quantity of FYM manure (22 tons ha⁻¹yr⁻¹) in agrihorticulture system which content up to 1.25 percent Ca in it. In the effect of soil layer, Ca and Mg were found to be pumping of these bases from the subsoil by the vegetation and return them in to top soil (Yimer *et al.*, 2008).

Table 51. Soil chemical properties as influenced by three way interaction between agroforestry systems, climatic conditions and soil depth under dry temperate conditions of north western Himalaya

Agroforestry system (T)	pH (1.2)	Organic carbon %	Total Nitrogen (N) %	Extractable P (mg/100g)	Available K (mg/100g)	Ex. Ca (mg/100g)	Ex. Mg (mg/100g)
C₁ × T₁ × D₁	6.60	1.14	0.30	0.87	1.69	6.76	4.45
C₁ × T₁ × D₂	7.13	0.95	0.11	0.77	0.86	4.79	3.40
C₁ × T₂ × D₁	6.77	1.28	0.24	1.00	1.91	5.88	4.90
C₁ × T₂ × D₂	7.27	0.81	0.11	0.66	0.88	4.37	3.64
C₁ × T₃ × D₁	6.80	1.18	0.28	0.85	1.91	5.97	5.18
C₁ × T₃ × D₂	7.27	0.87	0.06	0.55	0.85	4.24	3.52
C₂ × T₁ × D₁	8.19	1.80	0.24	0.81	1.77	5.70	4.57
C₂ × T₁ × D₂	8.34	1.08	0.13	0.73	0.74	4.81	3.56
C₂ × T₂ × D₁	8.14	1.41	0.22	1.09	1.47	5.95	5.10
C₂ × T₂ × D₂	8.20	1.07	0.06	0.49	0.88	4.65	3.56
C₂ × T₃ × D₁	8.13	1.93	0.21	1.22	1.40	5.95	4.45
C₂ × T₃ × D₂	8.28	1.06	0.06	0.52	0.70	4.61	3.07
SEm±	0.12	0.10	0.03	0.02	0.15	0.07	0.17
CD_{0.05}	NS	0.20	NS	0.05	NS	0.20	NS

4.6. ECONOMIC ANALYSIS

Economic analysis of different type the agroforestry systems, viz., agrihorticulture, agrisilviculture and agrihortisilviculture system prevailing in two type of climatic conditions-dry temperate high hills and high hills temperate dry and cold conditions is being presented in Table 52.

4.6.1. Gross returns (Rs ha⁻¹)

Data presented in the Table 52 shows that the gross returns were significantly influenced due to the average effects of agroforestry systems, climatic conditions and interaction between them. Irrespective of the agroforestry system, the land use system prevailing in the High hills temperate dry and cold climatic conditions realized higher gross returns than at the Dry temperate high hills. Irrespective of climatic conditions, the agrihorticulture (2065230.07 Rs ha⁻¹yr⁻¹) system gave significantly higher gross returns than agrisilviculture and agrihortisilviculture systems. In the interaction effect agrihorticulture and agrihortisilviculture systems the gross returns enhanced from C₁ to C₂ climatic conditions whereas, agrisilviculture system the returns declined.

4.6.2. Total expenditure (Rs ha⁻¹)

Total expenditure was significantly influenced due to the average effects of agroforestry system only (Table 52). The total expenditure was highest under the agrihorticulture system followed by agrisilviculture and agrihortisilviculture system respectively.

4.6.3. Net returns (Rs ha⁻¹)

It is clearly evident from the data in the Table 52 that net returns on per hectare basis were significantly higher under Dry temperate high hills conditions. Irrespective of the climatic conditions the net returns from the agrihortisilviculture systems is significantly higher than either agrihorticulture or agrisilviculture systems.

Maximum returns (Rs 1667249 ha⁻¹) were realized from the agrihortisilviculture systems situated in the High hills temperate dry and cold conditions, which however remained statistically identical to the treatment combinations C₁T₃ and C₁T₂.

Table 52. Effect of agroforestry systems, climatic conditions and their interaction on gross return, total expenses, net return and benefit cost ratio of different agroforestry systems under dry temperate climatic conditions of north western Himalaya

Agroforestry system (T)	Gross Return (Rs ha ⁻¹ yr ⁻¹)	Total Expenses (Rs ha ⁻¹ yr ⁻¹)	Net return (Rs ha ⁻¹ yr ⁻¹)	Benefit-cost ratio
T₁ (AH)	2065230.07	774526.32	1290703.75	2.09
T₂ (AS)	1381578.95	355847.31	1025731.65	5.87
T₃ (AHS)	1268006.31	734388.27	1648322.21	2.84
SEm±	23015.764	98526.48	13969.84	0.08
C.D_{0.05}	73461.33	314475.16	44588.69	0.26
Climatic Conditions (C)				
C₁ – Dry temperate high hills	1235599.292	553307.28	1425428.12	4.63
C₂ – High hills temperate dry and cold	1907610.931	689867.31	1217743.62	2.56
SEm±	18792.29	80446.53	11406.32	0.07
C.D_{0.05}	59980.93	NS	36406.51	0.21
Agroforestry systems (T) × Climatic conditions (C)				
T₁ × C₁	1634132.10	635640.79	998491.31	2.05
T₂ × C₁	1944593.78	296195.30	1648398.49	8.91
T₃ × C₁	128072.00	728085.77	1629394.57	2.93
T₁ × C₂	2496328.04	913411.85	1582916.19	2.12
T₂ × C₂	818564.13	415499.31	403064.81	2.83
T₃ × C₂	2407940.63	740690.78	1667249.85	2.75
SEm±	32549.206	139337.48	19756.33	0.12
C.D_{0.05}	103890.01	NS	63057.93	0.37

4.6.4. Benefit-cost ratio

Benefit-cost ratio was significantly influenced due to climatic conditions, agroforestry systems and their interaction (Table 52). Irrespective of the agroforestry system, benefit cost ratio in dry temperate high hills displayed significantly higher values than in high hills temperate dry and cold climatic conditions.

Irrespective of the climatic conditions, agrisilviculture system displayed significantly higher benefit-cost ratio than AHS and AH system. In the interaction effect AS system prevailing in Dry temperate high hills displayed significantly higher values than all other treatment combinations. Benefit-cost ratio did not vary appreciable in other treatment combinations.

From the above results it is clear that the gross return were highest in the agrihorticulture system, involving apple fruit tree in the association with the agriculture and vegetable crops viz Pear, rajmash, cabbage and barley *etc.* The higher per unit market price of apple growing in the region, the quality of rajmash produced in the region has got high demand in the market, which helps in fetching them high gross and net return. However, the net returns (Rs ha⁻¹ yr⁻¹) from the agrihorticulture system were lower than the agrisilviculture because of higher total expenses of these systems.

Moreover, in agrihortisilviculture system, apart from the production of quality apple, pears and rajmash the system also yields, Neoza pine, which fetches a very high price in the market. At the same time being the natural growing trees of the region, they require little or no inputs.

It is also observed from the above results that net return on per hectare basis were lower in the high hills temperate dry and cold climatic condition than the dry temperate high hills. This is because of higher total expenses of the High hills temperate dry and cold C₂ climatic conditions in the form of organic and inorganic inputs, more labour cost and higher transportation charges due to the inaccessibility of the area.

Chapter-5

SUMMARY AND CONCLUSION

The present investigations entitled **“Structure and function of agroforestry systems in dry temperate regions of north western Himalayas”** were carried out in Kinnaur district of Himachal Pradesh during the year of 2014-2015. The study was aimed at findings the land use systems, which are efficient in biodiversity conservation, locking up the nutrient content in plants and soil, nutrient cycling in agroforestry systems and can help us in yielding high economic return. The present study was carried out in dry temperate regions of Kinnaur district, mainly focused in Pooh, Spilloh and Reckong Peo region. The latitudinal and longitudinal range of dry temperate zone lies between 31° 05' 50"- 32° 05' 15" N and longitude 77° 45' -79° 00' 35" E. Altitudinal range of this zone is about 2350m to 6816m above mean sea level and climate is Dry temperate. In this area rainfall is approximately 682.24 mm; the precipitation is mainly in the form of snow.

The soils found in this area are generally brown, alluvial and grey brown podzolic. At each site, three agroforestry systems viz., agrihorticulture, agrisilviculture and agrihortisilviculture were identified through extensive survey work in two different climatic conditions viz Dry temperate high hills (C₁) and High hills temperate dry and cold(C₂). The data for desired characters were taken for all the identified agroforestry systems from desired sampling plots. For the study of biomass and density of trees sample plot of 10 m×10 m size was laid down in each agroforestry system which was replicated 10 times. Shrubs were studied in each agroforestry system by laying out 5 sub plot of size 5m × 5m. Herbaceous vegetation and litter in different agroforestry systems were studied in the growing season (September-October) by harvesting quadrates of size 1m × 1m each from every agroforestry system, which was replicated 10 times. Similarly 0.5m × 0.5m quadrate was made for grass in each agroforestry system, which was replicated 10 times.

Crop and fruit yield of trees were either determined on unit area basis or determined on the basis of interviews of the farmer of the respective land use systems. Soil attributes viz., bulk density, partial density pore space percentage, organic carbon, soil pH (1:2), total nitrogen, extractable phosphorus, available potassium, exchangeable calcium and exchangeable magnesium were also determined. These soil samples were drawn from 0-15

cm and 15-30 cm soil layers. A brief summary of the results emerging out from current investigations are presented as below:

- The density of herbage including agricultural crops under different agroforestry systems at different climatic conditions ranged from 13.001 to 15.465 (tillers m⁻²) and basal area ranged between 15.319 to 20.343 (cm² m⁻²). The maximum herbage density and herbage basal areas were found in climatic condition C₁ followed by climatic condition C₂.
- Under climatic condition C₁, the maximum herbage density was found in agrihorticulture system (15.465 tillers m⁻²) while maximum herbage basal area was found in agrisilviculture system (20.343 cm² m⁻²). Similarly at climatic condition of C₂ the maximum herbage density (14.566 tillers m⁻²) and maximum herbage basal area (18.886 cm² m⁻²) were found in agrisilviculture systems.
- Under climatic condition C₁, among all agriculture crops *Brassica oleracea* displayed maximum basal area (9.099 cm² m² and 9.865 cm² m²) at AH system and AHS system respectively, whereas *Zea mays* occupied maximum basal area (10.112 cm² m²) in AS system. Among weeds the maximum basal area was displayed by *Ajuga parviflora* (0.146 cm² m²) in AH system, *Thalictrum foliosum* (0.166 cm² m², 0.167 cm² m²) in AS and AHS system.
- Under climatic condition C₂, among all agriculture crops *Brassica oleracea* displayed maximum basal area (9.526 cm² m², 10.048 cm² m² and 7.725 cm² m²) at AH system, AS system and AHS system respectively, whereas *Zea mays* occupied maximum basal area (7.860 cm² m²) in AS system. Under weeds the maximum basal area was occupied by *Lathyrus emodi* (0.139 cm² m²) in AH system *Amerantus spinosus* (0.073 cm² m²) in AS system and *Ajuga parviflora* (0.066 cm² m²) in AHS system.
- Under climatic condition C₁ the maximum shrub density was found in agrihorticulture system (1573.33 plant ha⁻¹) while maximum basal area was found in agrisilviculture system (0.367 m² ha⁻¹). Similarly, at climatic condition C₂ the maximum density (706.67 plant ha⁻¹) and maximum basal area (3.021 m² ha⁻¹) were noticed in agrihorticulture system. Tree density was maximum in AH land use system under both climatic conditions. The order of tree density in both climatic conditions was; agrisilviculture system > agrihortisilviculture system > agrisilviculture system.
- In C₁ climatic condition, the maximum tree density was demonstrated by *Malus domestica* (503.33 tree ha⁻¹) in AH system. The minimum density was taken by

Diospyros kaki (3.33 tree ha⁻¹) in AH system. Under AHS system at (C₁) climatic condition, the minimum density was reported by *Salix alba* (6.67 tree ha⁻¹). Among all trees at AS system, *Celtis australis* (60.00 tree ha⁻¹) displayed maximum density whereas; minimum density was reported by *Cedrus deodara* and *Pinus wallichiana* (3.33 tree ha⁻¹).

- In C₂ climatic condition, the maximum density was demonstrated by *Malus domestica* (486.67 tree ha⁻¹) in AH system and AHS system (230.00 tree ha⁻¹). The minimum density was taken by *Prunus dulcis* (43.33 tree ha⁻¹) in AH system. Under AHS system at C₂ climatic condition, the minimum density was reported by *Juglans regia* and *Pinus gerardiana* (6.67 tree ha⁻¹). Among all trees at AS system *Quercus semecarpifolia* displayed maximum density (60.00 tree ha⁻¹) whereas minimum density was reported by *Populus ciliata* (20.00 tree ha⁻¹).
- In Dry temperate high hills climatic condition (C₁), the maximum grass total density was found in AS system (88.800 tiller m²) followed by AH system (76.000 tiller m²) whereas minimum density was observed in AHS system (75.333 tiller m²).
- The maximum grass total density at High hills temperate dry and cold (C₂) climatic condition was found in AH system (79.200 tiller m²) followed by AS system (68.400 tiller m²) while least total density was observed in AHS system (56.800 tiller m²).

Shannon Wiener and Simpson's diversity index

- Agrisilviculture system displayed higher Shannon Wiener index than either AHS and AH systems. AS system and AHS system though were statistically alike yet both were significantly superior to AH system.
- Simpsons diversity index was higher in agrihorticulture system followed by agrisilviculture system and agrihortisilviculture system.
- Irrespective of the agroforestry systems under climatic conditions. Simpsons diversity index displayed significantly higher value in the Dry temperate high hills (C₁) climatic condition than High hills temperate dry and cold (C₂) climatic condition, respectively.
- Interaction effects of the agroforestry systems and climatic conditions were not found to exert any significant influence on both the diversity indices.

Biomass production (t ha^{-1})

- Above ground biomass and below ground biomass production was found to be maximum in AS followed by AHS and AH systems, respectively. Similar trend was also observed for the litter biomass production.
- Unlike Agroforestry systems, climatic conditions failed to exert any significant influence on the different biomass components.
- In the interaction effect, agrisilviculture system in both climatic conditions displayed the maximum value of above ground biomass as compared to other combinations.

Carbon density (t ha^{-1})

- Vegetation carbon density displayed its maximum value (63.09 t ha^{-1}) in agrisilviculture system, followed by AHS and AH system.
- Soil carbon density (t ha^{-1}) was found to be maximum in the agrihortisilviculture system followed by AH and AS system, respectively.
- Litter carbon density followed the trend: AS~ AHS > AH system.
- Total carbon density was significantly higher in the AS and AHS systems over AH system. AS and AHS, however, remained statistically alike.
- Irrespective of the agroforestry systems, soil and total density of elements was found to be more in the agro-ecosystem of the dry temperate high hills C_1 climatic condition than C_2 high hills temperate dry and cold climatic condition.
- Among various treatment combinations- agrisilviculture system prevailing under the Dry temperate high hills climatic condition displayed maximum value of vegetation carbon density ($63.73 \text{ C t ha}^{-1}$).

Rate of biomass increment ($\text{t ha}^{-1} \text{ yr}^{-1}$)

- Rate of biomass increment (1.69 t ha^{-1}) was found to be highest in agrihorticulture system followed by AS and AHS system.
- In the interaction effect, the agrihorticulture system under both climatic conditions displayed highest rate of biomass increment.
- The rate of biomass increment in shrubs was not found to be influenced significantly due to agroforestry systems, climatic conditions and interaction between them.

Nutrient stock (Kg ha⁻¹)

Nutrient stock in different part of trees (Kg ha⁻¹)

- Among nutrients in trees bole in general trend was: Ca > K > N > P.
- In tree branches also the trend was Ca > K > N > P.
- In tree leaf, in general the trend was: N > K > Ca > P.
- The level of the nutrients in different components of the tree was found to be significantly influenced due to the agroforestry systems, excepting P in tree stem and the leaf and N in tree fruits.
- Irrespective of the agroforestry systems, the climatic conditions is not having any impact on the nutrient stocks.

Nutrient stock in different part of the shrubs (Kg ha⁻¹)

- In shrubs leaf, the trend was Ca > K > N > P.
- In AH system the maximum level of N stock was found in shrub leaf followed by shrub root, branch and stem.
- Only K stock in shrub leaf, branch and root were significantly influenced by interaction effect between agroforestry systems and climatic conditions.
- Ca stock in shrub roots was significantly influenced by agroforestry systems. The maximum level of Ca stock in shrub roots was found in AS system.

Total nutrient stock in trees and shrubs (Kg ha⁻¹)

- Amount of total nutrient stock of N, P, K and Ca in trees was appreciably higher than in shrubs.
- Total stock of K in trees is higher than N, Ca and P. Total stock of nutrients followed the order: Ca > N > K > P.
- The level of N, P and K in trees was found to be significantly influenced due to the agroforestry systems.

Nutrient stock in the 0-30 cm soil depth (Kg ha⁻¹)

- The level of the P and Ca was found to be significantly influenced due to the agroforestry systems. The nutrient stock of N, P, K and Ca in the soil followed the order: N > Ca > K > P.

- The nutrient P, K and Ca were found to be significantly higher in dry temperate high hills C₁ climatic conditions than high hills temperate dry and cold C₂ climatic conditions.

Total nutrient stock in the agro-ecosystems (Kg ha⁻¹)

- Of the four nutrient stocks studied only P and K were found to be significantly influenced due to agroforestry systems.
- The nutrient stock in the agro-ecosystem followed the order: N > Ca > K > P.
- In general, the nutrient stock of these elements in the agro-ecosystems were higher in the dry temperate high hills C₁ climatic conditions than high hills temperate dry and cold C₂ climatic conditions.

Rate of nutrient uptake by different part of the trees (Kg ha⁻¹)

- Rate of uptake of nutrients – N, P, K and Ca is maximum in tree fruits followed by tree stem or roots, tree leaf and tree branches.
- Ca uptake by tree branch was significantly influenced by climatic conditions. The maximum level of Ca in tree branch was found in climatic condition C₁.
- N, K and Ca uptake by tree leaf was found to be significantly influenced due to climatic condition. Higher level of N, K and Ca uptake by tree leaf was found in climatic condition C₂ than climatic condition C₁.
- The interaction between agroforestry systems and climatic conditions was found to significantly influence N, K and Ca uptake by tree leaf. The higher value of N, K and Ca uptake by tree leaf was found in treatment combination T₂C₂.
- An interaction between agroforestry systems and climatic conditions was found to significantly influence N, P, K and Ca uptake by tree fruits.

Rate of nutrients uptake by different part of the agricultural crops (Kg ha⁻¹)

- Rate of uptake of the nutrients- N, P, K and Ca is maximum in agricultural crop fruits/grains followed by agricultural crop shoots and crop roots, respectively.
- Similar to the uptake rate of the nutrients by the different part of trees, climatic conditions did not reveal any specific pattern, however, values generally higher uptake level of nutrients was found in C₁ climatic condition than C₂ climatic condition.

- The nutrient uptake of N, P, K and Ca by agriculture crops followed the order: $K > N > Ca > P$ under crop fruits, crop roots and crop shoots in AH system.

Rate of nutrient uptake by different components of the weeds and grasses (Kg ha^{-1})

- The nutrients uptake by the different components of the weeds and grasses is not much influenced by agroforestry systems, climatic conditions and interaction between them.
- The nutrient uptake by the weed shoots is quite higher than weed roots. Similarly, the uptake by grass shoots is markedly higher than grass roots.
- P uptake by weed roots was significantly influenced by agroforestry systems, climatic conditions and interaction between them.
- N uptake by grass shoots was significantly influenced due to climatic conditions, agroforestry systems and interaction between them.

Nutrient uptake by different components of shrubs (Kg ha^{-1})

- The uptake of N, P, K and Ca were not much found to be influenced due to the different components of the shrubs bole, branch, leaf and roots.
- The uptake of the N, P, K and Ca in different components of the shrubs was found to be significantly higher in High hills temperate dry and cold desert conditions than in dry temperate high hills climatic conditions.
- N, P, K and Ca uptake by shrub stem, branch, leaf and root were found to be significantly influenced due to climatic conditions. The maximum uptake of these entire nutrients was found in C_2 climatic condition than the C_1 climatic condition.

Total nutrient uptake by trees and shrubs (Kg ha^{-1})

- Total nutrient uptake by tree was not found to be significantly influenced due to agroforestry systems, climatic conditions.
- Total uptake of K by trees was found to be significantly influenced due to interaction between agroforestry systems and climatic conditions.
- The total nutrient uptake N, K and Ca uptake by shrubs were significantly influenced due to climatic conditions. The maximum level of N, K and Ca was found in C_2 climatic condition.
- The interaction between agroforestry systems and climatic conditions were significantly influenced N, K and Ca uptake by shrubs.

Total nutrient uptake by agricultural crops, weeds and grasses (Kg ha⁻¹)

- Among the annual components of the system maximum rate of nutrients uptake is by agricultural crops followed by grasses and weeds.
- In agricultural crops uptake rate of N and K were significantly influenced due to agroforestry systems, climatic condition and interaction between agroforestry systems and climatic conditions.
- The total uptake of N and Ca by weeds was significantly influenced due to agroforestry systems. The maximum level of N and Ca uptake by weeds were found in AS system.

Total nutrient stock in vegetation (Kg ha⁻¹) and total uptake (Kg ha⁻¹yr⁻¹) by vegetation

- The total stock of N, P and K nutrient in vegetation was significantly influenced due to the agroforestry systems excepting Ca. The maximum stock of N, P and K was noticed in AS system followed by AHS system whereas minimum stock was found in AH system.
- The climatic conditions were found to significantly influence the total stock of K under vegetation only. The maximum value of K stock (684.48 Kg ha⁻¹) was found in C₁ climatic condition which was significantly better to C₂ climatic conditions.
- Total uptake of N, K and Ca by whole vegetation significantly influenced due to the agroforestry systems. The maximum uptake was recorded in AH and AS system, whereas, maximum stock of K and Ca was found in AH system.
- Climatic conditions displayed significant influence on P uptake which found to be significantly higher in C₁ climatic condition than C₂ climatic condition.

Nutrients concentration (dry weight basis) under different part of trees

- Nutrient concentration percent follow the order; K > Ca > N > P under tree stem, branch and fruits in different agroforestry systems excepting tree leaf and tree roots.
- N, P, K and Ca concentration percent in tree stem was significantly influenced due to agroforestry systems. The maximum concentration of N, K and Ca was recorded in AH system while P concentration was similar in AH and AHS system.
- K concentration percent in tree stem was significantly influenced due to climatic conditions. Higher concentration of K under tree stem was recorded at C₁ Climatic condition than at C₂.

- N and K concentration percent in tree stem was significantly influenced due to interaction between agroforestry systems and climatic conditions.
- N, K and Ca concentration under tree branch was found to be significantly influenced due to agroforestry systems, climatic conditions and their interactions.
- The maximum concentration of N and Ca in tree branch was recorded in AS system while maximum level of K was observed in AH system which is situated in climatic condition C₁.
- The concentration of N, P and K in tree leaf was significantly influenced due to agroforestry systems.
- The concentration of N, P, K and Ca in tree leaf was significantly influenced due to climatic conditions. The maximum value of N and Ca was found in climatic condition C₂, while maximum level of P and K was observed in climatic condition C₁.
- The concentration of N, P and Ca in tree leaf was influenced significantly by interaction between climatic conditions and agroforestry systems.
- Significantly higher value of K and Ca concentration in tree roots was recorded in AHS system while the maximum concentration of N in tree roots was found in AS system.
- N, P, K and Ca concentration in tree fruits significantly influenced due to agroforestry systems and interaction between agroforestry system and climatic conditions.

Nutrients concentration (dry weight basis) under different part of shrubs

- N and Ca concentration in shrub stem significantly influenced due to agroforestry systems. The maximum concentration of N and Ca in shrub stem was found in AS system.
- Concentration P and K in shrub stem significantly influenced due to interaction between agroforestry systems and climatic conditions.
- N, P, K and Ca concentration in shrub stem was significantly influenced due to climatic conditions. The higher level of N, P and Ca concentration in shrub stem was found in C₂ climatic condition while the maximum concentration of K was found in climatic condition C₁.
- Only Ca concentration in shrub leaf was significantly influenced due to agroforestry systems. The maximum concentration in shrub leaf was found in AH system.

- Ca concentration in shrub roots was significantly influenced by the interaction between agroforestry systems and climatic conditions while the concentration of K in shrub roots was significantly influenced by climatic conditions.

Nutrients concentration (dry weight basis) under different part of agriculture crops

- N, K and Ca concentration in agriculture crop shoots significantly influenced due to agroforestry systems. The maximum concentration of N, K and Ca in crop shoots was found in AHS system.
- N, P and K concentration in agriculture crop shoot significantly influenced due to climatic conditions. The maximum concentration of N, P and K in crop shoots was found in climatic condition C₂.
- The concentration of P in crop roots was found to influence significantly due to agroforestry systems, climatic conditions and their interaction. The higher value of P concentration in crop roots was found in climatic condition C₂ than climatic condition C₁.
- The concentration of N in crop grains/fruits was found to influence significantly due to agroforestry systems and interaction between agroforestry systems and climatic conditions. The higher value of N concentration in crop grains/fruits were found in AHS system situated in climatic condition C₁.
- The significantly higher concentration of P and Ca in crop grains/fruits was observed in AH system which is higher than AS system and AHS system.

Nutrients concentration (dry weight basis) under different part of weeds and Grasses

- N concentration in weed shoots significantly influenced due to agroforestry systems, climatic conditions and their interactions. The maximum concentration of N in weed shoots was found in AH system situated in climatic condition C₂.
- K concentration in weed shoots significantly influenced due to agroforestry systems only, the maximum concentration of K (3.09 %) in weed shoots was observed in AH system.
- K concentration in weed roots significantly influenced due to agroforestry systems only, the maximum concentration of K in weed roots was observed in AH system.
- The concentration of Ca in weed roots significantly influenced due to the agroforestry systems as well as the interaction between agroforestry systems and climatic

conditions. The maximum concentration of Ca in weed roots was found in AH system.

- The concentration N and K in grass shoot significantly influenced due to agroforestry systems, the maximum concentration of N and K in grass shoots was observed in AHS system than AS and AH systems.
- Climatic conditions significantly influenced to concentration P, K and Ca in grass shoots. The maximum concentration of P, K and Ca in grass shoots was observed in climatic condition C₂.
- N concentration in grass roots was found to be significantly influenced due to agroforestry systems, climatic conditions and their interaction. The highest level of N concentration in grass roots was found in AS system situated in climatic condition C₂.
- The concentration of K in grass roots was significantly influenced by agroforestry systems only. The higher concentration of K in grass roots was observed in AHS system.
- The concentration of Ca in grass roots was significantly influenced by climatic conditions only. The higher concentration of Ca in grass roots was observed in climatic condition C₂.

Nutrients addition through litter fall (Kg ha⁻¹ yr⁻¹)

- Maximum addition of K through litter fall is in AS system followed by AHS and AH system, respectively.
- Climatic condition was seen to influence significantly the K content which was significantly higher in C₂ climatic condition than by C₁ climatic condition.

Nutrients addition through crop debris (Kg ha⁻¹ yr⁻¹)

- Agroforestry systems exercised significant effect on N, K and Ca addition through crop debris.
- The maximum addition of N, K and Ca through crop debris was recorded in AHS system followed by AS and AH system respectively.
- Non-significant but higher addition of N, K and Ca through crop debris was recorded in C₂ climatic condition than the C₁ climatic condition.

Nutrients addition through weed debris ($\text{Kg ha}^{-1} \text{ yr}^{-1}$)

- N, K and Ca addition through weed debris was significantly influenced due to agroforestry systems. The maximum addition of these nutrients was in AHS system followed by AH and AS system respectively.
- Interaction of agroforestry systems $\times$ climatic conditions did not significantly influence the nutrient addition through weed debris.

Amount of nutrients added by different fertilizers ($\text{Kg ha}^{-1} \text{ yr}^{-1}$)

- Maximum amount ($168.04 \text{ Kg ha}^{-1}$) of N was added in the agrihorticulture system, which was statistically identical to AHS system only.
- The addition of the N, K and Ca also followed the order: $\text{AH} > \text{AHS} > \text{AS}$ system.

Total amount of nutrients addition through different sources ($\text{Kg ha}^{-1} \text{ yr}^{-1}$)

- The total amount of N and K added by different sources was significantly influenced by the agroforestry systems only.
- The maximum values of N ($168.43 \text{ Kg ha}^{-1} \text{ yr}^{-1}$) and K ($209.16 \text{ Kg ha}^{-1} \text{ yr}^{-1}$) was recorded in AH system which was significantly higher than AHS and AS system.
- Climatic conditions and interaction between agroforestry systems and climatic condition did not significantly influence the total amount of N, P, K and Ca added through different sources.

Nutrients removal under different agroforestry systems ($\text{Kg ha}^{-1} \text{ yr}^{-1}$)

- The relatively higher removal of N ($114.13 \text{ Kg ha}^{-1} \text{ yr}^{-1}$), P ($28.29 \text{ Kg ha}^{-1} \text{ yr}^{-1}$), K ($169.88 \text{ Kg ha}^{-1} \text{ yr}^{-1}$) and Ca ($117.52 \text{ Kg ha}^{-1} \text{ yr}^{-1}$) was observed in C_2 climatic condition which was significantly higher than C_1 climatic conditions.
- Agroforestry systems were found to significantly influence to the removal of P nutrient only. The higher value of P removal was recorded in AHS system followed by AH system and AS system, respectively.
- Interaction between agroforestry systems and climatic conditions lacked to significantly influence the removal of all nutrients under agroforestry systems.

Annual turnover percentage of the nutrients in the soil and vegetation compartments

- The fractional annual turnover (%) of the nutrients- P, K and Ca in soil pool significantly influenced due to the agroforestry systems effects. The percent annual turnover of P, K and Ca was significantly higher under agrihorticulture system followed by agrisilviculture system and agrihortisilviculture system
- The annual turnover of P and K in soil pool was found to be significantly higher under C₁ climatic condition then C₂ climatic condition.
- Annual nutrient turnover of N, P, K and Ca in the vegetation pool was found to be significantly influenced due to agroforestry systems.
- Irrespective of the agroforestry systems, the annual turnover of the P, K and Ca turnover percentage was found to be significantly influenced due to the climatic conditions. C₂ climatic conditions displayed significantly higher value of the all nutrients annual turnover than C₁ climatic condition.

Physico-chemical analysis of soils

Physical properties of soil

- Under C₁ climatic condition, samples collected from 0 -15 cm soil depth of the AH land use system displayed silty clay loam texture. Whereas in the AHS system the top 0-15 cm soil depth displayed silty clay loam to two clay loam properties AS system at 0-15 cm as well as 15-30 cm soil depth two sample showed silty clay loam to silty clay texture.
- At C₂ climatic condition, the surface soil depth has clay loam to silt clay to texture whereas, subsurface depth (15-30 cm) displayed silty clay to silty clay loam properties. Surface layer under the AS system is having clay loam type of the texture whereas, the subsurface layer displayed silty clay to silty clay loam texture.
- Irrespective of the agroforestry system and soil depth, the soil under dry temperate high hills displayed significantly higher bulk density (1.38 g cm⁻³) than high hills temperate dry and cold conditions.
- Among different agroforestry systems the particle density followed the trend: AH > AS > AHS system.
- The pore space percent under different agroforestry systems followed the trend: AH > AS > AHS systems.

- In the average effect of climatic conditions, High hills temperate dry and cold conditions displayed significantly higher values than the Dry temperate high hills.
- In the average effect of the soil depth, the pore space percent declined significantly from D₁ to D₂.

Chemical properties of soil

- The organic carbon (%), exchangeable Ca and Mg were found to be significantly influenced due to the effects of the agroforestry systems. Maximum organic carbon (%) was registered in AHS system while maximum value of exchangeable Ca and exchangeable Mg were recorded in AH and AS system respectively.
- High hills temperate dry and cold climatic conditions (C₂) demonstrated higher values of the pH, organic carbon (%) and extractable P but available K content where significantly higher at C₁ than C₂.
- All the chemical characteristic displayed significantly higher values at D₁ (0-15 cm) than D₂ (15-30 cm) excepting pH which was found to be significantly higher at the surface layer.

Economic analysis

- Irrespective of climatic conditions, the agrihorticulture system gave significantly higher gross returns than agrisilviculture and agrihortisilviculture systems. In the interaction effect agrihorticulture and agrihortisilviculture systems the gross returns enhanced from C₁ to C₂ climatic conditions whereas in agrisilviculture system the gross returns declined.
- The total expenses were significantly higher under the agrihorticulture and agrihortisilviculture than agrisilviculture.
- Net returns per hectare basis were significantly higher under Dry temperate high hills conditions than High hills temperate dry and cold climatic condition. Irrespective of the climatic conditions, realizations of the net returns from the agrihortisilviculture systems were significantly higher than either AH or AS systems.
- Benefit cost ratio in dry temperate high hills displayed significantly higher values compared to high hills temperate dry and cold climatic conditions.
- Irrespective of the climatic conditions, agrisilviculture system displayed significantly higher benefit-cost ratio than AHS and AH system. In the interaction effect AS system prevalent in dry temperate high hills displayed significantly higher values than

all other treatment combinations. Benefit-cost ratio did not vary appreciable in other treatment combinations.

CONCLUSION

From the above study it is concluded that all types of agroforestry systems are important for the Dry temperate regions of the Kinnaur district of Himachal Pradesh. Agrihortisilviculture and agrihorticulture systems are more profitable from the economic point of nevertheless require lots of extern input for maintaining their sustainability. Resource poor farmers can keep on with agrisilviculture systems as these systems require less input externally and have got higher benefit-cost ratio, carbon storage and biodiversity and better nutrient cycling potential.

LITERATURE CITED

- Abaoli M. 2014. Comparison of Fine Root Biomass under *Grevillea robusta* and *Juniperus procera* in Gera Indigenous Agroforestry systems, Southwest Ethiopia. *International Invention Journal of Agricultural and Soil Science* **2**:99-104.
- Adhikari B S, Rikhari H C, Rawat Y S and Singh S P. 1991. High altitude forest: composition diversity and profile structure in a part of Kumaun Himalaya, *Tropical Ecology* **32**:86-97.
- Affendy H, Tan M S, Assis K and Mohammad Amizi A. 2013. Economic Viability of *Tectona grandis* sole Cropping and Intercropping for 20 years Planting Project. *Research Journal of Agriculture and Forestry Sciences* **1**:22-25.
- Ajit Dhyani A S K, Ramnewaj, Handa A K, Rajendra P, Badre A, Rizvi R H, Gupta G, Pandey K K, Jain A and Uma. 2013. Modelling analysis of potential carbon sequestration under existing agroforestry systems in three districts of Indo-gangetic plains in India. *Agroforest Systems* **87**:1129-1146.
- Albrecht A and Kandji S T. 2003. Carbon sequestration in tropical agroforestry systems. *Agriculture, Ecosystems and Environment* **99**:15-27.
- Albrecht A, Kandji S T 2003 Carbon sequestration in tropical agroforestry systems. *Agric Ecosyst Environ* **99**:15-27
- Ali A. 2007. Evaluation of natural regeneration status and site quality characteristics of *Taxus wallichiana* Zucc. Syn. *T. baccata* Hook. f. in Kullu and Mandi districts. M.Sc. thesis, Dr. YSP UHF, Nauni-Solan (H.P), India 107pp.
- Animon M M, Asokan P K, Sudhakara K, Jeysankar S and Kumar D P. 1999. Physico chemical and biological properties of soils under *Acacia auriculiformis*. *Journal of Tropical Forestry* **15**: 49-51.
- Assmann E. 1970. The principles of forest yield study. New York: Pergamon Press. 506p.
- Baral S K, Malla R and Ranabhat S. 2009. Above-ground carbon stock assessment in different forest types of Nepal. *Banko Jankari* **19**:10-14.
- Basumatary A and Bordoloi P K 1992. Forms of potassium in some soils of Assam in relation to soil properties. *Journal of the Indian Society of Soil Science* **40**:443-446.
- Bavappa K V, Kailasam C, Khader K B A, Biddappa C C, Khan H H, Kasthuri Bai K V, Ramadasan A, Sundararaju P, Bopaiah B M, Thomas G, Mishra L P, Balasimha D, Bhat N T and Bhat K S. 1986. Coconut and Arecanut based high density multispecies cropping systems. *Journal of Plantation Crops* **14**:74-87
- Bera G. 2015. Assessment of Apple Cultivation in Kalpa, Kinnaur District, Himachal Pradesh. *Journal of Humanities and Social Science* **20**:20-23.
- Bhardwaj S D, Panwar P, Gautam S. 2001. Biomass production potential and nutrient dynamics of *Populus deltoides* under high density plantations. *Indian Forester* **127**: 144-153.

- Bhowmik A K, Singh A K and Banerjee S K. 2003. Litter fall and nutrient dynamics in soil under Eucalyptus hybrid plantation. *Indian Agriculturist* **47**:95-106.
- Bhola N. 1995. Studies on relative growth performance and soil enrichment potential of some nitrogen fixing trees. M.Sc thesis, Dr Y S Parmar University of Horticulture and Forestry, Nauni-Solan, (H. P.), India. 94p.
- Bhuyan P, Khan M L and Tripathi R S. 2003. Tree diversity and population structure in undisturbed and human-impacted stands of tropical wet evergreen forest in Arunachal Pradesh, Eastern Himalayas, India. *Biodiversity Conservation* **12**:1753-1773.
- Bijalwan A. 2012. Structure, Composition and Diversity of Horticulture Trees and Agricultural Crops Productivity under Traditional Agri-Horticulture System in Mid Hill Situation of Garhwal Himalaya, India. *American Journal of Plant Sciences*. **3**:480-488.
- Bijalwan A. 2014. Alteration of tree species in traditional agri-silvi-horticulture systems along altitude and aspects of the Garhwal Himalaya, India. *International Journal of Agroforestry and Silviculture* **1**:37-51.
- Bitlerlich W. 1984. The Relaskop Idea Slough: Common Wealth Agricultural Bureause, Farnham Royal, England.
- Boruah H C and Nath A K. 1992. Potassium status in three major soil orders of Assam. *Journal of the Indian Society of Soil Science* **40**:559–561.
- Bouyocos G J. 1927. The hydrometer as a new method for the mechanical analysis of soils. *SoilScience* **23**: 343-354.
- Bray R H and Kurtz L T. 1945. Determination of total, organic, and available forms of phosphorus in soils. Illinois Agricultural Experiment Station, Urbana, IL. *Soil Science* **59**:39-45.
- Cairns M A, Brown S, Helmer E N and Baumgardener G A. 1997. Root biomass allocation in the world's upland forests. *Oecologia* **111**:1-11.
- Carlisle A, Brown A H F and White E J. 1966b. The organic matter and nutrient elements in the precipitation beneath sessile oak (*Quercus petraea*) canopy. *Jouranl of Ecology* **54**:87-98.
- Chaturvedi A N and Khanna L S. 1982. Forest Mensuration. International Book Distributors, Dehradun, India. 403p.
- Chauhan H S. 2000. Performance of poplar (*Populous deltoids*) based agroforestry systems using aromatic crops. *Indian Journal of Agroforestry* **2**:17-21.
- Chauhan S K, Gupta N, Walia R, Yadav S, Chauhan R and Mangat P S. 2011. Biomass and carbon sequestration potential of Poplar-Wheat inter-cropping system in irrigated agro ecosystem in India. *Journal of Agricultural Science and Technology*. **1**:575-586.
- Chauhan S K, Sharma R, Singh B and Sharma S C. 2015. Biomass production, carbon sequestration and economics of on-farm poplar plantations in Punjab, India. *Journal of Applied and Natural Science* **7**:452-458.

- Chavan B L and Rasal G B. 2011. Sequestered carbon potential and status of *Eucalyptus* tree. *International Journal of Applied Engineering and Technology* **1**:41-47.
- Chidumaya E N. 1990. Aboveground woody biomass structure and productivity in Zambesian. *Woodland Forest Ecology and Management* **36**:33-46s.
- Chisanga K, Bhardwaj D R and Shrama S. 2013. Bio-economics appraisal of agroforestry systems in dry temperate western Himalayas. *Journal of Tree Science* **32**:1-7.
- Curtis J T and McIntosh R P. 1950. The interrelations of certain analytic and synthetic phytosociological characters. *Ecology* **31**:434-455.
- Dalland A, Vaje P L, Mathews R B and Singh B R. 1993. The potential of alley cropping in improvement of cultivation systems in the high rainfall areas of Zambia. Effect on soil chemical and physical properties. *Agroforestry Systems* **21**:117-132.
- Dar J A and Sundarapandian S. 2016. Patterns of plant diversity in seven temperate forest types of Western Himalaya, India. *Journal of Asia-Pacific Biodiversity* **9**:280-292.
- Das K and Chaturvedi O P. 2008. Root phytomass recovery and rooting characteristics of five agroforestry tree species in eastern India. *Journal of Tropical Forest Science* **20**:156-166.
- Das S, Sharma S, Sharma K, Saharan N, Nimbole N and Reddy Y. 1993. Land use options on a semi-arid Alfisol. *American Journal of Alternative Agriculture* **8**:34-39.
- Deshmukh H K. 1998. Studies on the performance of wheat and soybean as intercrop with *Grewia optiva* pollarded at different heights. M.Sc. thesis, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni-Solan (H. P.), India. 90 p.
- Dey A N. 1996. Biomass studies on *Populus deltoides* Marsh under different landuse systems. M.Sc. Thesis, UHF-Nauni, Solan (H.P.) 144 + xvip.
- Dhand V A K, Tripathi R K, Manhas J D S, Negi and Chauhan. 2003. Estimation of carbon content in some forest tree species. *Indian Forester* **129**:918-922.
- Dhillon W S and Chauhan S K. 2012. Intercropping of fruit crops, spices and poplar trees pose high profits for farmers. *Asia-Pacific Agroforestry Newsletter* **40**:3-4.
- Dimri D C, Kumar Gaurav and Singh S C. 2010. Response of different organic materials on grafting success and scion growth of apple (*Malus domestica* Borkh.). *Progressive Horticulture* **42**:124-127.
- District disaster management plan of district Kinnaur, Himachal Pradesh (2009-2012). District disaster management authority (ddma) Kinnaur 4 p.
- Dossa E L, Fernandes E C M, Reid W S and Ezui K. 2008. Above- and belowground biomass, nutrient and carbon stocks contrasting an open-grown and a shaded coffee plantation. *Agroforest Systems* **72**:103-115.
- Dutt V and Gupta B. 2005. Interaction between trees and ground flora in different aged chir pine stands of sub-tropical region in India-I: Density of herbage and LAI. *Indian Journal of Forestry* **28**:28-36.

- Dutt V and Thakur P S. 2004. Bio- economics of cropping systems combining medicinal and aromatic herbs with commercial timber tree species. *Indian Journal of Agroforestry*. **6**:1-7.
- Dyal S K N, Grewal S S and Singh S C. 1996. An agri-silvi-horticultural system to optimize production and cash returns for shivalik foothills. *Indian Journal Soil Conservation* **24**: 150-155.
- Eyre B D, Maher D T and Squire P. Quantity and quality of organic matter (detritus) drives N₂ effluxes (net denitrification) across seasons, benthic habitats, and estuaries. *Global Biogeochemical Cycles* **27**:1083-1095.
- Fang S, Hailing L, Sun Q and Chen L. 2010. Biomass production and carbon stocks in poplar-crop intercropping systems: case study in north-western Jiangsu, China. *Agroforestry Systems* **79**:213–222.
- Fang S, Li H, Sun Q and Chen L. 2010. Biomass production and carbon stocks in poplar-crop intercropping systems: a case study in northwestern Jiangsu, China. *Agroforestry Systems* **79**:213-222.
- Fassbender H W, Alpizar L, Heuvelop J, Fölster H and Enriquez G. 1988. Modelling agroforestry systems of cacao (*Theobroma cacao*) with laurel (*Cordia alliodora*) and poro (*Erythrina poeppigiana*) in Costa Rica. III. Cycles of organic matter and nutrients. *Agroforestry Systems* **6**: 49-62.
- Feller M C, 1980. Biomass and nutrient distribution in two eucalypt forest ecosystems. *Australian Journal of Ecology* **5**:309-33.
- Fioretto A Papa S. and Pellegrino A 2008. Microbial activity and quality changes during decomposition of *Quercus ilex* leaf litter in three Mediterranean woods. *Applied Soil Ecology* **3**:401-410.
- Fittkau E J and Klinge H 1973. On biomass and tropic structure of Central Amazonian forest ecosystem. *Biotropica* **5**: 2-14.
- Fontes A G, Rodrigues A C G, Rodrigues E F G, Sales M V S, Costa M G and Machado R C R. 2014. Nutrient stocks in litterfall and litter in cocoa agroforests in Brazil. *Plant Soil* **383**:313-335.
- Fortier J, Truax B, Gagnon D and Lambert F. 2013. Root biomass and soil carbon distribution in hybrid poplar riparian buffers, herbaceous riparian buffers and natural riparian woodlots on farmland. *Springer Plus* **2**:539.
- FSI. 1996. Volume Equations for forests of India, Nepal and Bhutan. Forest Survey of India, Ministry of Environment and forests, Govt. of India 238p.
- Garkoti S C.1996. Nutrient dynamics in high altitudes shrubs of Central Hmalaya. *Proceedings of the Indian National Science Academy* **4**:281-286.
- Graham R L, Wright L L and Turhollow A F. 1992. The potential for short rotation woody crops to reduce US CO₂ emissions. *Clim Change*. **22**:223 -238.
- Gaur A and Gupta S R. 2012. Impact of Agroforestry Systems on Carbon Sequestration in Northern Haryana, India. *International Journal of Ecology and Environmental* **38**:73-85.

- Gholz H L, Wedin D A, Smitherma S M, Harmon M E and Parton W J. 2000. Long-term dynamics of pine and hardwood litter in contrasting environments: Toward a global model of decomposition, *Global Change Biology* **6**:751-765.
- Gomez K A and Gomez A A. 1984. Statistical Procedures for Agricultural Research (2 ed.). John Wiley and sons, New York. 680p.
- Grewal S S and Abrol I P. 1986. Agroforestry on alkali soils: effect of some management practices on initial growth, biomass accumulation, and chemical composition of selected tree species. *Agroforestry Systems* **4**:221-232.
- Grewal S S, Mittal S P, Dayal S and Agnihotri Y. 1992. Agroforestry system for soil and water conservation and sustainable production for foot hill areas of north India. *Agroforestry Systems* **17**:183-191.
- Guleria V, Nayital R K and Gupta B. 1999. Phytosociological studies under chirpine stands in mid hills of Himachal Pradesh. *Range Management & Agroforestry* **20**: 47- 54.
- Gupat H, Sharma K R and Meena R K. 2016. Effect of *Lantana camara* L. extract on specific gravity of wood species. *International journal of farm science* **6**:277-280.
- Gupta B, Sarvade S and Mahmoud A. 2015. Effects of selective tree species on phytosociology and production of understorey vegetation in mid-Himalayan region of Himachal Pradesh. *Range Management & Agroforestry* **36**:156-163.
- Gupta G, Yadav R S, Maurya D and Mishra S V. 2010. Litter dynamics under different pruning regimes of *Albizia procera* based agroforestry system in semi-arid region. *Asian Science* **5**:92-97.
- Gupta N K. 1996. Appraisal of vegetational pattern of Shimla district through remote sensing with special reference to the ecology of fir-spruce forests. Ph.D. thesis, Dr. YSP University of Horticulture and Forestry, Solan (H.P.), India, 113p.
- Gupta N, Kukal S S, Bawa S S and Dhaliwal G S. 2009. Soil organic carbon and aggregation under *Populus* based agroforestry system in relation to tree age and soil type. *Agroforestry Systems* **76**:27-35.
- Gupta R K, Arora Y K and Shukla D. 1982. Know peach cultivars of Doon Valley. Indian Horticulture, ICAR, New Delhi: 2-4.
- Handayanto K, Cadisch G and Giller K E. 1994. Nitrogen release from prunings of legume hedgerow trees in relation to quality of the prunings and incubation method. *Plant and Soil*. **2**: 237-248.
- Hailu H. 2017. Analysis of Vegetation Phytosociological Characteristics and Soil Physico-Chemical Conditions in Harishin Land. 2-17pp.
- Hartemink A K. 2005. Nutrient stocks, nutrient cycling, and soil changes in cocoa ecosystems: a review. ISRI–World Soil Information, Netherland. *Advances in Agronomy* **86**:227-253.
- Hatfield R D, Marita J M, Frost K, Grabber J, Ralph J, Lu F C and Kim H. 2009. Grass lignin acylation: p-coumaroyl transferase activity and cell wall characteristics of C3 and C4 grasses. *Planta* **229**:1253-1267.

- Hase H and Foelster H. 1983. Impact of plantation forestry with teak (*Tectona grandis*) on the nutrient status of young alluvial soils of West Venezuela. *Forest Ecology and Management* **6**: 33-57.
- Heard J and Hay D. 2006. Typical nutrient content, uptake pattern and Carbon: Nitrogen ratios of prairie crops. In Proceedings of Manitoba Agronomists Conference
- Herlich K.1990. Official methods of analysis of the association of official analytical chemists. (ED). Association of official analytical chemists inc. United state of America **15**:41-45.
- Hobbie S E, Nadelhoffer K J, Hogberg P. (2002). A synthesis: The role of nutrients as constraints on carbon balances in boreal and arctic regions. *Plant and Soil* **242**: 163-170.
- Hofmann A, Heim A, Christensen B T, Miltner A, Gehre M and Schmidt M W I. 2009. Lignin dynamics in two C-13-labelled arable soils during 18 years. *European Journal of Soil Science* **60**:250-257.
- Hooker J D. 1906. Sketch of Flora of British India. London.
- Hosur G C, Dasog G S and Satyanarayana T. 1977. Litter production and nutrient return of different tree species under plantation conditions. *Indian Journal of Forestry* **20**:231-235.
- Hussain A, Farooq M A, Ahmad M, Akbar M and Zafar M U. 2010. Phytosociology and structure of central Karakoram national park (CKNP) of northern areas of Pakistan. *World Applied Sciences Journal* **9**:1443-1449.
- Hussain M S, Sulatan, Aisha, Khan J A and Khan A. 2008. Species composition and community structure of forest stands in Kumaon Himalaya, Uttarakhand, India. *Tropical Ecology* **49**:167-181.
- Hussain A and Maqsood M A. 2011: Root zone temperature influences nutrient accumulation and use in maize. *Pakistan Journal of Botany* **43**:1551-1556.
- India state of Forest report (ISFR) 2015. Forest Survey of India. Dehradun , India.
- IPCC. 1996. Impacts, adaptations and mitigation of climate: scientific-technical analyses. In: Contribution of the second assessment report of the Intergovernmental Panel on Climate Change1995. Cambridge University.
- IPCC. 2003. Good practice guidance for land use, land-use change and forestry, IPCC National Greenhouse Gas Inventories Programme, Hayama, Japan. 295p.
- Jackson M L. 1973. Soil chemical Analysis.Prentice Hall of Englewood cliffs, New Jersey, USA.
- Jana B K, Biswas S, Majumder M, Roy P K and Mazumdar A. 2009. Carbon sequestration rate and aboveground biomass carbon potential of four young species. *J Ecol Nat Environ*. 1:15 –24.
- Jazib M J and Rather S A. 2015. An Ethno-Botanical Overview of Oak: A Multipurpose Wild Tree Species of the PirPanjal Himalayas. *Forest Research open Access*. <http://dx.doi.org/10.4172/2168-9776.1000140>.

- Jenkins J C, Chojnacky D C, Heath L S and Birdsey R A. 2003. National-scale biomass estimators for United States tree species. *Forest Science* **49**:12-35.
- Jenny H. 1930. A study on the influence of climate upon the nitrogen and organic matter content of the soil. *Research Bulletin of the Missouri Agricultural Experiment Station*. 152.
- Jiofack T, Guedje N M, Tchoundjeu Z, Fokunang C, Lejoly J and Kemeuze V. 2013. Agroforestry typology of some cocoa based agroforests in the Mbam and Inoubou division: The importance for local population livelihoods. *Journal of Ecology and the Natural Environment*. 5:378-386.
- Johnson F L and Risser P G. 1974. Biomass, annual net primary production and dynamics of six mineral elements in a post oak-blackjack oak forest. *Ecology* **55**:1246-58.
- Johnson J M, Barbour N W and Weyers S. L. 2007. Chemical composition of crop biomass impacts its decomposition,” *Soil Science Society of America Journal*, **71**:155-162.
- Jordan, C F. 1985. Nutrient Cycling in Tropical Forest Ecosystems. (ed.). John Wiley, New York, USA.
- Jordon C F and Kline J R. 1972. Menial cycling: some basic concepts and their application in tropical rain forest. *Annual Review of Ecology, Evolution, and Systematic*. California **3**:33-49.
- Jorgensen J R, Wells C G and Metz L J. 1975. The nutrient cycle. Ket to continuous forest production. *Journal of Forestry* **73**:400- 403.
- Jose D. 1992. Structure and productivity of homegaredns of Kerala: case study. In: Nair C G R R (ed.). *Proceedings of the Fourth Kerala Science Congress, Thrissure, Science, Technology and Environment Department of Kerala, Thiruvananthapuram*. 17-19 pp.
- Kanime N, Kaushal R, Tewari S K, Raverkar K P, Chaturvedi S and Chaturvedi O P. 2013. Biomass production and carbon sequestration in different tree based systems of Central Himalayan region. *Forest, Trees and Livelihoods* **1**:38-50.
- Kaul O N and Sharma K K. 1983. Biomass production systems of poplars and willows in India. *Indian Forester* **109**:645-654.
- Kaur B, Gupta S R and Singh G. 2000. Soil carbon, microbial activity and nitrogen availability in agroforestry systems on moderately alkaline soils in northern India. *Applied Soil Ecology* **15**:283-294.
- Kharkwal G, Mehrotra P, Rawat Y S and Pangtey Y P S. 2005. Phytodiversity and growth form in relation to altitudinal gradient in the Central Himalayan (Kumaun) region of India. *Current Science* **89**:873–878.
- Khybri M L, Gupta R K and Sewa Ram. 1983. Effect of *Grewia optiva*, *Morus alba* and *Eucalyptus tereticornis* hybrid on the yield of crops and rainfed conditions. Annual Report CSWCRTI. Dehra Dun, India.
- Kimmins J P. 1987. Forest ecology. New York, Macmillan. 530p.

- King K F S. 1969. Agri-silviculture, The Taungya system Bull. No 7. Department of Forestry, University of Ibadan 109pp.
- Kirby K R and Potvin C. 2007. Variation in carbon storage among tree species: implications for the management of a small scale carbon sink project. *Forest, Ecology and Management* **246**:208-221.
- Kjeldahl J Z. 1883. *Analytical Chemistry* 22:366-382.
- Komiyama A, Ong J E and Pongparn S. 2008. Allometry, biomass, and productivity of mangrove forests: A review. *Aquatic Botany* **89**:128-137.
- Korner C H, Bannister P and Mark A F. 1986. Altitudinal variation in stomatal conductance, nitrogen content and leaf anatomy in different plant life forms in New Zealand. *Oecologia* **69**:577-588.
- Kour K and Sharma S. 2014. Potential of Agroforestry, Inventorization, Distribution pattern and phytosociological analysis of tree species in Block Ramgarh, Samba (J&K), India. *Advances in Agricultural Science and Technology* 19-25 pp.
- Kraenzel M, Castillo A, Moore T and Potvin C. 2003. Carbon storage of harvest-age teak (*Tectona grandis*) plantations, Panama. *Forest Ecology and Management* **173**:213-225.
- Kumar A and Jeet R. 2005. Anthropogenic disturbances and plant biodiversity in forests of Uttaranchal, Central Himalaya. *Biodiversity Conservation* **14**: 309-331.
- Kumar B M, George S J, Jamaludheen V, and Suresh T K. 1998. Comparison of biomass production, tree allometry and nutrient use efficiency of multipurpose trees grown in woodlot and silvopastoral experiments in Kerala, India. *Forest Ecology and Management* **112**:145-163.
- Kumar B M, Jacob G S and Chinnamani S. 1994. Diversity, structure and standing stock of wood in the homegardens of Kerala in peninsular India. *Agroforestry Systems* **25**:243-262.
- Kumar J I N, Sajish P R, Kumar R N and Patel K. 2011. Biomass and net primary productivity in three different aged Butea forest ecosystems in western India, Rajasthan. *Iranica Journal of Energy and Environment* **2**:1-7.
- Kumar M B, Jacob S G and Chinnamani S. 1994. Diversity, structure and standing stock of wood in the homegardens of Kerala in peninsular India. *Agroforestry System* **25**: 243-262.
- Kumar P. 1989. Evaluation of biofuels of solan district, Himachal Pradesh. Ph D. Thesis. Department of silviculture and agroforestry. Dr. Y S Parmar university of Horticulture and Forestry. Solan, Himachal Pradesh. 86p.
- Kumar S, Verma K S and Kumar N. 2012. Aboveground Carbon Sequestration Potential of Agroforestry Systems of Western Himalaya. *Journal of Tree Sciences* **31**:20-28.
- Kumar S. 1998. Dimensional stabilization of wood factors influencing shrinkage-swelling behaviour. *Journal of Timber Development Association of India* **25**:31-44.
- Lal H, Sharma J S and Tewari R K. 2004. Effect of graveliness on peach based agroforestry agri-horti system in Doon valley. *Indian Journal of Agroforestry* **6**: 27-32.

- Lanker U. 2007. Studies on some edapho-ecological characteristics and regeneration status of Himalayan yew. M.Sc. thesis, Dr. Y S Parmar UHF, Nauni-Solan (H.P.), India, 113p.
- Lambers H, Chapin F S, III and Pons T L. 1998. Plant physiological ecology. *Springer-Verlag*, New York, 540 p.
- Lin Cheng Fang, Li Zhen, Niu Zhi Pen, Zhang You Li, Han Yong Gang and Chen Guang Shui. 2005. Litter fall nutrient dynamics in *Fokienia hodginsii* plantation. *Journal of Fujian Agriculture and Forestry University Natural Science* **34**:63-66.
- Liski J, Nissenen A, Erhard M and Taskinen O. 2003. Climatic effects on litter decomposition from arctic tundra to tropical rainforest, *Global Change Biology* **9**:575-584.
- Lodhiyal L S and Singh S P. 1995b. Structure and function of an age series of Poplar plantation in central Himalaya I. Dry matter dynamics. *Annals of botany* **76**:191-199.
- Lodhiyal N, Lothiyal L S and Pangey Y P S. 2002. Structure and function of Shisham forests in central Hiamalaya, India: Nutrient dynamics. *Annals of Botany* **89**:55-65.
- Lundren B. 1978. Soil conditions and nutrient cycling under natural and plantation forests in Tanzanian highlands. Report in For Ecol and For Soils 31. *Swedish University of Agricultural Sciences*, Uppasala.
- Luna R K. 1996. Plantation Trees. Dehradun; International Book Distributors: 1996. 975 pp.
- MacDicken. 1997. Guide to monitoring carbon storage in forestry and agro forestry, Forest carbon monitoring programme. Winrock publications, New York.1-87.
- Maghembe J A, Kariuki E M and Haller R D. 1983. Biomass and nutrient accumulation in young *Prosopis juliflora* at Mombasa, Kenya. *Agroforestry Systems* **1**:313-321.
- Mahajan A. 2010. Effect of forest composition on regeneration and growth attributes of chir pine. M.Sc. thesis, Dr. YSP UHF, Nauni-Solan (H.P.), India, 52-64pp.
- Maikhuri R K, Semwal R L, Rao K S, Singh K, Saxena K G. 2000. Growth and ecological impacts of traditional agroforestry tree species in central Himalaya, India. *Agroforestry Systems* **48**:257- 272. - doi: 10.1023/A:1006344812127 .
- Majumdar H K. 1991. Biomass productivity and nutrient budgeting in different agroforestry systems. Ph D Thesis, UHF, Solan, HP.120p.
- Manjunatha T. Bisht I.S, Bhat K.V. and Singh B P. 2007. Genetic diversity in barley (*Hordeum vulgare* L. ssp. *vulgare*) landraces from Uttaranchal Himalaya of India. *Genetic Resources and Crop Evolution*. **54**:55-65.
- Mani M S. 1974. Ecology and Biogeography of India. Junk Publishers, The Hague.
- Marschner, H. 1990. Mineral nutrition of higher plants. Academic Press, New York, 674 p
- Mathew T, Babu K V S, Maheswaran K V and Kumar B M. 1997. Chemical properties, soil moisture status and litter production influenced by the growth of MPTs. *Indian Journal of Forestry* **20**:251-258.

- McDaniel P.A. and Munn L.C. 1985. Effect of temperature on organic carbon-texture relationships in Mollisols and Aridisols. *Soil Science Society of America Journal* **49**: 1486-1489.
- Merwin H D and Peech M. 1951. Exchangeability of soils potassium in the sand silt and clay fractions as influenced by the nature of the complementary exchangeable cations. *Soil Science Society of the America Proceedings* **15**:125-128.
- Minj A V. 2008. Carbon sequestration potential of agroforestry systems- an evaluation in low & mid hills of western Himalayas. Ph. D. thesis, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni-Solan, (H.P.), India 124p.
- Minhas R S, Minhas H and Verma S D. 1997. Soil characterization in relation to forest vegetation in the wet temperate zones of Himachal Pradesh. *Journal of the Indian Society of Soil Science* **45**:146- 151.
- Mishra B P, Tripathi R S, Tripathi O P and Pandey H N. 2004. Effects of anthropogenic disturbance on plant diversity and community structure of a sacred grove in Meghalaya, Northeast India. *Biodiversity Conservation* **13**:421-436.
- Misra R. 1969. Ecology Workbook. Oxford and IBH, Calcutta. 244 p.
- Mohammed A. 2014. Comparison of fine root biomass under *Grevillea robusta* and *Juniperus procera* in gera indigenous agroforestry systems, Southwest Ethiopia. *International Invention Journal of Agricultural and Soil Science* **2**:99-104.
- Murovhi R N and Materechera S A. 2006. Nutrient cycling by *Acacia erioloba* (syn. *Acacia giraffae*) in smallholder agroforestry practices of a semi-arid environment in the North West Province, South Africa. *Southern African Forestry Journal* **208**:23-30.
- Nair K M and Chamuah G S. 1988 Characteristics and classification of some pine forest soils of Meghalaya. *Journal of the Indian Society of Soil Science* **26**: 142- 145.
- Nair P K R, Gordon A M and Losada, M R. 2008. Agroforestry. In: Encyclopedia of ecology, vol 1. Jorgensen, S.E. & Fath, B.D. (Eds). Elsevier, Oxford 101-110 pp.
- Nair P K R. 1993. Introduction to Agroforestry. Kluwer Academic Publishers, Dordrecht, Netherlands 277 pp.
- Nair P K R. 2011. Carbon Sequestration Potential of Agroforestry Systems: Opportunities and Challenges, (ED) *Advances in Agroforestry* **8**:3-16.
- Nautiyal A R and Negi G C S. 1994. Multipurpose tree species with potential for introduction in agroforestry system in Himalayan mountains. In: "Agroforestry system for degraded lands" (Singh P, Pathak PS, Roze MM eds). Oxford & IBH publishing co-pvt-Ltd, New Delhi, India 269-278 pp.
- Nayak B K. 1996. Studies on biomass productivity and nutrient content in *Eucalyptus tereticornis*, *Leucaena leucocephala* and *Melia azedarach* under high density plantation. M. Sc. thesis, Dr Y. S. Parmar University of Horticulture and Forestry, Nauni-Solan, (H. P.), India. 112p.
- Nayar P. 1989. Agroforestry ecosystem dynamics in Himachal Himalaya. Ph D. Thesis. Punjab University, Chandigarh, India.

- Ndungu C K, Bhardwaj S K and Nancy L. 2017. Impact of Mountain Cropping Systems on Soil Properties, Nutrient Availability and Their Carbon Sequestration Potential in Mid-Hills of Himachal Pradesh, India. *International Journal of Current Microbiology and Applied Sciences* **6**: 203-211.
- Nye P H and Greenland D J. 1960. The Soil under Shifting Cultivation. Commonwealth Bureau of Soils, Harpenden.
- Nyhus P and Tilson R. 2004. Agroforestry, elephants, and tigers: balancing conservation theory and practice in human-dominated landscapes of south-east Asia. *Agriculture, Ecosystems and Environment* **104**:87-97.
- Pandey D N. 2002. Carbon sequestration in Agroforestry systems. *Climate Change Policy* **2**: 367-377.
- Panwar V P and Gupta M K. 2015. Litter fall, nutrient return and soil fertility under *Celtis australis*: Indigenous agroforestry tree species in Himachal Pradesh, India. *International Journal of Environmental Science* **6**:318-329.
- Parihaar R S, Bargali K and Bargali S S. 2015. Status of an indigenous agroforestry system: A case study in Kumaun Himalaya, India. *Indian Journal of Agricultural Sciences* **85**:442-447.
- Perala D A and Alban D H. 1982. Biomass, nutrient distribution and litter fall in *Populus*, *Pinus* and *Picea* stands on two different soils in Minnesota. *Plant and Soil* **64**:177-92.
- Perez C A, Goya J F, Bianchini F, Frangi J L and Fernandez R. 2006. Aboveground productivity and nutrient cycle in *Pinus taeda* L. plantations in the north of the Misiones province, Argentina. *Interciencia* **31**:794-801.
- Pressler M. 1865. Das Gesetz der Stambildung Leipzig 153p.
- Quinkenstein A, Pape D, Freese D, Schneider B U and Huttel R F. 2012. Biomass, Carbon and Nitrogen distribution in living woody plant parts of *Robinia pseudoacacia* L. growing on reclamation sites in the mining region of lower Lusatia (Northeast Germany). *International Journal of Forestry Research Article* 10-20pp.
- Raizada A, Singh C and Singh G. 2002. Production, nutrient dynamics and breakdown of leaf litter in six forest plantations raised on gravelly flood plains in the lower Western Himalayas. *Journal of Tropical Forest Science* **14**:499-512.
- Rajput B S and Bhardwaj D R. 2014. Bio-economic appraisal of different land use systems with altitudinal gradients in the valley area of Kullu district, Himachal Pradesh. *Annals of Agri Bio Research* **19**:147-151.
- Rajput B S and Bhardwaj D R. 2014. Economic analysis of different land use systems in temperate North-Western Himalayas. *Annals of Agri Bio Research* **19**:152-156.
- Rajput B S, Bhardwaj D R and Nazir A P. 2015. Carbon dioxide mitigation potential and carbon density of different land use systems along an altitudinal gradient in north-western Himalayas. *Agroforestry Systems* **91**:479-486.

- Rajput B S, Bhardwaj D R and Nazir A P. 2017. Factors influencing biomass and carbon storage potential of different land use systems along an elevational gradient in temperate northwestern Himalaya. *Agroforestry Systems* **89**:525-536.
- Rajput B S. 2010. Bio-economic appraisal and carbon sequestration potential of different land use systems in temperate north-western Himalayas. Ph.D. Thesis. Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.), India 169p.
- Rajput B S. 2014. Bio-economic appraisal and carbon sequestration potential of different land use systems in temperate north-western Himalayas. (Ph. D. Thesis). Department of silviculture and agroforestry. College of forestry. Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni Solan - 173 230 (HP), INDIA.
- Rajput P. 2016. Carbon storage, soil enrichment potential and Bio-economic appraisal of different land use Systems in mid hill and sub-humid zone-ii of Himachal Pradesh. (Ph. D. Thesis). Department of silviculture and agroforestry. College of forestry. Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni Solan - 173 230 (HP), INDIA.
- Rajput S S, Shukla N K, Gupta V K. 1985. Specific gravity of Indian timber. *Journal of the Timber Development Association of India* **31**:12-41.
- Rana C S and Gairola S. 2009. Forest community structures and composition along an elevation gradient of Parshuram Kund area in Lohit district of Arunachal Pradesh, India. *Nature and Science* **8**:44-52.
- Ranabhat S, Awasthi K D and Malla R. 2008. Carbon sequestration potential of *Alnus nepalensis* in the mid hills of Nepal: case study from Kaski district. *Banko Janakari* **18**: 3-9.
- Rani S, Rajasekharan A, Benbi D K, Chauhan S K. 2016. Economic Evaluation of Different Land Use Systems in North Western Region of Punjab, India. *Forest Research: Open Access journal* **6**:1-7.
- Rao K S and Maikhuri R K. 1996. Agroforestry for sustainable development of rural people ecosystem of central Himalaya. Proceedings of the "IUFRO-DNAES international meeting on resource inventory techniques to support agroforestry and environment activities" (Kohali RK, Arya KS eds). Dyanand National Academy of Environmental Science, DAV. Collage. Chandigarh (India) Oct 1-3 301-305pp.
- Rawat and Singh 1988. Structure and Function of Oak Forests in Central Himalaya. II. Nutrient Dynamics. *Annals of Botany* **62**:413-427.
- Rawat K. 2016. Seedling growth and survival of seven multipurpose Agroforestry tree species of Garhwal Himalaya. Department of forestry. V. C. S. G. Uttarakhand University of Horticulture and Forestry, Bharsar, Pauri Garhwal-246 123.
- Rawat N, Nautiyal B P and Nautiyal M C. 2010. Litter decomposition rate and nutrient release from different litter forms in a Himalayan alpine ecosystem. *Environmentalist* **30**:279-288.

- Rawat Y S and Everson C S. 2012. Ecological status and uses of juniper species in the cold desert environment of the Lahaul valley, North-western Himalaya, India. *Journal of Mountain Science* **9**:676-686.
- Razakamanarivo R H, Razakavololona A, Razafindrakoto M A and Albrecht A. 2012. Below-ground biomass production and allometric relationships of *eucalyptus* coppice plantation in the central highlands of Madagascar. *Biomass and Bioenergy* **45**:1-10.
- Reiners W A and Reiners N M. 1970. Energy and nutrient dynamics of forest floors in three Minnesota forests. *Journal of Ecology* **58**:497-519
- Rezende G C Barros N F, Moraes T S A and Mendes C J. 1983. Production and macronutrients in *Eucalyptus* stands at two plant densities. *Revista-Arvore* **7**:165-176.
- Rosecrance R C, Brewbaker J L and Fownes J H. 1992. Alley cropping of maize with nine leguminous trees. *Agroforestry Systems* **17**:159 -168.
- Roswall T. 1980. Nitrogen cycling in West African ecosystems. (ed.) Royal Swedish Academy of Sciences, Stockholm, Sweden.
- Saha S K, Nair P K R, Nair V D and Kumar B M. 2009. Soil carbon stock in relation to plant diversity of homegardens in Kerala, India. *Agroforestry Systems* **76**:53-65.
- Saha S K, Nair P K R, Nair V D and Kumar B M. 2010. Carbon storage in relation to soil size-fractions under tropical tree-based land-use systems. *Plant Soil* **328**:433-446.
- Sanjeev K, Chauhan N, Gupta R, Yadav S and Chauhan R. 2009. Biomass and carbon allocation in different parts of agroforestry tree species. *Indian Forester* **135**: 981-993.
- Saralch H S. 1994. Nutrient dynamics and biomass production of *Eucalyptus tereticornis* Smith, in high density short rotation systems. M. Sc. thesis, Dr Y S Parmar University of Horticulture and Forestry, Nauni-Solan, (H. P.), India. 99p.
- Saxena A K and Singh J S. 1982. A phytosociological analysis of woody species in forest communities of a part of Kumaun Himalaya. *Vegetatio* **50**:3-22.
- Sehgal S. 1999. Influence of coppicing and pollarding on water use efficiency, light transmission and root characteristics in agroforestry tree species, M.Sc. Thesis, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni-Solan, (H.P.), India.
- Shamet G S and Gupta N K. 1999. Survey, regeneration and planting studies in yew (*Taxus baccata*) – An endangered medicinal species of Himalaya. Report National Medicinal Plant Board, Government of India, New Delhi, India 25p.
- Shanmughavel P and Francis K. 1999. Growth performance and economic returns of pigeon pea in agroforestry. *Indian Journal of Agroforestry* **22**:351-353.
- Shannon C E and Wiener W. 1963. The mathematical theory of communication. University Illinois Press, Urbana 117p.
- Sharma, P K, Bordoloi P K, Baruah T C, Das K N and Borah N. 1997. Physical characterization of soils in two command areas of Assam. *Journal of Indian Society of Soil Science* **45**: 709-712.

- Sharma S B, Pandey S, Upadhyaya S D and Agrawal R. 2006. Phytosociological studies of tree species out-side forest in traditional agroforestry of Chhattisgarh. *Indian Journal of Agroforestry* **8**: 26-34.
- Sheikh M K.1993. Trees of Pakistan.78p.
- Simpson E H. 1949. Measurement of diversity. *Nature* **163**:688p.
- Sing R, Bhardwaj D R, Nazir A P and Singh B S. 2016. Realizing the need of agroforestry based land use systems for better economic yield in Western Himalaya, India, *International Journal of Usuf Management* **17**:81-89.
- Sing R. 2014. Carbon storage, soil enrichment potential and bio-economic appraisal of different land use systems in sub-montane and low hills sub-tropical zone-I of Himachal Pradesh. Ph. D. thesis. Department of silviculture and agroforestry. UHF, Nauni (Solan).
- Singh B, Singh V, Singh R P and Srivastava B K. 1998. Economic prospects of vegetable intercropping in young *Eucalyptus* plantation. *Annals of Agricultural Sciences* **19**:470-474.
- Singh J S and Singh S P. 1992. Forest of Himalaya: Structure, function and impact of man. Nainital, India. Gyanodaya Prakshan.
- Singh L and Singh J S. 1991. Species structure, dry matter dynamics and carbon flux of a dry tropical forest in India. *Annals of Botany* **68**: 263-273.
- Singh M, Gupta B Sarvade S and Awasthi R K. 2015. Biomass and carbon sequestration potential in different agroforestry systems in Giri catchment of North Western Indian Himalaya. *Indian Journal of Agroforestry* **17**:42-48.
- Singh P, Singh P K, Sahu S, Singh A, Gaurav N and Singh N. 1975. Ecological and conservation study of herbs in Mukundpur forest area, Satna District, Madhya Pradesh. *Journal of Pharmacognosy and Phytochemistry* **6**:544-549.
- Singh S K, Kumar K S, Aier B, Kanduri V P, and Ahirwar S. 2012. Plant community characteristics and soil status in different land use systems in Dimapur district, Nagaland, India. *Forest Research Papers* **73**:305-312.
- Singh, R P, Ong C K, and Saharan N. 1989. Above and below ground interactions in alley cropping in semi-arid India. *Agroforestry Systems* **9**:259-274.
- Singh G. and Rawat G S. 2012. Depletion of Oak (*Quercus* spp.) Forests in the western Himalaya: grazing, fuelwood and fodder collection, global perspectives on sustainable forest management. Open access chapter. Global Perspectives on Sustainable Forest Management. 29-42.
- Singh, R N,. Singh R N P and Diwakar D P S. 2000. Characterization of old alluvial soils of Sone Basin. *Journal of Indian Society of Soil Science* **48**: 352-357.
- Smith D M. 1954. Maximum moisture content method for determining specific gravity of small wood samples. *U.S. Forest Products Laboratory Report* 8p.
- Smith J E and Heath L S. 2001. Identifying influences on model uncertainty: an application using a forest carbon budget model. *Environmental Management* **27**:253-267.

- Swamy S L and Puri S. 2005. Biomass production and C-sequestration of *Gmelina arborea* in plantation and agroforestry system in India. *Agroforestry Systems* **64**:181-195.
- Tahir B A E and Vishwanath A. 2015. Estimation of economic value of agroforestry systems at the local scale in Eastern Sudan. *Journal of Geoscience and Environment Protection* **3**: 38-56.
- Tamang B, Andreu M G, Staudhammer C L, Rockwood D L and Jose S. 2012. Equations for estimating aboveground biomass of cadaghi (*Corymbia torelliana*) trees in farm windbreaks. *Agroforestry Systems* **86**:255-266.
- Thakur N S, Gupta N K and Gupta B. 2004. Phytosociological analysis of woody and non-woody components under some agroforestry systems in western Himalaya. *Indian Journal of Agroforestry* **6**:65-71.
- Thang V H, Do V T, Kozan O and Catacutan D C. 2015. Cost-Benefit Analysis for Agroforestry Systems in Vietnam. *Asian Journal of Agricultural Extension, Economics & Sociology* **5**:158-165.
- Tian G, Kang B T and Brussard L. 1996. Effect of chemical composition on N, Ca and Mg release during incubation of leaves from selected agroforestry and fallow plant species. *Earth and Environmental Science* **16**:103-119.
- Tiwari J C, Bohra M D and Harsh L N. 1999. Structure and production function of traditional extensive agroforestry systems and scope of intensive agroforestry in Thar desert. *Indian Journal of Agroforestry* **1**: 243-262.
- Tokey O P, Pradeep K and Prem K. 1989a. Structure and function of traditional agroforestry systems in the western Himalaya-I: biomass and productivity. *Agroforestry Systems* **9**:47-70.
- Tokey O P, Kumar P and Khosia P K. 1989b. Structure and function of traditional agroforestry systems in the Western Himalaya - II. Nutrient Cycling. *Agroforestry Systems* **9**:71-79.
- Tokyo O P and Ramakrishnan P S. 1983a. Secondary succession following slash and burn agriculture in north-eastern India. I. Biomass, litterfall, and productivity. *Journal of Ecology* **71**:735-745.
- Tomar J M S and Bhatt B P. 2004. Studies on horti-agricultural system in a mid altitude of Meghalaya. *Indian Journal of Agroforestry* **6**:35-39.
- Torquebiau E Mary F. and Sibelet N. 2002. The multiple challenges of agroforestry associations. *Bios et Forests des Tropiques* **271**:23-35.
- Trup R S 1921. *Silviculture of Indian Trees*. I-III Clarendon Press, Oxford.
- Tukey H B Jr, Tukey H B and Wittwer S H. 1958. Loss of nutrients by foliar leaching as determined by radiotracer. *Journal of the American Society for Horticultural Science* **71**:496-506.
- Tumwebaze S B, Bevilacqua E, Briggs R and Volk T. 2012. Soil organic carbon under a linear simultaneous agroforestry system in Uganda. *Agroforestry Systems* **84**:11-23.
- Tynsong H and Tiwari B K. 2011. Diversity and population characteristics of woody species in natural forests and arecanut agroforests of south Meghalaya, Northeast India. *Tropical Ecology* **52**:243-252.

- Uniyal P, Pokhriyal P, Dasgupta S, Bhatt D and Todaria N P. 2010. Plant diversity in two forest types along the disturbance gradient in Dewalgarh Watershed, Garhwal Himalaya. *Current Science* **98**:938-947.
- Varghese, P T, Nelliath E and Balakrishnan, T. 1978. Beneficial interactions of coconut cacao combination. Proceedings PLACROSYM 1, *Indian Society for Plantation Crops*, Kasargod, 383-392
- Verma K S, Kohli S, Kaushal R, and Chaturvedi O P. 2014. Root structure distribution and biomass in five multipurpose tree species of western Himalayas. *Journal of mountain science* **11**:519-525.
- Verma K S, Sood S and Kaushal R. 2004. Varietal response of wheat to different levels of nitrogen in agri-horticulture system under rainfed hill farming system. *Indian Journal of Agriculture* **6**:1-7.
- Verma R K and Kapoor K S. 2013. Floristic diversity along an altitudinal gradient in Namgia valley of cold desert in district Kinnaur, Himachal Pradesh. *Indian Forester* **139**:202-211.
- Vishnu-Mittre. 1972. Paleobotanical Evidence of the Environment of early man in North Western India. *Grana* **18**:167-181.
- Vishvakarma S C R, Kuniyal J C, Singh G S. 1998. Indigenous agroforestry system of north western Himalaya. Research for mountain development: some initiative and accomplishment. Gyanodaya Prakashan, Nainital, Uttarakhand, India 99- 118 pp.
- Walkley A and Black I A. 1934. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* **37**:29-37.
- Wani B A, Bodha R H and Khan A. 2014. Wood specific gravity variation among five hard wood species of Kashmir Himalaya. *Pakistan Journal of Biological Science* **7**:395-401.
- Yadava A K. 2010. Biomass production and Carbon sequestration in different agroforestry system in terrain region of central Himalaya. *Indian Forester* **136**:234-244.
- Yadav J S P. 1963. Studies on soil properties in Chakrata forest division of Uttarakhand. *Indian Forester* **89**:18-38.
- Yadava D K and Singh L. 2010. Community structure and floristic diversity of tree stratum of deciduous forest of Achanakmar-Amarkantak Biosphere Reserve. *Indian Forester* **136**: 725-735.
- Yadav R P and Bisht J K 2013. Agroforestry: A way to conserve MPTs in North Western Himalaya. *Research Journal of Agriculture and Forestry Sciences* **1**: 8-13.
- Yimer F, Ledin S and Abdelkadir A. 2008. Concentration of exchangeable bases and cation exchange capacity in soils of cropland, grazing and forest in the Bale Mountains, Ethiopia. *Forest, Ecology and Management* **256**:1298-1302.
- Zhao M and Zhou G S. 2006. Carbon storage of forest vegetation in China and its relationship with climatic factors. *Climatic Change* **74**:175-189.
- Zhu B, Wang X, Fang J, Piao S, Shen H, Zhao S and Peng C. 2010. Altitudinal changes in carbon storage of temperate forests on Mt. Changbai, Northeast China. *Journal of Plant Research* **123**:439-452.

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ABSTRACT

The present study entitled **“Structure and function of agroforestry systems in dry temperate regions of north western Himalayas”** was carried out during 2014-2015. The three experimental sites were selected randomly from district Kinnaur and stratified in two climatic conditions viz., C₁ (Dry temperate high hills) and C₂ (High hills temperate dry and cold). Three agroforestry systems viz., agrihorticulture, agrisilvicultural and agrihortisilvicultural were selected, which were common in both climatic conditions. The plot size 10×10 m for trees, 05×05 m for shrubs, 0.5×0.5 m for grasses and 1×1 m for herbs and crops were used for enumeration of floral diversity, vegetation biomass and nutrient stock. For soil analysis samples were collected at two different depths i.e. 0-15 cm and 15-30 cm and samples analyzed for the bulk density, partical density, pore space percentage, pH, OC, total N, extractable P, available K, exchangeable Ca and Mg. The data regarding economics of each land use systems were collected by personal interviews with the farmers of agroforestry systems which were selected for study. The study revealed that herbage density and basal area was found to be maximum in agrihortisilviculture land use system (698.66 tillers m⁻²) and (305.39 cm² m⁻²), respectively. Shannon Weiner index (H') of vegetation was found to be maximum (2.26) for agrisilviculture system whereas, Simpson Diversity Index (0.22) displayed maximum value in agrihorticulture system. The maximum value of aboveground biomass (97.31 t ha⁻¹), belowground biomass (28.88 t ha⁻¹) and total biomass (126.19 t ha⁻¹) was recorded in agrisilviculture system. The maximum stock of total N (480.14 Kg ha⁻¹), P (99.45 Kg ha⁻¹), K (768.52 Kg ha⁻¹) and Ca (579.00 Kg ha⁻¹) in whole vegetation was found in AS system. The maximum P (17.96 Kg ha⁻¹ yr⁻¹), K (147.46Kg ha⁻¹ yr⁻¹), and Ca (114.03 Kg ha⁻¹ yr⁻¹) uptake by vegetation was observed in AH system whereas maximum but similar maximum amount of total N (104.58 Kg ha⁻¹ yr⁻¹) uptake was found in AH and AS system. Maximum addition of all nutrients by different sources was observed in AH system. The maximum annual turnover of P (5.72%), K (31.47%), and Ca (5.34%) percentage under soil pool was recorded in AH system, while maximum annual turnover of N (1.86%) percentage under soil pool was reported AS system. Under the physical properties, reverse trend was observed for bulk density. Maximum bulk density (1.47 g cm⁻³) was recorded at 15-30 cm depth whereas minimum bulk density (1.20 g cm⁻³) observed at 0-15 cm depth. Partical density (2.49 g cm⁻³) was higher in agrihorticulture system. The pore space (46.99%) percent was significantly higher in agrisilviculture system. Partical density (2.48 g cm⁻³) was significantly higher at 0-15 cm depth. The pore space (48.90%) percent was significantly higher at surface soil. Chemical parameters were found decreasing with increasing of soil depth. Organic carbon (1.26%) was significantly higher in agrihortisilviculture system. Organic carbon (1.26%) was significantly higher at 0-15cm depth in high hills temperate dry and cold C₂ climatic condition. Similarly exchangeable Ca (5.52 mg/100g) was significantly higher in AHS system. Exchangeable calcium (6.03 mg/100g) was significantly higher at 0-15cm depth. Most of the soil samples were alkaline property. Maximum soil pH (8.21) was recorded in high hills temperate dry and cold C₂ climatic condition which was significantly differ with C₁ climatic condition. Deep soil layer (15-30cm) showed maximum pH. N (0.25%), P (0.97 mg/100g) and K (1.69 mg/100g) was significantly higher at upper (0-15cm) layer of soil. Study revealed that maximum expenses were and maximum gross return incur in the agrihorticulture (Rs 774526.32 and Rs. 2065230.07) system whereas, higher net returns, (Rs 1648322.21) was generated by AHS system. Benefit: Cost ratio under above study was recorded for agrisilviculture system (5.87).

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APPENDIX-I

Months	2014	2015	2014	2015	2014	2015	2014	2015
	Maximum Temp (°C)	Maximum Temp (°C)	Minimum Temp	Minimum Temp	Rain Fall mm	Rain Fall mm.	RH (%)	RH (%)
Jan	4.5	3.7	-3.1	-4.1	2.6	0.0	51.3	48.5
Feb	4.0	3.7	-3.4	-2.9	4.7	4.8	43.2	56.7
Mar	9.2	7.0	-0.2	-0.1	3.6	4.8	62.6	54.2
Apr	15.5	21.7	2.8	7.1	3.3	0.9	49.9	54.2
May	19.8	25.9	6.4	9.5	1.9	0.9	60.8	48.6
Jun	24.1	26.3	10.7	11.8	0.3	1.4	62.2	58.3
Jul	22.7	27.7	13.7	16.5	2.3	1.1	76	71.3
Aug	23.2	27.9	12.9	16.3	0.8	0.5	72.2	68.3
Sep	22.2	26.1	9.8	12.1	0.9	0.9	72	59.6
Oct	19.4	22.9	5.0	7.8	0.2	0.2	63.9	48.8
Nov	16.2	18.5	2.1	4.9	0.0	0.4	41.1	41.8
Dec	9.6	13.6	-0.8	1.4	1.7	1.4	41.4	37.4

APPENDIX-II

Analysis of variance table for Simpson's Diversity Index and Shannon Weiner index as affected by agroforestry systems, climatic conditions and their interaction

Source of Variation	DF	Mean Squares	
		Simpson's Diversity Index	Shannon Weiner index
Replication	2		
Factor C	1	0.005	0.057
Factor T	2	0.008	0.389
Interaction C × T	2	0.001	0.004
Error	10	0.001	0.012
Total	17		

APPENDIX-III

Analysis of variance table for aboveground, below ground, total biomass and litter biomass production as affected by agroforestry systems, climatic conditions and their interaction

Source of Variation	DF	Mean Squares			
		Above ground biomass (t ha ⁻¹)	Below ground biomass (t ha ⁻¹)	Total biomass (t ha ⁻¹)	Litterfall biomass (t ha ⁻¹)
Replication	2				
Factor C	1	17.81	5.11	41.45	0.004
Factor T	2	1531.05	292.94	3112.24	0.008
Interaction C × T	2	178.77	5.72	231.64	0.002
Error	10	26.22	3.85	47.49	0.002
Total	17				

APPENDIX-IV

Analysis of variance table for vegetation, soil, total leaf litter and total carbon inventory as affected by agroforestry systems, climatic conditions and their interaction

Source of Variation	DF	Mean Squares			
		Vegetation (C t ha ⁻¹)	Soil (C t ha ⁻¹)	Leaf litter (C t ha ⁻¹)	Total (C t ha ⁻¹)
Replication	2				
Factor C	1	10.415	158.364	0.009	246.696
Factor T	2	778.159	68.787	0.008	1,282.086
Interaction C × T	2	57.848	18.737	0.002	40.569
Error	10	11.865	7.147	0.001	62.098
Total	17				

APPENDIX-V

Analysis of variance table for agroforestry systems, climatic condition and their interaction on the rate of biomass production (t ha⁻¹y⁻¹)

Source of Variation	DF	Mean Squares	
		Tree biomass increment (t ha ⁻¹)	Shrubs biomass increment (t ha ⁻¹)
Replication	2		
Factor C	1	0.006	0.030
Factor T	2	0.336	0.016
Interaction C × T	2	0.155	0.022
Error	10	0.002	0.020
Total	17		

Appendix-VI

Analysis of variance table for agroforestry systems, climatic conditions and their interaction nutrient stock (Kg ha⁻¹) by different parts of tree in dry temperate regions of north western Himalaya

Source of Variati on	DF	Mean Squares																			
		Bole				Branch				leaf				Root				Fruits			
		N	P	K	Ca	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
Replica tion	2																				
Factor C	1	331.27	0.67	477.08	1183.52	0.01	1.82	0.09	3.86	0.07	0.44	6.15	1.26	392.03	33.93	2255.05	1284.40	25.20	57.50	2128.85	1068.14
Factor T	2	5467.47	39.46	6428.79	14751.13	1.17	1.32	13.10	2.86	48.95	0.06	51.41	17.67	10210.15	2231.63	34890.80	16884.67	12599.38	215.11	10356.49	13057.69
Interac tion C × T	2	303.18	69.17	525.38	1008.01	0.48	0.05	0.58	1.64	3.53	0.65	2.18	3.36	1796.29	16.95	4040.38	1155.30	13855.12	610.60	16477.59	15416.47
Error	10	34.50	11.25	384.12	2759.55	0.11	0.19	2.45	0.28	1.77	0.15	0.92	0.50	326.77	194.53	1106.86	969.26	3586.71	51.24	1465.29	1533.78
Total	17																				

Appendix-VII

Analysis of variance table for agroforestry systems, climatic conditions and their interaction nutrient stock (Kg ha⁻¹) by different parts of shrubs in dry temperate regions of north western Himalaya

Source of Variation	DF	Mean Squares															
		Bole				Branch				leaf				Root			
		N	P	K	Ca	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
Replication	2																
Factor C	1	0.100	0.002	0.144	0.148	0.030	0.003	0.480	0.075	0.794	0.019	0.635	0.480	0.001	0.001	2.961	0.381
Factor T	2	0.225	0.013	0.605	0.655	0.233	0.005	0.530	0.903	0.040	0.003	0.118	0.365	0.193	0.000	5.247	1.708
Interaction C × T	2	0.027	0.003	0.127	0.286	0.063	0.002	0.726	0.607	0.346	0.014	0.973	1.010	0.016	0.014	0.339	0.477
Error	10	0.065	0.005	0.171	0.326	0.087	0.004	0.154	0.440	0.047	0.005	0.183	0.292	0.051	0.007	0.001	0.225
Total	17																

APPENDIX-VIII

Analysis of variance table for agroforestry systems, climatic conditions and their interaction on tree total nutrient stock

Source of Variation	DF	Mean Squares			
		N	P	K	Ca
Replication	2				
Factor C	1	1,065.187	213.608	13,838.976	1,221.911
Factor T	2	30,150.379	2,945.757	83,828.868	20,887.985
Interaction C $\times$ T	2	11,401.832	667.778	2,908.045	10,930.265
Error	10	4,137.347	194.784	2,401.201	8,069.728
Total	17				

Appendix-IX

Analysis of variance table for agroforestry systems, climatic conditions and their interaction on shrub total nutrient stock

Source of Variation	DF	Mean Squares			
		N	P	K	Ca
Replication	2				
Factor C	1	0.966	11.186	1.549	0.028
Factor T	2	1.570	3.075	11.932	4.449
Interaction C $\times$ T	2	0.550	1.864	6.595	7.306
Error	10	0.961	0.683	2.272	2.954
Total	17				

APPENDIX-X

Analysis of variance table for agroforestry systems, climatic conditions and their interaction on availability of the nutrients (Kg ha⁻¹) in 0-30 cm soil depth

Source of Variation	DF	Mean Squares			
		N	P	K	Ca
Replication	2				
Factor C	1	12,221,267.087	1,731.466	58,304.508	146,643.416
Factor T	2	4,848,298.181	272.269	1,778.778	22,146.710
Interaction C $\times$ T	2	107,088.677	4,921.721	2,424.716	79,811.842
Error	10	4,040,523.058	54.865	4,202.949	3,323.501
Total	17				

APPENDIX-XI

Analysis of variance table for agroforestry systems, climatic conditions and their interaction on total density of elements in different agro ecosystems (Kg ha⁻¹)

Source of Variation	DF	Mean Squares			
		N	P	K	Ca
Replication	2				
Factor C	1	12,047,661.980	3,913.173	1.225	163,199.460
Factor T	2	4,162,575.032	3,361.820	36,203.965	1,757.510
Interaction C $\times$ T	2	193,378.732	6,759.866	170,788.763	69,887.170
Error	10	4,074,749.360	303.498	4,108.952	10,391.462
Total	17				

APPENDIX-XII

Analysis of variance table for agroforestry systems, climatic conditions and their interaction nutrient uptake (Kg ha⁻¹ yr⁻¹) by different parts of tree in dry temperate regions of north western Himalaya

Source of Variation	DF	Mean Squares																			
		Bole				Branch				leaf				Root				fruits			
		N	P	K	Ca	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
Replication	2																				
Factor C	1	3.672	0.170	6.686	16.608	0.006	0.106	1.125	0.164	0.980	0.002	0.952	1.644	1.724	0.587	0.127	8.918	10.122	0.537	10.213	3.425
Factor T	2	4.705	0.366	22.382	39.393	0.060	0.229	0.688	0.176	0.282	0.020	0.760	0.549	5.591	0.639	6.576	10.800	80.354	5.175	34.875	18.159
Interaction C × T	2	5.010	0.345	23.402	23.184	0.026	0.033	1.861	0.015	0.488	0.018	0.700	0.705	10.076	0.306	12.898	10.866	260.143	27.202	563.977	313.799
Error	10	0.843	0.525	5.093	4.780	0.012	0.088	0.954	0.006	0.011	0.011	0.003	0.010	3.207	0.207	0.006	2.612	40.708	0.880	59.243	45.733
Total	17																				

APPENDIX-XIII

Analysis of variance table for agroforestry systems, climatic conditions and their interaction on nutrient uptake (Kg ha⁻¹ yr⁻¹) by different parts of shrub in dry temperate regions of north western Himalaya

Source of Variation	DF	Mean Squares															
		Bole				Branch				leaf				Root			
		N	P	K	Ca	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
Replication	2																
Factor C	1	0.176	0.018	0.572	0.781	0.353	0.009	0.470	1.027	0.580	0.016	1.222	1.406	0.098	0.002	0.238	0.320
Factor T	2	0.005	0.001	0.007	0.011	0.008	0.001	0.045	0.138	0.127	0.004	0.198	0.409	0.036	0.014	0.211	0.194
Interaction C × T	2	0.022	0.001	0.026	0.095	0.002	0.001	0.038	0.032	0.161	0.006	0.269	0.363	0.060	0.048	0.482	0.368
Error	10	0.007	0.001	0.038	0.059	0.027	0.002	0.076	0.010	0.036	0.001	0.076	0.138	0.004	0.021	0.012	0.023
Total	17																

APPENDIX-XIV

Analysis of variance table for agroforestry systems, climatic conditions and their interaction on nutrient uptake ($\text{Kg ha}^{-1} \text{ yr}^{-1}$) by different parts of agriculture crops in dry temperate regions of north western Himalaya

Source of Variation	DF	Crop Shoot				Crop roots				Crop fruits			
		N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
Replication	2												
Factor C	1	5.357	0.222	1.928	16.550	0.013	0.006	0.250	0.122	40.435	62.198	264.270	1.539
Factor T	2	1.215	0.074	1.153	0.051	0.093	0.031	0.655	0.030	277.792	10.781	307.291	233.642
Interaction C $\times$ T	2	1.923	0.002	1.548	4.209	0.082	0.045	0.164	0.070	64.205	4.676	129.257	30.509
Error	10	1.268	0.074	1.263	1.239	0.008	0.001	0.015	0.013	14.010	1.872	10.351	16.051
Total	17												

APPENDIX-XV

Analysis of variance table for agroforestry systems, climatic conditions and their interaction on nutrient uptake ($\text{Kg ha}^{-1} \text{ yr}^{-1}$) by different part of weeds and grasses under dry temperate region of north western Himalaya

Source of Variation	DF	Mean Squares															
		Weed shoots				Weed roots				Grass shoots				Grass roots			
		N	P	K	Ca	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
Replication	2																
Factor C	1	0.081	0.254	1.066	0.773	0.026	0.001	0.503	0.022	61.161	0.001	24.876	18.562	1.717	0.021	0.517	0.862
Factor T	2	0.874	0.151	7.478	5.406	0.067	0.003	0.664	0.262	29.232	0.065	14.819	20.350	1.631	0.051	0.144	4.912
Interaction C $\times$ T	2	3.205	0.279	6.410	7.178	0.004	0.003	0.214	0.174	10.092	0.047	110.339	10.651	1.131	0.009	0.134	1.117
Error	10	1.510	0.114	8.088	10.356	0.107	0.001	0.584	0.213	0.105	0.300	33.541	5.017	2.077	0.005	0.088	0.496
Total	17																

APPENDIX-XVI

Analysis of variance table for agroforestry systems, climatic conditions and their interaction on nutrient uptake ($\text{Kg ha}^{-1} \text{ yr}^{-1}$) by tree and shrubs under dry temperate climatic conditions of north western Himalaya

Source of Variation	DF	Mean Squares							
		Tree total nutrient uptake				Shrubs total nutrient uptake			
		N	P	K	Ca	N	P	K	Ca
Replication	2								
Factor C	1	7.057	8,725.204	0.118	14.614	4.292	0.100	9.202	13.227
Factor T	2	52.077	8,783.004	47.732	0.242	0.283	0.024	0.928	0.587
Interaction C $\times$ T	2	153.826	9,395.607	352.442	200.001	0.668	0.108	2.129	1.829
Error	10	50.203	9,134.180	60.344	57.959	0.132	0.033	0.351	0.286
Total	17								

APPENDIX-XVII

Analysis of variance table for agroforestry systems, climatic conditions and their interaction on total nutrient uptake ($\text{Kg ha}^{-1} \text{ yr}^{-1}$) by agriculture crop, weeds and grasses at different agroforestry systems under different climatic conditions

Source of Variation	DF	Agriculture crops total nutrient uptake				Weeds total nutrient uptake				Grass total nutrient uptake			
		N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
Replication	2												
Factor C	1	1413.40	1289.14	7448.10	550.24	0.017	0.264	3.034	0.527	42.443	0.020	32.644	27.528
Factor T	2	7954.48	308.24	8138.12	5276.90	1.411	0.155	12.568	8.009	24.302	0.202	17.666	45.149
Interaction C $\times$ T	2	2037.01	100.40	3714.21	528.86	3.418	0.234	8.831	8.976	4.610	0.092	103.808	17.084
Error	10	391.04	28.13	302.46	267.84	2.337	0.114	12.765	12.382	2.417	0.262	34.842	7.490
Total	17												

APPENDIX- XVIII

Analysis of variance table for effect of agroforestry systems, climatic condition and their interaction on total nutrient stock in vegetation (Kg ha⁻¹) and total nutrient uptake (Kg ha⁻¹yr⁻¹) by vegetation in different agroforestry systems at dry temperate climatic conditions of north western Himalaya

Source of Variation	DF	Mean Squares							
		Total nutrient stock in vegetation (Kg ha ⁻¹)				Total nutrient uptake by vegetation (Kg ha ⁻¹ yr ⁻¹)			
		N	P	K	Ca	N	P	K	Ca
Replication	2								
Factor C	1	1,816.44	283.30	15,380.07	1,166.40	73.53	41.83	5.99	95.79
Factor T	2	30,753.37	2,974.12	86,782.77	16,552.72	374.15	6.68	602.30	558.38
Interaction C × T	2	13,475.03	731.33	4,305.43	13,063.30	66.09	36.59	861.67	194.04
Error	10	4,030.39	181.42	2,439.06	8,160.70	82.30	2.02	99.93	73.02
Total	17								

APPENDIX-XIX

Analysis of variance table for agroforestry systems, climatic conditions and their interaction on tree nutrient concentration % (dry weight basis) under dry temperate climatic conditions of north western Himalaya

Source of Variation	DF	Mean Squares																			
		Bole				Branch				leaf				Root				Fruits			
		N%	P%	K%	Ca%	N%	P%	K%	Ca%	N%	P%	K%	Ca%	N%	P%	K%	Ca%	N%	P%	K%	Ca%
Replication	2																				
Factor C	1	0.001	0.0001	0.429	0.007	0.007	0.039	0.112	0.058	0.128	0.008	0.088	0.084	0.101	0.001	0.026	0.001	0.598	0.015	1.312	0.569
Factor T	2	0.005	0.0001	0.596	0.286	0.011	0.001	0.023	0.025	0.512	0.006	0.073	0.008	0.013	0.006	0.016	0.113	0.942	0.058	1.707	1.297
Interaction C × T	2	0.001	0.0001	0.299	0.018	0.004	0.004	0.025	0.028	0.009	0.017	0.051	0.121	0.161	0.001	0.262	0.080	0.582	0.052	1.868	1.271
Error	10	0.001	0.0001	0.004	0.066	0.0001	0.002	0.0001	0.003	0.001	0.001	0.016	0.017	0.0001	0.002	0.0001	0.016	0.001	0.007	0.202	0.228
Total	17																				

APPENDIX-XX

Analysis of variance table for agroforestry systems, climatic conditions and their interaction on nutrient concentration % (dry weight basis) of shrubs under dry temperate climatic conditions of north western Himalaya

Source of Variation	DF	Mean Squares															
		Bole				Branch				leaf				Root			
		N%	P%	K%	Ca%	N%	P%	K%	Ca%	N%	P%	K%	Ca%	N%	P%	K%	Ca%
Replication	2																
Factor C	1	0.493	0.005	0.005	0.551	0.534	5.511	0.115	0.002	0.182	0.001	0.0001	0.112	0.049	0.001	2.730	1.730
Factor T	2	0.567	0.002	0.002	0.327	0.055	5.780	0.167	0.372	0.561	0.0001	1.543	0.933	0.102	0.034	0.834	0.621
Interaction C × T	2	0.022	0.011	0.011	0.612	0.037	5.281	0.318	0.078	0.253	0.005	0.369	0.138	0.166	0.012	1.103	0.611
Error	10	0.012	0.001	0.001	0.077	0.102	5.493	0.266	0.379	0.233	0.003	0.521	0.186	0.047	0.003	0.300	0.117
Total	17																

APPENDIX-XXI

Analysis of variance table for agroforestry systems, climatic conditions and their interaction on agriculture crop nutrient concentration % (dry weight basis) under dry temperate climatic conditions of north western Himalaya

Source of Variation	DF	Agriculture crop shoots (%)				Agriculture crop roots (%)				Agriculture crop fruits/gains (%)			
		N%	P%	K%	Ca%	N%	P%	K%	Ca%	N%	P%	K%	Ca%
Replication	2												
Factor C	1	0.309	0.100	0.673	0.148	0.097	0.030	0.194	0.144	0.068	0.250	1.280	0.015
Factor T	2	0.103	0.006	0.263	0.273	0.609	0.073	1.557	0.097	0.076	0.026	0.009	0.582
Interaction C × T	2	0.088	0.006	0.092	0.079	0.076	0.119	0.728	0.057	0.232	0.007	0.019	0.041
Error	10	0.039	0.003	0.056	0.034	0.054	0.002	0.045	0.041	0.038	0.005	0.049	0.028
Total	17												

Appendix-XXII

Analysis of variance table for agroforestry systems, climatic conditions and their interaction on nutrient concentration percentage (dry weight basis) of grass and weeds under dry temperate climatic conditions of north western Himalaya

Source of Variation	DF	Mean Squares															
		Weed shoots				Weed roots				Grass shoots				Grass roots			
		N%	P%	K%	Ca%	N%	P%	K%	Ca%	N%	P%	K%	Ca%	N%	P%	K%	Ca%
Replication	2																
Factor C	1	0.364	0.042	0.252	1.901	0.040	0.012	0.057	0.130	0.115	0.026	1.076	6.686	1.736	0.015	1.307	3.745
Factor T	2	0.111	0.023	1.101	0.819	0.080	0.026	0.800	0.779	0.028	0.004	1.068	0.976	0.544	0.006	2.312	0.556
Interaction C × T	2	0.224	0.062	0.435	0.015	0.005	0.041	0.595	0.545	0.263	0.009	2.241	2.304	0.508	0.003	0.306	0.599
Error	10	0.022	0.041	0.243	0.327	0.032	0.020	0.189	0.038	0.092	0.003	0.001	0.474	0.001	0.007	0.442	0.412
Total	17																

APPENDIX-XXIII

Analysis of variance table for agroforestry systems, climatic conditions and their interaction on litter fall, crop debris and weed debris nutrient concentration percentage (dry weight basis) under dry temperate climatic conditions of north western Himalaya

Source of Variation	DF	Litter fall (%)				Crop debris (%)				Weed debris (%)			
		N%	P%	K%	Ca%	N%	P%	K%	Ca%	N%	P%	K%	Ca%
Replication	2												
Factor C	1	0.021	0.0001	0.0001	0.016	0.025	0.007	0.031	0.110	0.002	0.0001	0.001	0.007
Factor T	2	0.003	0.001	0.006	0.049	0.219	0.003	1.173	1.018	0.034	0.007	0.023	0.019
Interaction C × T	2	0.004	0.008	0.006	0.007	0.000	0.002	0.003	0.008	0.002	0.0001	0.0001	0.003
Error	10	0.003	0.003	0.004	0.001	0.025	0.0001	0.066	0.074	0.009	0.0001	0.009	0.009
Total	17												

APPENDIX-XXIV

Analysis of variance table for agroforestry systems, climatic conditions and their interaction on nutrients added through litter fall, crop debris, fertilizers and weed debris (Kg ha⁻¹ yr⁻¹) under dry temperate climatic conditions of north western Himalaya

Source of Variation	DF	Mean Squares															
		Litter fall				Crop debris				Weed debris				Fertilizers			
		N	P	K	Ca	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
Replication	2																
Factor C	1	0.259	0.066	0.284	0.367	0.027	0.0001	0.044	0.264	0.003	0.003	0.020	0.005	203.12	273.78	87.92	8768.53
Factor T	2	0.991	0.023	0.891	0.917	0.321	0.010	4.001	2.197	1.142	0.006	4.291	4.277	7137.50	306.87	14875.95	14443.72
Interaction C × T	2	0.319	0.229	0.021	0.472	0.078	0.001	0.666	0.367	0.007	0.014	0.004	0.007	266.14	174.15	387.75	30225.82
Error	10	0.262	0.144	0.040	0.313	0.057	0.007	0.386	0.450	0.006	0.010	0.012	0.005	1021.75	82.58	328.57	15906.23
Total	17																

APPENDIX-XXV

Analysis of variance table for agroforestry systems, climatic conditions and their interaction on total amount of nutrients added through different sources (Kg ha⁻¹ yr⁻¹) under dry temperate climatic conditions of north western Himalaya

Source of Variation	DF	Mean Squares			
		N	P	K	Ca
Replication	2				
Factor C	1	183.13	284.01	96.96	8772.39
Factor T	2	7128.46	306.55	14825.53	14864.01
Interaction C × T	2	272.66	181.62	390.71	30160.69
Error	10	1051.09	79.90	333.21	15925.55
Total	17				

APPENDIX-XXVI

Analysis of variance table for agroforestry systems, climatic conditions and their interaction on amount of nutrients removal (Kg ha⁻¹ yr⁻¹) under dry temperate climatic conditions of north western Himalaya

Source of Variation	DF	Mean Squares			
		N	P	K	Ca
Replication	2				
Factor C	1	897.02	139.443	4,136.671	4,453.177
Factor T	2	481.24	145.649	288.105	373.009
Interaction C × T	2	54.64	58.330	4.009	95.821
Error	10	166.28	15.193	166.576	181.317
Total	17				

APPENDIX-XXVII

Analysis of variance table for agroforestry systems, climatic conditions and their interaction on fractional annual turnover of elements percentage in soil pool and vegetation pool under dry temperate climatic conditions of north western Himalaya

Source of Variation	DF	Mean Squares							
		Soil compartment				Vegetation compartment			
		N	P	K	Ca	N	P	K	Ca
Replication	2								
Factor C	1	0.483	11.377	551.339	0.211	23.53	511.35	244.65	142.47
Factor T	2	0.269	2.953	395.436	2.859	297.42	1212.70	208.72	72.28
Interaction C × T	2	0.052	3.601	163.865	4.033	22.16	31.18	13.84	18.39
Error	10	0.299	0.307	24.912	0.287	12.02	64.23	7.52	9.33
Total	17								

APPENDIX-XXVIII

Analysis of variance table for agroforestry systems, climatic conditions and their interaction on physico-chemical properties of soil under dry temperate climatic conditions of north western Himalaya

Source of Variation	DF	Mean Squares									
		Pore Space %	Practical Density	Bulk Density	Soil pH	Total N %	O C %	Ext. P	avai. K	exch Ca	exch Mg
Replication	2										
Factor C	1	88.36	0.005	0.091	13.863	0.007	1.138	0.006	0.327	0.031	0.151
Factor T	2	64.12	0.030	0.002	0.009	0.006	0.049	0.002	0.016	0.395	0.308
Int C × T	2	32.55	0.005	0.008	0.056	0.0001	0.059	0.045	0.074	0.480	0.482
Factor D	1	620.34	0.107	0.647	0.859	0.229	2.083	1.120	6.838	19.082	15.589
Int C × D	1	242.32	0.023	0.011	0.329	0.004	0.234	0.095	0.083	0.720	0.0001
Int T × D	2	133.49	0.001	0.005	0.003	0.001	0.029	0.152	0.011	0.014	0.193
Int C × T × D	2	236.97	0.003	0.0001	0.003	0.003	0.112	0.036	0.092	0.162	0.059
Error	22	6.86	0.003	0.001	0.042	0.003	0.014	0.001	0.063	0.015	0.087
Total	35										

APPENDIX-XXIX

Local cost of agricultural inputs and outputs in different agroforestry systems of dry temperate high hills (C₁) climatic condition at Kinnaur district Himachal Pradesh

Sr. no.	Particulars	Rate (Rs)
	Input	
1.	Labour cost	
	a) Labour charges around year 2014-2015	300
	b) Bullock labour (per day)	500
2.	Seed cost (per kg)	
	a) Maize	218
	b) French bean	600
	c) Cabbage	30000
	d) Jo	30
3.	Manure and fertilizer	
	a) FYM (per quintal)	150
	b) NPK complex (per 50kg)	369
	c) Urea (per 100kg)	560
	d) CAN (per 50kg)	1280
	e) DAP (per 50kg)	1260
	f) SSP (per 50kg)	1500
	g) MOP (per 50kg)	850
	h) Calcium Nitrate water soluble	180
4.	Fungicides & Pesticides	
	Bavistin (per 100g)	160
	Dithene M-45 (500 g)	200
	Blytox- 50 (500 g)	180
	Bifenthrin 10% EC (500 ml)	670
	Thiamethoxam 70 WS (5g)	30
	Metasystox 25EC 100ml	120
	Glyphosate per litter	350
	Chlorophyriphos (250ml)	90
	Formalin (5 litre)	150
	Quinalphos 25 % EC per 500 ml	280
	DECIS insecticide 100 ml	80
	Output	
1.	Agriculture (per quintal)	
	a) Jo	1350
	i) Grain	550
	ii) Straw	
	b) Maize	1500
	i) Grain	
	c) Cabbage	2400

	d) Rajmash	9000
2.	Fruits (per quintal) a) Apple b) Chilgoza (kg)	4500 800
3.	Pasture (per quintal) a) Grass b) Chari (per beegha)	450 3000
4.	Wood (per cubic feet) a) <i>Celtis australis</i> b) <i>Prunus armeniaca</i> c) <i>Quercus incana</i> d) <i>Salix alba</i> e) <i>Populus ciliata</i> f) <i>Morus alba</i> g) <i>Pinus gerardiana</i> h) <i>Pinus wallichiana</i> i) <i>Cedrus deodara</i> Fuel wood (per quintal) a) Broad leaved b) Coniferous	 350 380 400 450 250 800 800 1500 430 360

*One cubic meter = 45.5 cubic feet

1. Crop cultivation cost for agrihorticulture system in dry temperate high hills climatic condition (C₁) at kinnaur district H. P.

APPENDIX-XXX

1.1 Ploughing and land preparation

Crops	Cost for using bullocks (Rs/ 800m ²)	Cost for labour (Manday)	Cost Rs/ 800m ²	Total cost (Rs/ha)
French Bean	500	300	800	10000
Maize	500	300	800	10000
Cabbage	500	600	1100	13750
Jo	500	300	800	10000

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-XXXI

1.2 Seeds for sowing-

Cost item	Seed rate Kg/ha	Price (Rs/kg)	Total cost (Rs/ha)
French Bean	50	600	30000
Maize	60	200	12000
Cabbage	0.75	30000	2250
Jo	80	30	2400

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-XXXII

1.3 Irrigation cost-

Crop	No of irrigation	Labour (Total man day)	Cost Rs/800m ²	Total cost (Rs/ha)
French Bean	2	1	300	3750
Maize	1	1	300	3750
Cabbage	6	1	300	3750
Jo	2	1	300	3750

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-XXXIII

1.4 Pesticides cost –

Crop	Cost Rs/ 800m ²	Total cost (Rs/ha)
French Bean	304.00	3800.00
Maize	337.92	4224.00
Cabbage	29.65	370.68
Jo	33.36	417.00
Total	1383.15	12985.36

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-XXXIV

1.5 Fertilizer supplied to annual crops

Fertilizer type	Quantity kg/800m ²	Rate (Rs/kg)	Cost Rs/800m ²	Total cost (Rs/ha)
FYM	372.4	1.5	558.60	6982.5
SSP	2.4	30	72.00	900
MOP	9.2	17	156.40	1955
DAP	4.08	25.2	102.816	1285.2
NPK-complex	8.56	7.38	63.17	789.66
Calcium Nitrate- W	3.2	180	576.00	7200

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-XXXV

1.6 Fertilizer supplied to annual crops, type of fertilizer, quantity and price in agrihorticulture system in (C₁) climatic conditions

Crop	Fertilizer	Kg/ha	Total price (Rs/ha)
French bean	FYM	500	7500.0
	MOP	30	510.0
	Calcium Nitrate- W	40	7200
			15210.0
Maize	FYM	450	6750.0
	Complex NPK - 16:16:16	30	221.4
			6971.4
Cabbage	FYM	600	9000.0
	NPK complex	47	346.9
	DAP	51	1285.2
	MOP	60	1020.0
	SSP	30	900.0
			12552.1
Jo	FYM	450	6750.0
	NPK complex	30	221.4
	MOP	25	425.0
			7396.4

APPENDIX-XXXVI

1.7 Weeding/Agronomic practices

Crop	No. of weeding	Man days	Cost Rs/800m ²	Total cost Rs/ha
French bean	2	1	300	3750
Maize	1	1	300	3750
Cabbage	2	3	900	11250
Jo	1	2	600	7500

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-XXXVII

1.8 Harvesting

Crop	Man days	Cost Rs/800m ²	Total cost (Rs/ha)
French bean	1	300	3750
Maize	1	300	3750
Cabbage	4	1200	15000
Jo	2	600	7500
Total		2400	30000

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-XXXVIII

1.9 Grading and packing

Crop	Man days	Cost Rs/800m ²	Total cost (Rs/ha)
French bean	1	300	3750
Maize	2	600	7500
Cabbage	1	300	3750
Jo	1	300	3750
Total		1500	18750

APPENDIX-XXXIX

1.10 Transportation to market

Crop	Three-wheeler carring capacity (Qt)	Cost (Rs) for three-wheeler	Average produce (q/ha)	Total transport cost (Rs/ha) produce
French bean	4	250	25.79	1611.56
Maize	5	300	22.54	1352.52
Cabbage	5	450	98.29	8846.01
Jo	7	250	21.23	758.14
Total			167.84	12568.24

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-XL

1.11 Cost of cultivation of apple trees at (C₁) climatic condition in Kinnaur district H. P.

Particulars	Quantity/man days	Rate(Rs)	Total Cost (Rs)
(A.) Cost of variable Resources:			
1. Manures and fertilizers cost:			
a. FYM	50 kg	1.5/kg	75
b. Urea	4.0 kg	5.60/kg	22.4
c. SSP	2. kg	30/kg	60
d. MOP	2. kg	17/ kg	34
e. Tracel	10 g	80/kg	0.8
2. Plant protection cost:			
(a) Pesticides/insecticides:			
Ziram 27%	10ml	150/500ml	3
Bavistin	2g	160/100g	3.2
3. Labour cost:			
(a) Land preparation			
(a1) Ploughing	¼ hrs	300/ mandays	9.38
(a2) Preparation of basin	¼ hrs	300/ mandays	9.38
(a3) Irrigation	¼ hrs	300/ mandays	9.38
(b) Application of manures and fertilizers	¼ hrs	300/ mandays	9.38
(c) Training and Pruning	½ hrs	300/ mandays	18.75
(d) Mulching	1/8 hrs	300/ mandays	4.69
(e) Weeding	¼ hrs	300/ mandays	9.38
(f) Irrigation	¼ hrs	300/ mandays	9.38
(g) Plant Protection	¼ hrs	300/ mandays	9.38
(h) Harvesting	½ hrs	300/ mandays	18.75
(i) Transportation	-	-	
a) orchard to road head		per/ box	18
b) Road head to Shimla market		per/ box	80
(j) Washing, Grading, Packaging	-	-	
a) One box price/bag			45
b) Price of one try	-		5
c) Roof			5
Total fixed cost			459.25
4. Miscellaneous(2% of total cost)			9.19
5. Interest on working capital (5%)			22.96
Total Variable cost			491.40

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-XLI

1.12. Total cost of cultivation of apple trees at (C₁) climatic condition in Kinnaur district H. P.

Orchard	Total expenses in Rs/ha Apple (400 trees)
Cost items	Expenses in Rs/ha
Basin Preparation	11256.0
Fertilization and Its Application	76880.0
Plant protection measures	23262.4
Weeding	3752.0
Irrigation	3752.0
Pruning	7500.0
Harvesting	7500.0
Picking, Grading, Packing	57365.0
Miscellaneous	3640.0
Transportation charges	102214.0
Sub Total	297121.4
Land Rent	50000.0
Management (5%)	14856.1
Interest (5%)	14856.1
Risk (5%)	14856.1
Total	391689.6

*Local wage rates prevailing in the area (2014-15 market prices)

2 Agrisilviculture systems

1. Crop cultivation cost for agrisilviculture system in dry temperate high hills climatic condition (C₁) at kinnaur district Himachal Pradesh

APPENDIX-XLII

2.1 Ploughing and land preparation

Crops	Cost for using bullocks (Rs/ 800m ²)	Cost for labour (Mandays)	Cost Rs/ 800m ²	Total cost (Rs/ha)
French bean	500	300	800	10000
Maize	500	600	1100	13750
Cabbage	500	600	1100	13750
Jo	500	300	800	10000

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-XLIII

2.2. Seeds for sowing

Crops	Seed rate (Kg/ha)	Price Rs/kg	Total cost (Rs/ha)
French bean	50	600	30000
Maize	60	200	12000
Cabbage	0.75	30000	2250
Jo	80	30	2400

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-XLIV

2.3. Irrigation cost

Crops	No of irrigation	Labour (Man day)	Cost Rs/800m ²	Total cost (Rs/ha)
French bean	2	1	300	3750
Maize	2	2	600	7500
Cabbage	5	1	300	3750
Jo	2	1	300	3750

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-XLV

2.4. Pesticides cost

Crops	Cost (Rs/ 800m ²)	Total cost (Rs/ha)
French bean	48.00	600.00
Maize	208.00	2600.00
Cabbage	73.25	915.68
Jo	115.52	1444.00
Total	1038.83	12985.36

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-XLVI

2.5. Fertilizer cost supplied to annual crops

Fertilizer type	Quantity kg/800m ²	Rate (Rs/kg)	Cost Rs/800m ²	Total cost (Rs/ha)
FYM	450.96	1.5	676.44	8455.5
Urea	3.2	5.6	17.92	224
SSP	2.08	30	62.40	780
MOP	7.2	17	122.40	1530
DAP	4	25.2	100.8	1260
NPK-complex	8.16	7.38	60.22	752.76
Calcium Nitrate w	2.4	180	432.00	5400

*Values calculated at 2014-15 market prices

APPENDIX-XLVII

2.6. Fertilizer supplied to annual crops, type of fertilizer, quantity and price

Crop	Fertilizer	Quantity (Kg/ha)	Total price (Rs/ha)
French bean	FYM	400	6000.0
	MOP	30	510.0
	Calcium Nitrate-W	30	5400
			11910.0
Maize	FYM	500	7500.0
	Urea	40	224.0
	Complex NPK - 16:16:16	30	221.4
			7945.4
Cabbage	FYM	470	7050.0
	NPK complex	42	310.0
	DAP	50	1260.0
	MOP	30	510.0
	SSP	26	780.0
			9910.0
Jo	FYM	550	8250.0
	NPK complex	30	221.4
	MOP	30	510.0
			8981.4

APPENDIX-XLVIII

2.7. Weeding/Agronomic practices

Crop	No. of weeding	Man days	Cost (Rs/800m ²)	Total cost (Rs/ha)
French Bean	3	1	300	3750
Maize	2	1	300	3750
Cabbage	3	2	600	7500
Jo	1	1	300	3750

* Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-XLIX

2.8. Harvesting

Crop	Man days	Cost (Rs/800m ²)	Total cost (Rs/ha)
French Bean	1	300	3750
Maize	2	600	7500
Cabbage	2	600	7500
Jo	1	300	3750
Total		1800	22500

* Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-L

2.9. Grading and packing

Crop	Man days	Cost (Rs/800m ²)	Total cost (Rs/ha)
French Bean	1	300	3750
Maize	2	600	7500
Cabbage	1	300	3750
Jo	2	600	7500
Total		1800	22500

* Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LI

2.10. Transportation to market

Crop	Three-wheeler carrying capacity (Qt)	Cost (Rs) for three-wheeler	Average produce q/ha	Total transport cost (Rs/ha) produce
French Bean	4	250	27.97	1748.25
Maize	5	250	26.83	1341.45
Cabbage	5	400	105.27	8421.72
Jo	7	250	21.07	752.64
Total			181.15	12264.06

*Values calculated at 2014-15 market prices

APPENDIX-LII

2.11. Cost of cultivation of silviculture trees (per tree) in agrisilviculture system at (C₁) climatic condition at Kinnaur district H. P.

Particulars	Quantity/man days	Rate	Total Cost (Rs)
(A.) Cost of variable Resources:			
1. Manures and fertilizers cost:			
a. FYM	Nil	Nil	Nil
b. Urea	Nil	Nil	Nil
c. SSP	Nil	Nil	Nil
d. MOP	Nil	Nil	Nil
e. Tracel	Nil	Nil	Nil
2. Plant protection cost:			
(a) Pesticides/insecticides:			
Ziram 27%	Nil	Nil	Nil
Bavistin	Nil	Nil	Nil
3. Labour cost:			
(a) Land preparation			
(a1) Ploughing	0	0	0
(a2) Preparation of basin	¼ hrs	300/ mandays	9.38
(a3) Irrigation	0	0	0
(b) Application of manures and fertilizers	0	0	0
(c) Training and Pruning	0	0	0
(d) Mulching	0	0	0
(e) Weeding	0	0	0
(f) Irrigation	0	0	0
(g) Plant Protection	0	0	0
(h) Harvesting	1days	300/ mandays	300
(i) Transportation	-	-	-
a) Orchard to road head		20/per bag 50kg	20
b) Road head to Shimla market		50/per bag 50kg	50
(j) Washing, Grading, Packaging	1days	300/ mandays	300
a)one box price/bag		15/bag	15
Total fixed cost			694.38
4. Miscellaneous(2% of total cost)			13.89
5. Interest on working capital (5%)			34.72
Total Variable cost			742.99

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LIII

2.12. Total cost of cultivation of silviculture trees in temperate high hills climatic condition (C₁) at Kinnaur district H.P.

Orchard/ Item cost	Total expenses in Rs/ha Pinus gerardiana (7 trees)
Basin Preparation	Nil
Fertilization and Its Application	Nil
Plant protection measures	Nil
Weeding	Nil
Irrigation	Nil
Pruning	Nil
Harvesting	8400.0
Picking, Grading, Packing	10500.0
bag price	480
Miscellaneous	97.2
Transportation charges	2240.0
Sub Total	21717.2
Land Rent	Nil
Management (5%)	1085.9
Interest (5%)	1085.9
Risk (5%)	1085.9
Total	24974.8

*Local wage rates prevailing in the area (2014-15 market prices)

3. Crop cultivation cost for agrihortisilviculture system in dry temperate high hills climatic condition (C₁) at Kinnaur district Himachal Pradesh

APPENDIX-LIV

3.1. Ploughing and land preparation

Crops	Cost for using bullocks (Rs/ 800m²)	Cost for labour (Mandays)	Cost Rs/ 800m²	Total cost (Rs/ha)
French bean	500	300	800	10000
Maize	500	600	1100	13750
Cabbage	500	600	1100	13750
Jo	500	300	800	10000

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LV

3.2. Seeds for sowing

Crops	Seed rate/ha	Price Rs/kg	Total cost (Rs/ha)
French Bean	50	610	30500
Maize	60	200	12000
Cabbage	0.75	30000	2250
Jo	80	30	2400

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LVI

3.3. Irrigation cost

Crops	No of irrigation	Labour (Man day)	Cost Rs/800m²	Total cost (Rs/ha)
French Bean	3	1	300	3750
Maize	2	2	600	7500
Cabbage	4	2	600	7500
Jo	2	1	300	3750

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LVII

3.4. Pesticides cost

Crops	Cost Rs/ 800m²	Total cost (Rs/ha)
French Bean	256.00	3200.00
Maize	337.92	4224.00
Cabbage	29.65	370.68
Jo	33.36	417.00
Total		8211.68

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LVIII

3.5. Fertilizer cost supplied to annual crops

Fertilizer type	Quantity kg/800m ²	Rate Rs/kg	Cost Rs/800m ²	Total cost (Rs/ha)
FYM	332.8	1.5	499.20	6240
Urea	3.2	5.6	17.92	224
SSP	2.4	30	72.00	900
MOP	5.6	17	95.20	1190
DAP	4.8	25.2	120.96	1512
NPK-complex	11.52	7.38	85.02	1062.72
Calcium Nitrate W	2.4	180	432	5400

*Values calculated at 2014-15 market prices

APPENDIX-LIX

3.6. Fertilizer supplied to annual crops, type of fertilizer, quantity and price

Crop	Fertilizer	Quantity (Kg/ha)	Total price (Rs/ha)
French Bean (Rajmash)	FYM	500	7500.0
	MOP	30	510.0
			8010.0
Maize	FYM	600	9000.0
	Urea	40	224.0
	Complex NPK - 16:16:16	45	332.1
	DAP	30	756.0
			10312.1
Cabbage	FYM	500	7500.0
	NPK complex	44	324.7
	DAP	30	756.0
	MOP	40	680.0
	SSP	30	900.0
	Calcium Nitrate W	30	5400
			15560.7
Jo	FYM	400	6000.0
	NPK complex	55	405.9
			6405.9

APPENDIX-LX

3.7. Weeding/Agronomic practices

Crop	No. of weeding	Man days	Cost Rs/800m ²	Total cost (Rs/ha)
French Bean	3	1	300	3750
Maize	2	2	600	7500
Cabbage	4	2	600	7500
JO	2	1	300	3750

* Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LXI

3.8. Harvesting

Crop	Man days	Cost Rs/800m ²	Total cost (Rs/ha)
French Bean	1	900	11250
Maize	1	900	11250
Cabbage	4	1200	15000
JO	1	900	11250
Total		3900	48750

* Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LXII

3.9. Grading and packing

Crop	Man days	Cost Rs/800m ²	Total cost (Rs/ha)
French Bean	1	300	3750
Maize	1	300	3750
Cabbage	2	600	7500
Jo	1	300	3750
Total		1500	18750

* Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LXIII

3.10. Transportation to market

Crop	Three-wheeler carrying capacity (Qt)	Cost (Rs) for three-wheeler	Average produce q/ha	Total transport cost (Rs/ha) produce
French Bean	4	300	16.01	1200.68
Maize	5	250	23.87	1193.35
Cabbage	5	350	105.89	7412.02
Jo	7	250	18.41	657.44
Total			164.17	10463.49

*Values calculated at 2014-15 market prices

APPENDIX-LXIV

3.11. Cost of cultivation of fruit tree (per tree) in agrihortisilviculture system at (C₁) climatic condition at Kinnaur district Himachal Pradesh

Particulars	Quantity/man days	Rate (Rs)	Total Cost (Rs)
(A.) Cost of variable Resources:			
1. Manures and fertilizers cost:			
a. FYM	35 kg	1.5/kg	52.5
b. Urea	3.5 kg	5.60/kg	19.6
c. SSP	2. kg	30/kg	60
d. MOP	2.5. kg	17/ kg	42.5
e. Tracel	10 g	80/kg	0.8
2. Plant protection cost:			
(a) Pesticides/insecticides:			
Ziram 27%	10ml	150/500ml	3
Bavistin	2g	160/100g	3.2
3. Labour cost:			
(a) Land preparation			
(a1) Ploughing	¼ hrs	300/ mandays	9.38
(a2) Preparation of basin	¼ hrs	300/ mandays	9.38
(a3) Irrigation	¼ hrs	300/ mandays	9.38
(b) Application of manures and fertilizers	¼ hrs	300/ mandays	9.38
(c) Training and Pruning	½ hrs	300/ mandays	18.75
(d) Mulching	1/8 hrs	300/ mandays	4.69
(e) Weeding	¼ hrs	300/ mandays	9.38
(f) Irrigation	¼ hrs	300/ mandays	9.38
(g) Plant Protection	¼ hrs	300/ mandays	9.38
(h) Harvesting	½ hrs	300/ mandays	18.75
(i) Transportation	-	-	
a) Orchard to road head		per/ box	18
b) Road head to Shimla market		per/ box	80
(j) Washing, Grading, Packaging	-	-	
a) One box price			50
b) Price of one try	-		5
c) Roof			5
Total fixed cost			447.45
4. Miscellaneous(2% of total cost)			8.95
5. Interest on working capital (5%)			22.37
Total Variable cost			478.77

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LXV

3.12. Cost of cultivation of fruit tree (per tree) in agrihortisilviculture system at (C₁) climatic condition at Kinnaur district Himachal Pradesh

Orchard cost items	Total expenses in Rs/ha (Apple 250 trees)
Basin Preparation	7035.0
Fertilization and Its Application	43850.0
Plant protection measures	14539.0
Weeding	2345.0
Irrigation	2345.0
Pruning	4687.5
Harvesting	4687.5
Picking, Grading, Packing	99060.0
Miscellaneous	2275.0
Transportation charges	161798.0
Sub Total	342622.0
Land Rent	50000.0
Management (5%)	17131.1
Interest (5%)	17131.1
Risk (5%)	17131.1
Total	444015.3

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LXVI

Local cost of agricultural inputs and outputs under different agroforestry systems at high hills temperate dry and cold (C₂) climatic conditions at Kinnaur district Himachal Pradesh

Sr. no.	Particulars	Rate (Rs)
	Input	
1.	Labour cost	
	c) Labour charges around year 2014-2015	300
	d) Bullock labour (per day)	500
2.	Seed cost (per kg)	
	e) Maize	200
	f) French bean	600
	g) Cabbage	30000
	h) Jo	35
3.	Manure and fertilizer	
	a) FYM (per quintal)	150
	b) NPK complex (per 50kg) 12:32:16	369
	c) Urea (per 100kg)	560
	d) DAP (per 50kg)	1260
	e) SSP (per 50kg)	1500
	f) MOP (per 50kg)	850
	g) Calcium Nitrate	340
4.	Fungicides & Pesticides	
	a) Bavistin (per 100g)	160
	b) Dithene M-45 (500 g)	450
	c) NSPE	160
	d) Bifenthrin 10% EC (500 ml)	670
	e) Thirum (500g)	190
	f) Atrazine 50% WP	320
	g) BT King (500 ml)	550
	h) Chlorpyrifos (250ml)	90
	i) Takumi 20 WG 100g	765
	j) Formathion 250ml	420
	k) Azadirachtin 250ml	90
	Output	
1.	Agriculture (per quintal)	
	e) Jo	1350
	iii) Grain	550
	iv) Straw	
	f) Maize	1500
	ii) Grain	
	g) Cabbage	2400
	h) Rajmash	9000

2.	Fruits (per quintal) c) Apple d) Prunus armeniaca (per qut.)	4500 1700
3.	Pasture (per quintal) c) Grass d) Chari (per beegha)	450 3000
4.	Wood (per cubic feet) j) <i>Celtis australis</i> k) <i>Prunus armeniaca</i> l) <i>Quercus incana</i> m) <i>Selix alba</i> n) <i>Populus ciliate</i> o) <i>Ailanthus excelsa</i> p) <i>Pinus gerardiana</i> q) <i>Pinus wallichiana</i> r) <i>Cedrus deodara</i> Fuel wood per quintal c) Broad leaved d) Coniferous	350 380 400 450 450 800 800 1500 430 360

*One cubic meter = 45.5 cubic feet

1. Crop cultivation cost for agrihorticulture system under high hills temperate dry and cold (C₂) climatic condition (Kinnaur district H. P.)

APPENDIX-LXVII

1.1. Ploughing and land preparation

Crops	Cost for using bullocks (Rs/800m²)	Cost for labour (Manday)	Cost Rs/800m²	Total cost (Rs/ha)
French bean	500	300	800	10000
Maize	500	300	800	10000
Cabbage	500	600	1100	13750
Jo	500	300	800	10000

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LXVIII

1.2. Seeds for sowing

Cost item	Seed rate Kg/ha	Price (Rs/kg)	Total cost (Rs/ha)
French bean	50	600	30000
Maize	60	200	12000
Cabbage	0.75	30000	2250
Jo	80	35	2800

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LXIX

1.3. Irrigation cost

Crop	No of irrigation	Labour (Total man day)	Cost Rs/800m²	Total cost (Rs/ha)
French bean	3	1	300	3750
Maize	2	1	300	3750
Cabbage	4	2	600	7500
Jo	2	1	300	3750

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LXX

1.4. Pesticides cost

Crop	Cost Rs/ 800m²	Total cost (Rs/ha)
French bean	288.00	3600.00
Maize	59.20	740.00
Cabbage	65.17	814.68
Jo	107.20	1340.00
Total	519.57	6494.68

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LXXI

1.5. Fertilizer cost supplied to annual crops

Fertilizer type	Quantity kg/800m ²	Rate (Rs/kg)	Cost Rs/800m ²	Total cost (Rs/ha)
FYM	416.8	1.5	625.20	7815
Urea	6	5.6	33.60	420
SSP	2	30	60.00	750
MOP	7.2	17	122.40	1530
DAP	1.6	25.2	40.32	504
NPK-complex	6.4	7.38	47.23	590.4
Calcium Nitrate	1.6	340	544	6800

*Values calculated at 2014-15 market prices

APPENDIX-LXXII

1.6. Fertilizer supplied to annual crops, type of fertilizer, quantity and price

Crop	Fertilizer	Kg/ha	Total price (Rs/ha)
French bean (Rajmash)	FYM	10000	15000.0
	MOP	30	510.0
	Calcium Nitrate	20	6800
			22310.0
Maize	FYM	700	10500.0
	Urea	50	280.0
	Complex NPK - 12:32:16	30	387.0
	DAP	20	504.0
			11671.0
Cabbage	FYM	400	6000.0
	MOP	30	510.0
	SSP	25	750.0
	Complex NPK - 12:32:16	50	645
			7905.0
Jo	FYM	50	7500.0
	MOP	30	387.0
	Urea	25	425.0
			8312.0

APPENDIX-LXXIII

1.7. Weeding/Agronomic practices

Crop	No. of weeding	Man days	Cost Rs/800m ²	Total cost Rs/ha
French bean	1	1	300	3750
Maize	2	1	300	3750
Cabbage	4	3	900	11250
Jo	2	1	300	3750

* Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LXXIV

1.8. Harvesting

Crop	Man days	Cost Rs/800m ²	Total cost Rs/ha
French bean	1	300	3750
Maize	1	300	3750
Cabbage	2	600	7500
Jo	1	300	3750
Total		1500	18750

* Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LXXV

1.9. Grading and packing

Crop	Man days	Cost Rs/800m ²	Total cost Rs/ha
French bean	2	600	7500
Maize	1	300	3750
Cabbage	2	600	7500
Jo	2	600	7500
Total		2100	26250

* Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LXXVI

1.10. Transportation to market

Crop	Three-wheeler carrying capacity (Qt)	Cost (Rs) for three-wheeler	Average produce (q/ha)	Total transport cost (Rs/ha) produce
French Bean	4	350	21.13	1848.44
Maize	5	350	23.18	1622.39
Cabbage	5	350	98.50	6894.72
Jo	7	350	20.36	1018.08
Total			163.16	11383.63

*Values calculated at 2014-15 market prices

APPENDIX-LXXVII

1.11. Cost of cultivation of apple tree (per tree) in agrihorticulture system under high hills temperate dry and cold (C₂) climatic condition (Kinnaur district H. P.)

Particulars	Quantity/man days	Rate	Total Cost (Rs/tree)
(A.) Cost of variable Resources:			
1. Manures and fertilizers cost:			
a. FYM	40 kg	1.5/kg	60
b. Urea	3. kg	5.60/kg	16.8
c. SSP	2.5 kg	30/kg	75
d. MOP	2. kg	17/ kg	34
e. Tracel	10 g	80/kg	0.8
2. Plant protection cost:			
(a) Pesticides/insecticides:			
Cleriperiphas	6 ml	360/500ml	8.3
Mancozeb	10g	220/500g	22.7
3. Labour cost:			
(a) Land preparation			
(a1) Ploughing	¼ hrs	300/ mandays	9.38
(a2) Preparation of basin	¼ hrs	300/ mandays	9.38
(a3) Irrigation	¼ hrs	300/ mandays	9.38
(b) Application of manures and fertilizers	¼ hrs	300/ mandays	9.38
(c) Training and Pruning	½ hrs	300/ mandays	18.75
(d) Mulching	1/8 hrs	300/ mandays	4.69
(e) Weeding	¼ hrs	300/ mandays	9.38
(f) Irrigation	¼ hrs	300/ mandays	9.38
(g) Plant Protection	¼ hrs	300/ mandays	9.38
(h) Harvesting	½ hrs	300/ mandays	18.75
(i) Transportation	-	-	
a) Orchard to road head		per/ box	18
b) Road head to Shimla market		per/ box	130
(j) Washing, Grading, Packaging	-	-	
a) One box price			50
b) Price of one try	-	-	5
c) Roof			5
Total fixed cost			533.45
4. Miscellaneous(2% of total cost)			10.67
5. Interest on working capital (5%)			26.67
Total Variable cost			570.79

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LXXVIII

1.12. Total cost of cultivation of apple trees in agrihorticulture system under high hills temperate dry and cold (C₂) climatic condition (Kinnaur district H. P.)

Orchard cost items	Total expenses in Rs/ha Apple tree (400 trees)
Basin Preparation	15008.0
Fertilization and Its Application	74640.0
Plant protection measures	116312.0
Weeding	3752.0
Irrigation	3752.0
Pruning	7500.0
Harvesting	7500.0
Picking, Grading, Packing	88680.0
Miscellaneous	3640.0
Transportation charges	216228.0
Sub Total	537012.0
Land Rent	50000.0
Management (5%)	26850.6
Interest (5%)	26850.6
Risk (5%)	26850.6
Total	667563.8

*Local wage rates prevailing in the area (2014-15 market prices)

2. Crop cultivation cost in agrisilviculture system under high hills temperate dry and cold (C₂) climatic condition (Kinnaur district H. P.)

APPENDIX-LXXIX

2.1. Ploughing and land preparation

Crops	Cost for using bullocks (Rs/ 800m²)	Cost for labour (Mandays)	Total cost Cost (Rs/ha)
French bean	500	1100	13750
Maize	500	1100	13750
Cabbage	500	1400	17500
Jo	500	800	10000

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LXXX

2.2. Seeds for sowing

Cost item	Seed rate Kg/ha	Price (Rs/kg)	Total cost (Rs/ha)
French bean	50	600	30000
Maize	60	215	12900
Cabbage	0.75	30000	2250
Jo	80	35	2800

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LXXXI

2.3. Irrigation cost

Crop	No of irrigation	Labour (Total man day)	Cost Rs/800m²	Total cost (Rs/ha)
French bean	3	1	300	3750
Maize	2	2	600	7500
Cabbage	4	1	300	3750
Jo	2	1	300	3750

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LXXXII

2.4. Pesticides cost

Crops	Cost Rs/ 800m²	Total cost (Rs/ha)
French bean	288.00	3600.00
Maize	140.80	1760.00
Cabbage	28.45	355.68
Jo	4.86	60.80
Total	462.12	5776.48

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LXXXIII

2.5. Fertilizer cost supplied to annual crops

Fertilizer type	Quantity kg/800m ²	Rate (Rs/kg)	Cost Rs/800m ²	Total cost (Rs/ha)
FYM	576	1.5	864.00	10800
Urea	5.84	5.6	32.70	408.8
SSP	2.4	30	72.00	900
MOP	6.4	17	108.80	1360
DAP	4	25.2	100.8	1260
NPK-complex	9.6	7.38	70.85	885.6
Calcium Nitrate	4.8	340	1632	20400

*Values calculated at 2014-15 market prices

APPENDIX-LXXXIV

2.6. Fertilizer supplied to annual crops, type of fertilizer, quantity and price

Crop	Fertilizer	Kg/ha	Total price (Rs/ha)
French bean	FYM	800	12000.0
	MOP	40	680.0
	Calcium Nitrate	60	20400
			33080.0
Maize	FYM	600	9000.0
	Urea	50	280.0
	Complex NPK - 12:32:16	70	903.0
	DAP	50	1260.0
			11443.0
Cabbage	FYM	600	9000.0
	MOP	40	680.0
	SSP	30	900.0
	Complex NPK - 12:32:16	50	645
			11225.0
Jo	FYM	700	10500.0
	MOP	30	510.0
	Urea	23	128.8
			11138.8

APPENDIX-LXXXV

2.7. Weeding/Agronomic practices

Crop	No. of weeding	Man days	Cost Rs/800m ²	Total cost Rs/ha
French bean	1	1	300	3750
Maize	1	2	600	7500
Cabbage	2	2	600	7500
Jo	2	1	300	3750

* Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LXXXVI

2.8. Harvesting

Crop	Man days	Cost Rs/800m ²	Total cost Rs/ha
French bean	1	300	3750
Maize	2	600	7500
Cabbage	2	600	7500
Jo	1	300	3750
Total		1800	22500

* Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LXXXVII

2.9. Grading and packing

Crop	Man days	Cost Rs/800m ²	Total cost Rs/ha
French bean	1	300	3750
Maize	1	300	3750
Cabbage	2	600	7500
Jo	1	300	3750
Total		1500	18750

* Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-LXXXVIII

2.10. Transportation to market

Crop	Three-wheeler carrying capacity (Qt)	Cost (Rs) for three-wheeler	Average produce (q/ha)	Total transport cost (Rs/ha) produce
French bean	4	300	20.04	1503.00
Maize	5	300	28.30	1697.70
Cabbage	5	350	106.91	7483.42
Jo	7	300	20.84	893.21
Total			176.08	11577.33

*Values calculated at 2014-15 market prices

APPENDIX-LXXXIX

2.11. Cost of cultivation of silviculture tree (per tree) in agrisilviculture system under high hills temperate dry and cold (C₂) climatic condition (Kinnaur district H. P.)

Particulars	Quantity/man days	Rate (Rs)	Total Cost (Rs)
(A.) Cost of variable Resources:			
1. Manures and fertilizers cost:			
a. FYM	Nil	Nil	Nil
b. Urea	Nil	Nil	Nil
c. SSP	Nil	Nil	Nil
d. MOP	Nil	Nil	Nil
e. Tracel	Nil	Nil	Nil
2. Plant protection cost:			
(a) Pesticides/insecticides:			
Cleriperiphas -	Nil	Nil	Nil
Mancozeb	Nil	Nil	Nil
3. Labour cost:			
(a) Land preparation			
(a1) Ploughing	Nil	Nil	Nil
(a2) Preparation of basin	Nil	Nil	Nil
(a3) Irrigation	Nil	Nil	Nil
(b) Application of manures and fertilizers	Nil	Nil	Nil
(c) Training and Pruning	Nil	Nil	Nil
(d) Mulching	Nil	Nil	Nil
(e) Weeding	Nil	Nil	Nil
(f) Irrigation	Nil	Nil	Nil
(g) Plant Protection	Nil	Nil	Nil
(h) Harvesting	1 days	300/ mandays	300
(i) Transportation	-	-	
a) Orchard to road head		per/ box/bag	15
b) Road head to Near market		per/ box/bag	50
(j) Washing, Grading, Packaging	-	per/bag-	30
a) One box/bag price			15
b) Price of one try	-		Nil
c) Roof			Nil
Total fixed cost			410
4. Miscellaneous(2% of total cost)			8.20
5. Interest on working capital (5%)			20.50
Total Variable cost			438.70

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-XC

2.12. Total cost of cultivation of silviculture trees in agrisilviculture system under high hills temperate dry and cold (C₂) climatic condition (Kinnaur district H. P.)

Orchard cost items	Total expenses in Rs/ha Prunus armeniaca (15 trees)
Basin Preparation	Nil
Fertilization and Its Application	Nil
Plant protection measures	Nil
Weeding	Nil
Irrigation	Nil
Pruning	Nil
Harvesting	4500.0
Picking, Grading, Packing	94050.0
Miscellaneous	123.0
Transportation charges	10465.0
Sub Total	109138.0
Land Rent	Nil
Management (5%)	5456.9
Interest (5%)	5456.9
Risk (5%)	5456.9
Total	125508.7

*Local wage rates prevailing in the area (2014-15 market prices)

3. Crop cultivation cost in agrihortisilviculture system under high hills temperate dry and cold (C₂) climatic condition (Kinnaur district H. P.).

APPENDIX-XCI

3.1. Ploughing and land preparation

Crops	Cost for using bullocks (Rs/ 800m²)	Cost for labour (Mandays)	Cost Rs/ 800m²	Total cost Cost (Rs/ha)
French bean	500	300	800	10000
Maize	500	300	800	10000
Cabbage	500	600	1100	13750
Jo	500	300	800	10000

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-XCII

3.2. Seeds for sowing

Cost item	Seed rate Kg/ha	Price (Rs/kg)	Total cost (Rs/ha)
French bean	50	600	30000
Maize	60	200	12000
Cabbage	0.75	30000	2250
Jo	80	35	2800

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-XCIII

3.3. Irrigation cost

Crops	No of irrigation	Labour (Man day)	Cost Rs/800m²	Total cost (Rs/ha)
French bean	2	1	300	3750
Maize	2	2	600	7500
Cabbage	4	2	600	7500
Jo	2	1	300	3750

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-XCIV

3.4. Pesticides cost

Crops	Cost Rs/ 800m²	Total cost (Rs/ha)
French bean	256.00	3200.00
Maize	132.80	1660.00
Cabbage	95.09	1188.68
Jo	107.20	1340.00
Total	591.09	7388.68

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-XCV

3.5. Fertilizer cost supplied to annual crops

Fertilizer type	Quantity kg/800m ²	Rate (Rs/kg)	Cost Rs/800m ²	Total cost (Rs/ha)
FYM	413.36	1.5	620.04	7750.5
Urea	10.24	5.6	57.34	716.8
SSP	1.6	30	48.00	600
MOP	5.2	17	88.40	1105
DAP	2	25.2	50.4	630
NPK-complex	4	7.38	29.52	369
Calcium Nitrate	4	340	1360	17000

*Values calculated at 2014-15 market prices

APPENDIX-XCVI

3.6. Fertilizer supplied to annual crops, type of fertilizer, quantity and price

Crop	Fertilizer	Kg/ha	Total price (Rs/ha)
French bean	FYM	570	8550.0
	MOP	35	595.0
	Calcium Nitrate	50	17000
			26145.0
Maize	FYM	500	7500.0
	Urea	55	308.0
	Complex NPK - 12:32:16	30	387.0
	DAP	25	630.0
			8825.0
Cabbage	FYM	600	9000.0
	Urea	50	280.0
	MOP	30	510.0
	SSP	20	600.0
	Complex NPK - 12:32:16	20	258
			10648.0
Jo	FYM	500	7500.0
	MOP	30	510.0
	Urea	23	128.8
			8138.8

APPENDIX-XCVII

3.7. Weeding/Agronomic practices

Crop	No. of weeding	Man days	Cost Rs/800m ²	Total cost (Rs/ha)
French bean	2	1	300	3750
Maize	2	1	300	3750
Cabbage	5	3	900	11250
Jo	2	2	600	7500

* Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-XCVIII

3.8. Harvesting

Crop	Man days	Cost Rs/800m ²	Total cost (Rs/ha)
French bean	1	300	3750
Maize	1	300	3750
Cabbage	2	600	7500
Jo	1	300	3750
Total		1500	18750

* Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-XCIX

3.9. Grading and packing

Crop	Man days	Cost Rs/800m ²	Total cost (Rs/ha)
French bean	1	300	3750
Maize	1	300	3750
Cabbage	2	600	7500
Jo	2	600	7500
Total		1800	22500

* Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-C

3.10. Transportation to market

Crop	Three-wheeler carrying capacity (Qt)	Cost (Rs) for three-wheeler	Average produce (q/ha)	Total transport cost (Rs/ha) produce
French bean	4	350	19.82	1734.25
Maize	5	350	27.92	1954.61
Cabbage	5	400	109.63	8770.16
Jo	7	350	20.90	1045.17
Total			178.27	13504.19

*Values calculated at 2014-15 market prices

APPENDIX-CI

3.11. Cost of cultivation of apple tree (per tree) in agrihortisilviculture system under high hills temperate dry and cold (C₂) climatic condition (Kinnaur district H. P.)

Particulars	Quantity/man days	Rate	Total Cost (Rs/tree)
(A.) Cost of variable Resources:			
1. Manures and fertilizers cost:			
a. FYM	30 kg	1.5/kg	45
b. Urea	3. kg	5.60/kg	16.8
c. SSP	2. kg	30/kg	60
d. MOP	2 kg	17/ kg	34
e. Tracel	10 g	80/kg	0.8
2. Plant protection cost:			
(a) Pesticides/insecticides:			
Cleriperiphas -	6 ml	360/500ml	8.3
Mancozeb	10g	220/500g	22.7
3. Labour cost:			
(a) Land preparation			
(a1) Ploughing	¼ hrs	300/ mandays	9.38
(a2) Preparation of basin	¼ hrs	300/ mandays	9.38
(a3) Irrigation	¼ hrs	300/ mandays	9.38
(b) Application of manures and fertilizers	¼ hrs	300/ mandays	9.38
(c) Training and Pruning	½ hrs	300/ mandays	18.75
(d) Mulching	1/8 hrs	300/ mandays	4.69
(e) Weeding	¼ hrs	300/ mandays	9.38
(f) Irrigation	¼ hrs	300/ mandays	9.38
(g) Plant Protection	¼ hrs	300/ mandays	9.38
(h) Harvesting	½ hrs	300/ mandays	18.75
(i) Transportation	-	-	
a) Orchard to road head		per/ box	25
b) Road head to Shimla market		per/ box	110
(j) Washing, Grading, Packaging	-	-	
a) One box price			45
b) Price of one try	-		5
c) Roof			5
Total fixed cost			485.45
4. Miscellaneous(2% of total cost)			9.71
5. Interest on working capital (5%)			24.27
Total Variable cost			519.43

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-CII

3.12. Total cost of cultivation of apple trees in agrihortisilviculture system under high hills temperate dry and cold (C₂) climatic condition (Kinnaur district H. P.)

Orchard cost items	Total expenses in Rs/ha Total cost (110 apple tree)
Basin Preparation	3095.4
Fertilization and Its Application	243.8
Plant protection measures	31985.8
Weeding	1031.8
Irrigation	1031.8
Pruning	2062.5
Harvesting	2062.5
Picking, Grading, Packing	82300.0
Miscellaneous	1001.0
Transportation charges	212085.0
Sub Total	336899.6
Land Rent	50000.0
Management (5%)	16845.0
Interest (5%)	16845.0
Risk (5%)	16845.0
Total	437434.5

*Local wage rates prevailing in the area (2014-15 market prices)

APPENDIX-CIII

Economics of different agroforestry systems dry temperate high hills (C₁) climatic condition at Kinnaur district of Himachal Pradesh

Treatment	Average yield (q ha ⁻¹)	Selling price (Rs kg ⁻¹), (Rs/cu ft.)	Gross Return (Rs ha ⁻¹ yr ⁻¹)	Total Expenses (Rs ha ⁻¹ yr ⁻¹)	Net return (Rs ha ⁻¹ yr ⁻¹)	Benefit-cost ratio
1) Agrihorticulture						
Cabbage	98.29	24.00	235893.60	71518.75	164374.85	3.30
French bean	25.79	80.00	206280.00	75621.56	130658.44	2.73
Zea mays	22.54	15.00	42063.00	53297.92	-11234.92	0.79
Jo	21.23	10.00	23478.00	43471.54	-19993.54	0.54
Apple	250.32	45.00	1126417.50	391689.61	734727.89	2.88
Total			1634132.10	635599.39	998532.71	2.05
2) Agrisilviculture						
French bean	27.97	80.00	223776.00	69258.25	154517.75	3.23
Maize	26.83	15.00	58243.50	63886.85	-5643.35	0.91
Cabbage	105.27	24.00	252651.60	57747.36	194904.24	4.38
Jo	21.07	10.00	24924.00	42328.04	-17404.04	0.59
<i>Pinus gerardiana</i>	16.17	800.00	1293473.68	24974.80	1268498.89	51.79
Fuel wood (cubic feet)	130.50	450.00	58725.00	30000.00	28725.00	1.96
<i>Populus ciliata</i>	23.50	8.00	18800.00	5000.00	13800.00	3.76
<i>Celtis australis</i>	17.50	8.00	14000.00	3000.00	11000.00	4.67
Total			1944593.78	296195.30	1648398.49	8.91
3) Agrihortisilviculture						
French Bean	16.01	80.00	128072.00	75410.68	52661.33	1.70
Maize	23.87	15.00	74439.00	71479.45	2959.55	1.04
Cabbage	105.89	24.00	254126.40	76843.42	177282.98	3.31
Jo	18.41	10.00	22847.94	42380.34	-19532.40	0.54
Apple	396.4	45.00	1783575.00	444015.30	1339559.70	4.02
Fuel wood (cubic feet)	155.60	450.00	70020.00	12000.00	58020.00	5.84
<i>Populus ciliata</i>	30.50	8.00	24400.00	6000.00	18400.00	4.07
Total			2357480.34	728129.19	1629351.15	2.93

APPENDIX-CIV

Economics of different agroforestry systems high hills temperate dry and cold (C₂) climatic condition at Kinnaur district of Himachal Pradesh

Treatment	Average yield (q ha ⁻¹)	Selling price (Rs kg ⁻¹), (Rs/cu ft.)	Gross Return (Rs ha ⁻¹ yr ⁻¹)	Total Expenses (Rs ha ⁻¹ yr ⁻¹)	Net return (Rs ha ⁻¹ yr ⁻¹)	Benefit-cost ratio
1) Agrihorticulture						
French bean	21.13	80.00	169000.00	86508.44	82491.56	1.95
Maize	23.18	15.00	72411.50	51033.39	21378.11	1.42
Cabbage	98.50	24.00	236390.40	65364.40	171026.00	3.62
Jo	20.36	10.00	25491.14	42220.08	-16728.95	0.60
Apple	442.90	45.00	1993035.00	667563.80	1325471.20	2.99
Total			2496328.04	912690.11	1583637.93	2.12
2) Agrisilviculture						
French bean	20.04	80.00	160320.00	96933.00	63387.00	1.65
Maize	28.30	15.00	80088.50	67800.70	12287.80	1.18
Cabbage	106.91	24.00	256574.40	65064.10	191510.30	3.94
Jo	20.84	10.00	25971.14	39892.81	-13921.68	0.65
<i>Prunus armeniaca</i>	104.65	18.00	188372.09	125508.70	62863.39	1.50
<i>Celtis australis</i>	23.90	9.00	21510.00	3800.00	17710.00	5.66
Fuel wood (cubic feet)	178.60	480.00	85728.00	16500.00	69228.00	5.20
Total			818564.13	415499.31	403064.81	2.83
3) Agrihortisilviculture						
French bean	19.82	80.00	158560.00	86079.25	72480.75	1.84
Maize	27.92	15.00	69096.45	53189.61	15906.84	1.30
Cabbage	109.63	24.00	263104.80	70356.84	192747.96	3.74
Jo	20.90	10.00	25401.88	45823.97	-20422.09	0.55
<i>Populus alba</i>	27.30	10.00	27300.00	7200.00	20100.00	3.79
Fuel wood (cubic feet)	180.50	480.00	86640.00	21000.00	65640.00	4.13
Apple	395.08	45.00	1777837.50	437434.54	1340402.96	4.06
Total			2407940.63	721084.21	1686856.42	2.77

BRIEF BIO-DATA

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M.Sc. (Ag) (Agroforestry)	2006	I	Bundelkhand University Jhansi (U.P.)

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