"Diversity, Productivity and Utilization pattern of plant species under Traditional agroforestry system: a case study of Chamba block, Tehri Garhwal, Uttarakhand"

Thesis

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By

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B.Sc. Life science

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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AGROFORESTRY

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CERTIFICATE

This is to certify that the thesis entitled "***Diversity, Productivity and Utilization pattern of plant species under Traditional agroforestry system: a case study of Chamba block, Tehri Garhwal, Uttarakhand***" submitted in partial fulfilment of the requirements for the degree of **Master of Science in Forestry** with major in **Agroforestry** of the College of Post-Graduate Studies, VCSG Uttarakhand University of Horticulture & Forestry, Bharsar, is a record of ***bonafide*** research carried out by **Mr. Surjeet Singh, Id. No. UUHF/13284** under my supervision and no part of the thesis has been submitted for any other degree or diploma.

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

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We, the undersigned, member of the Advisory Committee of **Surjeet Singh,Id. No. UUHF/13284,** a candidate for the degree of **Master of Science in Forestry** with major in **Agroforestry**, agree that the thesis entitled ***"Diversity, Productivity and Utilization pattern of plant species under Traditional agroforestry system: a case study of Chamba block, TehriGarhwal, Uttarakhand"*** may be submitted in partial fulfilment of the requirements for the degree.

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TO

MY BELOVED FAMILY

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"Distance doesn't matter only first step is difficult"

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Needless to mention, errors and omissions are mine.

Ranichauri Campus
July, 2016

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ABBREVIATIONS USED

%	-	Percentage
&	-	And
cm	-	Centimeter
C^o	-	Degree Celsius
DBH/ dbh	-	Diameter at breast height
Fig.	-	Figure
G	-	Gram
/	-	Per
et al.	-	et alia
min	-	Minimum
max	-	Maximum
m^2	-	Meter square
$m^{3/}$ha	-	Meter qube per hecter
t/ha	-	Ton per hecter
RBD	-	Randomized Block Design
kg ha^{-1}	-	Kilogram per hectare
M	-	Meter
m asl	-	Mean above sea level
i.e	-	That is
Viz	-	Namely
Fig.	-	Figure
S. No.	-	Serial number
Spp.	-	Species
S.E	-	Standard Error
S.D	-	Standard deviation

Since ages, agroforestry has been known as a traditional land-use system in India. It is a judicious integration of tree species with agricultural crops and/or animals has been practiced since ancient times across the world in both the tropics and temperate regions. Traditionally, people resorted to agroforestry practices for the inter-dependent benefits of the three components, *viz.* trees, crops, and livestock in addition to the 6Fs, i.e. food, fruit, fodder, fuel, fertilizer, and fiber. The nutrient cycling exchange and positive spill-off effects of each component brought sustainability to farm production mechanisms. Most of the agroforestry systems are part of indigenous traditional knowledge of local communities. These systems vary from one part of the country to another due to its diverse climatic conditions. The prominent traditional systems like shifting cultivation, taungya and homegardens have evolved long ago. The shifting cultivation, i.e. sequential agroforestry system, believed to have originated in the Neolithic period around 7000 BC, is still extensively practiced in the North Eastern Hill (NEH) region and other humid and hilly parts of the Indian subcontinent (Sharma *et al.*, 2007).

India faces a critical imbalance in its natural resource base with about 18% human and 15% of livestock population of the world being supported only by 2.4% of geographical area, 1.5% of forest and pasture lands and 4.2% of water resources. Besides, about 60% of the cropped area in the country is rainfed, where the yield levels are highly prone to a variety of risks. For such areas, diversification of land-use system with agroforestry is a necessary strategy for providing a variety of products for meeting the requirements of the people, insurance against risks caused by weather aberrations, controlling erosion hazards and ensuring sustainable production on a long-term basis (NRCAF, Vision 2050).

The species composition pattern in traditional agroforestry systems in Himalaya is mainly comprised of agrisilvicultural, agrihorticultural, and agrihortisilvicultural systems, which vary according to the size of the land holding and the basic requirements of the farmer (Toky *et al.,* 1989).Species diversity in agrihortisilvicultural systems is much higher as compared to agrisilvicultural and agrihorticultural systems (Mazumdar, 1991).

Agroforestry has established itself as one of the most promising land management systems, helping in the expeditious enhancement of productivity per unit area, on sustainable basis. It has been shown that the socially and culturally valued species in agroforestry systems, right across the Himalayan region and elsewhere in the world where traditional agriculture is practiced, are invariable ecological keystone species within the ecosystem (Ramakrishnan, 2007).

The Indian Himalayas represent 18% of the India's land area and occupies a special place in the mountain ecosystems of the world. This region is not only important from the stand point of climate and as a provider of life, giving water to a large part of the Indian subcontinent; but it also a rich variety of flora, fauna, human communities and cultural diversity (Singh, 2006). Uttarakhand state forms the major part of the central Himalaya that comprises diverse agroforestry system (Maikhuri *et al.*, 2000; Pratap, 2001).

Total geographical area of Uttarakhand is 53,483 sq. km. Out of this tree green cover under agroforestry is 1966 sq.km. It is equal to 3.68% of total geographical area of state. Growing stock and carbon stock of tree under agroforestry is 14.277 m cum and 4.21 m. tones respectively (Anon, 2013). In Garhwal Himalaya, out of 0.46 million ha of gross cropped area agrisilvi (AS), agrihorti (AH) and agrihortisilvi (AHS) systems occupy, respectively, 0.102,0.03 and 0.026 million ha. It indicates that AS, AH and AHS systems represent, respectively, 22.2, 6.5 and 5.7% area of the total cultivated land (Sachan, 2004).

Agroforestry is a land use system that integrates trees, crops and animals in a way that is scientifically sound, ecologically desirable, practically feasible and socially acceptable to the farmers (Nair, 1979). Presence of trees on the agricultural fields is a common practice of the Garhwal Himalayan region. The farmers undertake cultivation of various crops, trees and livestock on the same unit of the land for the maximum utilization of the land in an agroforestry system. In Garhwal Himalaya, agroforestry is permanent feature of agriculture landscape (Semwal and Maikhuri, 1996; Bhatt and Todaria, 1999). It forms integral relationships with the farmer community to supplement fuel, fodder, fruits and fibres in one hand and balance the environment on another. Farmers have common practice to integrate crops, trees, livestock to solve the problem of acute shortage of fuel, fodder etc. (Bhatt, 2002). Although the farmers have little choice in selection of trees

therefore, whatever is available on their field is accepted to them (Bhatt *et al*., 2010). Dispersed small settlements and terraced agricultural fields carved out of the hill slope for raising crops with numerous multipurpose tree species growing, particularly on the boundaries of rainfed terraces, are typical features in the temperate area of Garhwal Himalaya.

Varying topography of the Garhwal Himalaya changes its species diversity, composition and structure along the elevations even at the small distances. Moreover the direction of the sun (aspect) in the hilly topography also plays an important role in the vegetation pattern. Various studies show that agroforestry systems are dominantly consists of multipurpose tree species and horticulture tree species (Toky *et al*., 1989). Tree species present in the agroforestry systems which are multipurpose in nature provide fuel, fodder, fruits, and fibers to the rural community up to a greater extent.

The District Tehri Garhwal lies in the hilly areas of the state and agriculture is the major occupation of its inhabitants. This district consists of 182 villages with 61,569 ha area under cultivation, of which irrigated land is only 7.4% (Srivastava, 2007). So, animal husbandry play vital role in traditional agroforestry system for improving rural economy of farmers. In this survey, main emphasis is given on the type of tree species grown in different agroforestry system with annual crops *viz.* cereal crops, vegetables, legume crops and herb species, their uses by native villagers of Tehri Garhwal district. This study examine the plant diversity of agroforestry system, productivity potential, utilization pattern of trees and shrubs in the nine selected villages *viz.* Chopdiyalgaun, Dubakoti, Aarakot, Saur, Gaunsari, Guldi, Dandasali, Kot, Pali between 1200 and 2000m a.s.l. Farmers in the selected villages grow a variety of annual crops *viz.* Finger millet, Barnyard millet, Amranthus, Rice and wheat. Fruit trees and other perennial in the homegardens, important among them are Chulu, Akhrot and Lemon. *Grewia optiva* is grown mainly for the fodder purpose in different villages.

The objectives of the study have been to assess diversity, productivity potential and utilization pattern of plant species by local peoples in studied villages under the following heads:

1. Plant diversity assessment in a traditional agroforestry system
2. Productivity analysis of plant species in existing agroforestry system
3. Documentation of plant resource utilization pattern with reference to their role in livelihood support to the local people in the study area

The literature relevant to the present investigation entitled "Diversity, Productivity and Utilization pattern of plant species under Traditional agroforestry system: a case study of Chamba block, Tehri Garhwal, Uttarakhand." Under the following heads:

1. Plant diversity assessment in a traditional agroforestry system
2. Productivity analysis of plant species in existing agroforestry system
3. Documentation of plant resource utilization pattern with reference to their role in livelihood support to the local people in the study area

1. Plant diversity assessment in a traditional agroforestry system

Bijalwan *et al*. (2009) reported about traditional agrisilviculture system (agricultural crops + trees) in the northern and southern aspects of mid-hill situation in Garhwal Himalaya, Uttarakhand, India during the 2004-2006. A total of 19 tree species were studied in both northern and southern aspects, out of which 17 tree species were selected in northern aspect and 12 tree species in southern aspect in agrisilvicultural system. The most dominant tree species are *Grewia optiva, Celtis australis* and *Melia azedarach* and successively grown under traditional agrisilviculture system. The dominant agricultural crops were *Eleusine coracana* in summer cereals, *Phaseolus vulgaris* in summer pulses-oilseeds and *Triticum aestivum* in the winter season in the area.

Pant (2009) studied the diversity and economic importance of the trees and shrubs constituting the agroforestry system of the Dhanore region of district Rajouri of J&K state and found that a total of 44 species, 30 trees and 14 shrubs have been listed. The utilization pattern of these species has revealed that all species are used as fuel, 30 species are also used as fodder for cattle, 22 as edibles, 20 as curatives for various ailments and a few species for other purpose.

Kala (2010) documented 26 herbaceous food crop species and 21 woody species that were raised by farmers in the selected villages of Uttarakhand and 37 plant species available in the agro-forestry system used for curing various ailments by traditional healers were also documented during the survey. The major cereals produced by farmers

were *Oryza sativa* L., *Echinochloa frumentoacea* Link., *Eleusine coracana* (L.) Gaertner and *Triticum aestivum* L. The indigenous system of cropping was locally called as Baranaj a, which revolved around the production of > 12 varieties of crops. Besides food, the species grown in the agro-forestry system were used for multiple purposes.

Bijalwan *et al.* (2011) observed various agricultural crops existing under agrihortisi lviculture (AHS) system in northern and southern aspects of mid hills of Central Western Garhwal Himalaya (Narendra Nagar block of district Tehri Garhwal, Uttarakhand), India between 1000 and 2000 m a.s.l during Rabi (Winter) and Kharif (Summer) seasons. The northern aspect was more diverse and formed good vegetation composition, both in terms of forest crops and in agricultural productivity. The tree diversity and richness was record to be higher in northern aspect. 18 tree species were reported in the northern aspect and 13 in the southern aspect of agrihortisilviculture (AHS) systems. The *Grewia optiva* was observed as dominant tree species and *Citrus sinensis* as co-dominant species in the northern and southern aspects.

Bijalwan *et al.* (2012) studied traditional agri-horticulture system along with structure, composition and diversity of fruit trees and shrub species in mid hill situation of Garhwal Himalaya, India between 1000 and 2000 m asl during summer and winter seasons on northern and southern aspect were studied. A total of 12 fruit tree species were recorded in agrihorticulture sysem; of which 4 trees were common in northern and southern aspect and 6 trees were only noticed in northern aspect while 2 in the southern. The apple tree (*Malus domestica*) was recorded to be dominant fruit tree species on both northern and southern aspect with prime preference by the farmers for high additional economic return in agri-horticulture system. Among the shrubs, the 6 shrub species were recorded on the northern aspect whereas there number was 16 on southern aspect. The agricultural crop diversity was higher on the northern aspect in summer and winter seasons.

Bijalwan (2013) contemplated the vegetation status of agroforestry systems in Tehri district of Garhwal Himalays, India at different elevations ranging from 1000m to 2500m asl. There were total 31 forest tree species, 14 fruit tree (horticulture) species, 25 herbs and 20 shrubs recorded in different agroforestry systems. The enormous change in the vegetation particularly in tree species were recorded in the altering elevation. The tree species like *Grewia optiva, Celtis australis, Melia azedarach, Morus alba, Emblica officinalis etc.* were common in the lower Himalayan region. The *Grewia optiva* recorded

to be one of the very common agroforestry species and thrives the diverse altitudinal rage and used for the fodder purpose in the lean period during winter season. The species like *Quercus leucotrichophora, Q. floribunda, Toona ciliate, Cedrus deodra* found in the higher elevation. *Pinus roxburghii* was recorded to be one of the most dominant species occurred on the farmland of farmers in the middle Himalayan region. Among the fruit tree, the species like *Malus domestica, Prunus armeniaca, Citrus sinensis* and *Juglans regia* were usually present in agroforestry systems. The agrisilviculture, agrihorticulture and agri-hortisilviculture were the common agroforestry systems reported in the region.

Roy *et al.* (2013) carried out the status, ecological diversity and importance of homestead garden for biodiversity, conservation of the urban and rural households in Kishoreganj Sadar of northern Bangladesh. 62 plant species including 5 threatened species were identified. The majority of plant species are used as fruit as fodder (45%) followed by medicinal plants (38.71%), firewood (32.26%) and timber (29%). Ecological diversity indices indicated that the existing plant species in the homested gardens in the study area had moderately high biodiversity and species richness. Farmers perceived importance for homestead plant species conservation was fruit and food (85%) followed by building materials (78.75%), subsistence family income (73.75%) and source of firewood (68.75%).

2. Productivity analysis of plant species in existing agroforestry system

The productivity in agroforestry systems is higher as compared to sole cropping systems, because higher yield of crop has been observed in forest influenced soil than in ordinary soil (Chaturvedi, 1981; Sanghal, 1983; Verinumbe, 1987). Approximately 20 per cent higher yields of grain and wood have been reported in agroforestry areas of Haryana and Western U.P. as compared to pure agriculture (Dwivedi and Sharma, 1989). Observations taken from different areas have indicated that the total yield of agriculture crop and wood was more than simple agriculture without trees. In these areas however, it was seen that the growth and yield of crop, near the edges of the tree rows were poorer, however, the loss in growth and yield of crops was compensated, and when the wood produced was also taken into account (Tewari, 1995).

Semwal *et al., (*2002) observed that tree-crop mixed farming is the predominant traditional land use in the Central Himalaya. Knowledge on the effect of lopping the over

story of trees on the productivity of understory of intercropped food crops is limited. Five levels of lopping regime (no lopping, 25%, 50%, 75% and 100% lopping of branches) were established in a 6-year-old mixed plantation of locally valued multipurpose trees in a village at 1200 m altitude. Wheat (*Triticum aestivum* L.), mustard (*Brassica campestris* L.) and lentil (*Lens esculenta* Moench) were intercropped during winter season, and rice (*Oryza sativa* L.), foxtail millet (*Setaria italica* (L.) P. Beauv.) and barnyard millet (*Echinochloa frumentacea* Link) during warm rainy season following traditional practices. No lopping resulted in only 16% of estimated photosynthetically active radiation available in full lopping treatments in case of winter crops and 12% in case of rainy season crops. Mean day temperature was lower by 2°C in no lopping treatments as compared to full lopping treatments in both seasons. There were no significant differences in grain and byproduct yields between no lopping and 25% lopping, and between 75% and full lopping treatments in all crops, except lentil. For winter crops, grain yields in no lopping treatments were only 16 to 21% of the yields in full lopping treatments compared to 3 to 5% in rainy season crops. By-product yields from winter crops in no lopping treatments were 29 to 32% of the full lopping treatments compared to 6 to 8% in rainy season crops. Farmers frequently practice full lopping during winter season. This study shows that loss of crop yields may not be significant if 25% of branches are retained.

Datta and Singh (2007) observed that the productivity of pineapple, turmeric and cowpea was comparatively high under *Azadirachta indica*. The productivity of horticultural and forage crops in association with trees such as *G. arborea*, *A. procera*, *S. saman*, *T. grandis* and *M. champaca* of high timber value could be harnessed as viable agroforestry systems. Changes in soil properties were also monitored. Amelioration of soil acidity, increase in soil organic carbon, and enhanced humification of soil humus, high nutrient availability, low soil erodibility and high surface soil (0−15 cm) moisture availability were noted in soils under MPTs.

Bijalwan *et al.* (2009) reported productivity status of traditional agri-silvi system in northern and southern aspects in mid-hill situation of Garhwal Himalaya, the results show that the annual productivity of all tree species was 3775 kg. $ha^{-1}a^{-1}$ in northern aspect (site-N) and 3101 kg. $ha^{-1}a^{-1}$ in southern aspect (site-S). *Grewia optiva* had the highest productivity in both site-N and site-S among the tree species, followed by *M. azedarach, Quercus leucotrichophora* and *C. australis*. The dominant agricultural crops were *Eleusine coracana* in summer, cereals *Phaseolus vulgaris* in summer, pulses-oilseeds and *Triticum*

aestivum in the winter season in the area. The average biological productivity of agricultural crops in northern aspect was 16% higher as compare to southern aspect under traditional agrisilviculture system. The overall productivity in traditional agrisilviculture system (crop + tree) was 24% (in northern aspect) and 21% (in southern aspect) higher than that in sole cropping system.

According to one of the studies of Sharma *et al.* (2009) in the Rudraprayag and Tehri district of Garhwal Himalaya on five mid altitudinal villages showed that maximum production of wheat (1506 kg/ha), mustard (260 kg/ha) and pulses (598 kg/ha) was observed for village Dhaulana, whereas maximum production of paddy (1375 kg/ha) for village Karokhi, barley (782 kg/ha) for village Chunnikhal and finger millet (1478 kg/ha) and barnyard millet (1028 kg/ha) for village Bhanigram.

Bagwari and Todaria (2011) studied about agro-ecological resource use pattern in a traditional hill agricultural watershed in Garhwal Himalaya, was analysed along an altitudinal transect. Thirty-one food crops are found although only 0.5% agriculture land was under irrigation in the area. Fifteen different tree species within agroforestry systems were located and grain yield and crop residue were observed to be highest between 1200 and 1600 m a.s.l.

Kumar *et al.* (2012) studied that in six traditional agro forestry villages i.e., Budali, Manjakot, Manao, Dungripanth, Chamdaar and Keshu estimated structure and carbon sequ estration potential of traditional agroforestry villages. Among the traditional agroforestry system, majority of villages were dominant by *Grewia oppositifolia* followed by *Toona ciliata.* Among the traditional agroforestry system the highest carbon stock was reported 57.45 t/ha in village Chamdaare and lowest (19.85 t/h) in the village Manjakot. The values of total carbon in other villages were 34.98 t/ha in Budali, 31.47 t/ha in Dungripanth, 30.64 t/ha in Keshu and 20.94 t/ha in Manao. In the traditional agroforestry system an average total carbon stock in trees was 32.56 t/ha.

3. Documentation of plant resource utilization pattern with reference to their role in livelihood support to the local people in the study area

Varadaranganatha *et al.,* (2011) carried out their studies at different agroecological situations (lower elevation area, higher elevation area and coastal area) in the Uttara Kannada district during 2006-07 to analyze utilization pattern of tree/shrub species in prominent agroforestry systems in Uttara Kannada district of Karnataka. There were six prominent agroforestry systems practiced in the three distinct agroecological situations. In all the three situations, bund planting (21.66 to 36.67%) was the most prominent agroforestry practiced by farmers and less prominent practice was block plantation (5.0 to 11.66%). The most dominant tree species were mango (60.0%) in lower elevation area, arecanut and mango (83.33%) in higher elevation area and cashew (95%) in coastal area. In all the three situations, fruits (80.0 to 91.66%) and fuelwood (51.66 to 61.66%) were the dominant products obtained from the trees and among the service functions, shade from the trees (80.0 to 88.33%) was predominant The most commonly preferred trees in farmland were fruit bearing (11.66 to 58.33%) and timber species (21.66 to 35.0%) and less preferred type of species was green manure (3.33 to 11.66%) in all the situations

Satyal *et al*. (2002) observed that 34 medicinal plants on kumaun higher Himalaya are used by the Bhotia tribes. Most of the species are native to the Himalaya region. Angelica glauca and *Allium stracheyi* are narrow range endemic and *Allium stracheyi, Picrorchiza kurrooa* and *Nardostachys grandiflora* have been recorded in the Red Data Book of Indian plants. Apart from indigenous uses, the majority of the species are used in the pharmaceutical industry and a few are among the major source of income generation. The annual production of medicinal plants is comparable with the annual production of tradional crops.

Samant *et al.* (1998) studied biodiversity of a protected area of west Himalaya (ascot wildlife sanctuary) and analysed for landscape, faunal and floral diversity. Species were further analyzed for ethnobotanical use (medicine: 70, edible: 55, fodder: 115, fuel: 31, house building: 13 etc.), domesticated diversity (crops: 19, vegetables: 26, fruits: 16), agro forestry or marginal, threatened and endemic diversity. 432 (34.2%) taxa were native to Indian Himalaya of which 24 were endemic and 235 near endemics.

Samant *et al,* (2006) studied the utilization pattern of the species indicated that 71 species used as fuel, 44 species as fodder, 35 as medicine, 33 as edible, 8 as timber, 7 as agricultural tools and few species for other purpose. 18 species had multipurpose utility. The notable multipurpose species were *Grewia optiva, Aesculus indica, Juglans regia, Quercus leucotrichophora, Berberis lyceum, Cedrus deodara, Prunus armeniaca, Ulmus wallichiana* etc. Two species were identified rare, 27 species occasional and remaining comman.

Bisht and Sharma (2014) have conducted a study on the utilization of plant species by the communities of Bharsar and adjoining area of Garhwal Himalaya possesses luxuriant a varied vegetation with in the Himalaya region. Almost every plant has economic value in the form of shelter, food, water, medicine, fuel and industrial products and fodder. Surveys were conducted in entire Bharsar, Pauri Garhwal district of Uttarakhand, India in order to get information on traditional uses of plants by local inhabitants. A total of 169 plants were collected of which 40 species of vegetables, 19 species of forest and agroforestry, 24 species of ornamental flower, 71 species of less known medicinal plants and 15 species of agricultural crops were found economically important as they are used by the people frequently for various purposes.

The present study entitled "*Diversity, Productivity and Utilization pattern of plant species under Traditional agroforestry system: a case study of Chamba block, Tehri Garhwal, Uttarakhand*" undertaken to document the diversity of plant species, productivity potential and utilization pattern of plant species in a agroforestry system lies between 1200 and 2000m elevation in a part of Garhwal Himalaya.

The methods and procedures developed and adopted for conduction the investigation are explained as follows:

3.1 The study area

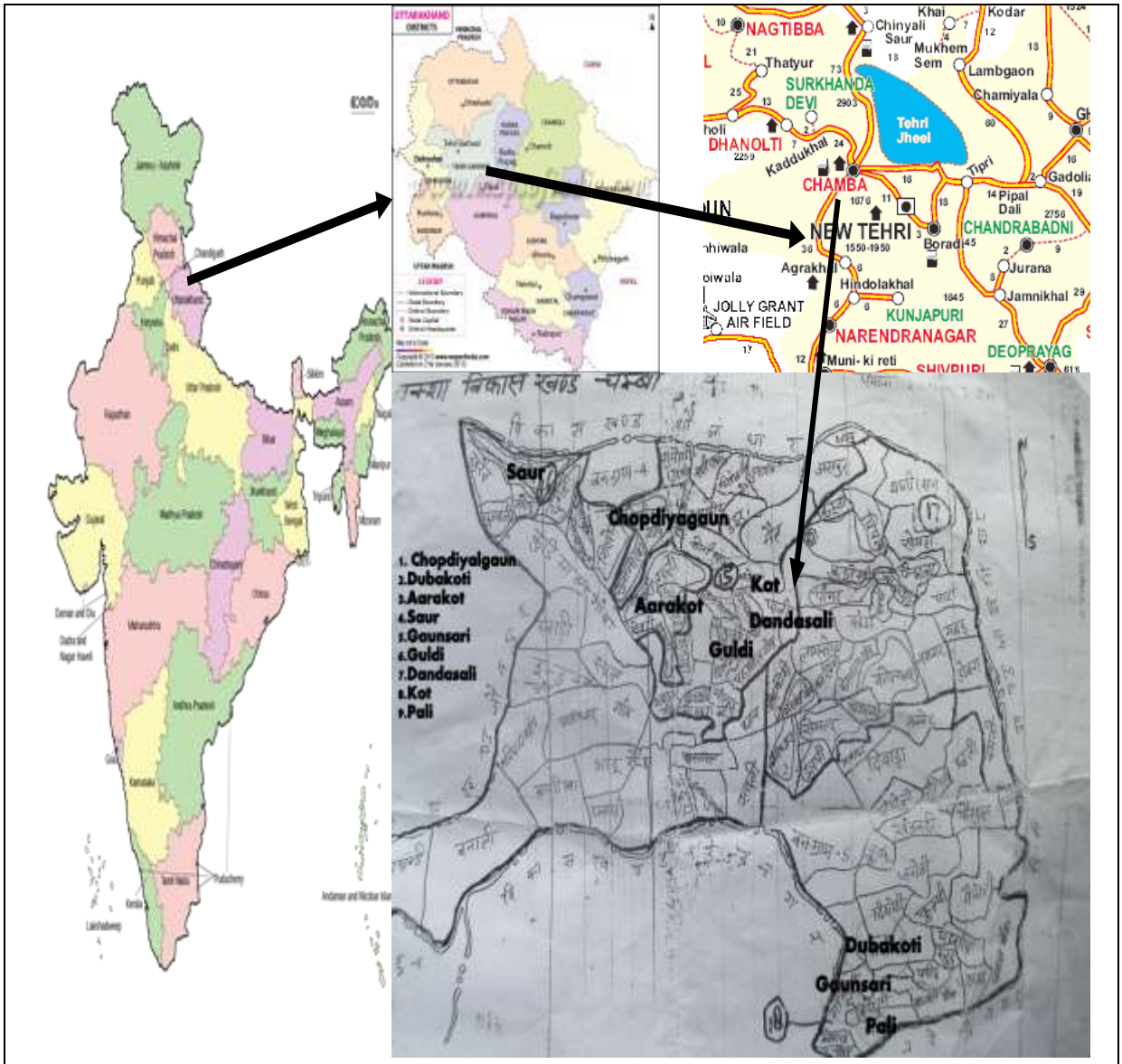
The geographical location and physiographic features of the study area are as follows:

3.1.1 Geographical location and physiography

The study was conducted between 1200 and 2000m asl in Chamba block of district Tehri Garhwal, Uttarakhand. The area falls between sub-tropical and temperate zones which lies between 30^0 22.791' to 30^0 21.928' N Latitude and $78^0$21.864' to78^0 23.876' E Longitude. The study was carried out in the agricultural fields, mostly dominated by trees on the fields. The elevations of the area were measured using GPS. The location map showing the details of the study area has been presented in Map 3.1.

Table 3.1.1: Description of the study site

Sl. no	Village Name	Altitude	Latitude(N)	Longitude (E)
1.	Chopidiyalgaun	1780-1981	30^0 22.4' 55"-30^0 22.7' 91"	78^0 21.1' 67"- 78^0 21.8' 64"
2.	Dubakoti	1772-1865	30^0 16.6' 46"- 30^0 16.7' 29"	78^0 27.0' 76"- 78^0 27.2' 01"
3.	Aarakot	1705-1822	30^0 21.7' 97"-30^0 21.9' 45"	78^0 22.7' 26"-78^0 22.5' 11"
4.	Saur	1665 -1733	30^0 23.34' 7"-30^0 23.9' 23"	78^0 20.4' 45"- 78^0 20.1' 61"
5.	Gaunsari	1635-1685	30^0 25.8' 27"- $30^0$15.9' 41"	78^0 25.3' 88"- 78^0 25.0' 75"
6.	Guldi	1441-1475	30^0 21.2' 12"-30^0 21.2' 21"	78^0 23.8' 78"- 78^0 23.9' 13"
7.	Dandasali	1337-1470	30^0 21.6' 57"-30^0 21.6' 86"	78^0 23.9' 05"- 78^0 23.8' 40"
8.	Kot	1304 -1465	30^0 21.9' 28"-30^0 21.6' 57"	78^0 23.8' 76"- $78^0$23.8' 39"
9.	Pali	1273-1415	30^0 25.7' 54"-30^0 25.8' 23"	78^0 15.7' 97"- 78^0 15.8' 35"



Map 3.1: Chamba block, Tehri Garhawal

3.1.2 Climate and Rainfall

The climate in Tehri Garhwal district varies from cold temperate to sub-tropical. The weather is very cold in winter and pleasant in summer. Snowfall is quite common during the winter in these area. Rainfall, in the study area, occurs almost throughout the year. Maximum rainfall is recorded during the monsoon period i.e. from July to September. There is slight decrease in rainfall from December till March. Rest of the year rainfall is quiet low. The mean temperature ranges between 9.47^0 and $19.31^0$and annual relative humidity between 54.7 and 79.5. The annual total rainfall is 1367.80 mm. (V.C.S.G, U.U.H.F metrological data, 2015-16).

3.2 Methodology

3.2.1 Land -use pattern

The landuse pattern refers to the utilization of land for various purposes including agriculture, fruit cultivation, forest plantation, agroforestry combinations, habitation, road, houses etc. The land use pattern of the study area between 1200 and 2000m asl was recorded with proper survey and feedback drawn from the 150 households/local people/farmers (Table 3.2.1) by using semi structured questionnaires (Appendix-I). The elevation and aspect of the area was measured with the help of GPS.

Table 3.2.1 Demographics of selected villages in Chamba block, Tehri Garhwal.

	Villages								
Variable	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**V8**	**V9**
Total no. of household*	93	95	115	58	359	159	96	172	93
No. of household sampled	20	20	20	20	20	20	20	20	20
Total population*	404	395	431	294	1337	460	390	678	375
Average population surveyed	80	80	100	80	100	80	80	100	80
Average family size	4	4	5	4	5	4	4	5	4

Note: From population census 2011

Abbreviations used: V1 -Chopdiyalgaun,V2 -Dubakoti, V3-Aarakot,V4- Saur, V5-Gaunsari, V6 -Guldi, V7- Dandasali, V8- Kot, V9- Pali.

3.2.2 Phytosociological analysis

Phytosociological analysis of the vegetation for the structural characterization, diversity of plant communities and composition of agroforestry systems in each study site was done. The aspect wise analysis was done to quantify the influence of physiographic variation in relation to structural variation in plant communities of a particular agroforestry system. Diversity was analyzed in agroforestry systems on different study sites.

The phytosociological analysis in agroforestry systems was carried out by laying randomly placed quadrats of 10 x 10m size for trees, 5 x 5m for shrubs and 50 x 50 cm for agriculture crops and herbal layer. The stratified random sampling and multi-stage sampling were carried out on each selected site to study the vegetation. The number of sample plots

varied 20 each for trees and shrubs and 40 for herbs and agricultural crops in each agroforestry system of every site, following Mishra, 1968; Bijlawan, 2009. In each sample plot, the trees were enumerated for their diameters and heights. The girth at breast height (GBH) of individual trees was measured at 1.37m using tree tap. The heights of trees were measured by Abney's level and Ravi's multimeter and shrubs were measured by pole marked in meters and centimetres.

3.3 Plants diversity in agroforestry

In the study site different tree, shrub, and agricultural crops were studied under different agroforestry models *viz.* agri-silivi, agri-silvihorti and home garden. The component of different agroforestry systems are described below

3.3.1 Tree species

The predominant agroforestry species in these sites were *Grewia optiva, Celtis australis, Melia azedirach, Ficus roxburghii, Quercus leucotrichophora, Bauhinia variegate, Ficus palmata and Morus serrata* among the trees which were mostly on the bunds of the agricultural fields, while *Malus domestica, Prunus persica, Prunus domestica, Prunus armeniaca* (mostly wild apricot called Chullu), *Citrus limon, Citrus aurantifolia and Citrus reticulata* among the horticultural trees.

3.3.2 Shrub species

Under agri-silvi and agri-silvihorti system different dominant shrub species were *Rhus parviflora, Rumex hastatus, Artimisia vulgaris, Murraya koenigii and Rosa brunonii* the shrub species were mostly grown in wasteland and forest land.

3.3.3 Herb species

In the agir-silvi and agro-silvo-pasture different herb species are grown i.e *Achyranthus aspera, Rumex nepalensis, Chenopodium album, Amaranthus viridis and spergula arvensis* they are mainly growing under-story of forest and bunds of field.

3.3.4 Agricultural crops

In *Kharif* and *Rabi* season different cereals and legumes are grown with agroforestry trees *viz., Eleusine coracana, Echinochloa frumentacea, Oryza sativa, Zea mays, Phaseolus vulgaris, Vigna umbellate* and *Cajanus cajan* (during *Kharif* season) and *Triticum aestivum, Hardium vulgare, Lens culinaris* etc (during *Rabi* season). Vegetable cultivation was confined mainly to the *Pisium sativum, Lycopersicon esculentum, Luffa acutangula, Cucumis sativus etc.* and they were restricted to homestead level only.

3.4 Productivity of existing agri-silvi systems

The estimation of productivity for different components under existing agrisilvi-culture systems was as follows:

3.4.1 The Trees

The tree productivity refers to increase in tree biomass per unit area. With the help of non-harvesting method, the measurement of tree diameter, height and volume was done to estimate the standing biomass. The trees from different quadrats were recorded in the intercropping system. The detailed volume and biomass estimation of trees was done as under

3.4.1.1 Volume estimation

The diameter and height of tree was measured from agri-silvi system in each quadrat for computation of volume of different tree species. The data was collected for trees in agri-silvi system at studied site. The species specific volume equations compiled by Forest Survey of India (FSI, 1996) were used to compute the volume of the forest trees (Table 3.4). Local, regional and general volume equations were used for all the agroforestry trees species. Related equations (same genus) were also used when no equations were available in some species. The volumes of all individual trees in a quadrat were summed to obtain the total volume present in that sampling quadrat. The mean standing volume was calculated by averaging the volumes of all sampling quadrat s and later the mean volume was extrapolated to hectare. Further, the total standing tree volume for agroforestry systems was calculated on per hectare basis for trees.

3.4.1.2 Computation of above ground biomass

In order to estimate the tree biomass, the volume of individual trees in each sampling quadrat was multiplied by its specific gravity (Table 3.4.1) The above ground biomass of

individual trees present in a quadrat was summed to obtain total above ground biomass present in that sampling quadrat. The mean aboveground biomass was calculated by averaging the biomass values in all sampling quadrats laid in a stratum and later the mean values were extrapolated on hectare basis to obtain above ground biomass storage per ha.

Table 3.4: Volume equations used for computation of above ground volume of different tree species

Sl. No	Name of species	Volume equation	N	R^2	References
1.	*Quercus sp.*	$V/D^2 = 5.09470+0.00563/D^2$			F.S.I., 1996
2.	*Grewia sp.*	$V = -0.44075 + 7.49221D – 36.09962D^2 + 71.91238D^3$			F.S.I., 1996
3.	*Ficus palmata*	$\sqrt{V} = 0.03629+3.95389D-0.84421\sqrt{D}$	149	0.98126	F.S.I., 1996
4.	*Melia azedarach*	$V = -0.03510+5.32981D^2$	18	0.94124	F.S.I., 1996
5.	*Toona ciliata*	$V=1.10314 - 3.52579\sqrt{D}+15.50182D^2$	63	0.98009	F.S.I., 1996
6.	*Bauhinia variegata*	$V = -0.04262 + 6.09491D^2$ (L)	222	0.94936	F.S.I., 1996
7.	*Celtis australis*	$V=0.23781-2.09431*D+7.78268*D^2$			Singh *et al.* (2012)
8.	*Juglans regia*	$V=0.23781-2.09431*D+7.78268*D^2$			Singh *et al.* (2012)

Source: Volume equations for India and Nepal (F.S.I., 1996); Forest Survey of India

Note: n = Total number of sample trees on which regression equations are based, R2 = Co-efficient of determination**;** L = Local volume equation, R = Regional volume equation, G = General volume equation

3.4.1.3 Specific gravity

AGB =Volume x specific gravity. Specific gravity of trees are describes in Table (3.4.1)

Table 3.4.1: Specific gravity computation for above ground biomass of different tree species.

S.No.	Name of species	Specific gravity	References
1.	*Quercus leuocotrichophora*	0.826	Raturi *et al*. (2002)
2.	*Grewia oppositifolia*	0.606	Purkayastha (1982)
3.	*Ficus palmata*	0.578	Sheikh *et al.* (2011)
4.	*Melia azedarach*	0.491	Raturi *et al*. (2002)
5.	*Toona ciliata*	0.554	Rajput *et al*. (1985)
6.	*Bauhinia variegata*	0.55	Kanawja *et al.* (2013)
7.	*Celtis australis*	0.716	Rajput *et al*. (1985)
8.	*Juglans regia*	0.490	Singh *et al.* (2012)

3.2.4 The Agriculture crops

The productivity estimation of major cereal crops was carried out during Rabi and Kharif seasons. The 40 quadrats of 50 x 50 cm dimension were laid out on different study sites. The samples of agriculture crops were taken from farmers' fields in Randomised Block Design (RBD). The agriculture crops from the quadrats were harvested at the maturity stage, which were under the agroforestry systems.

The mature agriculture crop was harvested and separated in grain (seeds) and straw (vegetative portion including shoots and leaves). Further, grain and straw were dried in natural conditions so as to obtain the dry biomass (kg/ha/corp/season). The agriculture productivity included (1) grain productivity referred to as yield of edible portion or economic yield (2) straw productivity referred to the yield of vegetative portion of agriculture crop, including shoot and leaves (3) biological yield which is referred to as the total productivity of agriculture crops including grain and crop residue yield.

3.3.4 Harvest index (H.I):- The Harvest Index (HI) is used to denote the fraction of economically useful products of a plant in relation to its total productivity (grain to straw ratio) and calculated using the following formula.

$$\mathbf{HI = (EY/BY) \times 100}$$

Where;

HI = Harvest Index,
EY = Economic Yield (grain yield),
BY = Biological Yield (grain + straw)

3.4 Utilization pattern of plant species

In the study area, nearest and dependent habitation were surveyed. During surveys, knowledgeable persons from the villages viz.., Chopdiyalgaun, Dubakoti, Aarakot, Saur, Gaunsari, Guldi, Dandasali, Kot, and Pali area were interviewed and information was generated on the utilization pattern (fuel, fodder, timber, edible, etc.) of the species by using semi structured questionnaire (Appendix II). Also, an extensive survey of literature was carried out to gather the status, nativity and for the compilation of indigenous uses of the plant species (Jain, 1991; Gaur, 1999; Samant *et al*., 2007).

3.5 Statistical analysis

Mean, standard deviation, standard error of mean for different quantitative parameters in each agroforestry system were calculated by using MS Excel, 2007.

The findings and discussion are presented under the following sections in accordance with thobjectives set for the study:

4.1 Plant diversity assessment in traditional agroforestry system

The list of agroforestry tree species including forest trees, fruit trees, shrubs and herbs at the elevation between 1200 and 2000m is presented in Table 1. The tables indicate that the proportion of forest trees, fruit trees, shrubs and herbs are found as 32.39%, 23.94%, 15.49% and 28.16%, respectively. There are a total of 23 forest tree species, in which 17 fruit tree species, 11 shrubs and 20 herbs were recorded. There is a great change in the occurrence of the species from 1200 to 2000m elevation. In Tehri Garhwal, the tree species like *Grewia optiva, Celtis australis, Melia azedarach, Morus alba, Emblica officinalis, Bauhinia variegata, Toona cliata* etc. were common in the lower region. The *Grewia optiva* is one of the species thrives the diverse altitudinal range and used for the fodder purpose in the lean period during winter season. *Pinus roxburghii* was recorded to be one of the most dominant species occurred on the farmland of farmers in the middle region. These tree species combined with agricultural crop forms the various agroforestry systems in the study area. The common existing agroforestry systems in the study areas were agrisiviculture (Trees + agricultural crops), agrisilvihorticulture system (Trees including edible fruit trees and forest trees + agricultural crops) generally livestock based and mixed type. Trees in agroforestry systems are commonly found in and around the field boundaries and homesteads which aim to increase the magnitude of the production. In most of the cases, the trees are neither protected nor properly managed. Hence, there is immense need for improvement of these traditionally managed systems to a great extent in order to realize the real production potential of traditional agroforestry systems. Among the fruit trees, the species like *Malus domestica, Prunus armeniaca, Citrus sinensis, Juglans regia* were commonly present in the agroforestry systems.

In the region, one of the very important species named Oak is boon for the conservation of water and governs the hydrological cycle of the region, the Oak (*Quercus leucotrichophora*) it belongs to family Fagaceae and locally known as Banj.

Table 4.1: List of the species in existing agroforestry system

S. No	Scientific name Forest trees	English/ local name	Family	Altitudinal rang(m)	Status
1	*Bauhinia purpurea* L.	Guriyal	Caesalpiniaceae	To 700	Uncommon
2	*Bauhinia variegata* L.	Kachnar	Caesalpiniaceae	1200 -1500	Common
3	*Boehmeria rugulosa*(Wedd&hook.f)	Genthi	Urticaceae	500-1600	Common
4	*Bombax ceiba* L.	Semal	Bombacaceae	800-1500	Uncommon
5	*Cedrus deodara* G.Don	Deodar	Pinaceae	1800-2800	Common
6	*Celtis australis* L.	Kharik	Ulmaceae	1400-2600	Common
7	*Dalbergia sisoo* Roxb.	Shisham	Fabaceae	1000-1500	Uncommon
9	*Ficus palamata* Frossk.	Bedu	Moraceae	1000-2800	Common
10	*Ficus roxburghii* Wallichi ex miq.	Timla	Moraceae	500-1700	Common
11	*Ficus religiosa* L.	Peepal	Moraceae	To 1600	Rare
12	*Grewia optiva* (Buch.Ham.ex.roxb)	Bhimal	Tiliaceae	800-2000	Common
13	*Lyonia ovalifolia*(Wallichi)	Anyar	Ericaceae	1000-3000	Rare
14	*Melia azadarach* L.	Dekkain	Meliaceae	1200-2600	Common
15	*Morus serrata* Roxb.	Sahtoot	Moraceae	1000-2200	Rare
16	*Myrica esculenta* Buch.-Ham ex D.Don	Kaphal	Myricaceae	1500-2100	Rare
17	*Pinus roxburghii* sarg.	Chir	Pinaceae	900-2500	Common
18	*Prunus ceracoides*d. D. Don	Panya	Rosaceae	1200-2200	Common
19	*Pyrus pashia* Buch.-Ham.ex D.Don	Mole	Rosaceae	1000-2000	Common
20	*Quercus leucotrichophora* A.Camus	Banj	Fagaceae	800-2000	Common
21	*Rhodendron arboreum* L.	Burans	Ericaceae	1200-3000	Rare
22	*Toona ciliata* Roemer	Toon	Meliaceae	1200-2000	Common
23	*Woodfordia fruticosa* (L.)	Dhaula	Lythraceae	200-1800	Common
Fruit tree species					
1	*Carica papaya* L.	Papeeta	Caricaceae	To 1200	Rare
2	*Citrus aurentium* L.	Narangi	Rutaceae	To1500	Uncommon
3	*Citrus aurantifolia*	Kagajinimbu	Rutaceae	To 1800	Common
4	*Citrus lemon* (L.) Burm.f	Nimbu	Rutaceae	1000-2000	Common
5	*Citrus reticulata*	santara	Rutaceae	To 1500	Uncommon
6	*Citrus sinensis*(L.) Osbeak	Malta	Rutaceae	1000-2000	Common
7	*Emblica officinalis* Gaertner	Amla	Euphorbiaceae	Upto-1500	Rare
8	*Juglans regia* L.	Akhrot	Juglandaceae	1000-3000	Common
9	*Mangifera indica* L.	Aam	Acanthaceae	To 1500	Uncommon
10	*Melus domestica* L.	Seb	Rosaceae	1000-2500	Common
11	*Prunus armeniaca* L.	Chullu	Rosaceae	1500-3000	Common
12	*Prunus domestica* L.	Pullu	Rosaceae	1500-3000	Common
13	*Prunus persica* (L.) Bastch	Aadu	Rosaceae	1500-3000	Common
14	*Psidium guajava* L.	Amrood	Myrtaceae	To 1200	Uncommon

15	*Punica granatum* L.	Anar	Punicaceae	1000-2000	Uncommon
16	*Pyrus communis* L.	Nashpati	Rosaceae	1000-2000	Common
17	*Vitis vinifera* L.	Angoor	Vitaceae	To 1200	Rare
List of Shrubs					
1	*Berberis asiatica* Roxb.ex DC.	Kingore	Barberidaceae	600-2500	Common
2	*Carissa opaca* Stapf ex Haines	Karonda	Apocyanceae	To 1200	Rare
3	*Desmodium elegans* DC.	Chamlai	Fabaceae	1400-2400	Common
4	*Indigofera gerardiana* Wallich ex. Baker	Sakina	Fabaceae	To 2000	Common
5	*Murraya koenigii* (L.) Sprengel	Curry patta	Rutaceae	Upto 1500	Rare
6	*Nerium indicum* Miller	Kaner	Myrtaceae	To 1000	Rare
7	*Rhus parviflora* Roxb.	Tungla	Anacardiaceae	To 1800	Common
8	*Rosa brunonii* Lindley	Kunja	Rosaceae	600-2000	Common
9	*Rubus eliptcus* Smith.	Hisalu	Rosaceae	800-2100	Common
10	*Rubus niveus* Thunb.	Kala hisalu	Rosaceae	1000-2500	Common
11	*Zanthoxylum alatum* Roxb.	Timru	Rutaceae	900-2100	Common
List of herbs					
	Achyranthus aspera L.	Latjira	Aceraceae	1200-3300	Common
1	*Amaranthus viridis* L.	Jungali chaulai	Amaranthaceae	To 1200	Common
2	*Artemisia vulgaris*(C.B Clarke)	Kunja	Asteraceae	To 1500	Common
3	*Avena fastua* L.	Jangali jai	Poaceae		Common
4	*Cannabis sativa* L.	Bhang	Cannabaceae	To 2300	Rare
5	*Chenopodium album* L.	Bathua	Chenopodiaceae	To 1400	Common
6	*Cyprerus rotundus* L.	Morya	Cyoreraceae	To 1500	Rare
7	*Datura metel* L.	Dhatura	Solanaceae	To 1500	Rare
8	*Euphorbia hirta* L.	Dudhi	Euphorbiaceae	To 1200	Common
9	*Fragaria nubicola* Lindley ex.Lacaita	Wild strawberry	Rosaceae	1500-3000	Common
10	*Lathyrus aphaca* L.	Jungali matar	Fabaceae		Common
11	*Oxalis corniculata* L.	Bhilmori	Oxalidaceae	1300-2200	Common
12	*Polygonum capitatum* Buch.Ham. Ex D.Don	Ghundi	Polygonaceae	To 2500	Uncommon
13	*Rumex hastatus* D.Don	Amilada	Polygonaceae	600-2100	Common
14	*Rumex nepalensis* Sprengel.	Pahadi palak	Polygonaceae	1300-3000	Common
15	*Salvia lanata* Roxb.	Ghaniya	Lamiaceae	800-2500	Uncommon
16	*Senecio nudicaulis* Buch.-Ham.ex D.Don	Neelkanthi	Asteraceae	Upto 1500	Rare
17	*Solanum nigram* L.	Makoi	Solanaceae	To 2800	Rare
18	*Spergula arvensis* L.	Jangali dhaniya	Caryophyllaceae	To 1000	Common
19	*Urtica dioca* L.	Kandali	Urticaceae	1200-3000	Common
20	*Tephrosia pururea* L.	Kurphali	Fabaceae	To 2000	Common

In different traditional agroforestry systems, only three models were found viz., agrisilviculture, agrisilvihorticulture and homegarden.

4.1.1 Agrisilviculture system

This system was mainly comprised of agriculture crops along with forest trees (mainly on the bunds of agriculture fields.). The tree species were mostly on the bunds, but occasionally the trees were also found in between and middle of the agricultural fields. In this system, total 33 species were documented during the present investigation. Out of 33 species, 13 were woody and 20 species were herbaceous food crops raised by the farmers in the selected villages. In all the agroforestry systems, agrisilviculture system was dominated in all type of systems under the studied villages.

4.1.1.1 Species grown in agrisilviculture system

In this system, woody component was comprised with annual agricultural crops. All woody species found in this system were multipurpose tree species; these were planted on the bunds of the agriculture field. They were mainly used for fodder, fuel and timber purpose. Total 13 woody species, viz. *Q. Leucotrichophora, Bauhinia variegata, Morus serrata, Ficus palmata, Toona ciliata, Celtis australis, Boehmeria rugulosa, Melia azedarach, Rhododendron arboretum, Myrica esculenta* were recorded. Out of these species, eight species were multi usage species except *Rhododendron* and *Myrica. Grewia optiva* was the most important multipurpose tree species. Apart from fuelwood, fiber, fodder and medicine, the bark and stem of *Grewia optiva* were also used to make baskets.

Total 20 herbaceous food crops species were documented in two prominent cropping seasons. In *kharif* season cereals, pulses, oil crop, oilseed crop are cultivated. Among all the cultivated *kharif* season crops, *Eleusine coracana, Echinochloa frumentacea, Oryza sativa, Phaseolus vulgaris, Vigna umbellata, Psophocarpus tetragonolabus, Dolichos lablab, Dolichos uniflorus* and *Brassica campestris* were main food crops they were cultivated in all the villages. In *Rabi* season *Triticum aestivum, Hordeum vulgare* and *Lens culinaris* were prominent food crops.

Result of the present study are in line with **Bijalwan *et al.* (2009).** Their study indicated a total of 19 tree species in northern and southern aspects in agrisilvicultural system in mid-hill situation of Garhwal Himalaya between 1000 and 2000 m a.s.l. The most dominant tree species were *Grewia optiva, Celtis australis* and *Melia azedarach* and

successively grown under traditional agrisilviculture system. The dominant agricultural crops *Eleusine coracana* in summer cereals, *Phaseolus vulgaris* in summer pulses-oilseeds and *Triticum aestivum* in the winter season.

The another study done by the **Kala *et al.* (2010)** in an indigenous agroforestry systems in changing climate of the middle Himalayan region of Tehri Garhwal reported 21 woody species like *Grewia optiva, Celtis australis, Melia azedarach, Ficus auriculata* and *Toona ciliata* etc., 26 herbaceous food crop species, which consists 12 crop species, 5 cereals, such as *Oryaza sativa* L. (Dhan), *Amaranthus cruentus* L. (Chaulai), *Echinochloa frumentacea* Link. (Jhangora), *Eleusine coracana* (L.) Gaertner (Maduwa), and *Zea mays* L. (Mungri), and 6 pulses. *Echinaochloa frumentacea* was produced in the highest quantity, followed by *Eleusine coracana* and *Oryza sativa* of the pulses, *Macrotyloma uniflorum* (Lam.) Verdc. (Gahath) produced the highest yield, followed by *Phaseolus vulgaris* L. (Chhemi) and *Cajanus cajan* (L.) Millsp. (Tor). In the *kharif* season, a total of 6 crops were cultivated by the farmers, of these 3 were cereals and 3 were pulses. *Triticum aestivum.* (Gehun) was the major cereal crop in *kharif season*.

Table 4.1.1.1: List of the Species grown in agrisiliviculture system

S. No	**Scientific name** / **Forest trees**	**Common name**	**Family**	**Status of Species**
1	*Bauhinia purpurea*	Guriyal	Caesalpiniaceae	Common
2	*Bauhinia variegata*	Kachnar	Caesalpiniaceae	Common
3	*Boehmeria rugulosa*	Genthi	Urticaceae	Un-common
4	*Celtis australis*	Kharik	Ulmaceae	Common
5	*Ficus palamata*	Bedu	Moraceae	Common
6	*Ficus roxburghii*	Timla	Moraceae	Common
7	*Grewia optiva*	Bhimal	Tiliaceae	Common
8	*Melia azadarach*	Dekkain	Meliaceae	Common
9	*Morus serrata*	Sahtoot	Moraceae	Un-common
10	*Myrica esculenta*	Kaphal	Myricaceae	Rare
11	*Quercus leucotrichophora*	Banj	Fagaceae	Common
12	*Rhodendron arboreum*	Burans	Ericaceae	Rare
13	*Toona ciliata*	Toon	Meliaceae	Common
	Herbaceous food crops			
S. No	**Scientific name**	**Common/ English name**	**Family**	**Status of species**
	Kharif cereal			
1	*Amarunthus caudatus*	Marshu	Amaranthaceae	Un-common

2	*Echinochloa frumentacea*	Jangora	Poaceae	Common
3	*Eleusine corcana*	Manduwa/kodu	Poaceae	Common
4	*Oryza sativa*	Dhaan/ rice	Poaceae	Common
5	*Perilla frutescens*	Bhangjeera	Lamiaceae	Un-common
6	*Zea mays*	Zai/maize	Poaceae	Rare
	Pulses			
1	*Cajanus cajan*	Tour/pigeon pea	Fabaceae	Common
2	*Dolichos lablab*	Bean	Fabaceae	Common
3	*Dolichos uniflorus*	Gahat/horse gram	Fabaceae	Common
4	*Phaseolus vulgaris*	Chhemi/rajma	Fabaceae	Common
5	*Psophocarpus tetragonolabus*	Winged bean	Fabaceae	Common
6	*Vigna mungo*	Urd/black gram	Fabaceae	Un-common
7	*Vigna sinesis*	Lobia/cow pea	Fabaceae	Rare
8	*Vigna umbellata*	Naurangi/ricebean	Fabaceae	Common
	Oilseed crop			
1	*Brassica campestris*	Sarson/mustard	Brassicaceae	Common
2	*Glycine max*	Soyabean	Fabaceae	Un-common
3	*Sesamum indicum*	Til/sesame	Pedaliaceae	Rare
	Rabi cereal			
1	*Hordeum vulgare*	Barley	Poaceae	Common
2	*Triticum aestivum*	Genhu/wheat	Poaceae	Common
	Pulses			
1	*Lens culinaris*	Musoor/lentil	Fabaceae	Common

4.1.2 Agrisilvihorticultural (ASH) system

Agroforestry systems in the Garhwal Himalayan region are preferred by the farmers in order to produce fruits and crops from the same piece of land. Agrisilvihorticulture (ASH) system is one of the predominant systems in this region and the results of trees and agricultural crops recorded in ASH system are presented and discussed hereafter. In this system total 51 species were documented during present investigation. Out of 51 species, 13 were woody species, 18 were fruit trees and 20 species herbaceous food crops raised by the farmers. The agrisilvihorticulture is a common practice by the farmers mostly having high land holding in order to produce fruits and crops from the same piece of land and to achieve more income. The tree species were mostly on the bunds, but occasionally the trees were also found in between and middle of the agriculture fields.

4.1.2.1 Species grown in agrisilvihorticulture system

There were a total of 13 tree species on the studied villages under agrisilvihorticulture system. In this system, were multipurpose tree species were planted on the bunds of the agriculture field. They were mainly used for fodder, fuel and timber purpose. Total ten woody species, viz. *Q. Leucotrichophora, Bauhinia variegata, Morus serrata, Ficus palmata, Rhododendron arboretum, Myrica esculenta* was recorded. Out of these species, eight species were multi usage species except *Quercus*, *Rhododendron* and *Myrica*. *Grewia optiva* was the most important multipurpose tree species. Apart from fuelwood, fiber, fodder and medicine, the bark and stem of *Grewia optiva* were also used to make baskets. In middle story, mainly fruits plants were dominant. In this system 17 species of temperate and sub-tropical fruits are identified *i.e Prunus persica, Prunus domestica, Prunus armeniaca, Juglans regia, Citrus sinensis etc.* are common and *Malus domestica, Pyrus communis* etc. are un-common and *Vitis vinifera, Emblica officinalis , Musa paradisiacal, Carica papaya* etc. are rare fruits species.

Total 20 herbaceous food crops species were documented in two prominent cropping seasons. In *kharif* season cereals, pulses, oil crop, oilseed crop are cultivated. Among all the cultivated *kharif* season crops, *Eleusine coracana, Echinochloa frumentacea, Oryza sativa, Phaseolus vulgaris, Vigna umbellata, Psophocarpus tetragonolabus, Dolichos lablab, Dolichos uniflorus* and *Brassica campestris* were main food crops they were cultivated in all the villages. In *rabi* season *Triticum aestivum, Hordeum vulgare* and *Lens culinaris* were prominent food crops.

Bijalwan (2011) has reported a total of 18 tree species in the northern aspect and 13 in the southern aspect of ASH systems. The *Grewia optiva* was observed as dominant tree species and *Citrus sinensis* as co-dominant species in the northern and southern aspects.

In another study, **Bijalwan (2011)** has reported a total of 12 fruit tree species in agri horticulture system, of which 4 trees were common in northern and southern aspect and 6 trees were only noticed in northern aspect while 2 in the southern. The apple tree (*Malus domestica*) was recorded to be dominant fruit tree species with highest IVI values on both northern and southern aspect with prime preference by the farmers for high additional economic return in agri-horticulture system.

Table 4.1.2.1 List of the species grown in agrisilvihorticulture system

S. No	Scientific name Forest tree species	Common/English name	Family	Status of species
1	*Bauhinia purpurea*	Guriyal	Caesalpiniaceae	Common
2	*Bauhinia variegata*	Kachnar	Caesalpiniaceae	Common
3	*Boehmeria rugulosa*	Genthi	Urticaceae	Un-common
4	*Celtis australis*	Kharik	Ulmaceae	Common
5	*Ficus palamata*	Bedu	Moraceae	Common
6	*Ficus roxburghii*	Timla	Moraceae	Common
7	*Grewia optiva*	Bhimal	Tiliaceae	Common
8	*Melia azadarach*	Dekkain	Meliaceae	Common
9	*Morus alba*	Sahtoot	Moraceae	Un-common
10	*Myrica esculenta*	Kaphal	Myricaceae	Rare
11	*Quercus leucotrichophora*	Banj	Fagaceae	Common
12	*Rhodendron arboreum*	Burans	Ericaceae	Rare
13	*Toona ciliata*	Toon	Meliaceae	Common
Fruit tree species				
1	*Carica papaya*	Papeeta	Caricaceae	Rare
2	*Citrus aurentium*	Narangi	Rutaceae	Common
3	*Citrus aurantifolia*	Kagajinimbu	Rutaceae	Common
4	*Citus lemon*	Nimbu	Rutaceae	Common
5	*Citrus reticulata*	santara	Rutaceae	Uncommon
6	*Citrus sinensis*	Malta	Rutaceae	Common
7	*Emblica officinalis*	Aonla	Euphorbiaceae	Rare
8	*Juglans regia*	Akhrot	Juglandaceae	Common
9	*Mangifera indica*	Aam	Acanthaceae	Rare
10	*Melus domestica*	Seb	Rosaceae	Uncommon
11	*Prunus armeniaca*	Chullu	Rosaceae	Common
12	*Prunus domestica*	Plum	Rosaceae	Common
13	*Prunus persica*	Aadu	Rosaceae	Common
14	*Psidium guajava*	Amrood	Myrtaceae	Uncommon
15	*Punica granatum*	Anar	Punicaceae	Uncommon
16	*Pyrus communis*	Nashpati	Rosaceae	Common
17	*Vitis vinifera*	Angoor	Vitaceae	Rare
Herbaceous food crops				
S. No	**Scientific name**	**Common/english name**	**Family**	**Status of species**

	Kharif			
1	*Amaranthus caudatus*	Marshu/amarnthus	Amaranthaceae	Un-common
2	*Echinocholoa frumentacea*	Jhangora/barnyard millet	Poaceae	Common
3	*Eleusine corcana*	Mandua/finger millet	Poaceae	Common
4	*Oryza sativa*	Paddy/rice	Poaceae	Common
5	*Perilla frutescens*	Bhangjeera	Lamiaceae	Rare
6	*Zea mays*	Maize	Poaceae	Un-common
	Pulses			
1	*Cajanus cajan*	Tour/pigeon pea	Fabaceae	Un-common
2	*Dolichos lablab*	Bean	Fabaceae	Common
3	*Dolichos uniflorus*	Gahat/horse gram	Fabaceae	Common
4	*Phaseolus vulgaris*	Chhemi/rajma	Fabaceae	Common
5	*Psophocarpus tetragonolabus*	Winged bean	Fabaceae	Common
6	*Vigna munga*	Urd/black gram	Fabaceae	Common
7	*Vigna sinensis*	Lobia/cow pea	Fabaceae	Rare
8	*Vigna umbbellata*	Naurangi/ricebean	Fabaceae	Common
	Oilseed crop			
1	*Brassica campestris*	Sarson/mustard	Brassicaceae	Common
2	*Glycine max*	Soybean	Fabaceae	Common
3	*Sesamum indicum*	Til/sesame	Pedaliaceae	Rare
	Rabi cereal			
1	*Hordeum vulgare*	Jau/barley	Poaceae	Common
2	*Triticum asetivum*	Wheat	Poaceae	Common
	Pulses			
1	*Lens culinaris*	Musoor/lentil	Fabaceae	Common

4.1.3 Homegardens

Homegardens have showedn to provide a diverse and stable supply of products and benefits to the families in the villages that maintained them and have improved their livelihood. Home gardening has been a way of life for centuries in the hills for fulfills the household needs.

4.1.3.1 Species grown in homegarden

All the species grown in homegarden are illustrated Table 4.1.3.1**.** A homestead garden is stratified into different strata like under story, middle story and top story. In under story, all annuals like weed grass and vegetables are grown. In all the study sites, 25 species of vegetables was noted in two seasons. Maximum species are common in all the villages viz. tomato, ladies finger, bitter gourd, pumpkin, potato, capsicum, cabbage, arabi, coriander, turmeric, potato, radish and garlic. Elite species like pea and pointed gourd are grown rare in villages. Some weed species growing in kitchen garden were used as a fodder. Mainly three grasses species are growing in under story.

In middle story, all the shrubs and trees were raised, mainly fruits plants were dominant. In home garden 17 species of temperate and sub-tropical fruits are identified *i.e Prunus persica, Prunus armeniaca, Juglans regia, Citrus sinensis etc.* are common and *Malus domestica, Pyrus communis* etc. are un-common and *Vitis vinifera, Annona squamosa, Carica papaya* etc. are rare fruits species.

In top story, all the emergent canopy layer plants were present principally multipurpose trees grown by the farmers for fodder, fuel and timber purpose that is *Grewia optiva* and *Celtis australis* were common species. Other species mainly *Morus serrata* and *Morus alba* are un-common.

Homestead gardens have rich diversity of vegetables, fruits, multipurpose trees and fodder grasses. In comparison to all species of kitchen garden, it is a source of agro-biodiversity conservation. All vegetable and fruit plants growing in home garden is a source of income, related to food security, reservoir of nutrients in reference to vitamins, minerals and fiber. Multi-usage species are used for fodder, fuel and timber according to household needs. All the green cover near the home increase aesthetic and scenic value.

Like wise to present study, **Sahoo (2009)** documented a total of 231 species with 105 trees, 50 shrubs and 76 herbs species from 45 indigenous agroforestry homegardens. These tree, shrub and herb species were distributed in 84 and 49; 31 and 22 and 59 and 39 genera and families respectively. Overall, there were 88 families, out of which 24 tree species (23%) were common to all the homegardens.

Abebe (2005) reported that integral homegardens not only provide supplementary crops such as fruits and vegetables, but also staple food crops and cash crops. The enset (*Enset ventricusum)* and coffee (*Coffea arabica)* in homegarden system in southern Ethiopia was found to be a typical example of integral homegardens.

4.1.3.1 List of the Species grown in homegarden

S.No	Scientific name	Common /English name	Family	Status of Species
	Kharif Vegetables			
1	*Abelmoschus esculentum*	Bhindi/ladies finger	Malvaceae	Common
2	*Allium cepa*	Piaz/onion	Amaryllidaceae	Common
3	*Brassica oleracea var.botrytis*	Phulgobi/cauliflower	Brassicaceae	Common
4	*Brassica oleracea var.capitata*	Bandhgobi/cabbage	Brassicaceae	Common
5	*Brassica juncea*	Prain rai	Brassicaceae	Common
6	*Capsicum frutescens*	Mirch/chilli	Solanaceae	Common
7	*Colocasia antiquorum*	Pindalu/arabi	Araceae	Common
8	*Coriandrum sativum*	Dhaniya/coriander	Apiaceae	Common
9	*Cucumis maxima*	Kaddu/pumpkin	Cucurbitaceae	Common
10	*Cucumis sativus*	Kakree/cucumber	Cucurbitaceae	Common
11	*Curcuma longanon*	Haldi/turmeric	Zingiberaceae	Common
12	*Lagenaria siceraria*	Lauki/bottle gourd	Cucurbitaceae	Common
13	*Luffa acutangula*	Torai/ribbed gourd	Cucurbitaceae	Common
14	*Lycopericon esculentum*	Tamatar/tomato	Solanaceae	Common
15	*Momordica charantia*	Karela/bitter gourd	Cucurbitaceae	Common
16	*Pisum sativum*	Mattar/pea	Fabaceae	Rare
17	*Trichosanthes dioica*	Parwal/pointed gourd	Cucurbitaceae	Rare
18	*Zingiber officinale*	Adark/ginzer	Zingiberaceae	Common
	Rabi			
1	*Allium cepa*	Piaz/onion	Amaryllidaceae	Common
2	*Allium sativum*	LASHun/garlic	Amaryllidaceae	Common
3	*Capsicum annumm*	Shimla mirch/capsicum	Solanaceae	Common
4	*Coriandrum sativum*	Dhaniya/coriander	Apiaceae	Common
5	*Daucus carota*	Gajar/carrot	Apiaceae	Rare
6	*Raphanus sativus*	Muli/radish	Brassicaceae	Common
7	*Solanum tuberosum*	Aalu/potato	Solanaceae	Common

S.No	Fruit trees species			
1	*Carica papaya*	Papeeta	Caricaceae	Rare
2	*Citrus aurentium*	Narangi	Rutaceae	Common
3	*Citrus aurantifolia*	Kagajinimbu	Rutaceae	Common
4	*Citus lemon*	Nimbu	Rutaceae	Common
5	*Citrus reticulate*	santara	Rutaceae	Uncommon
6	*Citrus sinensis*	Malta	Rutaceae	Common
7	*Emblica officinalis*	Aonla	Euphorbiaceae	Rare
8	*Juglans regia*	Akhrot	Juglandaceae	Common
9	*Mangifera indica*	Aam	Acanthaceae	Rare
10	*Melus domestica*	Seb	Rosaceae	Uncommon
11	*Prunus armeniaca*	Chullu	Rosaceae	Common
12	*Prunus domestica*	Plum	Rosaceae	Common
13	*Prunus persica*	Aadu	Rosaceae	Common
14	*Psidium guajava*	Amrood	Myrtaceae	Uncommon
15	*Punica granatum*	Anar	Punicaceae	Uncommon
16	*Pyrus communis*	Nashpati	Rosaceae	Common
17	*Vitis vinifera*	Angoor	Vitaceae	Rare
	Multi-purpose trees(MPTs)			
1	*Celtis australis*	Kharik	Ulmaceae	Common
2	*Grewia optiva*	Bhimal	Tiliaceae	Common
3	*Melia azadarach*	Dekkain	Meliaceae	Common
4	*Morus serrata*	Sahtoot	Moraceae	Un-common
5	*Toona ciliata*	Toon	Meliaceae	Common

4.2 Productivity analysis of plant species in existing agroforestry

The production potential/productivity of tree species in agrisilviculture systems was estimated through non-harvesting methods, using species specific volume equations whereas, agricultural crops was estimated through harvesting method.

4.2.1 Volume estimation

Volume of trees under agrisilviculture system have been presented in Table 4.2.1, which showeded that mean volume of trees in this system ranged from 2.01 to 2.67 m^3/ha in V2 village (Dubakoti) and V3 village (Aarakot), respectively. The volume of *Grewia optiva* ranged from 3.38 in V2 village (Dubakoti) to 6.95 m^3/ha V3 village (Aarakot), followed by *Q. leucotrichophora* recorded 4.90 m^3/ha. For *C. australis* volume was recorded between 1.00 and 1.13 m^3/ha in V6 (Guldi) and V5 village (Gaunsari), respectively, followed by *T. ciliata* that vary from 0.85 to 1.22 m^3/ha in V4 (Saur) and V7 (Dubakoti) village respectively. Volume of *Juglans regia* was recorded between 1.09 and 1.38 m^3/ha in V2 (Dubakoti) and V3 (Aarakot) village, respectively. Average volume of trees, in all the villages ranged from 0.44 to 5.69 m^3/ha in *Melia* and *Grewia*, respectively.

The volume of all trees in this system varied from 2.01 to 2.67 m^3/ha that was recorded in V2 (Dubakoti) and V3 (Aarakot) village, respectively. In all the documented species, maximum mean volume was recorded 5.69 m^3/ha for *G. optiva* and minimum was recorded 0.44 m^3/ha for *M. azedarach.* In comparison to all species, *C. australis* and *G. optiva*, were common species in all villages and the volume of these species recorded varying between 1.06 and 5.69 m^3/ha.

In traditional agrisilviculture systems, **Bijalwan *et al.* (2009)** recorded standing volume of several fodder tree species in northern aspect was 5.54, 3.15, 2.48, 2.12, 1.82, 0.61, 052 m^3/ha for *Grewia optiva, Celtis australis, Melia azedarach, Celtis australis, Ficus roxburghii, Quercus leucorichophora,* respectively.

Bijalwan *et al.* (2015) had reported standing volume in conventional agroforestry (Agrisilviculture systems) along altitude and aspects in the hills of two of Distt. Tehri

Garhwal and Uttarkashi in Uttarakhand Himalaya between 1000 and 2500m altitudinal range. The standing volume of trees under AS systems in Tehri district ranged from 37.82 to 62.78 m^3/ha and in Uttarkashi districts it varied from 33.04 to 63.75 m^3/ha. The values of their study land support to present study.

Table 4.2.1: Standing volume (m^3/ha) of trees under agrisilviculture system

Species	V1	V2	V3	V4	V5	V6	V7	V8	V9	Mean
G. optiva	6.15	3.38	6.95	4.98	5.45	5.72	6.19	6.61	5.76	5.69
Q. leucotrichophora	5.05	4.22	6.75	4.53	4.68	3.59	--	5.50	--	4.90
C. australis	1.06	1.04	1.09	1.10	1.13	1.00	1.03	1.07	1.02	1.06
M. azedarach	0.41	0.31	0.33	--	0.20	0.31	0.68	0.81	0.24	0.44
T. ciliata	1.01	--	1.05	0.85	1.10	1.04	1.22	1.00	1.09	1.05
F. palmata	0.94	--	1.13	1.34	0.90	--	1.99	0.83	1.09	1.17
B. variegata	--	--	--	--	--	--	0.76	0.93	0.30	0.66
J. regia	1.20	1.09	1.38	--	--	--	--	--	--	1.22
Total	15.82	10.04	18.68	12.37	13.46	11.66	11.87	16.75	9.50	
Mean	2.26	2.01	2.67	2.47	2.24	2.33	1.98	2.39	1.58	

*Abbreviations used: V1 -Chopdiyalgaun,V2 -Dubakoti, V3-Aarakot,V4- Saur, V5-Gaunsari, V6 -Guldi, V7- Dandasali, V8- Kot, V9- Pali.

4.2.2 Above ground biomass estimation (ABG)

AGB of trees under agrisilviculture system have been presented in Table 4.2.1, which showed that AGB of trees in this system ranged from 0.85 to 1.74 t/ha in V9 (Pali) and V3 village (Aarakot), respectively. In this system, biomass of *Q. leucotrichophora* varied from 2.96 to 5.57 t/ha in V6 (Guldi) and V3 (Aarakot) village, respectively. The biomass of *G. optiva* was recorded between 2.04 and 4.20 t/ha at V2 (Dubakoti) and V3 village (Aarakot). The lower range of biomass was recorded for *M. azedarach* between 0.09 to 0.39 t/ha in V5 and V8, respectively. Average biomass of trees, in this system ranged from 0.19 to 4.06 t/ha in *Celtis* and *Quercus*, respectively.

The result of the study showeded that the above ground biomass of trees in this system varied from 0.88 to 1.74 t/ha in V9 (Pali) and V3 village (Aarakot), respectively. In all the documented species, maximum above ground biomass (4.06 t/ha) was recorded in

Q. leucotrichophora and minimum was recorded (0.19 t/ha) in *M. azedarach*, In comparison to all species, *C. australis* and *G. optiva* were common species in all villages, biomass of these species recorded between 0.49 and 3.44 t/ha.

Similar agroforestry system was recorded by **Bijalwan *et al.* (2009)** their study observed that biomass of various tree species as 8.59, 4.58, 3.05, 2.23, 0.83 and 0.32 t ha^{-1} for *Grewia optiva, Celtis australis, Quercus leucotrichophora, Ficus roxburghii, Morus serrata* and *Alnus nepalensis* in northern aspect and 7.01, 4.16, 2.31, 1.74 t h^{-1} for *Grewia optiva*, *Celtis australis*, *Quercus leucotrichophora*, *Ficus roxburghi* on southern aspect. The distribution of biomass under traditional agrisilviculture system showeds that the *G. optiva* had highest biomass followed by *Celtis australis.*

Kumar *et al* (2012) also reported above ground biomass of agroforestry trees viz. *Grewia optiva, Celtis australis, Bauhinia retusa, Toona ciliata, Morus alba, Melia azedarach* at six different villages of Garhwal Himalayan region. They had reported that above ground biomass of *Grewia optiva* varied from 14.39 to 25.95 t/ha, followed by Celtis *australis* (2.34 to 24.65 t/ha), *Bauhinia retusa* (2.34 to 24.6), *Toona ciliata* (0.40 to 25.41). In *Melia azedarach* varied from 2.14 to 11.79 t/ha and minimum was recorded for *Morus alba* (0.85 t/ha).

Table 4.2.2: Above ground biomass (ABG) of trees under agrisilviculture system (t/ha)

Species	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**V8**	**V9**	**Mean**
G. optiva	3.72	2.04	4.20	3.01	3.30	3.46	3.76	4.00	3.48	3.44
Q. leucotrichophora	4.28	3.48	5.57	3.74	3.86	2.96	--	4.54	--	4.06
C. australis	0.47	0.46	0.48	0.55	0.50	0.44	0.45	0.47	0.45	0.47
M. azedarach	0.20	0.15	0.16	--	0.09	0.17	0.33	0.39	0.11	0.19
T. ciliate	0.42	--	0.44	0.36	0.46	0.44	0.51	0.42	0.45	0.44
F. palmata	0.54	--	0.65	0.52	0.51	--	1.15	0.47	0.62	0.64
B. variegata	--	--	--	--	--	--	0.41	0.51	0.16	0.36
J. regia	0.70	0.50	0.67	--	--	--	--	--	--	0.62
Total	10.33	6.63	12.17	7.78	8.72	7.47	6.61	10.80	5.27	
Mean	1.48	1.33	1.74	1.56	1.45	1.49	1.10	1.54	0.88	

*Abbreviations used: V1 -Chopdiyalgaun,V2 -Dubakoti, V3-Aarakot,V4- Saur, V5-Gaunsari, V6 -Guldi, V7- Dandasali, V8- Kot, V9- Pali.

4.2.3 Productivity of agricultural crops

4.2.3.1 Grain yield (Economic yield)

The economic yield includes the yield of grain/seeds or edible parts of the agriculture crops. The productivity of major cereals are described in Table 4.2.3.1, which showed that maximum and minimum value of *Echinochloa frumentacea* grain yield was reported 1502 kg/ha in V9 village (Pali) and 843 kg/ha in V1 village (Chopdiyalgaun) respectively. The highest and lowest value of *Eleusine coracana* grain yield were reported as 941 kg/ha in V7 village (Dandasali) and 671 kg/ha in V1 village (Chopdiyalgaun) respectively. The highest and lowest values of yield of grain *Oryaza sativa* was 1052 kg/ha in V9 village (Pali) and 213 kg/ha in V2 village (Dubakoti), respectively. In case of *rabi* season, maximum and minimum values of *Triticum aestivum* grain yield was recorded as 1369 kg/ha in V7 village (Dandasali) and 853 kg/ha in V2 village (Dubakoti), respecively. The highest and lowest value of *Hardium vulgare* grain yield obtained from 1110 kg/ha in V8 village (Kot) and 564 kg/ha in V1 village (Chopdiyalgaun), respectively. Average productivity of cereal crops in *rabi* and *kharif* season varied from 611.78 to 1253.56 kg/ha in *Oryaza sativa* and *Echinochloa frumentacea*. The total productivity of *rabi* and *kharif* season was from 3266 to 5708 kg/ha in V1 village (Chopdiyalgaun) and V7 village (Dandasali), respectivity. The mean productivity of cereals varied from 653.2 to 1141.6 kg/ha in V1 village (Chopdiyalgaun) and V7 village (Dandasali), respectively.

On the basis of above mentioned results it could be conducted that the average grain yield in *rabi* and *kharif* season varied from 611.78 kg/ha in *Oryaza sativa* to 1253.56 kg/ha *Echinochloa frumentacea.* The total grain yield productivity of *rabi* and *kharif* season cereals varied from 3266 kg/ha V1 (Chopdiyalgaun) to 5708 kg/ha V7 village (Dandasali), respectively. The mean productivity of cereals within the villages varied from 653.2 to 1141.6 kg/ha in V1 and V7 villages, respectively. As compared to other villages average grain yield of cereals reported maximum 1141.6 kg/ha in V7 villages, (Dandasali).

Bijalwan *et al.* (2009) had reported grain yield of agriculture crops under traditional agrisilviculture system. He reported grain yield in northern aspect was 763, 811 and 662 kg/ha/a for *Eleusine coracana, Echinochloa frumentacea* and *Triticum aestivum*.

Bagwari *et al.* (2011) recorded grain yield in Rawangana watershed was 870, 616, 530 and 1030 kg/ha for *Oryzy sativa, Triticum aestivum, Echinochloa frumentacea* and *Eleusine coracana* at lower altitude. In case of middle altitude reported 1058, 1368, 1041 and 1076 kg/ha for *Oryza sativa, Triticum aestivum, Echinochloa frumentacea* and *Eleusine coracana.* In case of higher altitude they reported 625, 423, 864 and 464 kg/ha for *Oryaza sativa, Triticum aestivum, Echinochloa frumentacea, Eleusine coracana,* and *Eleusine coracana.* In case of higher altitude they reported 625, 432, 864 and 464 kg/ha for *Oryza sativa, Triticum aestivum, Echinochloa frumentacea, Eleusine coracana*, and *Hordeum vulgare*.

4.2.3.2 Productivity of crop residue

The crop residue includes the yield of above ground vegetative part per unit area. The crop residue of cereals are described in Table 4.2.3.2, which showed that the maximum and minimum value of *Echinochloa frumentacea* crop residue was 6082 kg/ha in V7 village (Dandasali) and 4120 kg/ha in V4 village (Saur) respectively. The highest and lowest value were reported for *Eleusine coracana* as 4832 kg/ha in V4 village (Saur) and 2585 kg/ha in V3 village (Aarakot), respectively. The highest and lowest values for *Oryza sativa* crop residue of 2390 kg/ha were noted in V7 village (Dandasali), and 432 in V1 (Chopdiyalgaun), respectively. The maximum and minimum values of *Triticum aestivum* crop residue was recorded (4092 kg/ha) in V8 village (Kot) and 2265 kg/ha in V5 village (Gaunsari), respectively. The highest and lowest value of *Hordeum vulgare* crop residue yield obtained 2529 kg/ha in V7 village (Dandasali) and 1342 kg/ha in V1 village (Chopdiyalgaun), respectively. Productivity of crop residue of cereals in *rabi* and *kharif* season varied from 1353.78 to 5087.56 kg/ha in *Oryza sativa* and *Echinochloa frumentacea.* The total crop residue in *rabi* and *kharif* season from 12047 to 18177 kg/ha in V1village (Chopdiyalgaun) and V8 village (Kot) respectively. The mean crop residue of cereals within the villages varied from 2409.4 to 3635.4 kg/ha in V1 village (Chopdiyalgaun) and V8 (Kot), respectively.

On the basis of above mentioned results it could be concluded that mean crop residue in *rabi* and *kharif* season varied 1353.78 to 5087.56 kg/ha in *Oryza sativa* and *Echinochloa frumentacea*, respectively. The total crop residue in *Rabi* and *Kharif* season varied from 12047 kg/ha to 18177 kg/ha in V1 (Chopdiyalgaun) and V8 village (Kot) respectively. The mean crop residue within the villages varied from 1271.3 to 1824.4

kg/ha in V6 (Guldi) and V9 (Pali) village, respectively. As compared to other villages average crop residue of cereals reported most prominent (1824.4 kg/ha) in V9 village (Pali).

Bijalwan *et al.* (2009) has reported crop residue of agriculture crops under traditional agrisilviculture system. He reported crop residue in northern aspect was 1610, 1774 and 1321 kg/ha/annum for *Eleusine coracana, Echinochloa frumentacea* and *Triticum aestivum.*

Bagwari *et al.* (2011) recorded crop residue in Rawanganga watershed was 2428, 2154, 1966 and 8223 kg/ha for *Oryza sativa, Triticum aestivum, Echinochloa frumentacea* and *Eleusine coracana* at lower altitude. In case of middle altitude reported 1527, 2732, 5038 and 11191 kg/ha for *Oryza sativa, Triticum aestivum, Echinochloa frumentacea* and *Eleusine coracana*. In case of middle altitude reported 1879, 2154, 3410 and 2130 kg/ha for *Oryza sativa, Triticum aestivum, Echinochloa frumentacea, Eleusine coracana,* and *Horadeum vulgare.*

4.2.3.3 Biological yield (Grain+Straw)

It is referred as the biological yield of agriculture crops including grain and crop residue yield. The biological yield of cereals are described in Table 4.2.3.3, which showeded that maximum and minimum value of *Echinochloa frumentacea* biological yield was 7534 kg/ha in V8 village (Kot) and 5124 kg/ha in V1 village (Chopdiyalgaun), respectively. The highest and lowest biological yield of *Eleusine coracana* were reported 5447 kg/ha in V9 village (Plai) and 3176 kg/ha in V3 village (Aarakot), respectively. The highest and lowest values of *Oryaza sativa* crop residue were noted 3331 kg/ha and 690 kg/ha in V7 (Dandasali) and V1 village (Chopdiyalgaun), respectively. The maximum and minimum values of *Triticum aestivum* crop residue was recorded 5385 kg/ha in V8 village (Kot) and 3217 kg/ha in V5 village (Gaunsari), respectively. The highest and lowest value of *Hordeum vulgare* biological yield obtained 3557 kg/ha in V7 village (Dandasali) and 1906 kg/ha in V1 village (Chopdiyalgaun), respectively. Cereals mean productivity of biological yield in *rabi* and *kharif* season varied 1965.56 to 6341.11 kg/ha in *Oryaza sativa* and *Echinochloa frumentacea.* The total biological yield in *rabi* and *kharif* season varied from 15313 to 23765 kg/ha in V1 (Chopdiyalgaun) and V8 village (Kot),

respectively. Mean biological yield of cereals within the villages varied from 3062.6 to 4753 kg/ha in V1 village (Chopdiyalgaun) and V8 (Kot) respectively.

On the basis of above mentioned results it could be concluded that mean biological yield of cereal crop in *Rabi* and *Kharif* season varied 1965.56 to 6341.11 kg/ha in *Oryza sativa* and *Echinochloa frumentacea,* respectively. The total biological yield of cereals varied from 15313 kg/ha to 23765 kg/ha in V1 (Chopdiyalgaun) and V8 village (Kot), respectively. Mean biological yield within the villages varied from 3062 kg/ha to 4753 kg/ha in V1 village (Chopdiyalgaun) and V8 village (Kot), respectively. As compared to other villages average biological yield of cereals reported as highest 4753 kg/ha in V8 village (Kot).

Bijalwan *et al.* (2009) had reported biological yield of agriculture crops under traditional agrisilviculture system. He reported biological yield in northern aspect was 2373, 2585 and 1983 kg/ha/a for *Eleusine coracana, Echinochloa frumentacea* and *Triticum aestivum.*

Bagwari *et al.* (2011) recorded biological yield in Rawanganga watershed was 3298, 2770, 2496 and 9253 kg/ha for *Oryza sativa, Triticum aestivum, Echinochloa frumentacea* and *Eleusine coracana* at lower altitude. In case of middle altitude reported 2585, 4100, 6079 and 12267 kg/ha for *Oryza sativa, Triticum aestivum, Echinochloa frumentacea* and *Eleusine coracana.* In case of higher altitude they reported 2522, 2586, 4274 and 2594 kg/ha for *Oryza sativa, Triticum aestivum, Echinochloa frumentacea, Eleusine coracana,* and *Hordeum vulgare.*

4.2.3.4 Harvest Index (HI)

The Harvest Index (HI) is used to denote the fraction of economically useful products of a plant in relation to its total productivity (grain to straw ratio).The harvest index of cereals are described in Table 4.2.3.4, which showed that maximum and minimum value of *Echinochloa frumentacea* harvest index as 23.25 in V8 (Kot) and 16.25 in V1 village (Chopdiyalgaun) respectively. The highest and lowest value of *Eleusine coracana* harvest index was reported 25.66 in V7 village (Dandasali) and 17.11 in V1 village (Chopdiyalgaun) respectively. The highest and lowest values of *Oryza sativa* harvest index noted 37.39 in V1 (Chopdiyalgaun) and 26.66 in V2 village (Dubakoti). In case of *rabi* season maximum and minimum values of *Triticum aestivum* harvest index

was recorded 31.58 in V9 village (Pali) and 22.02 in V3 village (Aarakot) respectively. The highest and lowest value of *Hordeum vulgare* harvest index obtained 37.04 in V6 village (Guldi) and 24.84 in V3 village (Aarakot), respectively. Mean harvest index of cereals in *rabi* and *kharif* season varied 18.53 to 31.48 in *Eleusine coracana* and *Oryza sativa,* respectively.

On the basis of above mentioned result it might be concluded that the mean harvest index of cereals in *rabi* and *kharif* season varied 18.53 to 31.48 in *Eleusine coracana* and *Oryza sativa* respectively. The total harvest index of cereals varied from 115.02 to 135.26 in V2 (Dubakoti) and V6 villlage (Guldi). Mean harvest index within the villages varied from to 23.02 to 27.05 inV2 village (Dubakoti) and V6 village (Guldi), respectively. As compared to other villages average crop residue of cereals reported highest (27.05) in V6 village (Guldi).

Bijalwan *et al.* (2009) had reported harvest index of agriculture crops under traditional agrisilviculture system. He reported harvest index in northern aspect was 32.15, 31.37 and 33.38 for *Eleusine coracana, Echinochloa frumentacea* and *Triticum aestivum.* He calculate harvest index on the basis of grain yield and biological yield ratio. In biological yield he take grain+straw yield but in present study harvest index is low as compare to his study because straw yield is lower than crop residue.

Bagwari *et al.* (2011) not calculate harvest index but through grain and biological yield data of their study harvest index was 26.38, 22.23, 21.23 and 11.13 for *Oryza sativfa, Triticum aestivum, Echinochloa frumentacea* and *Eleusine coracana* at lower altitude. In case of middle altitude 40.92, 33.37, 17.12 and 8.77 for *Oryza sativa, Triticum aestivum, Echinochloa frumentacea* and *Eleusine coracana.* In case of higher altitude they reported 24.68, 16.70, 20.21 and 17.89 for *Oryza sativa, Triticum aestivum, Echinochloa frumentacea, Eleusine coracana,* and *Hordeum vulgare*

4.3 Documentation of plant resource utilization pattern with reference to their role in livelihood support to the local people in the study area

4.3.1 Utilization pattern of plant species

Of the total 47 species recorded, 37 species are used commonly for food (edible), 36 for medicinal, 30 for fuel, 20 for fodder, 6 for Agricultural tools, 4 for religious, 12 for timber, 1 for fibre and 12 species for miscellaneous uses (Table 4.3.1 & Fig.1). Most of the species are used for more than one purpose and thus, overlapped in the number of species under different category of uses and parts used. In the present study, maximum species were found to be used for medicine purpose. Analysis of utilization pattern of these species indicated that the whole plant, root stock, leaves, flowers, stem, seeds and bark of roots have been used to cure various diseases. Plant parts are used either alone and or in combination according to diseases. Major diseases and conditions cured by these plants include fever, cough, diarrhea, dysentery, gastric complaints, gonorrhea, headache, asthma, cholera, rheumatism, bleeding from nose, bleeding from urine, leucorrhoea, menstrual complaints, snake bite, stomachache, tonic, ulcer on tongue, wounds, antiseptic, digestive troubles, Jaundice, eye ailments, skin eruption, worms, boils and pimples, etc. The extract of *Berberis aristata* roots is prepared and its 1-1.5 drops are given orally twice a day once a week in fever and as blood purifier. Likewise, Leaf juice of *Indigofera heterantha* is taken in diarrhea, dysentery and cough fever. Medicinal plants are now emerging as an important bio-resource. Earlier they have been used only by specialized herbal healers and rural communities, but now the herbal products have become the first choice of every household.

The rural people of the study area have selective preference for specific tree species for medicine, edible, fuel wood, fodder, house making, agriculture implements etc. A total of 47 trees and shrubs species from the forest or agroforestry are utilized by the villagers (Table4.3.1). As the terraced agricultural lands are carved out by clearing the natural forests, some multipurpose tree species from existing forests like *Grewia optiva, Bauhinia variegata*, *Celtis australis*, *Pyrus pashia* and *Quercus leucotrichophora* are retained and maintained as agroforestry tree species. *Quercus leucotrichophora* and *Grewia optiva* are the most preferred multipurpose tree species. They are not only used for fuel wood and fodder, but also for making household articles and agricultural implements.

Villagers prefer *Bauhinia variegata, Pinus roxburghii* and also *Cedrus deodara* for house making, whereas for agricultural implements they generally prefer the stems and branches of *Q. leucotrichophora, Grewia optiva, and Bauhinia variegata.*

The interviews with knowledgeable persons indicated that the local inhabitants exploited some of the plant species for income generation also. The area is occupied by the horticultural species such as *Punica granatum, Juglans regia, Pyrus malus, P. communis, Prunus armeniaca, P. persica, and Citrus spp.* etc. having very high productivity and is one of the major source of income generation for the inhabitants. Therefore, there is an urgent need to develop a proper mechanism for the of such important plant species, so that their population can be maintained for posterity.

The notable multipurpose species are *Grewia optiva, Celtis australis, Bauhinia variegate, Quercus leucotrichophora, Barberis aristata, Prunus armeniaca, Prunus persica,* etc. that are used as fodder, fuel, edible (food) medicine, timber, making agriculture tools and various other purpose by the inhabitants.

4.3.2 Nativity

Amongst recorded species, 17 were native to the Himalayan region, 4 species native to Himalayan region and neighbouring countries, and the remaining species were non-natives (Table 4.3.1). The rich diversity of non-native species in the area indicates that these species have the ability to establish under diverse environmental conditions. The non- native species represent various biogeographic regions, such as Africa, Australia, Oriental India, Tropical Asia, Europe, America, China, Malaya and Japan.

In the present study, occurrence of 17 native species (e.g. *Grewia optiva, Melia azadarach, Quercus leucotrichophora, Pyrus pashia, Berberis aristata, Carissa opaca)* and 4 species to Himalayan region and neighbouring countries (e.g. *Bauhinia variegate, Dalbergia sisoo, Desmodium elegans, Murraya koenigii*).

The similar agroforestry system was recorded by **Samant *et al.* (2006)** the utilization pattern of the species indicated thet 71 species are used as fuel, 44 species as fodder, 35 as medicine, 33 as edible, 8 as timber, 7 as agricultural tools and few species for other purpose. 18 species had multipurpose utility.

Samant *et al.* (1998) studied biodiversity of a protected area of west Himalaya (ascot wildlife sanctuary) and analysed for landscape, faunal and floral diversity. Species were further analyzed for ethnobotanical use (medicine: 70, edible: 55, fodder: 115, fuel: 31, house building: 13 etc.),

All these studies on utilization pattern of the plant species indicate that these is a great dependency of local inhabitants on forest and agroforestry resources.

Agroforestry has been known as a traditional land-use system in India. It is a judicious integration of tree species with agricultural crops and /or animals that has been practiced since ancient times across the world in both the tropics and temperate regions. Traditionally, people resorted to agroforestry practices for the inter-dependent benefits of the three components, *viz,* trees, crops, and livestock in addition to the 6Fs, i,e. food, fruit, fodder, fuel, fertilizer, and fiber. The nutrient cycling exchange and positive spill-off effects of each component brought sustainability to farm production mechanisms. Most of the agroforestry systems are part of indigenous traditional knowledge of local communities.

The present study was conducted in nine villages lies between 1200 and 2000m elevation in Chamba block of District Tehri. The detailed survey was done for documentation of diversity of different traditional agroforestry systems used by local peoples, productivity potential of existing agroforestry system and utilization pattern of woody species on the basis of semi structured questionnaire, interview of family and visual basis. Under of the following objectives:

5.1Plant diversity assessment in a traditional agroforestry system

- Agroforestry tree species including trees, fruit trees, shrubs and herbs are found in the proportion of 32.39%, 23.94%, 15.49% and 28.16%, respectively. A total of 23 forest tree species, 18 fruit tree species, 14 shrubs and 19 herbs were recorded in the study area. There is a great change in the occurrence of the species from 1200 to 2000m elevation. The tree species like *Grewia optiva, Celtis australis, Melia azedarach, Morus alba, Emblica officinalis, bauhinia variegata, toona cliata* etc were common. The *Grewia optiva* is one of the species thrives the diverse altitudinal rage and used for the fodder purpose in the lean period during winter season.
- In agrisilviculture system, 13 woody species *viz. Grewia optiva, Celtis australis, Ficus roxburghii, Quercus leucotrichophora, Bauhinia variegata, Ficus palmata, Melia azedarach, Rhododendron arboretum and Myrica esculenta* were multipurpose tree species. Among them *Grewia optiva* was the most important multipurpose tree species. 20 annual crops of cereals and pulses were growing in *rabi* and *kharif* season. *Eleusine coracana, Echinochloa frumentacea, Oryza sativa, Phaseolus vulgaris, Vigna*

umbellata, Psophocarpus tetragonolabus, Dolichos lablab, Dolichos uniflorus and *Brassica campestris* were common in all the villages.

- In agrisilvihorticulture system, 13 woody species documented. They were mainly used for fodder, fuel and timber purpose. Total ten woody species, viz. *Q. Leucotrichophora, Bauhinia variegata, Morus serrata, Ficus palmata, Rhododendron arboretum, Myrica esculenta* were recorded. Out of these species, eight species were multi usage species except *Quercus*, *Rhododendron* and *Myrica. Grewia optiva* was the most important multipurpose tree species. 18 species of temperate and sub-tropical fruits are identified *i.e Prunus persica, Prunus domestica, Prunus armeniaca, Juglans regia, Citrus sinensis etc.* are common and *Malus domestica*, *Pyrus communis* etc. are un-common and *Vitis vinifera, Emblica officinalis* etc. are rare fruits species. Total 20 herbaceous food crops species were documented in two prominent cropping seasons. Among the all *kharif* and *rabi* season crop are *Eleusine coracana, Echinochloa frumentacea, Oryza sativa, Phaseolus vulgaris, Vigna umbellata, Psophocarpus tetragonolabus, Dolichos lablab, Dolichos uniflorus* and *Brassica campestris* were main food crops they were cultivated in all the villages. In *rabi* season *Triticum aestivum, Hordeum vulgare* and *Lens culinaris* were prominent food crops.
- In homegardens, 26 under story vegetables species were recorded that include tomato, ladies finger, bitter gourd, pumpkin, potato, capsicum, cabbage, arabi, coriander, tumeric, potato, raddish and garlic. Mainly three grass species were found in all villages. In middle story vegetation, 20 species of temperate and sub-tropical fruits were identified *viz. Pruns persica, Prunus armeniaca, Juglans regia, Citrus sinensis* were common, *Malus domestica, Pyrus communis* are un-common and *Vitis vinifera, Annona squmosa* and *Carica papaya* are rare fruit species. In top story *Grewia optiva* and *Celtis australis* were common species.

5.2Productivity analysis of plant species in existing agroforestry system

- Volume of trees in agrisilviculture system varied from 1.58 in V9 (Pali) to 2.67 m^3 /ha in V3 village (Aarakot). In all the documented species, maximum volume of 5.69 m^3/ha was recorded in *Grewia optiva* and minimum of 0.44 m^3/ha was recorded in *Melia azedarach,* followed by *Q. leucotrichophora* (4.90 m^3/ha). In comparison to all species, *Grewia optiva* and *Quercus leucotrichophora* were common species in all villages; volume of these species were recorded as 5.69 and 1.06 m^3/ha, respectively.

Average volume of trees, in this system ranged from 0.44 to 5.69 m^3 /ha in *Melia and Grewia,* respectively.

- Aboveground biomass of trees in agrisilviculture sytesm varied from 0.88 to 1.74 t/ha in 9 (Pali) and V3 village (Aarakot), respectively. In all the documented species, maximum above ground biomass. 4.06 t/ha was recorded in *Q. leucotrichophora* and minimum was recorded 0.19 t/ha in *M. azedarach,* In comparison to all species *Celtis australis* and *Grewia optiva,* these are common species in all villages; biomass of these species recorded 0.49 and 3.44 t/ha.
- Average grain yield in *rabi* and *kharif* season varied from 796.78 kg/ha to 1253.56 kg/ha for *Eleusine coracana* and *Echinochloa frumentacea*, respectively. . The total grain yield productivity of *rabi* and *kharif* season cereals varied from 3266 kg/ha V1 (Chopdiyalgaun) to 5708 kg/ha V7 village (Dandasali), respectively. The mean productivity of cereals within the villages varied from 653.2 to 1141.6 kg/ha in V1 and V7 villages, respectively. As compared to other villages average grain yield of cereals recorded maximum 1141.6 kg/ha in V7 villages, (Dandasali).
- Mean crops residue in *rabi* and *kharif* season varied from 1353.78 to 5087.56 kg/ha in *Oryza sativa* and *Echinochloa frumentacea* respectively. The total crop residue in *rabi* and *kharif* season vary from 12047 kg/ha to 18177 kg/ha in V1 (Chopdiyalgaun) and V8 village (Kot), respectively. The mean crop residue within the villages varied from 1271.3 to 1824.4 kg/ha in V6 (Guldi) and V9 (Pali), respectively. As compare to other villages average crop residue of cereals reported most prominent 1824.4 kg/ha in V9 village (Pali).
- Mean biological yield of cereal crop in *rabi* and *kharif* season varied from 1965.56 to 6341.11 kg/ha in *Oryza sativa* and *Echinochloa frumentacea,* respectively. The total biological yield of cereals varied from 15313 kg/ha to 23765 kg/ha in V1 (Chopdiyalgaun) and V8 village (Kot), respectively. Mean biological yield within the villages varied from 3062 kg/ha to 4753 kg/ha in V1 village (Chopdiyalgaun) and V8 village (Kot), respectively. As compared to other villages average biological yield of cereals recorded highest 4753 kg/ha in V8 village (Kot).
- Mean harvest index of cereals in *rabi* and *kharif* season varied from 18.53 to 31.48 in *Eleusine coracana* and *Oryza sativa* respectively. The total harvest index of cereals varied 115.02 to 135.26 in V2 (Dubakoti) and V6 villlage (Guldi). Mean harvest index within the villages varied from to 23.02 to 27.05 inV2 village (Dubakoti) and V6

village (Guldi), respectively. As compared to other villages average crop residue of cereals recorded highest 27.05 in V6 village (Guldi).

5.3 Documentation of plant resource utilization pattern and importance with reference to their livelihood support to the local people in the study area

- All the recorded species have high economic importance for the local inhabitants. A total of 47 species recorded, 37 species were used commonly for food (edible), 36 for medicinal, 30 for fuel, 20 for fodder, 6 for Agricultural tools, 4 for religious, 12 for timber, 1 for fibre and 12 species for miscellaneous uses. Amongst recorded species, 17 were native to the Himalayan region, 4 species native to Himalayan region and neighbouring countries, and the remaining species were non-natives. In the present study, maximum species were found to be used for medicine purpose. Plant parts are used either alone and or in combination according to diseases. *Quercus leucotrichophora* and *Grewia optiva* are the most preferred multipurpose tree species. They are not only used for fuel wood and fodder, but also for making household articles and agricultural implements. Villagers prefer *Bauhinia variegata, Pinus roxburghii* and also *Cedrus deodara* for house making, whereas for agricultural implements they generally prefer the stems and branches of *Q. leucotrichophora, Grewia potiva, and Bauhinia variegata.*

Conclusion

On the basis of overall results, sustainable development and management of these lands through agroforestry innovations not only meets the multiple need or food, fodder fuelwood, fibre, fertilizer etc. the role of agroforestry in addressing the challenges of livelihood, economic development and environmental management through the approach of integrated farming system. In the present study, major traditional agroforestry models in studied villages was found as agrisilviculture, agrisilvihorticulture and homegarden. Among them homegarden is most useful for livelihood of the farmers. Species those are highly used in agrisilviculture system would be sustainably managed through plantation. Farmers mainly used homegarden model for daily needs of the household like vegetables

and fruits they cannot grow it away from the household because of the main problems of wild animals like monkey and wild boar. So, farmers are mainly concerned one homegarden system. The arrangement of agrisilvihorticulture (agricultural crops + horticulture tree + forest tree) systems on the same piece of land provides the stable and better output to the farmers. It is worthwhile mention that in hilly regions the existence without agroforestry is difficult because trees not only supplement the fodder, fuel, fiber, fruits etc. but also reduces the pace of land sliding in the fields, protect crops to adverse wind and climatic condition, conserve the moisture, improve the soil quality through nitrogen fixing and organic matter in terms of leaf fall etc. In traditional agrisilviculture system productivity is low but sufficient for household consumption of the villages. In this system traditional crops were grown by the farmers. Some of the agroforestry species have very high potential, as fodder and fuel and other economic importance. These species to the inhabitant for transplantation in the agroforestry systems and marginal lands will not only meet the need of the fodder and fuel but also help in reducing the pressure of natural forests. Furthermore, the financial support to the farmers in the form of good subsidy would be required at the beginning from government and different non-government funding agencies for developing of integrated agroforestry systems.

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Plate 1: Different agroforestry systems

Agrisilviculture system

Homegardens

Agrisilvihorticulture systems

Plate 2: Productivity assessment of Agrisiliviculture system

Drying yield of barnyard millet

Wheat crop

Girth measurement at 1.37m height

Yield of finger millet

Harvesting of rice

Productivity of crop residue

Plate 3: Interaction with local/old persons of the villages

Interview with head of the family

Interview in homegarden

Interview with field worker

Plate 4: Utilization of woody species by villagers

Agriculture implements

Q. *leucotrichophora*

P. roxburghii

Fuel species

Q. leucotrichophora

P. roxburghii

Timber species

B. rugulosa

C. deodara

Edible species

M. esculenta

F. roxburghii

Medicinal species

R. arboreum

B. aristata

Fodder species

Q. leucotrichophora

G. optiva

APPENDIX - 1

SITE-

1) NAME OF THE VILLAGE
2) BLOCK
3) DISTRICT
4) LONGITUDE
5) LATITUDE
6) ASPECT

7) Type of agroforestry systems and their production:

Type of system	Tree-crop combinations					Area (bigha or hectare)	Production								
	Agricultural crop		Vegetable crops	Fruit trees	Forest trees/ grasses		Crop yield (q/ha)			Fruit and forest tree yield					
	Kharif crop	Rabi crop					Grain	straw	Total	medicinal	Timber	Fodder	Fuel	edible	other
Agri- silviculture															
Agri-silvi-pastoral															

Agri-hort-silviculture															
			1												

8. Why you have adopted this system?

Table 4.3.1 Utilization pattern of all woody species in study region

S. No	Scientific name Forest tree species	Local name	Altitude (m)	Nativity	Economic importance	Uses
1	*Bauhinia purpurea* L.	Guriyal	to 700	Ind Or	Fl, Fd, Ti, Ag. Tools	Flower buds cooked as vegetables and foliage used as fodder, wood used for agriculture implement.
2	*Bauhinia variegata* L.	Kachnar	1200 -1500	Ind or Burma China	M, Fl, Fd, Ed, Ag tools	Leaves provide good quality fodder, young flower eaten as vegetable. Wood used for agriculture implement. Bark used in medicine as detergent of wound.
3	*Boehmeria rugulosa* (Wedd&hook.f)	Genthi	500-1600	Reg Himal	Fd, Fl, Ti, Ag. tools	Leaves provide fodder, wood often used for combs, boxes cups and other articles, as well as agriculture implements.
4	*Bombax ceiba* L.	Semal	800-1500	Am Austr	M, Ed, Fl, Ti	Gum exuded from stem medicinal, flower buds as vegetable. Wood light in used for packing cases, boats match sticks etc.
5	*Cedrus deodara* G.Don	Deodar	1800-2800	Reg Himal	Ti, M, Fl, Misc	Medicinal (Aqueous paste of bark used in bowel complaints and piles; wood-oil massaged in lumbago, rheumatic arthritis and urticaria); Fuel; Timber
6	*Celtis australis* L.	Kharik	1400-2600	Europe As Temp Ind Or	Fd, Fl, Ti, Ag. tools	Fruit edible; leaves provide good fodder. Wood used from making small articles. Bark pasre applied on bones, pimples, contusions, sprains and joint pains; an important tree of agroforestry
7	*Dalbergia sisoo* Roxb.	Shisham	1000-1500	Ind or Afgan	M, Fl, Fd	Resin used in skin ailments; wood commercially well known for construction and furniture; leaves lopped for fodder.
8	*Emblica officinalis* Gaertner	Amla	to-1500	As Trop	Ed, Fl	Fruits eaten raw or pickled; also used as fuel.
9	*Ficus palmata* Frossk.	Bedu	1000-2800	Afr Trop Arab	M, Fd, Fl, Ed	Medicinal (Dysentery, indigestion, laxative); Edible; Fuel; Fodder
10	*Ficus roxburghii* Wallichi ex miq.	Timla	500-1700	Ind Occ	Fd,Fl, Ed	Fruit edible; leaves fodder purpose. Fuel.

11	*Ficus religiosa* L.	Peepal	to 1600	Indo Or	M, Ed, Rl	Bark and figs medicinal used in bronchitis and skin ailments; used in worship.
12	*Grewia optiva* (Buch.Ham.ex.roxb)	Bhimal	800-2000	Reg Himal	M, Fd, Fl, Fb, Ed	Fruit edible and medicinal; leaves provide good fodder. Bark fibre used for ropes, net bruses brooms etc; stickes after peeling off the bark used to lit fire.
13	*Lyonia ovalifolia* (Wallichi)	Anyar	1000-3000	Reg Himal Japon	Md, Fl	Medicinal (skin eruption, worms, wounds; seed paste applied on wounds, boils and pimples); Fuel
14	*Melia azadarach* L.	Dekkain	1200-2600	Reg Himal	M, Fd, Fl, Ti	Leaves, fruits and seeds are useful in skin diseases as well as in rheumatic pains. Leaves as fodder; wood useful for household and agriculture implements.
15	*Morus serrata* Roxb.	Sahtoot	1000-2200	Reg Himal	Ed, Misc	Fruits edible; wood used for cabinet works and other articles.
16	*Myrica esculenta* Buch.-Ham ex D.Don	Kaphal	1500-2100	As Trop Et Subtrop	M,Fl, Ed, Misc	Medicinal (Asthma, cholera, cough, diarrhoea, dysentery, fever, indigestion, malaria, menorrhoea and rheumatism); Edible; Fuel; Fodder; Miscellaneous (Bark yields yellow dye)
17	*Pinus roxburghii* sarg.	Chir	900-2500	Reg Himal	Ti, Fl, Misc	Medicinal (Saw-dust with honey used in asthma and bronchitis); Fuel; Timber; Miscellaneous (Resin for varnishes, paints and turpentine)
18	*Prunus ceracoides*d. D.Don	Panya	1200-2200	Reg Himal	M, Fd,Ed, Rl, Misc	Medicinal (Bark as psychomedicines and applied for body swellings and contusions; Edible; Fodder; Religeous (Plant regarded as sacred in several rituals of locals); Miscellaneous (Branches for walking sticks)
19	*Pyrus pashia* Buch.-Ham.ex D.Don	Mole	1000-2000	Reg Himal	M, Fl, Ed, Misc	Medicinal (Fruits in digestive disorder; eye complaints); Edible (Fruits are eaten); Fuel; Miscellaneous (To check soil erosion; wood made into sticks; flowers used in apiculture)
20	*Quercus leucotrichophora* A.Camus	Banj	800-2000	Reg Himal	Fd, Fl, Ti, Ag. tools	Edible by wild animals; Fuel; Fodder; Timber; Miscellaneous (Agr tls, decomposed leaves for organic manure, social forestry tree), Agriculture tools

21	*Rhodendron arboreum* L.	Burans	1200-3000	Reg Himal Ind Or Zeylan	M, Ed, Fl, Misc	Medicinal (Flower and bark used for digestive and respiratory disorders; dysentery, fever, headache); Edible; Fuel; Religious; Miscellaneous
22	*Toona ciliata* Roemer	Toon	1200-2000	Malaya Austr	Fl, Fd, Ti	Fuel; leaves as fodder; wood priced for construction purpose, furniture and other articles.
23	*Woodfordia fruticosa* (L.)	Dhaula	200-1800	As et Afr Trop	M, Fl	Leaves and bark medicinal, as febrifuge; also used in fuel.
	Fruit tree species					
1	*Citrus aurentium* L.	Narangi	to 1500	As Trop	M, Ed	Fruits are edible, fuel.
2	*Citrus aurantifolia*	Kagajinimbu	to 1800	South Est Asia	M, Ed	Source of vitamin C, frequently used for lime juice as pickles, raw or made into various products.
3	*Citrus lemon* (L.) Burm.f	Nimbu	1000-2000	As Trop	M,Ed	Source of vitamin C, frequently made into pickles amd juice.
4	*Citrus sinensis* (L.) Osbeak	Malta	to 1500	China	M, Ed, Fd, Fl	Fruit edible; rind of fruits used to check dysentery, leaves used as fodder; fuel.
5	*Juglans regia* L.	Akhrot	1000-3000	As Occ Reg Himal	Ed, M, Ti, Fl	Fruit edible and also provide oil; wood is hard, excellent for furniture. Leaves mixed with stored grains as fungicide and insecticide.
6	*Mangifera indica* L.	Aam	to 1500	South Asia Ind Burma	M, Ed, Ti	Yields fruits of commerce; wood for furniture and construction purpose. Bark in haemorrhage; resin and seeds in diarrhea.
7	*Melus domestica* L.	Seb	1000-2500	Reg Himal	Ed, Fd	Well know apple fruits of commerce; fuel, fodder.
8	*Prunus armeniaca* L.	Chullu	to 2000	Reg Cauc	Ed, M, Fl, Misc	Fruit edible; seed oil edible and also used medicinally in fever and massaged in body pain; the dried fruit pulp used in local brews. Also used in fuel.
9	*Prunus domestica* L.	Pullu	1500-3000	Europe Reg Cauc	Ed, Fl	Fruit edible; sometimes used in fuel.
10	*Prunus persica* (L.) Bastch	Aadu	1500-3000	As Temp	M, Ed	Fruits edible; seeds yield edible oil; infusion of leaves and bark used to relieve cough and cold.
11	*Psidium guajava* L.	Amrood	to 1200	Am Mexi	M, Ed	Fruits edible; decoction of root bark given in diarrhea; leaves chewed in throat infections.

12	*Punica granatum* L.	Anar	1000-2000	Europe Austr Maurit	M, Ed	Fruits edible; bark and rind of fruits used in tannig and medicines, especially in cough and cold.
13	*Pyrus communis* L.	Nashpati	1000-2000	Reg Himal	Ed	Fruit edible
14	*Vitis vinifera* L.	Angoor	to 1200	Cen Europe	Ed,	The juice o young shoots and leaves given in suppressed urination; fruits as tonic.
	List of shurbs					
1	*Berberis aristata* Roxb.ex dc.	Kingore	600-2500	Reg Himal	M, Ed, Fd, Misc	Medicinal (Bite of rat, snakes, boils, eye complaints); Edible; Fuel; Agricultural tools
2	*Carissa opaca* stapf ex haines	Karonda	to 1200	Reg Himal	Fd, Ed, Fl	Leaves browsed by sheep and goats; wood used for turnery. Fruits edible.
3	*Desmodium elegans* DC.	Chamlai	1400-2400	Reg Himal China	Fl, Fd	Leaves use for fodder purpose
4	*Indigofera gerardiana* Wallich ex. Baker	Sakina	to 2000	Reg Himal	M, Fd, Ed, Misc	Medicinal (Leaf juice taken in diarrhea, dysentery and cough); Edible; Fodder; Miscellaneous (Twigs made into baskets or containers)
5	*Murraya koenigi*i (L.) Sprengel	Curry patta	Upto 1500	Ind & S. Lanka	M, Ed, Misc	Bark, roots, leaves medicinal. Mostly as pisicide and insecticide. Leaves used for flavouring curries, not commonly used in the area.
6	*Rhus parviflora* Roxb.	Tungla	to 1800	Asm et Austr trop	M, Ed,Fl, Ag. tools	Fruit edible; leaves mixed tobacco; fruit grinded and mixed with flour; wood used in fuel as well agriculture tools.
7	*Rosa brunonii* Lindley	Kunja	600-2000	Reg Himal	M	Leaf and flower juice used in wounds and ophthalmia; dried flower powder given in diarrhea.
8	*Rubus elipticus* Smith.	Hisalu	800-2100	Ind Or	M, Ed, Fl, Fd	Medicinal (Root extract used in local beverages as intoxicating ingredient; other uses for dysentery, malaria, stomachache and worms); Edible; Miscellaneous (Plant is good soil binder)
9	*Rubus niveus* Thunb.	Kala hisalu	1000-2500	Reg Himal	M, Ed	Fruit edible; extract or boiled fruits taken in dysmenorrheal; root juice used as an antidote of snake bite

10	*Zanthoxylum alatum* Roxb.	Timru	900-2100	Reg Himal	M, Ed, Rel	Leaves and fruits chewed for wash and tooth care. Walking stickes, believed to get rid of all evils; bark used for intoxicating the fishes.

Abbreviations used: Reg Himal=Himalayan Region; Am=America; Ins=Insular; Ind Or= Indian Oriental; Geront= Gerontia; As=Asia; Trop=Tropical; Subtrop=Subtropical; Cen= Central; South= Southern; et=And; Austr=Australia; Occ= Occcidentalis;= Cauc= Caucasus; Afr=Africa; Afr. Trop= Tropical Africa; As et Afr Trop= Tropical Asia and Africa; Ins=Insular; Temp= Temperate; Euro=Europe; Reg Medit=Mediterranean Region; M=Medicinal; Fd=Fooder; Fl=Fuel; Ed=Edible; Ti=Timber; Fb=Fibre; Ag.tools= Agricultural tools; Rel= Religious Misc=Miscellaneous;

4.2.3.1 Grain yield (Economic yield)

Grain Yield of cereal crops (Kg/ha)										
Agri. Crop	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**V8**	**V9**	**Mean**
Kharif										
E. frumentacea	843	980	1042	1162	1472	1372	1429	1502	1480	1253.56
E. coracana	671	741	591	851	765	854	941	820	937	796.78
O. sativa	258	213	492	561	281	845	941	863	1052	611.78
Rabi										
T. aestivum	930	853	932	1073	952	1186	1369	1293	1100	1076.44
H. vulgare	564	730	678	992	746	942	1028	1110	841	847.89
Total R+K	3266	3517	3735	4639	4216	5199	5708	5588	5410	4586.444
Mean	653.2	703.4	747	927.8	843.2	1039.8	1141.6	1117.6	1082	917.2889
S.D	263.2	292.2	232.0	234.8	429.8	231.2	238.6	288.1	244.3	250.5
S.E	83.29	92.47	73.43	74.30	136.01	73.16	75.50	91.17	77.31	79.28

*Abbrevation used:- *R-Rabi, K- Kharif,* S.E.± Standard error

4.2.3.2 Productivity of crop residue

Crop residue of cereal crops (Kg/ha)										
Agri. Crop	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**V8**	**V9**	**Mean**
Kharif										
E. frumentacea	4281	4823	4461	4120	5420	4528	6082	6032	6041	5087.556
E. coracana	3251	3271	2585	4832	3541	3681	2726	3688	4510	3565
O. sativa	432	586.00	862	1259	681	1842	2390	2094	2038	1353.778
Rabi										
T. aestivum	2741	2481	3301	3210	2265	3619	3059	4092	2383	3016.778
H. vulgare	1342	1923	2051	2418	1851	1601	2529	2271	1910	1988.444
Total R+K	12047	13084	13260	15839	13758	15271	16786	18177	16882	15011.56
Mean	2409.4	2616.8	2652	3167.8	2751.6	3054.2	3357.2	3635.4	3376.4	3002.311
S.D	1530.6	1574.7	1347.5	1403.9	1808.2	1271.3	1543.8	1596.3	1824.4	1450.1
S.E	484.36	498.34	426.44	444.27	572.22	402.32	488.54	505.15	577.34	458.88

*Abbrevation used:- *R-Rabi, K- Kharif,* S.E.± Standard error

4.2.3.3 Biological yield (Grain+Straw)

Biological Yield (kg/ha)										
Agri. Crop	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**V8**	**V9**	**Mean**
Kharif										
E. frumentacea	5124	5803	5503	5282	6892	5900	7511	7534	7521	6341.111
E. coracana	3922	4012	3176	5683	4306	4535	3667	4508	5447	4361.778
O. sativa	690	799	1354	1820	962	2687	3331	2957	3090	1965.556
Rabi										
T. aestivum	3671	3334	4233	4283	3217	4805	4428	5385	3483	4093.222
H. vulgare	1906	2653	2729	3410	2597	2543	3557	3381	2751	2836.333
Total R+K	15313	16601	16995	20478	17974	20470	22494	23765	22292	19598
Mean	3062.6	3320.2	3399	4095.6	3594.8	4094	4498.8	4753	4458.4	3919.6
S.D	1755.4	1833.3	1565.5	1550.1	2205.0	1444.5	1733.6	1823.6	2006.0	1664.4
S.E	555.49	580.17	495.41	490.53	697.77	457.14	548.60	577.07	634.81	526.71

*Abbrevation used:- *R-Rabi, K- Kharif,* S.E.± Standard error

4.2.3.4 Harvest Index (HI)

Harvest Index										
Agri. Crop	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**V8**	**V9**	**Mean**
Kharif										
E. frumentacea	16.45	16.89	18.94	22.00	21.36	23.25	19.03	19.94	19.68	19.73
E. coracana	17.11	18.47	18.61	14.97	17.77	18.83	25.66	18.19	17.20	18.53
O. sativa	37.39	26.66	36.34	30.82	29.21	31.45	28.25	29.18	34.05	31.48
Rabi										
T. aestivum	25.33	25.58	22.02	25.05	29.59	24.68	30.92	24.01	31.58	26.53
H. vulgare	29.59	27.52	24.84	29.09	28.73	37.04	28.90	32.83	30.57	29.90
Total R+K	125.88	115.12	120.74	121.94	126.65	135.26	132.75	124.15	133.08	126.17
Mean	25.18	23.02	24.15	24.39	25.33	27.05	26.55	24.83	26.62	25.23
S.D	8.80	4.96	7.27	6.29	5.43	7.19	4.61	6.16	7.62	5.87
S.E	2.79	1.57	2.30	1.99	1.72	2.28	1.46	1.95	2.41	1.86

*Abbrevation used:- *R-Rabi, K- Kharif,* S.E.± Standard error

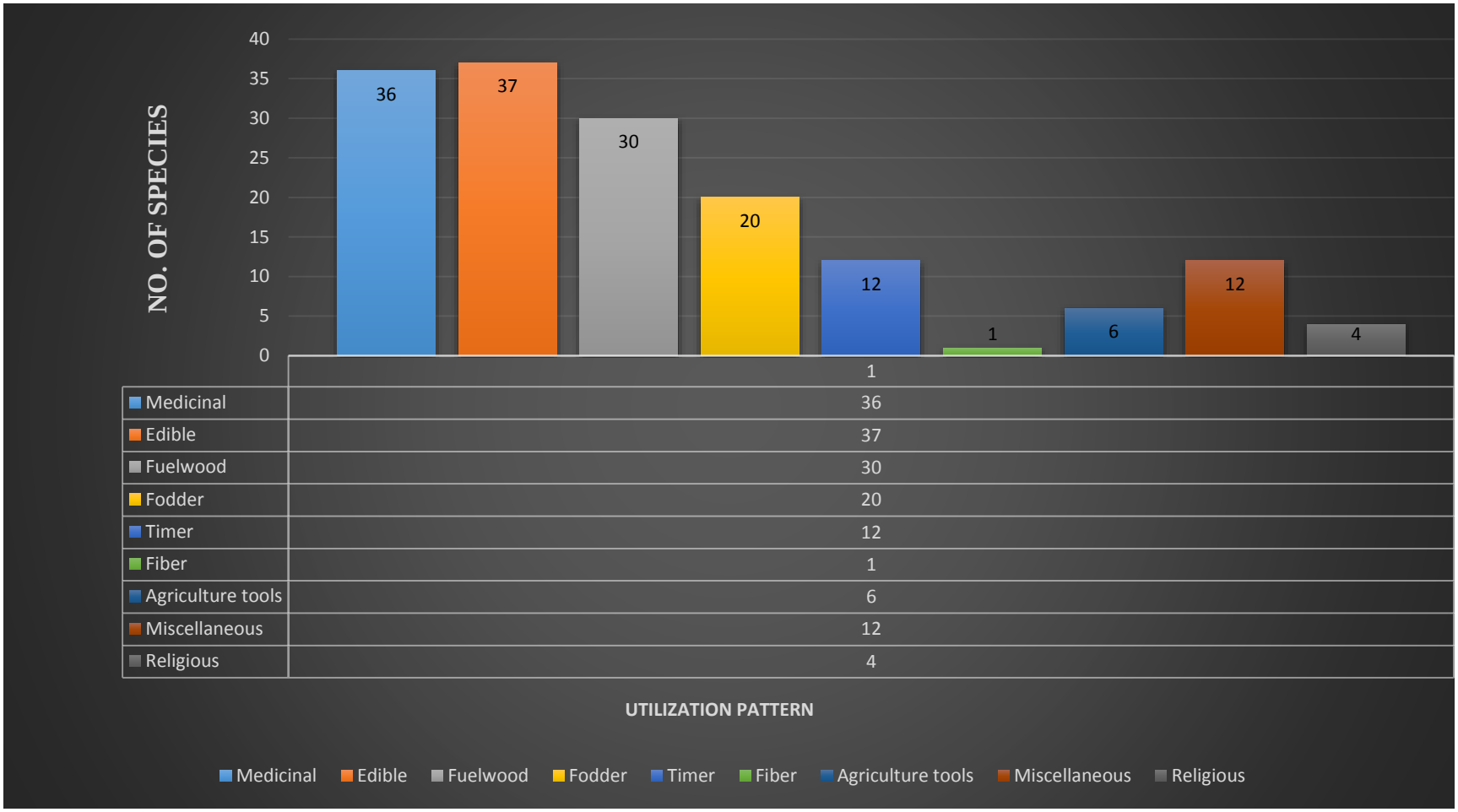

Fig: 1 Utilization pattern of woody species under agroforestry system in the Chamba block (Tehri Garhwal).

ABSTRACT

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Thesis Title: "*Diversity, Productivity and Utilization pattern of plant species under Traditional agroforestry system: a case study of Chamba block, Tehri Garhwal, Uttarakhand"*

The present investigation was conducted in 9 villages of Chamba block, Tehri Garhwal lies between 1200 and 2000m asl. There were objectives of the study as 1. Assessment of plant species diversity under traditional agroforestry system, 2. Analysis of productivity potential of existing agroforestry systems, 3. Documentation of utilization pattern of woody species used by local inhabitants in the region. The diversity of plant species was assessed using random sampling method. Productivity of plant species including tree species and agriculture crops was assessed adopting standard methodology. However, utilization pattern of wood species was studied with the help of a semi-structured questionnaire, personal inter-views with head or the old person of the family and field observations.

Results pertaining to diversity of plant species showed that there were a total of 23 forest tree species, 17 fruit tree species, 11 shrubs and 20 herbs in the study area. The productivity of tree species in agrisilviculture system was estimated by measuring the height and girth of all individual trees. However, the agriculture crop productivity included grain productivity, straw productivity and biological yield of *Rabi* and *Kharif* seasons was assessed using random sampling methods. The data were analyzed statistically to find out significant difference amongst the parameters. The volume of all trees under sampling plots in different villages varied from 2.01 to 2.67 m^3/ha in V2 (Dubakoti) and V3 (Aarakot) village. In all the documented species, maximum mean volume was recorded 5.69 m^3/ha for *G. optiva* and minimum as 0.44 m^3/ha for *M. azedarach.* Above ground biomass of trees in the selected system varied from 0.88 to 1.74 t/ha in V9 (Pali) and V3 village (Aarakot). In case of above ground biomass, it was found maximum (4.06 t/ha) in *Q. leucotrichophora* and minimum (0.19 t/ha) in *M. azedarach.* The total grain yield productivity of cereals in *Rabi* and *Kharif* seasons varied from 3266 kg/ha V1 (Chopdiyalgaun) to 5708 kg/ha V7 village (Dandasali). The crop residue varied from 12047 kg/ha to 18177 kg/ha in V1 (Chopdiyalgaun) and V8 village (Kot). The total biological yield of cereals varied from 15313 kg/ha to 23765 kg/ha in V1 (Chopdiyalgaun) and V8 village (Kot). The total harvest index of cereals varied 115.02 to 135.26 in V2 (Dubakoti) and V6 villlage (Guldi). Utilization pattern showed that all the recorded species have high economic importance for the local inhabitants. A total of 47 species was recorded, in which 37 species were used commonly for food (edible), 36 for medicinal, 30 for fuel, 20 for fodder, 6 for agricultural tools, 4 for religious, 12 for timber, 1 for fibre and 12 species for miscellaneous uses.

Based on the results, it is suggested that despite good diversity there is a huge potential of planting multipurpose tree species especially in wasteland nearby villages. Innovative livelihood activities can be adopted to increase productivity of existing agroforestry systems by developing integrated agroforestry models *i.e. Agricultural crops+MPTs+Medicinal Plants/ Ornamental plants+Dairy farming/Goat farming*. Capacity building and training activities need to be organized on different aspects of sustainability and up-gradation of existing traditional agroforestry system. The rural communities must be made aware of financial and technical support extended by different government agencies especially enhancement of sustainably rural livelihood opportunities so that the amplitude of migration could be mitigated.

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VITAE

The author was born on Oct. 10, 1991 at Tehri, Uttarakhand. He passed High School and Intermediate examination in 2007 and 2009, respectively from Uttarakhand Board. Later on, he passed B.Sc. (Life science) programme from D.B.S (PG) College Dehradun, (HNB Garhwal University, Shrinagar) in 2013. He was admitted to the College of Post Graduate Studies in August 2013 in VCSG, Uttarakhand University of Horticulture and Forestry, Ranichauri for his Master's degree with major in Agroforestry.

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