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Full Length Research Paper

Alteration of tree species in Traditional Agri-silvi-horticulture systems along altitude and aspects of the Garhwal Himalaya, India

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Alternation of tree species in traditional agri-silvi-horticulture (ASH) systems along altitudinal changes (1000 to 1500m, 1500 to 2000m and 2000 to 2500m asl) and aspects (northern and southern) were studied in two districts (Tehri Garhwal and Uttarkashi) of Garhwal Himalaya, India during 2012-13. Analysis of tree vegetation for the structural characterization, diversity of plant communities and composition under agri-silvi-horticulture systems in each study site was studied. The horticultural trees were found mottled throughout the agricultural fields, while forest trees were mostly seen on the bunds of the farmers' fields. The highest tree density was recorded in 1000-1500m (northern aspect) while the lowest was recorded in 2000-2500m elevation (northern aspects). The *Grewia optiva*, *Melia azedarach* in the lower elevation and *Quercus leucotrichophora* in the higher elevation recorded dominant species among forest tree species while *Malus domestica* and *Prunus armeniaca* noticed dominant species among fruit tree species. In general, the higher number of tree species and individuals were recorded on northern aspect with lower elevation compared to southern aspect with higher elevation. It is concluded that elevation and aspects played a significant role in structure, composition and combination in agri-silvi-horticulture systems.

Key words: Agri-silvi-horticulture, agroforestry, altitude, Northern aspect, Southern aspect, diversity, phyto-sociology.

INTRODUCTION

Availability of trees on the agricultural fields is tradition of Indian agriculture. The trees are generally present in an unorganized manner on the traditional agricultural systems, yet farmers retain this tree along with agricultural crops for their daily domestic demand in terms of fruit, fuel, fodder, fiber, timber etc. Such multifarious fruits and forest trees when present with agricultural crops form Agri-silvi-horticulture a type of agroforestry system. The presence of these tree on the farmers filed in the Garhwal Himalayan regions are considered to be more significant which eventually form fundamental association with the farm community for obvious regions.

The elevational gradient of climates is a base for understanding the relationship between climate and vegetation in mountainous areas (Tang and Fung, 2006). The vegetation of the varying topography of the Garhwal Himalayan region changes its species diversity, composition and structure along altitudinal gradient. The vegetation in the hilly terrains changes with elevation and aspect as a result the composition and tree-crop combination in agri-silvi-horticulture systems are also changes which are important to be documented. The change in elevation and slope change the vegetation (Tang, 2003; Tang and Fung, 2006), however, the unusually change in altitudinal gradient even at small distances and high endemism make it interesting for studies (Singh and Singh, 1992). Furthermore the track of the sun (aspect) in the hilly landscape also plays significant role in the vegetation and land use pattern. The identification and inventory of such important trees present on the agricultural fields of the farmers along variable altitudinal range is an important facet of this study.

Today agro forestry has generated much interest among the researchers, policy makers and programme exe-

Table 1. Study sites in two districts along elevation and aspects.

District	Elevation (m)	Aspect	Study site
Tehri Garhwal (D_1)	1000-1500m (E_1)	North (N_1)	$D_1E_1N_1$
		South (S_1)	D_1E_1S1
	1500-2000m (E_2)	North (N_2)	$D_1E_2N_2$
		South (S_2)	$D_1E_2S_2$
	2000-2500m (E_3)	North (N_3)	$D_1E_3N_3$
		South (S_3)	$D_1E_3\ S_3$
Uttarkashi (D_2)	1000-1500m (E_1)	North (N_1)	$D_2E_1N_1$
		South (S_1)	$D_2E_1S_1$
	1500-2000m (E_2)	North (N_2)	$D_2E_2N_2$
		South (S_2)	$D_2E_2S_2$
	2000-2500m (E_3)	North (N_3)	$D_2E_3N_3$
		South (S_3)	$D_2E_3\ S_3$

cutors throughout the world. As a result, India has been launching the National Agro forestry Policy 2014 which also focuses on research on indigenous and multipurpose fast growing tree species. The National Action Plan for Climate Change (NAPCC) under its green India mission has exclusively emphasized the agro forestry interventions. There is now full agreement that the traditional systems and practices hold viable potential to meet the present basic human needs, besides addressing major agro-ecological and socioeconomic issues. Such agroforestry system guarantees for sustained yield potentials and multiple output possibilities in resource sharing units, while sole agriculture or forestry is not viable option.

The different study show that the species composition pattern in traditional agroforestry systems in the Himalayan region has mainly includes forest and horticulture trees which vary depending upon the size of the land holding and the basic requirements of the farmer (Toky et al., 1989). The quantitative characters of the vegetation including density, frequency, dominance and basal area of any plant community was measured (Mishra, 1968), and further these primary variables are used for deriving secondary variables (Odum, 1983). Likewise, the ecological importance of species and their association as plant communities, assessed in terms of dominant, co-dominant and suppressed vegetation are based on the phyto-sociological analysis (Mishra, 1968, Odum 1983). Land-use systems in the Himalayan region of India are comprised of forestry, agriculture, horticulture, agroforestry, and animal husbandry (Sundiriyal et al., 1994). Though number of studies on the Himalayan agroforestry systems is existing (Bijalwan, 2012; Toky et al., 1989; Sharma et al., 1995; Semwal and Maikhuri, 1996; Singh et al., 1997), but the specific studies on agri-silvi-horticulture system are limited.

MATERIALS AND METHODS

The study was conducted in Traditional Agroforestry systems (agri-silvi-horticulture) along change in altitude and aspects in the hills of Garhwal Himalaya, India. The study comprised six study sites each in district Tehri Garhwal and Uttarkashi of varying altitudinal ranges of 1000 to 1500m, 1500 to 2000m and 2000 to 2500m asl covering northern and southern aspects in during 2012-13 (Table 1). The location map of the study area is depicted in Figure 1.

The Garhwal Himalaya lies between 29^0 40' to 31^0 28" N latitudes and 77^0 51' 30" to 80^0 30" E longitudes. The area falls between sub- tropical to temperate zone (1000 to 2500m asl), with an average annual rainfall of 1200mm. Mostly the rain occurs during monsoon period (from July to September) with the mean annual temperature ranging from 8^o to 35^o C. The main agricultural crops grown in these traditional agroforestry systems of the selected areas are finger millet, barnyard millet, soybean, horse gram, etc during Kharif season and wheat, lentil, mustard, etc during Rabi season. Vegetable cultivation is restricted mostly to potato, pea, tomato, cucumber, radish, rye etc and that too, is restricted to homestead level only. Fruit tree comprising mainly of apple, apricot, citrus, peach, plum, walnut, guava, are grown sporadically near the habitation for meeting domestic requirements. Natural agroforestry systems are consisted of the fodder tree species like *Grewia optiva, Celtis australis, Ficus palmata, Toona ciliata, Bahunia spp.* in the low to middle Himalayan region and *Quercus leucotricophora and Quercus floribunda* in the higher Himalayan region.

Phytosociological analysis of the vegetation for the structural characterization, diversity of plant communities and composition of agri-silvi-horticulture systems in each

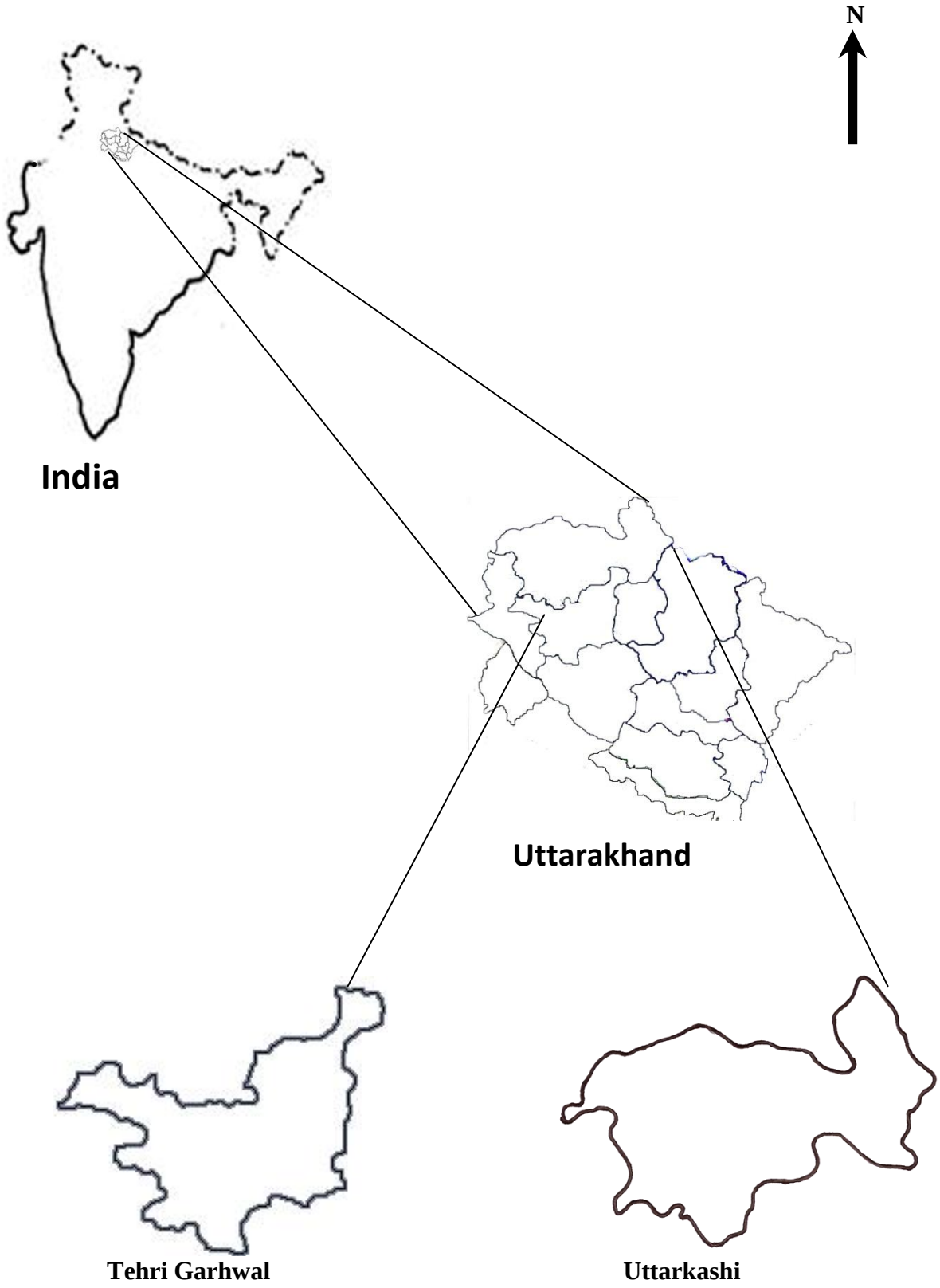


Figure 1. Location Map of the Study Area.

Table 2. Phyto-sociological analysis of tree layer in the agri-silvi-horticulture (ASH) system in Tehri district (1000-1500m).

Species	% Freq. (F)	Density (Trees/100m^2)	Abund. (A)	A/F Ratio	TBC (cm^2/100m^2)	IVI
Northern aspect (site -$D_1E_1N_1$)						
Forest trees						
Grewia optiva	65.00	1.20	1.85	0.03	234.18	36.69
Melia azedarach	45.00	0.75	1.67	0.04	348.54	31.04
Celtis australis	40.00	0.60	1.50	0.04	348.78	28.10
Bauhinia variegata	40.00	0.50	1.25	0.03	239.68	22.84
Pyrus pashia	25.00	0.30	1.20	0.05	244.25	17.51
Ficus palmata	25.00	0.45	1.80	0.07	149.90	16.11
Pinus roxburghii	30.00	0.35	1.17	0.04	153.94	15.87
Prunus cerasoides	30.00	0.35	1.17	0.04	124.41	14.81
Horticultural trees						
Prunus armeniaca	40.00	0.55	1.38	0.04	383.50	28.69
Carica papaya	40.00	0.65	1.63	0.04	96.70	19.69
Musa paradisiaca	35.00	0.35	1.00	0.03	55.76	13.28
Psidium guajaya	25.00	0.40	1.60	0.06	73.76	12.71
Juglans regia	20.00	0.25	1.25	0.06	154.00	12.65
Citrus aurentium	25.00	0.30	1.20	0.05	94.29	12.11
Citrus sinensis	20.00	0.20	1.00	0.05	45.41	8.07
Carica opaca	15.00	0.20	1.33	0.09	15.71	6.06
Citrus limon	10.00	0.10	1.00	0.10	15.25	3.77
Total		7.50			2778.07	300.00
Southern aspect (site - $D_1E_1S_1$)						
Forest trees						
Melia azedarach	45.00	0.75	1.67	0.04	444.68	37.04
Celtis australis	55.00	0.75	1.36	0.03	361.85	36.26
Grewia optiva	65.00	0.80	1.23	0.02	188.56	32.99
Morus alba	50.00	0.60	1.20	0.02	276.09	29.83
Ficus roxburghii	45.00	0.65	1.44	0.03	231.49	27.91
Bauhinia variegata	25.00	0.55	2.20	0.09	238.04	22.28
Ficus palmata	30.00	0.40	1.33	0.04	125.71	17.08
Horticultural trees						
Prunus armeniaca	35.00	0.70	2.00	0.06	364.12	31.23
Juglans regia	40.00	0.40	1.00	0.03	271.29	24.45
Emblica officinalis	25.00	0.30	1.20	0.05	115.13	14.10
Psidium guajava	15.00	0.30	2.00	0.13	50.80	9.62
Citrus limon	20.00	0.25	1.25	0.06	23.00	8.96
Mangifera indica	10.00	0.15	1.50	0.15	106.50	8.25
Total		6.60			2797.24	300.00

study site was done. Density and basal area of trees in different study sites were analyzed on different elevation and aspects. Similarly, diversity parameters were analyzed in agri-silvi-horticulture systems on different study sites.

The phytosociological analysis was carried out by laying randomly placed quadrats of 10 x 10m size. 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 for each study sites in respect to elevation and aspects, following Mishra, 1968. In each sample plot, the trees were enumerated for their diameters and heights. The diameter at breast height (DBH) of individual trees was measured at 1.37m using tree caliper and the girth was measured using measuring tape. The vegetational data in

each stratum was quantitatively analyzed for frequency, density and abundance by using the standard expressions (Curtis and Mc Intosh, 1950; Phillips, 1959). The Abundance/Frequency (A/F) ratio was used to interpret the distribution pattern of the species (Whitford, 1949). The importance value index (IVI) was determined as the sum of relative frequency, relative density and relative dominance/basal area (Curtis, 1959; Curtis and Mc Intosh, 1950; Phillips, 1959).

The plant diversity (Shannon Index) in different study sites was quantified as per Shannon and Wiener, 1963, Concentration of dominance (Simpson Index) by Simpson, 1949, Equitability (e) was calculated as suggested by Pielou (1975), Species richness was calculated following Margalef equation (1958) and Beta diversity was calculated as per Whittaker, (1972, 1977). The trees present in the agri-silvi-horticulture systems were divided into different diameter and height classes. The diameter classes used for trees as at 10 cm interval (0-10, 10-20 to 70-80 cm), while height classes used as 5m interval (0-5, 5-10 to 25-30m). The number of trees falling in each diameter class was recorded and density of trees was calculated on diameter and height class basis.

RESULTS AND DISCUSSION

In the present study on agri-silvi-horticulture (ASH) system comprised of agriculture crops along with forest and horticultural trees. The horticultural trees were found spotted throughout the agricultural fields, while forest trees were mostly seen on the bunds of the farmers' fields. The major agri-silvi-horticulture systems on the study sites in Tehri district included *Grewia optiva* + *Melia azedarach* + *Prunus armeniaca* + agricultural crops (1000-1500m); *Quercus leucotrichophora* + *Grewia optiva* + *Prunus armeniaca* + *Malus domestica* + agricultural crops (1500-2000m); *Quercus leucotrichophora* + *Quercus floribunda* + *Malus domestica* + agricultural crops (2000-2500m). In district Uttarkashi integrated *Grewia optiva* + *Celtis australis* + *Ficus roxburghii* + *Prunus armeniaca* + agricultural crops (1000-1500m); *Quercus leucotrichophora* + *Quercus floribunda* + *Prunus armeniaca* + *Juglans regia* + agricultural crops (1500-2000m); *Quercus floribunda* + *Quercus semicarpifolia* + *Juglans regia* + agricultural crops (2000-2500m).

Structure and composition (phytosociology) in traditional agri-silvi-horticulture systems

The results on structural analysis of tree species in agri-silvi-horticulture (ASH) system of Tehri district between elevation 1000-1500m both on northern and southern aspect are presented in Tables 2. It is noticed from the results that a total of 17 species (8 forest tree species and 9 horticultural tree species) were enumerated on the northern aspect (site- $D_1E_1N_1$) while on the southern aspect (site- $D_1E_1S_1$) a total of 13 species (7 forest tree species and 6 horticulture tree species) were recorded. On the northern aspect the maximum values of frequency and Importance Value Index (IVI) were found for *Grewia optiva* in forest tree species and *Prunus armeniaca* in horticulture tree species which were 65%, 36.69 and 40 %, 28.69 respectively, hence these two species were considered to be the dominant species. The suppressed tree species on this system was *Prunus cerasoides* followed by *Pinus roxburghii* among the forest tree species and *Citrus limon* and *Carica opaca* in horticulture tree species. Overall IVI values in this site varied from 3.77 – 36.69 and maximum TBC value was 383.50cm^2/100m^2 for *Prunus armeniaca* while the minimum TBC values was recorded for *Citrus limon* (15.25cm^2/100m^2). Data on southern aspect of elevation 1000-1500m (site-$D_1E_1S_1$) has revealed that among the forest tree species *Melia azedarach* had the maximum IVI value (37.04) followed by *Celtis australis* (36.26) and *Grewia optiva* (32.99) while the tree density was higher for the *Grewia optiva* (0.80 trees/100m^2) followed by *Celtis australis, Melia azedarach* (each 0.75 trees/100m^2). In horticultural tree species, the *Prunus armeniaca* had highest frequency, TBC and IVI values as 35 %, 364.12 cm^2/100m^2 and 31.23 respectively while the lowest IVI value were recorded for *Mangifera indica* (Table 2).

Results on tree structure of agri-silvi-horticulture system in the elevation 1500-2000m on the northern aspect (site-$D_1E_2N_2$) have shown that a total of 13 tree species (9 forest tree species and 4 horticultural tree species) were present in this site. Amongst the tree species *Grewia optiva* have shown the highest frequency, density (60%, 1.25 trees/100m^2) followed by *Quercus leucotrichophora* (50%, 0.85 trees/100m^2) while the TBC and IVI values were found to be higher for the *Quercus leucotrichophora* (485.07cm^2/100m^2, 39.47). Lowest IVI values were recorded for *Morus alba* in forest tree species (14.73) and for *Musa paradisiaca* in horticulture tree species as 10.86 (Table 3).

On the southern aspect of same elevation (site-$D_1E_2S_2$) a total 10 tree species were recorded with 5 each for forest and horticultural trees. Data on structural parameters of agri-silvi-horticulture system in this aspect showed that, among the forest tree species the Frequency, density, TBC and IVI values were found higher for *Quercus leucotrichophora* (80%, 1.25 trees/100m^2, 626.18 cm^2/100m^2, 56.22) followed by *Grewia optiva* and *Celtis auatralis* which were 80%, 1.15 trees/100m^2, 289.84 cm^2/100m^2 and 42.12 and 55%, 0.85 tree/100m2, 394.36cm2/100m and 37.16 respectively. TBC value of *Celtis australis* were found higher than that of *Grewia optiva*. In the horticulture tree species maximum IVI value were recorded for *Malus domestica* (34.45) while the lowest IVI value were recorded for *Musa*

Table 3. Phyto-sociological analysis of tree layer in the agri-silvi-horticulture (ASH) system in Tehri district (1500-2000m).

Species	% Freq. (F)	Density (Trees/100m^2)	Abund. (A)	A/F Ratio	TBC (cm^2/100m^2)	IVI
Northern aspect (site- $D_1E_2N_2$)						
Forest trees						
Quercus leucotrichophora	50.00	0.85	1.70	0.034	485.07	39.47
Grewia optiva	60.00	1.25	2.08	0.035	265.12	39.29
Bauhinia variegata	45.00	0.65	1.44	0.032	247.19	27.19
Ficus palmata	45.00	0.50	1.11	0.025	180.59	22.74
Ficus roxburghii	40.00	0.45	1.13	0.028	210.33	22.06
Celtis australis	35.00	0.45	1.29	0.037	223.82	21.50
Melia azedarach	40.00	0.40	1.00	0.025	178.17	20.22
Prunus cerasoides	25.00	0.40	1.60	0.064	126.47	15.26
Morus alba	30.00	0.30	1.00	0.033	121.35	14.73
Horticulture trees						
Prunus armeniaca	25.00	0.70	2.80	0.112	412.62	29.60
Citrus sinensis	40.00	0.55	1.38	0.034	120.09	20.24
Juglans regia	20.00	0.35	1.75	0.088	219.00	16.82
Musa paradisiaca	25.00	0.35	1.40	0.056	22.28	10.86
Total		7.20			2812.09	300.00
Southern aspect (site- $D_1E_2S_2$)						
Forest trees						
Quercus leucotrichophora	80.00	1.25	1.56	0.020	626.18	56.22
Grewia optiva	80.00	1.15	1.44	0.018	289.84	42.12
Celtis australis	55.00	0.85	1.55	0.028	394.36	37.16
Ficus roxburghii	45.00	0.55	1.22	0.027	177.21	22.90
Prunus cerasoides	20.00	0.20	1.00	0.050	62.11	8.94
Horticulture trees						
Malus domestica	60.00	0.90	1.50	0.025	279.47	34.45
Prunus armeniaca	55.00	0.80	1.45	0.026	312.02	33.35
Prunus persica	60.00	0.65	1.08	0.018	210.67	28.42
Juglans regia	30.00	0.45	1.50	0.050	215.36	20.09
Musa paradisiaca	35.00	0.50	1.43	0.041	73.09	16.35
Total		7.30			2640.30	300.00

paradisiaca (16.35). The *Prunus armeniaca, Prunus persica,* were considered as co-dominant plant species due to their higher IVI values, while *Musa paradisiaca* considered as suppressed tree species (Table 3).

Data presented in Tables 4 shows on structural variations in agri-silvi-horticulture system of elevation 2000-2500m in both northern and southern aspect (site-$D_1E_3N_3$ and $D_1E_1S_3$). A total of 9 tree species (6 forest tree species and 3 horticulture tree species) were recorded on the northern aspect while on southern aspect 12 tree species (8 forest and 4 horticulture tree species) were recorded in the agri-silvi-horticulture system. On the northern aspect (2000-2500m) the highest frequency value were recorded for the *Quercus leucotrichophora* and *Quercus floribunda* (each 70%). The highest density (1.35 plants/100m^2), TBC (825.67 cm^2/100m^2) and IVI (59.55) values were recorded for *Quercus leucotrichophora* followed by *Quercus floribunda* for which the density, TBC, IVI values were 1.5 trees/100m^2, 762.53cm2/100m2, 54.76 respectively among the forest tree species. In the horticulture tree species *Malus domestica* had the highest frequency (70%), density (1.10 trees/100m2) and IVI (41.17), therefore considered to be dominant horticulture species.

On the other hand on the southern aspect in 2000-2500m (site-$D_1E_3S_3$), a total of 12 tree species (8 forest and 4 horticulture tree species) were recorded. Out of which the highest IVI values were recorded for *Quercus leucotrichophora* (57.13) in forest tree species and for *Malus domestica* (35.44) in horticulture tree species (Table

Table 4. Phyto-sociological analysis of tree layer in the agri-silvi-horticulture (ASH) system in Tehri district (2000-2500m).

Species	% Freq. (F)	Density (Trees/100m^2)	Abund. (A)	A/F Ratio	TBC (cm^2/100m^2)	IVI
Northern aspect (site -$D_1E_3N_3$)						
Forest trees						
Quercus leucotrichophora	70.00	1.35	1.93	0.03	825.67	59.55
Quercus floribunda	70.00	1.15	1.64	0.02	762.53	54.76
Cedrus deodara	40.00	0.75	1.88	0.05	440.48	32.82
Rhododendron arboreum	60.00	0.60	1.00	0.02	343.67	32.37
Carpinus viminea	50.00	0.70	1.40	0.03	316.80	30.85
Aesculus indica	25.00	0.30	1.20	0.05	283.33	18.20
Horticulture trees						
Malus domestica	70.00	1.10	1.57	0.02	308.40	41.17
Prunus persica	40.00	0.50	1.25	0.03	122.38	20.07
Juglans regia	15.00	0.20	1.33	0.09	134.26	10.21
Total		6.65			3537.53	300.00
Southern aspect (site - $D_1E_3S_3$)						
Forest trees						
Quercus leucotrichophora	80.00	1.00	1.25	0.02	709.97	57.13
Quercus floribunda	60.00	0.75	1.25	0.02	509.01	42.11
Cedrus deodara	50.00	0.55	1.10	0.02	429.61	33.99
Rhododendron arboreum	40.00	0.45	1.13	0.03	310.20	26.30
Carpinus viminea	30.00	0.45	1.50	0.05	220.98	21.27
Prunus cerasoides	40.00	0.50	1.25	0.03	111.28	20.87
Aesculus indica	15.00	0.25	1.67	0.11	213.91	14.32
Pinus roxburghii	20.00	0.20	1.00	0.05	88.94	10.64
Horticulture trees						
Malus domestica	55.00	0.95	1.73	0.03	225.47	35.44
Pyrus communis	25.00	0.40	1.60	0.06	141.52	16.80
Prunus armeniaca	15.00	0.20	1.33	0.09	131.97	10.89
Juglans regia	20.00	0.20	1.00	0.00	76.06	10.23
Total		5.90			3168.92	300.00

4). The *Quercus floribunda, Cedrous deodara,* and *Rhododendron arboretum, Pyrus communis* had lower IVI values, therefore considered to be co-dominant species. The analytical characters of woody vegetation of traditional agroforestry systems have made it clear that *Grewia optiva, Celtis australis, Melia azedarach, Prunus armeniaca, Citrus sinensis, Juglans regia* in the lower elevation*, Grewia optiva, Celtis australis, Quercus leucotrichophora, Prunus armeniaca, Malus domestica, Juglans regia* in the middle elevation and *Quercus leucotrichophora, Quercus floribunda* and *Malus domestica contributes* more than 50 per cent of the total IVI values (Table 4).

The results on structural analysis for Uttarkashi district of agri-silvi-horticulture system in the elevation 1000-1500m on northern aspect (site- $D_2E_1N_1$) are presented in Tables 5. A total of 13 species (8 forest and 5 horticultural tree species) were recorded. Maximum density, total basal cover and Importance Value Index (IVI) were recorded for the species *Grewia optiva* (1.45 trees/100m^2, 604.26 cm^2/100m^2 and 54.41) followed by *Morus serrata* (0.85 trees/100m^2, 276.85cm^2/100m^2, 28.55) in forest tree species. Among the horticulture tree species *Prunus armeniaca* was dominant tree while *Citrus limon* was recorded to be suppressed tree species (Table 5).

On the southern aspect of 1000-1500m (site- $D_1E_1S_1$) a total of 14 tree species were recorded. Out of which 8 species recorded in forest tree species and 6 species under horticulture tree species. The *Grewis optiva* showed highest density (0.85 trees/100m2) followed by *Prunus cerasoides* (0.75 trees/100m^2) while *Quercus leucotrichophora* (0.45 trees/100m^2), *Morus serrata* (0.40 trees/100m^2) showed relatively low density. In fruit tree species on the basis of IVI value *Prunus armeniaca* was

Table 5. Phyto-sociological analysis of tree layer in the agri-silvi-horticulture (ASH) system in Uttarkashi district (1000-1500m).

Species	% Freq. (F)	Density (Trees/100m^2)	Abund. (A)	A/F Ratio	TBC (cm^2/100m^2)	IVI
Northern aspect (site-$D_2E_1N_1$)						
Forest trees						
Grewia optiva	75.00	1.45	1.93	0.03	604.26	54.41
Morus serrata	40.00	0.85	2.13	0.05	276.85	28.55
Ficus roxburghii	45.00	0.45	1.00	0.02	217.64	22.23
Melia azedarach	40.00	0.45	1.13	0.03	224.53	21.45
Prunus cerasoides	30.00	0.50	1.67	0.06	249.88	20.96
Celtis australis	35.00	0.40	1.14	0.03	205.97	19.17
Ficus palmata	35.00	0.45	1.29	0.04	161.01	18.36
Bauhinia variegata	35.00	0.40	1.14	0.03	133.50	16.78
Horticulture trees						
Prunus armeniaca	45.00	0.65	1.44	0.03	286.62	27.19
Citrus jambhiri	40.00	0.55	1.38	0.03	227.21	22.88
Citrus sinensis	40.00	0.70	1.75	0.04	153.76	22.47
Juglans regia	25.00	0.35	1.40	0.06	243.72	17.74
Citrus limon	15.00	0.25	1.67	0.11	44.20	7.81
Total		**7.45**			**3029.14**	**300.00**
Southern aspect (site- $D_2E_1S_1$)						
Forest trees						
Grewia optiva	55.00	0.85	1.55	0.03	249.29	32.33
Celtis australis	45.00	0.70	1.56	0.04	345.68	31.53
Prunus cerasoides	40.00	0.75	1.88	0.05	268.61	28.47
Quercus leucotrichophora	35.00	0.45	1.29	0.04	288.00	23.86
Morus serrata	35.00	0.40	1.14	0.03	146.23	18.14
Ficus roxburghii	30.00	0.40	1.33	0.04	152.25	17.31
Ficus palmata	30.00	0.40	1.33	0.04	140.85	16.90
Bauhinia variegata	25.00	0.40	1.60	0.06	125.84	15.33
Horticulture trees						
Prunus armeniaca	30.00	0.60	2.00	0.07	396.47	28.78
Prunus persica	40.00	0.65	1.63	0.04	253.75	26.53
Juglans regia	35.00	0.50	1.43	0.04	249.88	23.22
Prunus domestica	35.00	0.40	1.14	0.03	98.35	16.44
Citrus limon	25.00	0.30	1.20	0.05	49.22	11.20
Citrus sinensis	20.00	0.25	1.25	0.06	63.64	9.96
Total		**7.05**			**2828.05**	**300.000**

the dominant tree species and *Prunus persica* and *Juglans regia* were recorded as co-dominant tree species whereas *Citrus limon and Citrus sinensis* as suppressed tree species (Table 5).

Results on structural parameters of agri-silvi-horticulture system (1500-2000m) on both northern and southern aspect (site-$D_2E_2N_2$ and $D_2E_2N_2$) are presented in Table 6. On the northern aspect (1500-2000m) a total of 16 tree species (9 forest tree species and 7 horticultural tree species) were observed. Among forest tree species *Quercus leucotrichophora* and *Alnus nepalensis* had shown the highest frequency, density and IVI (65%, 0.80 trees/100m^2, 42.99 and 45%, 0.65 trees/100m^2, 35.73) and therefore considered dominant species. In fruit tree species *Prunus armeniaca* have shown maximum TBC (218.22 cm^2/100m^2) and IVI (21.08) value therefore, it is considered to be dominant fruit tree species in this site (Table 6).

On the southern aspect of 1500-2000m (site- $D_2E_2S_2$), 14 tree species were recorded in which 9 were forest tree species and 5 were fruit tree species (Table 6). In this site frequency, density, TBC and IVI values were recorded

Table 6. Phyto-sociological analysis of tree layer in the agri-silvi-horticulture (ASH) system in Uttarkashi district (1500-2000m).

Species	% Freq. (F)	Density (Trees/100m^2)	Abund. (A)	A/F Ratio	TBC (cm^2/100m^2)	IVI
Northern aspect (site-$D_2E_2N_2$)						
Forest trees						
Quercus leucotrichophora	65.00	0.80	1.23	0.02	486.48	42.99
Alnus nepalansis	45.00	0.65	1.44	0.03	459.64	35.73
Carpinus viminea	45.00	0.45	1.00	0.02	216.76	23.78
Grewia optiva	40.00	0.60	1.50	0.04	134.96	22.14
Rhododendron arboreum	35.00	0.35	1.00	0.03	231.28	20.78
Morus serrata	30.00	0.50	1.67	0.06	154.48	19.32
Celtis australis	35.00	0.40	1.14	0.03	166.26	19.19
Lyonia ovalifolia	40.00	0.45	1.13	0.03	108.65	18.86
Prunus cerasoides	25.00	0.45	1.80	0.07	141.43	17.08
Horticulture trees						
Prunus armeniaca	35.00	0.40	1.14	0.03	218.22	21.08
Juglans regia	20.00	0.30	1.50	0.08	184.80	15.34
Prunus persica	25.00	0.25	1.00	0.04	78.57	11.69
Citrus sinensis	20.00	0.25	1.25	0.06	65.93	10.24
Citrus aurentium	20.00	0.25	1.25	0.06	48.23	9.59
Punica granatum	15.00	0.20	1.33	0.09	35.36	7.36
Citrus limon	10.00	0.15	1.50	0.15	14.26	4.83
Total		**6.45**			**2745.31**	**300.00**
Southern aspect (site- $D_2E_2S_2$)						
Forest trees						
Quercus leucotrichophora	45.00	0.70	1.56	0.04	343.75	41.76
Quercus floribunda	40.00	0.55	1.38	0.03	356.45	37.89
Morus serrata	35.00	0.50	1.43	0.04	157.14	26.72
Prunus cerasoides	30.00	0.35	1.17	0.04	145.48	21.77
Rhododendron arboreum	25.00	0.35	1.40	0.06	162.25	21.14
Aesculus indica	20.00	0.25	1.25	0.06	232.99	20.85
Carpinus viminea	25.00	0.35	1.40	0.06	154.07	20.78
Alnus nepalensis	25.00	0.30	1.20	0.05	147.32	19.46
Lyonia ovalifolia	25.00	0.30	1.20	0.09	84.56	16.70
Horticulture trees						
Prunus armeniaca	20.00	0.25	1.25	0.06	164.17	17.82
Juglans regia	20.00	0.25	1.25	0.06	135.04	16.53
Prunus persica	20.00	0.25	1.25	0.06	95.07	14.77
Prunus domestica	15.00	0.30	2.00	0.13	68.12	13.23
Prunus amygdalus	20.00	0.20	1.00	0.05	22.63	10.56
Total		**4.90**			**2269.04**	**300.00**

recorded higher for *Quercus leucotrichophora* and *Quercus floribunda* (45%, 0.70 trees/100m^2, 343.75 cm^2/100m^2, 41.76 and 40%, 0.55 trees/100m^2, 356.45 cm^2/100m^2, 37.89) among forest trees. In horticulture tree IVI value ranged from 10.56 to 17.82 with highest IVI by *Prunus armeniaca* as a dominant tree (Table 6).

Table 7 shows the data on structural variations in agri-silvi-horticulture system of varying elevation 2000-2500m on both northern and southern aspect (site-$D_2E_3N_3$ and $D_2E_1S_3$). A total of 8 tree species including 6 forest tree and 2 fruit tree species were recorded on the northern aspect. The highest frequency, density, TBC and IVI value (65%, 0.80 plants/100m^2, 392.86 cm^2/100m^2, 53.14) were recorded for the tree species *Quercus floribunda* and hence this is the dominant species on this site. The dominant fruit tree was recorded in the site was *Juglans regia* on the basis of higher IVI value. On the southern aspect of this elevation (2000-2500m) a total of

Table 7. Phyto-sociological analysis of tree layer in the agri-silvi-horticulture (ASH) system in Uttarkashi district (2000-2500m)

Species	% Freq. (F)	Density (Trees/100m^2)	Abund. (A)	A/F Ratio	TBC (cm^2/100m^2)	IVI
Northern aspect (site-$D_2E_3N_3$)						
Forest trees						
Quercus floribunda	65.00	0.80	1.23	0.02	392.86	53.14
Quercus semicarpifolia	50.00	0.70	1.40	0.03	396.51	46.47
Populous ciliata	40.00	0.45	1.13	0.03	339.78	35.65
Morus serrata	40.00	0.65	1.63	0.04	204.29	34.68
Alnus nepalensis	35.00	0.55	1.57	0.05	292.13	34.42
Abies pindrow	30.00	0.45	1.50	0.05	272.08	29.89
Horticulture trees						
Juglans regia	30.00	0.50	1.67	0.06	333.13	33.41
Prunus armeniaca	35.00	0.45	1.29	0.04	294.69	32.33
Total		**4.55**			**2525.46**	**300.00**
Southern aspect (site- $D_2E_3S_3$)						
Forest trees						
Quercus floribunda	55.00	1.25	2.27	0.04	877.46	95.97
Quercus semicarpifolia	60.00	1.05	1.75	0.03	789.25	89.69
Abies pindrow	45.00	0.70	1.56	0.04	575.23	64.23
Horticulture trees						
Juglans regia	35.00	0.65	1.86	0.05	375.63	50.11
Total		**3.65**			**2617.57**	**300.00**

4 tree species were recorded (3 forest trees and 1 fruit tree). The *Quercus floribunda* and *Quercus semicarpifolia* were dominantly present with their higher IVI values as 95.97 and 89.69. The only fruit species *Juglans regia* was recorded in this site with their IVI value as 50.11 (Table 7).

Similar study on traditional agroforestry systems including agri-silvi-horticulture system was conducted for Himanchal Pradesh by Kumar et al. (2011). Many studies have also established the similar facts as in present study that the aspect influences the vegetation composition, structure, tree density and diversity in different existing vegetation systems (Bijalwan *et al*., 2009; Bijalwan *et al*., 2008; Bijalwan, 2002; Sharma and Baduni, 2000; Dhanai and Panwar, 1999). The IVI values of present investigation were in concurrence with the studies conducted in the traditional agroforestry systems in the Bilaspur and Raipur districts of Chhattisgarh region (Sharma *et al.*, 2006). In another study Kusumlata and Bisht (1991) had also reported that phyto-sociological characters vary along the aspects even at the same place.

Diversity indices in traditional agri-silvi-horticulture systems

The different diversity indices *viz.,* Shannon Index (H'), Simpson Index (cd), species richness (d), equitability (e) and beta diversity (bd) were calculated for traditional agri-silvi-horticulture (ASH) systems to analyze the variation in trees diversity on different elevation and aspects in both Tehri and Uttarkashi districts of Uttarakhand. Efforts were also made to work out change in various parameters of diversity for different elevation and aspects (physiographic variations) on plant diversity. The results on diversity of trees in different agroforestry systems are summarized in Tables 8.

It is concluded from the data presented in Table 8 that in Tehri Garhwal the Shannon index (diversity) values in tree species of different agroforestry systems ranged from 0.88 to 1.12. The highest tree diversity was recorded in 1000-1500m elevation on northern aspect (site- $D_1E_1N_1$), while it was lowest in higher elevation (2000-2500m) on northern aspect (site- $D_1E_3N_3$). Differing to this, the Simpson index values were found to be highest (0.16) in 1500-2000m on southern aspect (site- $D_1E_2S_2$) and the lowest value of Simpson Index (0.09) was reported in 1000-1500m on northern aspect (site- $D_1E_1N_1$). The species richness in agri-silvi-horticulture systems for trees ranged from 0.98 to 2.02. The highest species richness value (2.02) was recorded in the northern aspect for the elevation 1000-1500m (site- $D_1E_1N_1$) whereas the lowest species richness value (0.98) was reported in northern aspect for 2000-2500m (site- $D_1E_3N_3$). The highest equitability (0.41) was observed on northern aspect in 1500-2000m (site- $D_1E_2N_2$)

Table 8. Plant diversity in agri-silvi-horticulture (ASH) systems in district Tehri and Uttarkashi.

Elevation/Aspect	Shannon Index	Simpson Index	Richness	Equitability	Beta Diversity
District- Tehri Garhwal					
$D_1E_1N_1$	1.12	0.09	2.02	0.40	1.80
$D_1E_1S_1$	1.04	0.10	1.51	0.40	2.30
$D_1E_2N_2$	1.05	0.10	1.51	0.41	2.30
$D_1E_2S_2$	0.97	0.16	1.41	0.40	3.00
$D_1E_3N_3$	0.88	0.15	0.98	0.40	3.30
$D_1E_3S_3$	0.98	0.13	1.37	0.39	2.50
District- Uttarkashi					
$D_2E_1N_1$	1.01	0.10	1.50	0.41	2.20
$D_2E_1S_1$	1.09	0.09	1.64	0.38	2.00
$D_2E_2N_2$	1.11	0.08	1.90	0.39	1.80
$D_2E_2S_2$	1.08	0.09	1.68	0.41	2.00
$D_2E_3N_3$	0.90	0.13	0.89	0.43	3.50
$D_2E_3S_3$	0.58	0.27	0.38	0.42	7.00

ASH = Agri-silvi-horticulture, D_1= District Tehri Gahwal, D_2= District Uttarkashi
E_1= Elevation 1 (1000-1500m), E_2= Elevation 2 (1500-2000m), E_3= Elevation 3= (2000-2500m)
N_1, N_2, N_3 = Northern aspects, S_1, S_2, S_3 = Southern aspects.

and lowest (0.39) on southern aspect of an elevation of 2000-2500m (site-$D_1E_3S_3$). Beta diversity was highest (3.30) on northern aspect in 2000-2500m (site- $D_1E_3N_3$), although it was lowest (1.80) in 1000-1500m on northern aspect (site- $D_1E_1N_1$) under agri-silvi-horticulture system (Table 8).

Results on diversity of trees in agri-silvi-horticulture systems in Uttarkashi district are presented in Table 8. The Shannon index values were found to be highest (1.11) on the sites- $D_2E_2N_2$ and lowest (0.58) on the site-$D_2E_3S_3$. The highest Simpson index value (0.27) was found in site- $D_2E_3S_3$ and lowest (0.08) in site- $D_2E_2N_2$. The species richness values ranged from 0.38 to 1.90. Site- $D_2E_2N_2$ has shown highest species richness followed by site- $D_2E_2S_2$ and lowest in site- $D_2E_3S_3$. Among the different sites the highest equitability (0.43) was observed for site- $D_2E_3N_3$ and lowest (0.38) on site-D_2E_1 S_1. Beta diversity was highest (7.00)) on site-$D_2E_3S_3$ while it was lowest (1.80) on sites- $D_2E_2N_2$ (Table 8).

The diversity parameters of agroforestry are also reported by various workers for other regions (Deb *et al*., 2008; Sharma *et al.*, 2006; Ralhan *et al.*, 1982; Singh and Sigh, 1991; Toky *et al.*, 1989). The study conducted by Dev et al. (2008) in the agroforests of foothills of Indian Eastern Himalaya for the trees showed the species richness as 17±0.33, Basal area 37.01±0.34 M^2 ha^{-1}, density 1006±17.2 plants $ha^{-1}$and species diversity Index as1.13±0.02.

Thakur *et al.* (2004) in a similar study in Western Himalaya, reported that among all the three agroforestry systems (AS, SP, HSP), HSP system was more diversified, as it had as many as 12 trees, 4 shrubs, 7 herbs and 6 fruit species. Similar results had also been reported by Toky *et al.* (1989). Singh and Singh (1991) reported the Shannon-Wiener index values from 1.9 to 2.8, concentration of dominance from 0.18 to 0.75, species richness from 0.21 to 0.93 and beta diversity as 3.1 for mixed dry deciduous forest of U.P., India. Ramprasad and Pandey (1992) in their study of Sal and Teak forests of Madhya Pradesh found that the species diversity was from 0.32 to 3.76 and concentration of dominance from 0.07 to 0.63 at different distances from habitation in Bilaspur, Mandla, Balaghat and Jabalpur districts of Madhya Pradesh.

The Shannon index values of this study were comparatively lower than those reported by many scientists for other ecosystems (Swamy, 1998; Singh *et al.*, 1984). The low diversity values under the present investigation were attributed to the sharing of large proportion of resources by few species, whereas, in tropical evergreen forests, more number of species (>75) efficiently shared the resources (Pascal, 1992; Swamy, 1998). The inverse relationship was found between Shannon index and Simpson index. These results were in agreement with the findings of Singh and Singh (1991) and Swamy (1998). In the present study, the higher diversity (Shannon Index) was recorded in lower elevation (1000-1500m) compared to higher elevation (2000-2500m) while the reverse the case in concentration of dominance (Simpson Index), the study in congregate with the study conducted by Sharma et al. (2009). The

Table 9. Distribution of trees (per 100 m2) in various diameter and height class under the agri-silvi-horticulture system (ASH) in Tehri District.

AFS/Site	Trees under Diameter class (cm)								Trees under Height Class (m)					
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	0-5	5-10	10-15	15-20	20-25	25-30
$D_1E_1N_1$	1.20	1.70	2.70	1.25	0.65	-	-	-	2.20	2.55	2.10	0.55	-	-
$D_1E_1S_1$	2.45	2.15	1.25	0.50	0.15	-	-	-	0.55	3.50	2.05	0.40	-	-
$D_1E_2N_2$	1.60	2.00	2.25	1.00	0.20	0.15	-	-	0.85	3.15	1.80	1.20	-	-
$D_1E_2S_2$	1.15	1.50	2.65	1.70	-	0.30	-	-	1.15	3.40	2.30	0.45	-	-
$D_1E_3N_3$	0.40	1.10	2.25	2.60	-	0.10	0.20	-	0.50	1.80	3.10	0.50	0.75	-
$D_1E_3S_3$	0.60	1.25	2.20	1.40	0.15	-	0.20	0.10	0.40	2.10	2.40	0.45	0.55	-
Mean	1.23	1.62	2.22	1.41	0.19	0.09	0.07	0.02	0.94	2.75	2.29	0.59	0.22	-

Table 10. Distribution of trees (per 100 m2) in diameter and height class under the agri-silvi-horticulture system (ASH) in Uttarkashi District

AFS/Site	Trees under Diameter class (cm)								Trees under Height Class (m)					
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	0-5	5-10	10-15	15-20	20-25	25-30
$D_2E_1N_1$	1.50	3.60	2.05	-	0.20	0.10	-	-	1.50	3.65	2.29	-	-	-
$D_2E_1S_1$	1.10	2.70	1.60	1.10	0.25	0.30	-	-	1.30	4.70	1.05	-	-	-
$D_2E_2N_2$	0.75	3.00	1.95	0.45	-	0.10	0.20	-	0.65	3.95	1.85	-	-	-
$D_2E_2S_2$	1.05	1.65	2.10	0.65	0.15	-	0.30	-	0.75	1.80	1.95	0.40	-	-
$D_2E_3N_3$	-	0.45	2.05	1.75	-	-	0.10	0.20	-	0.55	2.60	1.40	-	-
$D_2E_3S_3$	-	1.00	1.10	1.20	-	0.05	-	0.35	-	-	2.30	1.35	-	-
Mean	0.73	2.07	1.81	0.86	0.10	0.09	0.10	0.09	0.70	2.44	2.01	0.53	-	-

species richness was also higher in the lower elevation and lower in higher elevation as reported by the many workers (Sharma et al., 2009; Rawal et al., 1991). One of the reasons could be for higher species richness in the lower elevation that people generally encourage the agroforestry practices for their own benefits in the areas where they live in abundant, however, lower and middle elevation areas are highly populated area. The species richness was also recorded higher in northern aspect compared to southern aspect; the higher values on northern aspects may be due to the higher moisture content and low insolation rates as compared to southern aspects, which receive the Sun rays in later part of the day, when the atmosphere is sufficiently warmed. The effect of aspect on structure and diversity of vegetation was also quantified by several workers (Joshi and Tiwari, 1990; Singh *et al.*, 1991; Jha, 2001).

Distribution of trees under different diameter and height classes in the traditional agri-silvi-horticulture systems

In Tehri district the maximum numbers of tree (2.70/100m^2) were recorded in 1000-1500m, on the northern aspect (site- $D_1E_1N_1$) under 20-30cm diameter class while in the southern aspect (site- $D_1E_1S_1$) of this elevation it was recorded maximum (2.45/100m^2) under 0-10 cm diameter class. The least number of trees in this elevation were recorded under diameter class 40-50cm in both northern and southern aspect. In the elevation 1500-2000m on both northern and southern aspect (site- $D_1E_2N_2$, $D_1E_2S_2$), the maximum numbers of trees were found under (20-30cm) diameter class i.e. 2.25/100m^2 and 2.65/100m^2 respectively while the least numbers of trees were found under 50-60cm diameter class as 0.15/100m^2 and 0.30/100m^2 respectively. In

Figure 2. Distribution of tree in diameter classes (Tehri Garhwal).

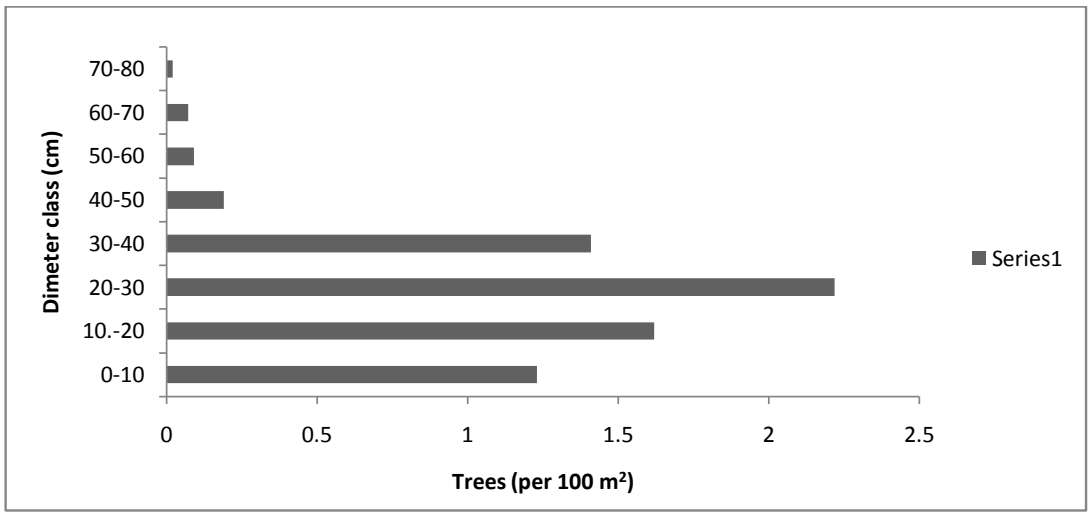
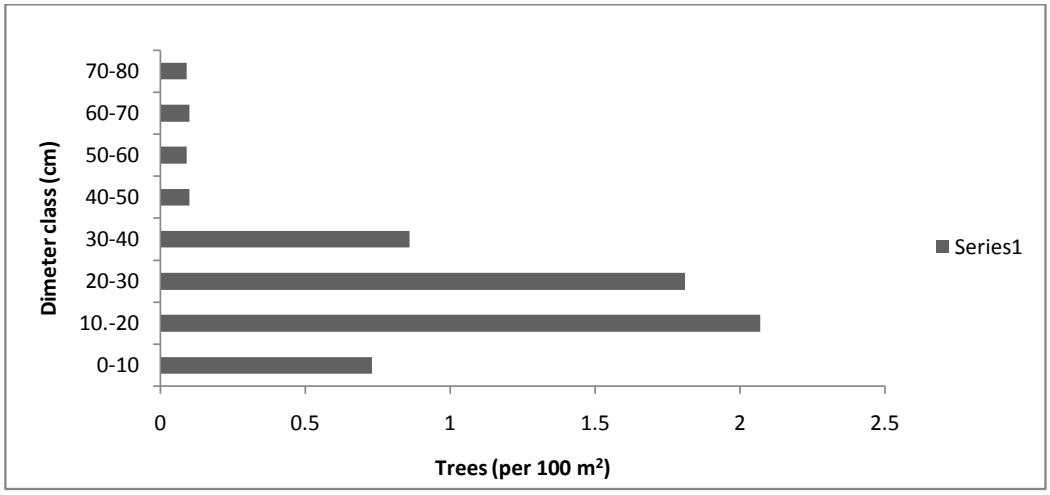


Figure 3. Distribution of tree in diameter classes (Uttarkashi).



2000-2500m elevation (site- $D_1E_3N_3$), the maximum number of trees (2.60/100m^2) were found under 30-40cm diameter class followed by 20-30cm diameter class and least numbers of trees (0.20/100m^2) were found under 60-70cm diameter class. In southern aspect of this elevation (2000-2500m) site- $D_1E_3S_3$, the maximum numbers of trees were found under 20-30cm diameter class followed by the 30-40cm diameter class and least trees numbers (0.10/100m^2) were recorded under 70-80cm diameter class (Table 9). The average number of trees present in different diameter classes in Tehri is depicted in Figure 2.

In Uttarkashi district under agri-silvi-hoticulture (ASH) system in the elevation 1000-1500m, the trees in different diameter class varied from 0.10/100m^2 to 3.60/100m^2 (Table 10) On the northern aspect (site- $D_2E_1N_1$) the maximum number of trees (3.60/100m^2) found under 10-20cm diameter class while the least number of trees (0.10) were recorded under 50-60 cm diameter class. On the southern aspect of this elevation (site- $D_2E_1S_1$) the maximum numbers of tree (2.70/100m^2) were recorded in diameter class 10-20cm followed by the diameter class 20-30 cm where numbers of tree were recorded as 1.60/100m^2. In the elevation 1500-2000m on northern aspect (site- $D_2E_2N_2$) maximum numbers of trees (3.00/100m^2) were recorded in diameter class 10-20cm while on the southern aspect (site- $D_2E_2S_2$) maximum numbers of trees (2.10/100m^2) were found under diameter class 20-30cm. In elevation 2000-2500m, the maximum numbers of trees (2.05/100m^2) were recorded in northern aspect under 20-30 diameter class while the lowest numbers of trees (0.05/100m^2) were recorded in diameter class 50-60cm in southern aspect (site- $D_2E_3S_3$) (Table 10). The average number of trees present in different diameter classes in Uttarkashi is depicted in Figure 3.

Figure 4. Distribution of tree in height classes (Tehri Garhwal).

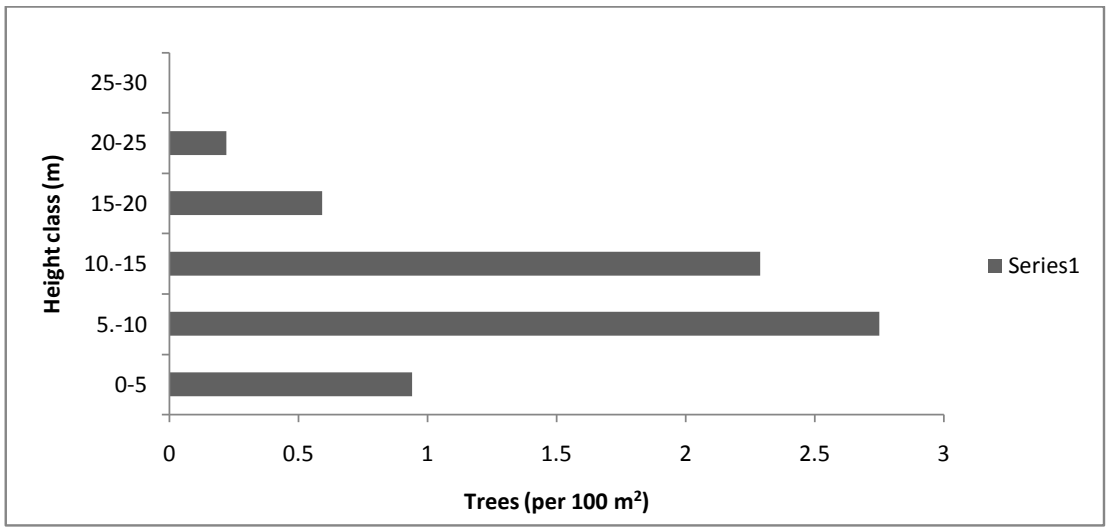
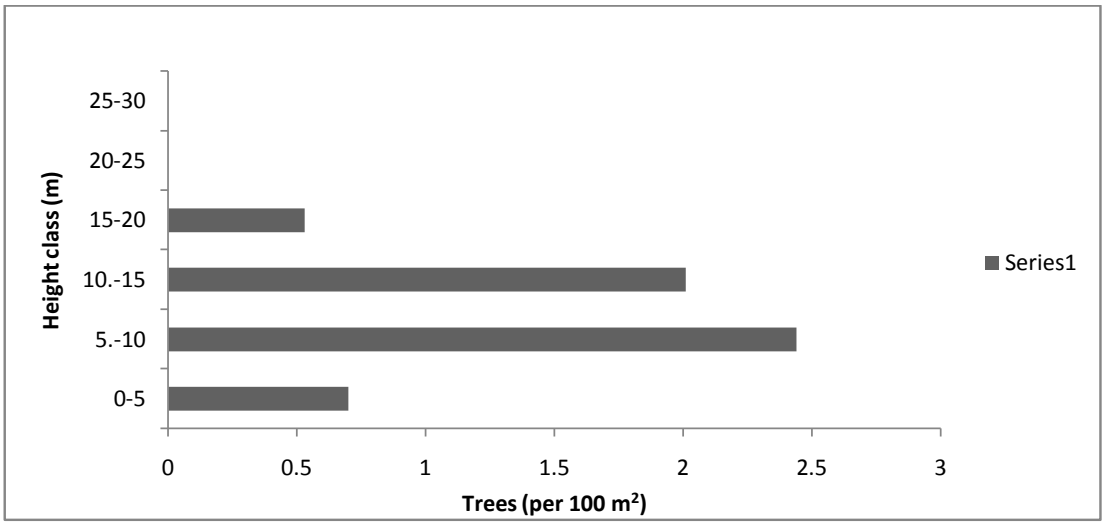


Figure 5. Distribution of tree in height classes (Uttarkashi).



It is apparent from Table 9 that maximum number of trees (3.50/100m^2) were found in height class 5-10m in site $D_1E_1S_1$ while the least number of trees (0.40/100m^2) were recorded in height class 15-20m and 0-5m in sites $D_1E_1S_1$ and $D_1E_3S_3$ in Tehri district. The average number of trees present in different height classes in Tehri is depicted in Figure 4.

In Uttarkashi district the maximum numbers of trees were observed in height class 5-10m and 10-15m. The maximum value (4.70/100m^2) of tree numbers were recorded in height class 5-10m in the southern aspect of 1000-1500m of elevation while the least numbers of tree (0.40/100m^2) were observed on the southern aspect of 1500-2000m elevation under 15-20m height class. In an elevation of 2000-2500m, the highest numbers of tree (2.60/100m^2 and 2.30/100m^2) were recorded on both northern and southern aspect under height class 10-15m while lowest numbers of trees (0.55/100m^2) were recorded under 5-10m height class on the northern aspect of elevation 2000-2500m (Table 10). The average number of trees present in different height classes in Uttarkashi is depicted in Figure. 5. In the present study the maximum number of trees was observed in 10-12 and 20-30cm diameter classes while lower in higher diameter classes. The reason behind is that as the big and giant trees are generally not preferred on the agricultural fields as they create more competition for resources particularly for sun light with the agricultural crops

therefore, less trees were observed in higher diameter classes and same the case with height classes as well. Similar pattern of a continuous decrease of number of tree individuals from lower to upper diameter classes was also noticed by Biswas and Misbahuzzaman (2006).

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