

**SITE CHARACTERISTICS AND REGENERATION STUDIES
OF BANI OAK (*Quercus glauca* THUNBERG)
IN HIMACHAL PRADESH**

Thesis

by

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(F-2012-27-D)**

Submitted to



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This is to certify that the thesis entitled, “**Site characteristics and regeneration studies of bani oak (*Quercus glauca* Thunberg) in Himachal Pradesh**”, submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy (Forestry) Silviculture** of Dr. Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP)-173230 is a bonafide research work carried out by **Mr. Amare Tesfaye (F-2012-27-D)** son of Shri Tesfaye Bizuneh under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

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

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Date: 04/01/2016

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CERTIFICATE - II

This is to certify that the thesis entitled, “**Site characteristics and regeneration studies of bani oak (*Quercus glauca* Thunberg) in Himachal Pradesh**”, submitted by **Mr. Amare Tesfaye (F-2012-27-D)** son of Shri Tesfaye Bizuneh to the Dr. Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP)-173230 India in partial fulfilment of the requirements for the award of degree of **Doctor of Philosophy (Forestry)** in the discipline of **Silviculture** has been approved by the Advisory Committee after an oral examination of the same in collaboration with the External Examiner.

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(Amare Tesfaye)

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ABBREVIATIONS USED

%	Per cent
°C	Degree Celsius
masl	Meters above Sea Level
BA	Basal area
CD _{0.05}	Critical Difference at P= 0.05
CD	Collar diameter
Cm	Centimetre
D	Density
dbh	Diameter at breast height
e.g.	Example
<i>et al.</i>	And others
etc.	etcetera
F	Frequency
Fig.	Figure
Fym	Farm yard manure
g	Gram
GA3	Gibberellic acid
H.P.	Himachal Pradesh
Ha	Hectare
hr	Hour
i.e.	That is
IVI	Importance Value Index
K	Potassium
Kg	Kilogram
KNO ₃	Potassium nitrate
LA	Leaf area index
M	Metre
MDG	Mean daily germination
Mm	Millimetre
N	Nitrogen
p.	Page
P	Phosphorus
PB-	Periodic block (Numbered)
pp.	Pages
ppm	Parts Per Million
RBA	Relative basal area
RD	Relative density
RF	Relative frequency
SE	Standard Error
Mg	Milligram
spp.	Species
Viz.	Such as
yr	Year
USDA	United States Department of Agriculture
t	Ton

Chapter-1

INTRODUCTION

The Himalayan region comprises one of the highest mountain systems of the world. The region lies between 21°57' and 37°5' N latitudes and 72°40' and 97°25' E longitudes, covering about 18 per cent of the total geographical area of India. This region is well known for its biological diversity as the region harbors about 50 per cent of India's flora in its various altitudinal gradients (Singh and Rawat, 2012). In this region, oak species are the dominant climax species extensively growing between 1000 to 3500m elevation along with conifer and mixed forests.

The economical and ecological benefit of oak forests is strongly linked to hill agriculture (Shrestha, 2003). In addition to fuel, fodder and timber, oak forests provide higher diversity than other Himalayan forests tree species like chir pine or deodar forests (Hawn *et al.*, 1999; Zheng *et al.*, 1998). Oak forests play a significant role in maintaining the structure and species composition, litter production and soil fertility of the Himalayan ecosystem. Many of oak trees are considered as a keystone species without which the proper functioning of the ecosystem will be adversely affected (Chaubey, 2012; Lorite *et al.*, 2008). However, human population growth in and around forest ecosystems leads to unsustainable pattern of resource consumption driven by economic activities that maximize short-term gains without considering long-term consequences (Baria and Kiran, 2012). The anthropogenic pressures have shown their detrimental influence on many of the Himalayan oak forests. Indiscriminate and uncontrolled lopping not only affect growth and seed production but also expose the site to severe erosion, land degradation, and loss of soil fertility (Kumar, 2012; Singh and Rawat, 2012). Uncontrolled fire enhances growth of fire resistant species, like chir pine over oak trees, causing loss of biological diversity (Sharma *et al.*, 2010). Grazing, on the other hand, suppresses growth of seedlings and saplings causing site domination by older trees; which in later stages lead to replacement by other nonpalatable trees and shrubs (Singh and Rawat, 2012; Maren and Vetaas, 2007).

There are about 30 to 40 known species of oaks in India. Majority of oaks are growing in the Himalayas. Various authors reported the distribution of major oak species in

the northwest of Himalaya (Bisht *et al.*, 2013; Singh and Rawat, 2012; Kharkwal *et al.*, 2009; Rawal and Pangtey, 1994; Mandal 1986; Troup, 1921). *Quercus leucotrichophora* is the most common species that usually occurs between 1200 to 2500 masl but can be found up to 580 masl in moist areas. The species is found in Mothron Wala swam in Dehra Dun, Kangara valley, Ratwadab and Mandal rivers in Garhwal and Beas valley in Kulu. *Quercus dilatata*, which is distributed between 2100 to 2750 masl, is common in Kumaun hills, Kangara hills, Mussorie hills, Burba forests, Hazara, Dir and Chitral. The species can be found in lower, moist and cool places up to an elevation of 1650 masl. The other high altitude oak species, *Quercus semecarpifolia*, is mainly distributed between 2500 and 3660 masl, although it can be found in lower altitudes upto 1980 masl. The species was observed growing in Mohna forest in Chakrata, Jeota ridges in Tehri Garhwal, Muri forest in Jubal state, Lahar Baik in Hazara. *Quercus lanuginosa*, a very local species, is distributed between 1200 to 2500 masl and it was growing in Garhwal and Kumaun Himalaya, and hills of Naini Tal district. *Quercus ilex* occurs between 1500 and 2750 masl and it has wider distribution in dry hills and arid situations. The species is growing Suliman ranges, Kurram valley, Pehswar valley, Kagan valley, Kishanganga valley, in Chitral, and arid valleys of Jhelum, Chenab, Ravi and Sutlej. Bani oak (*Quercus glauca* Thunberg) is an evergreen broadleaf tree, which has got an oval, rounded crown and clear cylindrical bole to a height of 20m that occurs in the northern subtropical and warmer temperate zones of Asia at an elevation of 300 to 3100 m. It grows well in moist and cool locations with sufficient light condition (Orwa *et al.*, 2009). It provides variety of products to the local people. Seeds can be used as food after leaching out the bitter tannin with running water or streams. The leaves are intensively used as fodder in winter time. Tannin which can also be used as dyestuff is produced from stem galls. The wood is a good quality timber with fine texture and straight grain. It is hard and fairly durable that makes it preferable for heavy as well as light construction including railway sleepers, poles, posts, stakes, and for furniture productions. Traditionally, it has also been used as medicinal plant for the treatment of haemorrhoids (Zulfiqar *et al.*, 2015; Singh *et al.*, 2010).

Regeneration of oak species was reported to be problematic usually resulting in poor germination in its natural habitat (Ibanez *et al.*, 2015; Brose *et al.*, 1999; Thadani and Ashton, 1995). There are various reasons for the poor performance of natural regeneration and establishment of oaks including *Quercus glauca*. One of the major problems associated with regeneration of oak species is that the fruit is widely eaten by bears, monkeys, squirrels, and birds under natural conditions (Thadani and Ashton, 1995; Troup, 1921). Although

partial consumption of acorns has been reported to favour germination and seedling emergence, (Mancilla-Leyton *et al.*, 2012) but the timing and intensity of consumption may have adverse effect on germination. Competition from less-desirable species is another factor that affects germination and establishment of *Quercus* seedlings (Brose *et al.*, 1999; Chaar *et al.*, 1997). Jensen *et al.* (2011) reported a 60-74 % reduction in leaf area; 29-36 % reduction in basal diameter and 38-78 % reduction in total biomass of *Quercus robur* seedlings exposed to under above-ground and below-ground shrub competition. In contrary to these studies, Duncan and Chapman (2003) reported the significantly positive and significant relation between shrub density and tree saplings, which may be due to facilitation effect. Light shading has a strong influence on the growth and survival of seedlings and saplings (Montes-Hernandez and Lopez-Barrera, 2013). Similarly, Collet *et al.* (1998) also reported about the benefit of shading on height growth of *Quercus petraea* seedlings although diameter growth was recorded high in an open growing condition. Seedlings and saplings are highly sensitive to drought and frost (Orwa *et al.*, 2009; Chaar *et al.*, 1997). Besides this, the seeds of *Quercus* species are attacked by insects and fungi causing a serious problem to the regeneration of Himalayan oaks (Camilo-Alves *et al.*, 2013; Orwa *et al.*, 2013).

Despite its wider distribution, *Quercus glauca* has restricted occurrence in the Himalayas due to its specific site requirements. A little attention has been given by the scientific community and thus insufficient information is available about the distribution, association pattern, and stand structure of this species (Zulfiqar *et al.*, 2015; Ito *et al.*, 2007; Troup, 1921). Lack of natural regeneration as well as the degradation of many of oak forests and replacement of these forests by other adaptable species can be tackled by involving direct seeding or seedling planting as a part of forest management practices (Cole *et al.*, 2011; Evans, 1982). However, before introducing such practices having a comprehensive knowledge about seed behavior, germination, seedling growth patterns and phytosociological behavioural studies are mandatory.

Studies on regeneration behavior of a species have wider scope. Broadly, it encompasses availability and behavior of the seed, suitability of the seed bed and the environment around the forest or the stand. Based on this fact, regeneration studies used to incorporate stand characteristics and species composition of the forest, soil and other site

conditions, and germination studies. Such comprehensive studies will address the problem that oak forests are facing in the Himalayas.

Various studies reported that stand structure and species composition will affect seed production, germination and growth of seedlings (Steiner *et al.*, 1993). The age of the stand definitely influences its seed production and regeneration capacities (Espahbodi *et al.*, 2007). Seeds from different provenances have also shown variation in germination (Saha *et al.*, 2012). Density on the other hand, determines the availability of space for germination of species. Reports indicate that regeneration of oaks are high in moderately dense and shaded stands (Rist, 2006, Thadani and Ashton, 1995). Ashton and Larson (1996) reported lag in germination with increasing overshade from dense forest stands. However, growth of seedlings requires lighter density with sufficiently high light on the ground.

The maintenance of biodiversity in certain forests is also determined by the type of species, availability of trees which serve as seed source. In case of light demanding species, the characteristics of seeds allow them to disperse in a wider area. However, most shade tolerant species produce larger seeds in wider lapse of time. Such seeds lack dispersion in wider area unless assisted by gravity, birds and mammals (Coomes and Grubb, 2003). Hence, the availability of mother trees in the forest ecosystems is highly determining. The biodiversity and species composition of broad leaved forests was reported to be higher than most conifer forests. The species composition of these forests enables them to maintain their diversity through maintaining regeneration of various plant species (Higo *et al.*, 1995).

In contrast to their socioeconomic and ecological benefits, the degradation of oak forest ecosystems enforces various environmentalists and forest managers to look for other options mainly artificial plantation establishment (Mercker *et al.*, 2012). Although, artificial plantations are easily established successfully, the knowledge about seed behavior and nursery management requires some sort of expertise. Seed sources, seed collection methods and the type of seed selected to use are basic consideration in this respect. Even with the same species seed collection sites (provenances) showed variation in the amount of germinating seed they provide as well as the vigour of seedlings obtained from seeds (Caliskan, 2013). Seeds collected from the tree or from the ground had different results on germination. Singh and Lavania (2004) reported the freshly fallen *Quercus leucotrichophora* seeds collected from the ground gave better germination than seeds collected from the tree

branches. In various tree species, the use of larger seeds has been reported to have a beneficial effect on germination and seedling growth (Tiliki, 2010; Bonfil, 1998).

The type of pre-sowing treatment is one of the focal point of various nursery practices. The three most commonly applied practices are chemical, physical and stratification pre-sowing treatments. The success of these practices depends on the type of seeds they are applied for and the type of dormancy the seeds have. In general, these practices are not recommended for delicate and easily perishable seeds. Seeds which are affected by chemical inhibitors or embryonic immaturity can be treated with chemical or stratification treatments (Caliskan *et al.*, 2012; Drake and Ewing, 1997). On the other hand, seeds with hard seed coat which affect imbibitions of water to the embryo or inhibit growth and expansion of the embryo are usually treated with physical pre-sowing treatments (Zulfiqar *et al.*, 2015).

Keeping in view the importance of oak forest in general and *Quercus glauca* in particular, the study entitled **“Site characteristics and regeneration studies of bani oak (*Quercus glauca* Thunberg) in Himachal Pradesh”** was carried out with the following objectives:

- i) To study plant associations and natural regeneration status of the species in its natural zone;
- ii) To evaluate various site characteristics and its influence on regeneration of the species;
- iii) To study the effect of various stratification and pre-sowing treatments on germination and growth of seedlings.

Chapter-2

REVIEW OF LITERATURE

Various studies reported the declining in natural regeneration of *Quercus* species and its replacement by other adaptable species in its natural habitat (Petritan *et al.*, 2012; Singh and Rawat, 2012; Sharma *et al.*, 2010; Higo *et al.*, 1995). This study entitled “**Site characteristics and regeneration studies of bani oak (*Quercus glauca* Thunberg) in Himachal Pradesh**” is concerned with the less emphasized *Quercus* species, i.e. *Quercus glauca* and investigates its regeneration behavior under natural and nursery conditions. The characteristics of a forest site as well as the structure and composition of the forest are vital components of natural regeneration. This study addresses these issues, while studying natural regeneration. In case of failure in natural regeneration, it is a common practice by forest managers to supplement natural regeneration through direct seeding or seedling planting. Knowledge on seed behavior and seedling growth characteristics is relevant for the application of these practices. Therefore, this study encompasses germination and seedling growth studies through the application of pre-sowing and stratification treatments as this will enable us to understand seed behavior and seedling growth characteristics. Relevant literatures pertaining to various aspects of the study have been reviewed under the following headings:

- 2.1 Phytosociology
- 2.2 Stand characteristics
- 2.3 Natural regeneration
- 2.4 Site characteristics
- 2.5 Stratification of seeds
- 2.6 Seed germination

2.1 PHYTOSOCIOLOGY

Plant sociology, also called phytosociology, is one part of biological sciences that studies plant communities and interactions with their biotic and abiotic environment. Phytosociology investigates structure and composition of a plant community, dependence upon one another and their environment, development and decline of plant communities, their

spatial distribution, classification and systematic arrangement of social units (Fuller and Conard, 1932).

Phytosociological studies are commonly used to describe species and ecosystem diversities. Gupta and Sharma (2012) assessed the biodiversity of Solan forest division by using GIS. The study identified six forest vegetation classes comprising of chir pine, bamboo, khair, ban oak, deodar, and broad-leave forests. Trees are more dominant in the altitude classes between 1200-1500 m and 1500-1800 m, whereas, shrubs dominate the altitude between 900-1200m elevations.

Pant and Samant (2007) studied phytosociology of Mornaula reserve forest of western Himalaya lying at an altitudinal range of 1500-2200 m. In this forest, they identified 289 species of which trees, shrubs, and herbs accounted for 12.8, 12.8, and 74.4 per cents of the total vegetation, respectively. They recorded 31 forest communities including *Quercus* forests at 18 sites. *Quercus leucotrichophora* and *Quercus floribunda* were found to be dominant at these sites; growing as pure stands as well as in association with other species. In general, herbs were found to be more species rich followed by shrubs and trees.

The phytosociological analysis of thermophilous oak woodland at Pomarolo, Italy indicated that the woodland contain a total of 214 species belonging to 52 families of which *Quercetalia pubescentis* was dominant. The woodland was characterized as mixed thermophilous forest of Mediterranean and Sub-Mediterranean mountain that occurred in the northern part of the Mediterranean basin. It was considered as a young forest in transition to climax vegetation being influenced by past land use of coppicing and grazing which changed the physiognomy and species composition of original forest (Rigobello *et al.*, 2005).

Blasi and Di Pietro (1998) studied phytosociological types of *Quercus pubescens* woodland communities of southern Latium and found two main groups of *Quercus* vegetation associations. The first group of oak woods was characterized as moderately mesophylous; where *Quercus cerris*, *Fraxinus ornus* and *Acer campestre* were found together with *Quercus pubescens*, while the second category was characterized as thermo-xerophylous woods mainly of *Quercus ilicis* and *Pistacio-Rhamnetalia alaternii* associations. The bioclimatic as well as edaphic condition of the site was responsible for this variation of vegetation associations in the oak woodlands.

Pandy and Joshi (1998) made phytosociological study at Kumaun Himalaya along altitudinal gradients between 1500-2000 m.a.s.l. Their investigation indicated that *Quercus leucotrichophora* being the dominant species in higher altitudes, whereas *Pinus roxburghii* dominated the lower altitudes. Deodar mixed with chir pine, chir pine mixed with oak, and oak dominated broad leaved were also found among the vegetation formation of the site.

Sharma *et al.* (2010) indicated the dominance of pine forests in the dry temperate Himalayan forests of Kinnaur as a result of succession over broadleaved forests of the area. These forests not only replace broadleaved species but also reduce the diversity of shrub species. Similarly, Hawn *et al.* (1999) and Zheng *et al.* (1998) also reported that in addition to altitude and site factors, vegetation type has an influence on plant diversity. They recorded higher diversity in broad leaved mixed forests than conifer forests.

Based on their IVI values Amjad *et al.* (2013) classified the vegetations of Nikyal valley into thirteen plant communities. Among these plant communities *Quercus dilatata* was found to be the dominant one due to less deforestation and non-palatable characteristics of the species. *Quercus* species were also found intermixed with six plant communities forming associations with *Rubhus*, *Oxalis*, *Justica*, *Myrsine*, *Berberies*, *Rabdopsia*, *Themeda*, *Pinus*, *Indigofera* species, etc.

In the phytosociological study of plantations at Rajpipla Taluka, Baria and Kiran (2012) recorded 42 tree species belonging to 25 families. The largest family was Mimosae with 3 tree species, while Verbenaceae and Combretaceae comprised of 2 species each. Many trees predominantly *Tectona grandis* L., *Butea monosperma* Lam., *Madhuca indica* J.f Gmel., *Acacia catechu* (Willd.), *Morinda tomentosa* Heyne, and *Dendrocalamus strictus* Nees were recorded. These communities were characterized based on their IVI values; maximum IVI value (185.47) was recorded for Teak. The Diversity Index ($\bar{H}$) of trees was between 0.352 and 0.998 at Survani and Nanaraypara villages, respectively. The Richness Index (d) also varied between 5 at Kothi, Survani, Zer, Vanji villages and 14 at Khutamba village. The lower value of richness index in the degraded area clearly indicates its ecological poverty.

Bergmeier and Dimopoulos (2008) recognized 13 plant communities and 850 plant species, of which 193 occurred with at least 33 % in one or more of the 13 plant communities in the thermophilous deciduous woodlands of Greece. The common species in the study area

were: *Dactylis glomerata* (80 %), *Veronica chamaedrys* (79 %), *Luzula forsteri* (73 %), *Quercus frainetto* (69 %), *Brachypodium sylvaticum* (60 %), *Potentilla micrantha* (58 %), *Silene italic* (57 %), *Lathyrus laxiflorus* (56 %) and *Viola alba* (50 %), etc.

Some Phytosociological studies recorded long term changes in forest communities based on information from permanent plots or inventories. Chapman *et al.* (2006) used data from the 1934 and 2002 inventories to investigate long-term changes in forest structure and species composition in an upland oak forest in Arkansas. Increase in tree density from 364 to 1032 trees ha⁻¹ and basal area from 10 to 23 m² ha⁻¹ were recorded in these periods. Although there was increase in the upper, middle and lower storey trees for most species, decline in Ozark chinkapin (*Castanea ozarkensis* Ashe.) and black oak (*Quercus velutina* Lam.) were observed. By 2002, shade-tolerant and fire-intolerant species, such as red maple, blackgum, dogwood, and eastern hophornbeam had become increasingly important in the understorey. Shade tolerant species have got competitive advantage over oaks and pines that are intolerant to canopy shades.

Based on data from forest inventory and analysis of USDA Forest Service, Fei *et al.* (2011) assessed the status of oak species from 1980-2008. They analyzed a total of 25 species, out of which eight species showed a significant decline in IVI, while two showed an increase. Although *Quercus nigra* showed a universal increase, oak species, likes *Quercus alba*, *Quercus stellata*, *Quercus rubra*, *Quercus velutina* showed significant decrease in IVI and density. However, this decrease was not uniform geographically and species wise.

Negi *et al.* (2008) compared vegetations of Panchayat forest with that of Reserve forests of Garhwal Himalaya, India. Unlike Reserve forests, which are protected from anthropogenic effects, Panchayat forests are under continuous human exploitation that might have influence on floristic composition. A total of 101 species, which are composed of 35 trees, 24 shrubs, and 42 herbs were recorded in the study area. Although, little difference was observed for shrubs and herbs, total species richness was high in Panchayat forests. Plant families, like Asteraceae, Ericaceae, Poaceae and Rosaceae were found to be more species rich than other families.

Tiwari and Tiwari (2012) studied species diversity of Subtropical Montane forests of Central Himalaya. One of the study sites contain oak forests, in which *Quercus leucotrichophora* was a dominant species and *Rhododendron arborium* was co-dominant in

all the three stages of plants, i.e. tree, sapling and seedlings layers. A tree density of 687 trees ha⁻¹ was recorded for oak forests and it was the highest for all the study sites. However, seedling regeneration status of oak forests was recorded to be the lowest (41.17 %) at all the study sites.

Petritan *et al.* (2012) studied the structure and diversity of Sessile oak (*Quercus petraea*) and European Beech (*Fagus silvatica*) forests of Runcu-Grosi Natural Reserve of western Romania. Species diversity and species richness was recorded higher for oak dominated plots than mixed or pure beech plots with values of 1 and 4.7, respectively. The study recorded higher proportion of dead wood (135 m³ ha⁻¹) in mixed plots of which 70 % is dead coarse wood debris of sessile oak. He owed it to the process of replacement of shade intolerant sessile oak with shade tolerant beech.

Singh and Gupta (2009) studied on floristic diversity of *Cedrus deodara* forest of Shimla district. They recorded 6 tree, 14 shrub, 32 herb and 3 fern species in different periodic blocks. Although *Cedrus deodara* was the most abundant and dominant tree species, but *Quercus leucotrichophora* was found to be associated species in periodic block II and III, whereas, *Quercus floribunda* was the co-dominant one under Periodic block IV.

2.2 STAND CHARACTERISTICS

Forest lands are usually managed to provide both economical and ecological benefits to the land owner in particular and to the society at large. Most forests are managed mainly for the provision of timber products although minor non timber forest products can also be obtained in the process. Oak forests in the Himalayan mountains are managed to provide both timber and non timber forest products (Babic *et al.*, 2010).

Estimation of timber production and assessment of carbon stocks of oak forests require measuring tree volume and stand density of the forest. According to Petritan *et al.* (2012) the stocking density of living trees ≥ 5 cm was found greater for oak dominated plots (713 individuals ha⁻¹) compared to pure beech (499 individuals ha⁻¹) and mixed plots (487 individuals ha⁻¹). Contrary to this, the mean volume of living trees ≥ 7 cm dbh was lowest in the sessile oak dominated plots at 577 m³ ha⁻¹, and highest in the pure beech plots which 675 m³ ha⁻¹. Despite their high stocking density, the comparatively low volume of sessile oak dominated plots was because of their lower tree height and mean dbh values.

Babic *et al.* (2010) reported that an even aged 100 years sessile oak forest had a density of 164 to 253 trees ha⁻¹ and volume ranging from 145 to 221 m³ ha⁻¹. The mean stand diameter and the mean stand height were 32.8 cm and 23.9 m, respectively. While, Devine and Harrington (2013) reported that *Quercus garrayana* forest with an age of 94 to 130 had an average dbh, height, and crown area ranging from 29.8 to 31.9 cm, 15.5 to 16.4 m and 22.7 to 53.8, respectively. The average dbh and height of encroaching *Pseudotsuga menziesii* ranged from 80.4 to 88.5 cm and 39.0 to 39.4 m, respectively although its age was about 74 years. Density and basal area of *Quercus baloot* forest in Pakistan has been recorded to be in the range of 166.4 to 351.6 trees ha⁻¹ and 12.1 to 30.1 m² ha⁻¹, respectively (Khan *et al.*, 2010).

Ainalis *et al.* (2010) assessed the impact of stocking density on wood production of oak coppice forest in Greece, which is managed under different grazing pressure. The average stocking density in 1991 under low, medium and heavily grazed sites were 96.0, 93.5 and 107.2 m³ ha⁻¹, respectively. In 2005, this average stocking density increased to 107.9, 105.8 and 112.6 m³ ha⁻¹ providing a total wood harvest of 17.7, 21.4 and 20.9 m³ ha⁻¹ for light, moderate and heavy grazing sites, respectively. Loewenstein and Johnson (2000) found a reverse J shaped diameter frequency distribution and a normal bell shaped frequency distribution of age in uneven-aged forest of Missouri.

Crown parameters are usually measured in order to assess foliage biomass, leaf area index, the amount of photosynthetically active radiation captured or the amount of light passed on to the middle and lower canopy layers, etc. Many *Quercus* species in the Himalayas are lopped for fodder (Singh and Rawat, 2012; Chhetri, 2010), which influence crown area and so the amount of litter fall on the ground. Andivia *et al.* (2012) reported that litter fall which is responsible for the return of nutrients into the soil are significantly correlated with tree size and crown surface area. While, Boulmane *et al.* (2013) measured the total above ground biomass and nutrient pool of two evergreen oak stands of Morocco. The result showed that the two stands had an above ground biomass of 96 t ha⁻¹ and 86.4 t ha⁻¹ with an average litter fall production of 3030 and 3560 kg ha⁻¹ yr⁻¹, respectively. In contrast to their aboveground biomass (which is influenced by tree density), litter fall production in the second plot was higher because of the larger size of trees it had.

Gonzalez *et al.* (2012) studied the effect of tree density on soil organic carbon, hence fertility of the forest site. The result showed that minimum soil organic carbon stock (3.6 kg

m⁻²) was recorded in grassland ecosystems with scattered oak trees, whereas, dense Holm oak forests had moderate (7.6 kg m⁻²) soil organic carbon stocks. The maximum soil organic carbon stock (>10 kg m⁻²) was recorded in mixed dense Holm oak forest. While, Nunes *et al.* (2013) studied the above ground biomass and net primary productivity of oak, pine, and oak-pine forests of Villa Real district of Portugal. It was observed that above ground biomass of the above mentioned forests were 61.4, 83.4 and 110.5 Mg ha⁻¹, while, the above ground net primary productivity was 7.3, 7.9 and 12.1 Mg ha⁻¹ yr⁻¹, respectively. Pretzsch *et al.* (2013) also reported the higher biomass productivity (30 % more) of oak-European beech mixed stands than the pure oak or pine stands. However, volume and dry mass growth of mixed stands changed from 50 % gains in nutrient poor sites to 10 % loss in fertile sites probably due to competition. Hosseini *et al.* (2011) reported that the productivity and sustainability of oak forests can be maintained by mixing *Quercus castaneifolia* with *Carpinus betulus* in 1:1 proportions. Piotto (2008) discussed the positive effect on diameter growth of non-nitrogen fixing species, when planted with nitrogen fixing tree species.

2.3 NATURAL REGENERATION

Natural regeneration is the process of replacement of old trees by younger ones in a forest stand maintained under natural condition. Natural regeneration is a function of three inter-related factors: seed supply, seed bed receptivity, and environmental conditions. It is an important component of forest management and natural regeneration studies are a vital tools to understand population dynamics of a species.

Regeneration capacity of species varies depending on behavior of the species as well as macro and micro environmental conditions. A lack of natural regeneration of *Quercus species* in its natural habitat was reported by McCreary (2009). Hence, in most managed forests, lack of natural regeneration can be assisted by silvicultural practices to secure proper stocking of the desired species.

Shrestha (2003) studied the ecology, exploitation and threats of *Quercus semecarpifolia* of Himalayan region and observed lack of sufficient natural regeneration of the species in both disturbed and undisturbed sites. The poor natural regeneration was associated to heavy and indiscriminate annual lopping, litter collection, overgrazing, forest fire, available light, and herbaceous cover of the forest site. Although there was no long-term data, climate change was also suggested as one of the reasons for the failure of natural

regeneration. Maren and Vetaas (2007) also reported the influence of lopping (anthropogenic effect) on the regeneration of *Q. semecarpifolia* allowing the *Rhododendron arborium* to dominate the site due to less biotic stress in response to its poor fodder and fuel qualities.

Fire is one of the important silvicultural methods to enhance regeneration of oaks. Brose *et al* (1999) studied the effect of prescribed fire after shelter wood harvest in reducing the dominance of yellow poplar (*Liriodendron tulipifera*) and increasing regeneration of oaks. They recommended that high-intensity fire during the spring will develop into oak-dominated stands after just one burn, whereas, the control and areas treated with low intensity fire will be dominated by yellow poplar. However, the application of fire alone, without partial harvesting, didn't improve oak regeneration consistently (Hutchinson *et al.*, 2005).

Many studies revealed the importance of prescribed fire in assisting natural regeneration and seedling establishment of various oak species (Royse *et al.*, 2010, Wang *et al.* 2005.). In its ability to open canopy gaps, modified forest floor, reduce competitors and breaks acorn dormancy, fire has a positive effect on natural regeneration of oak species. However, effect of prescribed fire on germination is highly variable among oak species which calls for the need to target management for individual oak species (Royse *et al.*, 2010).

Higo *et al.* (1995) studied regeneration behavior of major tree species in *Pinus densifolia*-*Quercus serrata* dominated secondary forest of Japan. In this study, regenerations of 17 species with an average density of 45 seedlings per 2m⁻² was recorded. Although, *Q. serrata* was one of the dominant tree species in the upper canopy level, its regeneration was among the lowest (2.78 %) recorded. There were no saplings at all in the forest mid canopy which affirms gradual substitution of *Quercus* by other shade tolerant species. However, contrary to Higo *et al.* (1995), Major *et al.* (2013) found that *Quercus rubra* had the highest regeneration (a mean of 24 seedlings m⁻²) and abundance of saplings in mid canopy layers with densities ranging from 200 to 1500 stems ha⁻¹. The higher regeneration and abundant saplings of *Quercus rubra* in the closed canopy of these forests was associated to periodic selective harvesting which allows its seedlings to persist and recruit in to the midstorey as canopy gaps become available.

Coppice regeneration is one method of reproduction for many oak species. Pyttel *et al.* (2013) investigated that there was prolific stump sprouts of sessile oak (*Quercus petraea*), although, the stump age was as high as 80 to 100 years. However, 16 % of stools died within

two growing seasons after coppicing. Browsing has an effect on stump mortality and height reduction of the sprouts compared to fenced plots. Papachristou and Platis (2011) also reported the height, diameter, and volume of oak coppice shoots were affected by grazing. Smit *et al.* (2012) reported that 83 % of oak samplings were browsed with 55.6 % of branches showing signs of browsing. Ainalis *et al.* (2010) reported that moderate grazing improved tree growth and provided significant wood production of oak coppice forests.

Acorns are one of the major feeds for monkeys, birds, rodents, pigs, and other animals including insects and fungi. The loss of acorns from forest floor due to its consumption by animals has a direct effect on germination and growth of these species (Yoko-o and Tokeshi, 2012). Pinero *et al.* (2010) recorded 83 to 88 % loss of acorns due to predator species (mice and wild boar). However, some rodents and birds play an important role in acorn dispersal (Yu *et al.*, 2013; Steele *et al.*, 2001) and enhanced regeneration from partial consumption of acorns (Mancilla-Leyton *et al.*, 2012). Terborgh *et al.* (2008) investigated that the decline in larger birds, arboreal and terrestrial mammals in Boca Manu biological station in Peru had changed the sampling cohort with high proportion of species dispersed by wind and low proportion of species dispersed by large animals.

Depletion of oak forest and lack of natural regeneration of Himalayan oak forests is mostly associated with anthropogenic effects. Singh and Rawat (2012) assessed the effect of fuelwood collection, grazing, and fodder collection (lopping) on oak forests and concluded that these three live-support activities of the local people have a significant effect on the depletion of oak forests of western Himalaya.

Rodriguez *et al.* (2008) revealed better survival of Pyrenean oak in thinned than uncut stands. The difference in survival of seedlings was due to the effect of overstorey canopy on light and soil moisture available to seedlings. Available light was lower in higher overstorey densities inhibiting proper growth of seedlings. The relationship between overstorey canopy density and soil moisture was not very clear, since climatic and edaphic conditions also interplay their role on soil moisture conditions. However, the higher survival of seedlings in less overstorey canopy suggested its positive impact on moisture availability at near surface soil.

Rajwar *et al.* (1999) studied the density of seedlings and saplings in three forest stands, *Quercus leucotrichophora*-*Pinus roxburghii* mixed stand at elevation of 1800-2000m,

Quercus leucotrichophora stand at elevation of 2000-2200m, and *Quercus floribunda* stand at elevation of 2200- 2400 m.a.s.l. . They found that density of seedlings and saplings ranged from 5.3 to 14.5 and from 2.6 to 7.7 in a plot of 25m², respectively.

2.4 SITE CHARACTERISTICS

In addition to climatic conditions, site factors, like soil conditions, topography, light, biotic factors and cultural practices have influence on establishment and growth of forest vegetation. Studies on site characteristics are helpful to assess site productivity as well as decision making process in forest management.

It is widely known that soils vary from place to place in their physical and chemical composition. Fernandez (2008) reported importance of available soil nutrients in the forest to predict site quality and its productivity. Fertility indicators such as total N pool or C:N ratios are related to climate and soil texture (Callesen *et al.*, 2007).

Royse *et al.* (2010) and Major *et al.* (2013) reported that high litter depth and soil fertility leads to high seedling mortality and less natural regeneration of oak species. However, Shrestha (2003) reported that lack of sufficient natural regeneration in *Q. semecarpifolia* in both disturbed and undisturbed sites of Himalayan region didn't have clear relationships with soil factors. Rather, anthropogenic and other environmental factors are suggested to be more influential than soil conditions.

Welander and Ottosson (2000) studied the influence of light, water and nutrients on seedlings growth of *Quercus robur*. The result showed that transpiration rate increased with light intensity for the first 11 weeks and it decrease with seedling age. Water use efficiency was highest with increasing N content and reduced soil moisture. Dry mass production was strongly correlated with transpiration in relation to light, but the correlation was weaker when nutrient strength and water availability changed. On the other hand, Davis *et al.* (1999) revealed that herbaceous competition significantly affected seedling survival, growth, and photosynthesis in oak seedlings but the effect varied with multiple resource gradients. Seedling survival was found higher in wetter and shaded plots with herbaceous vegetation removed. Seedling survival and rate of photosynthesis was highly correlated with soil water availability.

Aspect is one of the many site factors which influences the growth and distribution of vegetations. Singh (1998) found that the northern and southern aspects of Tirthan valley of Kulu district of Himachal Pradesh showed variation in species composition. The dominant species in the northern aspect are *Cedrus deodara*, *Abies pindrow*, and *Picea smithiana*, whereas, in the southern aspect the dominant species are *Pinus wallichiana*, *Rhododendron arboretum*, and *Quercus semecarpifolia*. Collins and Carson (2004) also evaluated the importance of aspect, slope position, elevation, site index, and stand age in determining the abundance of seedlings, saplings and trees of three *Quercus* species. According to this study, these site characteristics are significantly correlated with oak densities for atleast one life stage and species combination. However, no single site characteristic has emerged as being significantly correlated with oak densities across all life stages and species.

Cerny *et al.* (2013) recognized three types of vegetations along the slope of Korean peninsula: *Quercus mongolica*- *Lindera obtusiloba* dominated forests in the lower altitude, *Carpinus tschonoskii*- *Abies koreana* dominated forests in the middle altitude and *Acer pseudosieboldianum*- *Rhododendron schlippenbachii* dominated forests in the upper altitudes.

Ali (2007) found a strong correlation of soil chemicals and elevation of *Taxus wallichiana* forests of Kulu and Mandi districts. He observed that organic carbon, soil moisture, available phosphorus and organic matter layer increase with increasing elevation. On the other hand, soil PH, available nitrogen and potassium decreased with increasing elevation range. Griffiths *et al.* (2009) also reported significant increase in soil moisture, mean annual precipitation, soil organic matter, labile C, mineralizable N, microbial activities, extractable ammonium, and denitrification potentials, whereas, bulk density, soil pH and soil temperature decreased with increasing altitude. According to Lanker (2007) soil moisture, organic carbon, available nitrogen, and available phosphorus decreased with increasing soil depth, but soil pH and available phosphorus increased with increase in soil depth.

There are various disturbance factors in forest ecosystems, like past logging activities, illicit logging, grazing, lopping, fuel wood collection, and other anthropogenic factors. Although heavy disturbance has a negative impact on forest communities, low disturbance has shown certain advantage in improving species richness and biodiversity (Anitha *et al.* 2009). Comparing protected and unprotected (disturbed) vegetations in Nepal, Thapa and

Chapman (2010) observed that tree density, basal area, diversity and species richness are affected by disturbance. While, Pokhriyal *et al.* (2012) reported decline in the tree density and basal area with increasing disturbance, but species richness decreased in *Quercus leucotrichophora* forest and increased in *Anogeissus latifolia* forest with increasing disturbance regime. Thadani and Ashton (1995) reported that moderate disturbance benefited regeneration of *Quercus leucotrichophora* forests of central Himalaya. Rawat *et al.* (2011) advocated climate change and anthropogenic factors to be the main cause of the declining pine, oak and mixed forests of Dabka watershed of lesser Himalaya. Singh and Rawat (2012) listed three important anthropogenic factors, viz., grazing, fuelwood and fodder collection responsible for the decline of oak forests of western Himalaya.

Lhotka (2013) emphasized the importance of available light (canopy opening) in determining stand structure and species composition of mixed broadleaf forests following 48 years of treatment. The study recorded the dominance of *Acer* species, *Quercus* specie, and *Liriodendron tulipifera* in the lower (0.02 ha), moderate (16 ha) and higher (0.46 ha) openings, respectively. After 48 years treatment basal area, top height, and quadratic mean diameter was found lower in the lower openings. Mahajan (2010) recorded higher solar intensity and lower leaf area index in lower diameter classes of chir pine forests than upper diameter classes.

Lochhead and Comeau (2012) recorded a strong correlation of light condition and understorey vegetation. They observed that light enhances the growth and abundance of natural regeneration in Douglas-fir dominated forests of British Colombia. Whereas, Lof *et al.* (1998) identified the interactive effect of light intensity and soil water content in influencing the growth of oak seedlings. Rao *et al.* (1997) reported the positive correlation between photosynthetically active radiation (PAR) and soil moisture.

Welander and Ottosson (1998 & 2000) observed that low light conditions has no effect on the growth of oak and beach seedlings during the first year, but light intensity should increase after one year to maintain the proper growth of oak seedlings. They also studied the influence of light, moisture, and fertilization on the transpiration and growth of *Quercus robur* seedlings. The study also concluded that water use efficiency and growth increased with nutrient availability and reduced soil water content.

Ashton and Larson (1996) investigated the influence of demographic features and light conditions on germination and early growth of three *Quercus* species. Seedling growth and flushing rate in the first growing season were higher in treatments, which obtained direct sun light. Considering demographic features, valley centers were found better than ridge tops in augmenting the height of seedlings after three growing seasons.

Pausas and Austin (2001) reviewed literatures that related plant species richness with environmental factors. They observed that soil pH and nutrient availability was found to be one of the factors, which determine species richness. Moderate nutrient availability and soil pH were found to be species rich than the lower and higher available nutrient and soil pH values. Different studies suggested that species richness to be positively correlated with water availability but negatively correlated with light intensity. Sagar *et al.* (2008) also reported that intermediate levels of light intensity, soil moisture and soil carbon are associated with highest herbaceous diversity of forests in the Gangetic plains of India

According to Cerny *et al.* (2013) total species richness is positively associated with soil reaction and negatively associated with soluble phosphorus and solar radiation (site dryness). Tree richness was associated mainly with soil factors. The relationship between herbaceous plant richness and altitude forms a U-shaped curve; herbaceous richness being higher in the upper and lower altitudes. There was no correlation between the degree of canopy openness and herb layer richness. However, Dech *et al.* (2008) revealed that canopy cover and soil fertility determined the composition of understorey plant communities in *Quercus ruber* dominated forests of Canada.

According to Collet *et al.* (1998) vegetation manipulation around young oak seedlings affects their growth by altering light, temperature and vapour pressure conditions. In open grown seedlings height growth was suppressed, while diameter growth was enhanced. The reverse was true for seedlings grown under competition. Generally, lateral shades afforded by adjacent vegetation affects stem allometry and fork development. Jensen *et al.* (2011) also observed that shrub competition resulted in 60-74 % reduction in leaf area, 29-36 % reduction in basal diameter, and 38-78 % reduction in total biomass of *Quercus robur* seedlings. However, root-shoot ratio was not affected by shrub competition. Chaar *et al.* (1997) also reported the effect of environmental factors, grass competition, partial shading, and frost on the shoot growth of *Quercus petraea* seedlings. All these treatments reduced number of flushes in the growing season. Grass competition reduced annual seedling growth,

while partial shading increased annual seedling growth. Frost increased the death of terminal buds. In addition to silvicultural practices (pruning) that increased the diameter and height growth of Holm oak plantations, site factors such as gravel cover, vegetation cover and slope position had also effect on the diameter and height growth of younger plantations in central-western Spain (Lacambra *et al.*, 2012).

Vegetations are known to modify the micro environment where they grow. Biswas and Khan (2010) reported that variation in nutrient use efficiency and nutrient retranslocation efficiency between different species. Hence, oaks are more efficient in nutrient dynamics than pines (Jina *et al.* 2009). However, soil nutrient content in *Acer rubrum* had been found better than oak dominated sites and the least nutrient content was recorded in pine dominated sites (Washburn and Arthur, 2003).

2.5 STRATIFICATION OF SEEDS

2.5.1 Effect of stratification duration on germination

Stratification is the process of treating seeds with cold or warm temperature condition for certain period of time in order to break dormancy. It is mimicry of nature whereby seeds germinate well after a period of cold/chilly condition in temperate areas or warm/hot conditions in the tropics. Stratification is an important treatment of seeds to obtain uniform seed germination in a relatively short period of time.

Pandey and Tamta (2013) studied the effect of scarification and cold stratification on *Q. serrata* seeds. They concluded that seeds treated with scarification and a 20 days cold stratification was the most effective treatment with 88.7 percent germination in 11 days as compared to 14.7 percent germination in 28 days in the control. Separate treatments of scarification and stratification showed lower improvements than combined treatments.

Merouani *et al.* (2001) stratified *Quercus suber* seeds at 0 °C for 0, 2, 4 and 6 months to examine its effect on emergence and physiological status of seedlings. Seedling emergence rate was reported to be higher than 90 %, irrespective of the duration of seed storage. However, the duration of seed stratification affected significantly seedling emergence time and uniformity by breaking epicotyl dormancy, which is a cause of delay in emergence of seedlings from fresh seeds as compared to stored seeds. Castro *et al.* (2012) also studied the effect of stratification, heat, and scarification treatments on germination of *Quercus rugosa*

seeds. The germination percentage and lag time showed significant difference among treatments. Acorns treated at 5 °C for one week had maximum germination percentage. Similarly, Doody and Oreilly (2008) studied the effect of three treatments (i) drying (ii) soaking (iii) drying and soaking on the germination of acorns of *Quercus robur* before and after storage at -3 °C for six months. Their result indicates that germination was significantly reduced for soaked and stratified seeds (from 79 % to 69 %) but it had no effect on acorns treated with cold storage after drying and soaking (80 % before and after stratification). Ozbingol and Oreilly (2005) reported improvement in germination of *Quercus robur* seeds from 18 % for untreated seeds (control) to a maximum of 76 % for adjusting acorn moisture content at 46 % and storing it for six months.

In the tropical tree species, it is common to apply warm stratification to break their dormancy. Martin *et al.* (2009) applied heat (40 °C) for 40, 60 and 80 days to break the dormancy of *Elaeis guineensis* seeds. A 60 days heat application had been proved to improve the germination percentages (56.3 %) than other treatments. Similarly, Mubvuma *et al.* (2013) stratified *Moringa olifera* seeds at 10, 25 and 35 °C for 0, 30, 60, 90 and 120 days to evaluate their effect on their germination. The study revealed that the use of low temperature (10 °C) increases germination with increased duration. They observed that the use of high temperature (35 °C) for 60 days yielded maximum germination (83.0 %) but has no significant difference with 30 or 90 days duration at the same temperature.

2.5.2 Effect of stratification medium on germination

Not only stratification duration, but stratification medium has also an impact on the germination of tree seeds. For instance, Pasquini *et al.* (2011) studied the effect of stratification medium on germination, moisture content, and electrolyte leakage of Holm oak (*Quercus ilex*). The result indicated that seed stored in polyethylene bag had maintained viability up to the test time (1 year), whereas seeds stored in peat and moist sand lost their viability over time.

Mc Creary (2009), on the other hand reported moist and well drained sand, or sand and peat can be used for 30 to 90 days at a temperature of 0 to 5°C to break dormancy of black oaks. Venkatesh *et al.* (2009) also studied the effect of seed size and stratification medium on germinability and seedling biomass of *Sapindus emarginatus* and found a 1:1:1

ratio of Sand, soil and humus to be the best stratification medium with highest germinability of seeds.

Cicek and Tilki (2008) studied the effect of stratification on germination of *Pterocarya fraxinifolia* seeds and concluded that cold stratification for five weeks without media improved germination percentage and germination values of the species. Malik and Shamet (2009) reported that cold stratification (0 ± 1) with earthen pots maintain better viability of *Pinus gerardiana* seeds up to a year.

2.6 SEED GERMINATION

2.6.1 Effect of pre-sowing treatments on germination

Seed germination can be defined as the emergence of primary roots and shoots from seed embryo, which have the ability to produce normal plant under favorable condition. In most laboratory trials a seed is considered as germinated only by looking the protrusion of primary roots. However, seed germination is not a straight forward physiological process in many seed plants. Seed dormancy is a common problem in various trees that can be broken by physical, chemical, and/or physiological means. Processes which involve one or more of these methods in order to break seed dormancy before seed sowing are called pre-sowing treatments. Most pre-sowing treatments are effective in breaking seed dormancy and producing uniform germination in a short period of time.

Adams *et al.* (2010) tested the effect of 100, 200, 300ppm concentrations of Gibberellic acid soaking for 24 hours on germination of *Quercus pagida* and *Quercus nuttallii*. They concluded that there was no significant difference among germination values of *Q. nuttallii*, while a 300 ppm concentration of GA₃ was found to be effective for enhancing germination value of *Q. pagida*.

Purohit *et al.* (2009) studied the effect of different pre-sowing treatments on seed physiology and germination of central Himalayan oaks. They found that KNO₃ (1 %) to be the most effective pretreatment in increasing germination percentages.

Struve (1998) studied the effect of seed conditioning of red oak (*Quercus rubra*). He found that seed conditioning treatment of soaking for 10 days in aerated water resulted in higher germination, uniformity and speed compared to control seeds. The effect of seed conditioning was found to be ineffective on dormant seeds. On the other hand, soaking

Cedrus deodara seeds for 2 days at 4°C showed higher germination than seeds stratified for 2 weeks at 4°C (Brand and Rivo, 1999). Doody and Oreilly (2008) also reported a significant increase in germination of *Q. robur* acorns after soaking as well as drying and soaking pretreatments.

McCreary and Koukoura (1990) observed that any pre-sowing treatment of *Quercus douglasii* acorns should avoid loss of its moisture content. A 10 % loss of moisture content reduced the germination by 40 % and a loss of 25 % moisture content resulted in germination failure. Under natural condition, fire and flooding are found to improve regeneration and growth of oak seedlings (Wang *et al.* 2005, Kuhne and Bartsch, 2007). In addition to pre-sowing treatments, Navarro and Guitian (2003) emphasized the influence of seed source population on the variation in germination of *Petrocoptis grandiflora* and *P. viscosa* trees.

2.6.2 Effect of seed size on germination

Seed size is one of the many factors, which regulate seed germination and initial seedling growth. Large seeds generally contain much food reserves that support germination and seedling growth during initial stages.

Landergott *et al.* (2012) studied the effect of seed mass on seedling height and competition of European white oak species (*Quercus robur*, *Q. petraea*, *Q. pubescens*) and concluded that seed size influenced both seedling height and competitive advantage of seedlings. Similarly, Lommasson (1986) studied germination and seedling survival of red oak (*Quercus rubra*) in prairie habitats. Small seeds (under 5.5 g), medium seeds (5.5 to 6.5 g) and bigger sized seeds (over 6.5 g) had a 31, 76, and 100 % root biomass production thereby indicating better success in bigger seeds. Venkatesh *et al.* (2009) reported that seedlings of *Sapindus emarginatus* germinating from larger seeds exhibited higher seedling biomass (2.17 g) than seedlings produced from medium (1.86 g) and small sized seeds (1.62 g). Suresha *et al.* (2007) reported 98 %, 80 % and 70 % germination in larger, medium and smaller seeds, respectively of *Sapindus emarginatus*. According to Tilki (2010) germination percentage of *Quercus petraea* was found to be higher (95 %) for medium sized acorns followed by large (93 %) and small (87 %) ones. However, these values dropped to 68 %, 64 % and 54 %, respectively after 17 months of storage. Venudevan and Srimathi (2013) reported higher germination, seedling vigor, and biochemical content of larger seeds of bael (*Aegle*

marmelos). Gunaga and Vasudeva (2011) also reported higher (79.2 %) germination of larger seeds of *Mammea suriga* than medium (59 %) and smaller (22 %) ones.

In addition to germination, seed size has a direct effect on initial seedling growth and survival. Bonfil (1998) studied the effect of seed mass on the growth and survival of *Quercus rugosa* and *Q. laurina* species and reported that seed size significantly affected seedling height, diameter, leaf area, and biomass after 6 months of growth. Gonzalez-Rodriguez *et al.* (2011) reported that seed mass has an effect on reserve food, initial growth, metabolism and seedling growth of four *Quercus* species. Merouani *et al.* (2001) and Singh *et al.* (2010) reported positive correlation between seed size and seedling biomass.

Caliskan (2013) reported significant variation in acorn morphology (length, width and weight) and germination parameters among provenances of *Quercus Ilex*. Germination of *Quercus Ilex* was found better in alternating temperature 10/20 °C than at constant 20 °C. Similarly, Singh *et al.* (2010) reported that acorns of *Quercus glauca* collected from different population, which vary in altitude, had significant differences in seed length, seed weight and germination percent.

2.6.3 Effect of biochemical content of seeds on germination

The biochemical content of seeds is used as food reserves during germination and seedling growth. The quality and quantity of food reserves is usually associated to the success of germination of seeds and initial growth of seedlings. These characteristics of seeds also have a negative impact on seeds by attracting diverse predators which is a common phenomenon on most oak seeds.

Venudevan and Srimathi (2013) investigated the close relationship between physical, physiological, and biochemical qualities of Bael (*Aegle marmelos*) seeds. They found that bigger seeds which were retained by a 6.4mm sieve had higher germination rate, seedling vigor and biochemical content than smaller seeds, which passed on 5.5mm sieve. α - amylase activity (5.2 cm), dehydrogenase (0.193), protein (17.4 %), and oil content (34.1 %) were also found to be higher in bigger seeds.

Connor and Sowa (2004) found that germination of *Quercus alba* and *Quercus pagoda* was sensitive to moisture content of acorns. *Quercus pagoda* had high amount of lipids and its concentration was not affected by desiccation of acorns. *Quercus alba*, on the

other hand, had high amount of carbohydrates (sucrose) and this amount fluctuated constantly as acorns desiccate.

Chaitanya *et al.* (2000) investigated rapid loss of viability of *Shorea robusta*. They associated it to gradual decline in total protein content and the corresponding increase of protease activity. Loss of total protein content within 3 days after collection was recorded to be 43.7 % in embryonic axis and 52 % in cotyledons. Protease activity, which was 0 in freshly harvested viable seeds detected after 12 hours of storage, reached its peak ($0.71 \pm 0.04 \text{ min}^{-1} \text{ mg}^{-1}$ of protein) at 6th day after harvest.

Zitnik *et al.* (1999) found that the amount of phytic acid both in fresh seeds as well as stored seeds is responsible for germination of sessile oak (*Quercus petraea*). Phytic acid content of seeds had direct relation with phosphorus content of the leaf and the soil. Seeds with high phytic acid showed better germination. However, the content of phytic acid was significantly reduced on seeds stored at -1⁰c for six months along with significant reduction in germination.

Andarwulan *et al.* (1999) studied biochemical changes of seeds of *Pangium edule* during germination. The study observed changes in antioxidant activities and mobilization of lipids and phenolics. On germination, lipid content decreased, while dominant fatty acids do not change significantly. Antioxidant activity of phenolic extracts increased in proportion to total phenolics and free proline. Alencar *et al.* (2012) studied seed reserve composition and mobilization of biochemicals during germination and early seedling growth of *Cereus jamacaru* seeds. They reported that lipids and soluble protein encompass 55 % and 40 % of the dry mass of cotyledon while soluble sugar and starch cover only 2.2 % of the dry mass of cotyledon. During germination, soluble protein reduced by 81 %. Soluble sugar and starch also showed significant reduction in germinated seeds. Similarly, Satyanaranaya *et al.* (2011) studied biochemical changes in the germinating seeds of *Sterculia urens*. In 15 days germination period, total protein content decreased in cotyledons while amino acid content increased reaching its maxima on 9th day of germination and it decreased thereafter. The level of reducing sugar and total soluble sugar increased upto 6th day of germination and declined thereafter. Lipid content was also high at initial stage, which also showed decrease in later stages.

Rakic *et al.* (2005) evaluated the nutritional value of *Quercus robur* acorns. They reported the presence of tannins, proteins, crud ash, K, P, Fe and Cu with a concentration of 11.2 %, 14.2 %, 8.3 %, 3.4 %, 0.4 %, 23.2 mg kg⁻¹, and 13.2 mg kg⁻¹, respectively. While, Rodriguez-Estevez *et al.* (2009) reported variations in nutrient composition of *Quercus ilex rotundifolia* acorns and the average minimum and maximum chemical constituents reported were: 4.22 and 5.56 % crud protein, 49.81 and 60.43 % starch, 5.62and 13.46 % sugars, and 7.05 and 11.1 % crude fat.

Chapter-3

MATERIALS AND METHODS

The present investigation entitled “**Site characteristics and regeneration studies of bani oak (*Quercus glauca* Thunberg) in Himachal Pradesh**” was conducted during the years 2013-2015. Field studies were conducted at six *Quercus glauca* bearing forests of Solan, Narag, and Sarhan forest ranges, (HP). Nursery and laboratory studies were conducted at laboratory and nurseries of the department of Silviculture and Agroforestry, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP). This chapter provides details of experimental sites, materials used, and methods adopted during the course of the study period. Sampling designs, data collection methods, and data analysis methods that helped to draw necessary conclusions have been discussed as below.

3.1 EXPERIMENTAL SITE

3.1.1 Location I

After reviewing literature on the distribution of *Quercus glauca* bearing forests in Himachal Pradesh, six *Quercus glauca* forest stands at Solan and Sirmour district were selected non-randomly in Solan and Sirmour districts of Himachal Pradesh, India. The presence of over story *Quercus glauca* trees in the forest ecosystems and accessibility were the main criteria for selection. The selected forests were: Shilli and Oachghat from Solan forest range, district solan; Deothal and Narag from Narag forest range, district Sirmour; and Chakla and Tikri from Sarhan forest range, district Sirmour (Figure 1). *Quercus glauca* forests of Kangra valley, Khasi hills, Kumaun hills, Mandi state, Beas valley, and moist valleys of Solan and Sirmour districts were assessed during the preliminary survey, which were conducted in September and October 2013. Phytosociology, stand characteristics, natural regeneration and site characteristics studies were conducted in the selected *Quercus glauca* bearing forests of Solan, Narag and Sarhan forest ranges. Details of each study site were presented below in Table 1.

3.1.2 Location II

Seed germination studies, stratification experiments, biochemical and soil chemical analysis were conducted under nursery and laboratory of the Departmental of Siviculture and

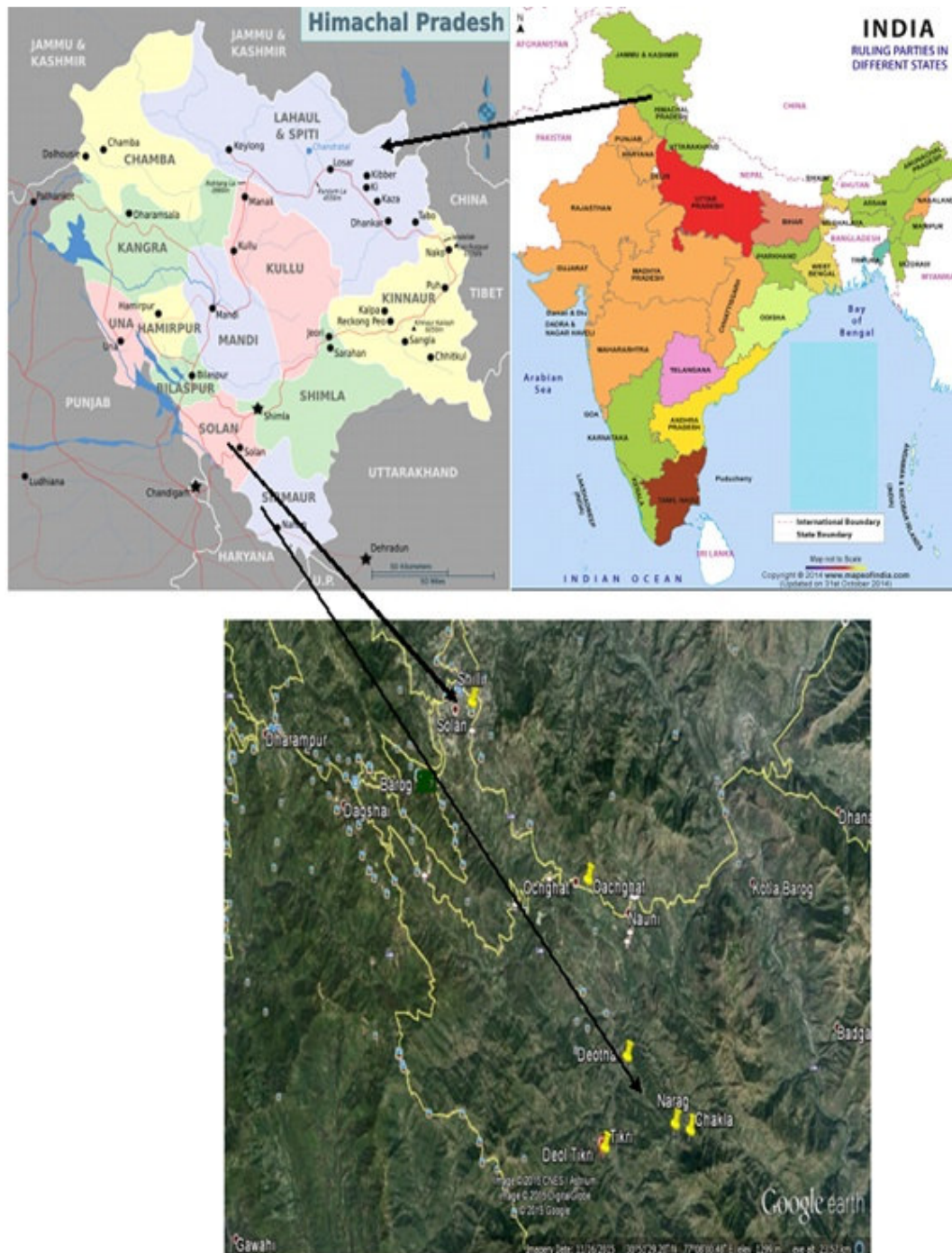


Figure 1: Map of the study area

Agroforestry of Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni-Solan (HP). The university is located at 30°51' North latitude and 76°11' East longitude at an average elevation of 1250m above sea level at a distance of 14 km from Solan along the Solan- Rajgarh road. It has a subtropical to sub-temperate climate with annual rainfall of 953 mm to 1465 mm. Most of the rains are received during monsoon season of July and August supplemented by small showers of rain during winter. Frost occurs recurrently from December to February. December and January are the coldest months, while May and June are the hottest ones.

Table 1: General details of the study sites

Forest area	Forest Range	Latitude	Longitude	Altitude	Forest type	Access
Shilli	Solan	30°54.563N	77°07.172E	1467	Protected	Restricted
Oachghat	Solan	30°52.055N	77°07.432E	1220	Private	Open (to owner)
Deothal	Narag	30°49.767N	77°09.538E	1052	Communal	Open
Narag	Narag	30°49.385N	77°10.251E	1127	Protected	Restricted (loose)
Chakla	Sarhan	30°48.352N	77°10.581E	1165	Community	Open
Tikri	Sarhan	30°48.024N	77°09.894E	1096	Community	Open

3.2 EXPERIMENTAL METHODOLOGY

Experiment 1: Study on site characteristics and natural regeneration status of *Quercus glauca* in its natural habitat

The aim of this study was to assess the regeneration status of *Quercus glauca* and the influence of biotic and abiotic environment on establishment of seedlings and saplings of the species. Phytosociology and stand characteristics of the forest are the major biotic factors investigated while soil characteristics and solar influx were the abiotic factors considered in the study.

3.2.1 Phytosociological study

Assessment of the phytosociology and floristic composition of *Quercus glauca* bearing forests recognized all trees, shrubs and herbs observed in the sample plots. A sketch of the forest stands with a grid of 100 m × 100 m was prepared and each grid was given a number from which three grids were randomly selected by lottery method. The selected grids were considered as replications. At the center of the grid a 20m × 20m sample plot was laid to investigate tree related traits. Within each tree sample plot, five quadratic sub-plots of size

5m × 5m and ten quadratic sub-sub-plots of size 1m × 1m were laid out to investigate shrub and herb related traits, respectively. Non random sampling method was used to allocate shrub and herb sample plots. The four corners and the center of the tree plot were used to lay the shrub sub-plots, whereas opposite sides of the shrub sub-plot was used to lay the herbaceous sub-sub-plots. Species assessment was made and species-area curve was drawn during preliminary survey in order to determine plot sizes of trees, shrubs and herbs. Phytosociological parameters, such as density, basal area and frequency of plant communities, were assessed from the collected data by using formulas (Raunkiaer, 1934; Misra, 1968; Menon and Balasubramanyan, 1985) which are described as follows:

3.2.1.1 Density (D)

It measures the total number of individuals per unit area and calculated as:

$$\text{Density (D)} = \frac{\text{Total number of individuals}}{\text{Total number of quadrates studied}}$$

3.2.1.2 Basal area

It measures the cross-sectional area of the stem and it is obtained by the following relationship with diameter/girth

$$\text{Basal area} = \frac{\pi d^2}{4}$$

Where:

d – Diameter at breast height (1.37m)

3.2.1.3 Frequency (F)

It measures the degree of occurrence of a species in sampling units, thus it expresses the distribution of various species in the community.

$$\text{Percent frequency (\%)} = \frac{\text{Number of sampling units in which the species occurs}}{\text{Number of sampling units studied}} \times 100$$

3.2.1.4 Relative density, relative basal area and relative frequency

These parameters were obtained from per cent frequency, density and basal area by using the following relationships:

$$\text{Relative density (RD)} = \frac{\text{Number of individuals of the species}}{\text{Number of individuals of all species}} \times 100$$

$$\text{Relative basal area (RBA)} = \frac{\text{Total basal area of the species}}{\text{Total basal area of all the species}} \times 100$$

$$\text{Relative frequency (RF)} = \frac{\text{Number of occurrence of the species}}{\text{Number of occurrence of all species}} \times 100$$

3.2.1.5 Importance value index (IVI)

IVI is the sum total of relative density, relative basal area and relative frequency and was calculated for all herbs, shrubs and tree species separately at each study sites.

$$\text{IVI} = \text{Relative basal area (RBA)} + \text{Relative density (RD)} + \text{Relative frequency (RF)}$$

3.2.1.6 Similarity Index (SI)

It expresses the ratio of common species to all the species found in the vegetation and is determined by the method given by Sorenson (1948).

$$\text{SI} = \frac{\text{Number of common species in two stands (stand A and B)}}{\frac{1}{2} (\text{Total number of species in stand A} + \text{stand B})} \times 100$$

3.2.1.7 Shannon diversity index ($\bar{H}$)

Species diversity was determined by Shannon's diversity index and it was calculated by using Margalef formula (Odum, 1971) as given below:

$$\bar{H} = - \sum (n_i/N) \times \text{Log} (n_i/N)$$

Where:

n_i = Importance value of each species

N = Total importance value

3.2.1.8 Species richness (D_{mg})

Species richness was calculated by Margalef's index of species richness (Magurran, 1988).

$$D_{mg} = \frac{(S-1)}{\ln N}$$

Where: D_{mg} = Margalef's species richness index
 S = total number of species
 N = total number of individuals

3.2.1.9 Species dominance (D)

Species dominant was calculated by using Simpson (1949) index of dominance and the equation was presented as follows:

$$D = \sum (p_i)^2$$

Where, D = Simpson index of dominance.
 P_i = the proportional important value of the i^{th} species ($p_i = n_i/N$, n_i is the important value index of i^{th} species and N is the important value index of all the species).

3.2.2 Stand characteristics study

3.2.2.1 Tree identification and counting

Trees within each sample plot were identified and counted to determine density and species composition of the stand. Plant specimens were collected for all plants that occurred in the plots, sub-plots and sub-sub-plots of each study site. These specimens were submitted to the herbarium of college of forestry, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) for proper identification and botanical nomenclatures.

3.2.2.2 Tree height (m)

Tree height of a standing tree refers to total distance along the stem between base of the stem at ground level and tip of the leading shoot. Height was measure from the uphill side of the tree in slope areas (Chaturvedi and Khanna, 1982) with the help of Spiegel relaskop.

3.2.2.3 Diameter at breast height (m)

Two diameter measurements of the stem (major and minor axis) at breast height (1.37m) were taken with tree caliper and their mean was combined as dbh of a tree. Whenever, meter tape was used for diameter measurement, the following formula was applied to convert circumference (c) to diameter at breast height.

$$Dbh = c/\pi$$

Where c stands for circumference at breast height

3.2.2.4 Form factor (ff)

Form factor was calculated using the formula given by Pressler (1865) and Bitterlich (1984).

$$ff = \frac{2h_1}{3h}$$

Where,

- ff = Form factor
- h_1 = Height (m) at which diameter is half of the dbh
- h = Total height (m) of the tree

3.2.2.5 Volume of standing trees (m^3)

Volume of standing trees was calculated by Pressler (1865) formula and expressed in cubic meters.

$$V = \frac{\pi \times d^2 \times h \times ff}{4}$$

Where,

- V = Volume (m^3)
- d = Diameter at breast height (cm)
- h = Tree height (m)
- ff = Form factor

3.2.2.6 Crown width (m)

The crown width was measured in two directions (North-south and East-west) and their average was calculated as suggested by Assmann (1970) and Chaturvedi and Khanna (1982). Crown width is expressed in meters.

$$CW = \frac{D1 + D2}{2}$$

Where:

- CW = Crown width (m)
- D_1 = First measured crown diameter (m)
- D_2 = Second measured crown diameter at right angle to the first Measurement (m)

3.2.2.7 Crown length (m)

It is the vertical measurement of the crown of a tree from the tip to the point half way between the lowest green branches forming green crown all round and the lowest green branch on the bole and was measured with the help of Spiegel relaskop and expressed in meters.

3.2.2.8 Crown projection ratio (CPR)

It is the ratio which states that by how many times the crown diameter is larger than the stem diameter (Assmann, 1970).

$$\text{Crown projection ratio} = \frac{\text{Crown width}}{\text{Stem diameter}}$$

3.2.2.9 Crown fullness ratio (CFR)

Crown fullness ratio is the ratio between crown width and crown length as indicated by the following formula:

$$\text{Crown fullness ratio} = \frac{\text{Crown width}}{\text{Crown length}}$$

3.2.2.10 Specific gravity

Specific gravity was estimated by using maximum moisture method (Smith, 1954) for samples taken from the main stem. The wood in the form of disc (5-8cm) was removed from two places (one at base and another at breast height) for the determination of specific gravity of wood. The fresh weight of samples was taken immediately after cutting. Then these samples were kept in oven at $102 \pm 1^\circ\text{C}$ until they obtain a constant weight. Dried samples were weighed and specific gravity of these samples was determined by applying the following formula:

$$\text{Specific gravity} = \frac{1}{\frac{M_f - M_o}{M_o} + \frac{1}{GS_o}}$$

Where,

- M_f - fresh weight of sample that has maximum moisture content
- M_o - Oven dry (constant) weight of sample
- GS_o - Average density of wood, a constant having value of 1.53

The final value was determined by taking out the average of samples taken from basal end and at breast height.

3.2.3 Natural regeneration study

Natural regeneration survey was carried out inside pre-demarcated sample plots of trees. Five sub-plots of size 2 m × 2 m were laid down for conducting regeneration survey. 2500 established saplings per hectare were considered to express satisfactory regeneration. Similarly, the plot was considered fully stocked when it contained at least one established plant (Chako, 1965).

The survey was conducted for recruits (defined as current years seedlings), unestablished regeneration (seedling other than recruits which has not yet established and their height is less than 2 m) and established regeneration (that have a height of 2m or more).

3.2.3.1 Data recording

The regeneration data for *Quercus glauca* and associated species was collected on the basis of number of individuals occurring at seedling, sapling and pole stage in each sub-plot. The height of unestablished plants was also measured for the assessment of regeneration (Champion, 1935).

3.2.3.2 Regeneration assessment

The data thus collected was analyzed using the formulas given by Chako (1965) as follows:

$$\text{Recruits (r) ha}^{-1} = 2500 \sum_{i=1}^n r_i / m$$

$$\text{Unestablished regeneration (u) ha}^{-1} = 2500 \sum_{i=1}^n u_i / m$$

$$\text{Established regeneration (e) ha}^{-1} = 2500 \sum_{i=1}^n e_i / m$$

Where:

n - Number of sampling units

m – Total number of recording units in the survey

ri – Total number of recruits in each sampling unit

ui – Total number of unestablished plants in each sampling unit

ei – Total number of established plants in each sampling unit

$$\text{Weighted Average height (m)} = \frac{\text{Total height of unestablished regeneration} + (\text{Number of established plants} \times \text{establishment height})}{\text{Total unestablished plants} + \text{Total established plants}}$$

On the basis of the above estimates the following indices were calculated:

$$\text{Establishment index (I}_1\text{)} = \frac{\text{Weighted average height}}{\text{Establishment height (2 m)}}$$

$$\text{Stocking index (I}_2\text{)} = \frac{1/2500 \times \text{unestablished regeneration ha}^{-1} + \text{established regeneration ha}^{-1}}{4}$$

$$\text{Established stocking per cent} = 100 (I_1 \times I_2)$$

$$\text{Regeneration success (\%)} = \text{Stocking index (I}_2\text{)} \times 100$$

3.2.4 Site characteristics study

3.2.4.1 Soil studies

3.2.4.1.1 Soil physical property

Soil moisture content and thickness of soil organic matter were considered as a measure of soil physical property. Soil moisture content was assessed in April by taking three soil samples from each plot and pooled together. Separate samples were collected for 0-15 cm and 15-30 cm soil depths. Fresh samples within moisture boxes were weighed and then oven dried till constant weight to measure their dry weight.

$$\text{Soil moisture content (\%)} = \frac{\text{Fresh weight} - \text{Oven dry weight}}{\text{Oven dry weight}} \times 100$$

Organic matter layer was assessed in all selected forest sites by taking the average of three random measurements from top, middle and bottom of the plot along the slope. Measurements were made with the help of scale and expressed in centimeters.

3.2.4.1.2 Soil chemical analysis

Composite soil samples were used for soil chemical analysis. Three soil samples, from top, middle and bottom of the plot along the slope, were collected from two depths 0-15 cm and 15-30 cm to assess depth-wise distribution of soil nutrients in all sites. These samples were then air dried and mixed before they were grounded with mortar and pestles and sieved

with 2 mm mesh sieve before analysis. Details of methodologies employed for estimating different soil chemical parameters are given in table 2 as below:

Table 2: Methods applied for soil chemical analysis

Particular	Method employed
Soil pH	1:2.5 soil: water suspension, with the help of digital pH meter (Jackson, 1973).
Organic carbon	Walkley and Black method (1934).
Available nitrogen	Alkaline potassium permanganate method of Subbiah and Asija (1956).
Available phosphorus	Olsen <i>et al.</i> (1954).
Available potassium	Flame photometer method of Merwin and Peach (1951)

3.2.4.2 Solar influx

Light illumination under the canopy of selected *Quercus glauca* forests and in an open field outside the forest area was recorded by using luxmeter during day time. The value in percentage of light intensity under canopy to that of the open was calculated as under (Rao, 1998).

$$\text{Solar influx (\%)} = \frac{\text{Total solar radiation beneath the canopy}}{\text{Total solar radiation in open}} \times 100$$

Experiment 2: Study on the effect of stratification medium and duration on germination and seedling growth of *Quercus glauca*

3.2.5 Stratification study

Stratification is a process of exposing seeds for cold or hot environmental conditions in order to break seed dormancy. Stratification media, temperature, and duration are important components of stratification which influence success in breaking seed dormancy. Stratification can be done in various ways by using different types of media under different temperature conditions (moist and dry) that usually last from few weeks to several months. In this particular experiment, seven stratification media and three durations were tested.

3.2.5.1 Seed Source

The seeds for stratification studies were collected from *Quercus glauca* forests at Deothal during late October 2013 and 2014. Collected seeds were packed in gunny bags and brought for the University for laboratory and nursery studies. Details of the treatments are given below:

3.2.5.2 Stratification medias

The following seven types of stratification media were used:

M₁: Sand

M₂: Farm Yard Manure (FYM)

M₃: forest soil (collected from *Quercus glauca* forest)

M₄: Sand + FYM (1:1)

M₅: Sand + FYM (2:1)

M₆: Sand + FYM + forest soil (2:2:1)

M₇: Control (local soil)

3.2.5.3 Stratification periods

The stratification was done for three different durations as below:

D₁: 15 days

D₂: 30 days

D₃: 45 days

3.2.5.4 Seedling growth studies

The seeds were stratified by keeping them inside pits dug out in the field and filled with the above mentioned stratification media for 15, 30 and 45 days durations. Stratification treatment was given during January-February, 2014 and 2015.

The experiment contained 21 treatment combinations, which were replicated thrice in Randomized Block Design (R.B.D). Twenty five viable seeds were used in each treatment. Viability of seeds was tested by immersing them in a bucket of fresh tap water. Seeds which sank were considered as viable. Then, seeds were there after sown in nursery and observations on seedling parameters were recorded after one growing season. Two independent experiments were conducted under open nursery and shade growing conditions with the same treatment combinations.

Germination counts were made for the first three months and data were recorded on weekly basis. Survival count was made at the end of the experiment and seedling growth parameters were assessed from five randomly selected seedlings of each replication at the completion of the study. The following attributes were recorded:

3.2.5.4.1 Germination (%)

Germination per cent was calculated as the number of seeds germinated from the total number of seeds sown and expressed in percentage.

3.2.5.4.2 Plant height (cm)

Plant height was recorded in centimeters from ground level up to the tip of stem.

3.2.5.4.3 Collar diameter (mm)

Collar diameter of the seedling was measured in millimeters (mm) using digital caliper.

3.2.5.4.4 Root - shoot ratio

It refers the ratio to the oven dry weight of the root divided by the oven dry weight of the shoot of each plant separately.

3.2.5.4.5 Number of lateral roots

It refers those roots that emerged from the main tap root and grow stronger having root hairs and further branches.

3.2.5.4.6 Root length (cm)

The length of tap root was recorded in centimeters (cm) using measuring scale by placing it horizontally on the ground.

3.2.5.4.7 Total biomass of seedlings (g)

It was expressed in grams as the sum of oven dry weight of the root and oven dry weight of the shoot.

3.2.5.4.8 Leaf number

Refers to the number of leaves that grown on the stem

3.2.5.4.9 Leaf area (cm²)

It is the area occupied by a single leaf as measured by leaf area meter and expressed as cm². Average of small, medium and large leaves was considered as leaf area for a seedling.

3.2.5.4.10 Survival (%)

It measures the number of seeds germinated and escaped mortality until the end of the season.

3.2.5.5 Study of stratification media

Available nitrogen (N), available phosphorus (P) and available potassium (K) of different stratification media were assessed by using the methods discussed in Table 2 of section 3.2.4.1.2.

3.2.5.6 Biochemical study

At the end of the stratification period 10 seeds were taken from each treatment for analysis of biochemical differences among the different stratification media and duration. Assessment was made for total sugar, total phenol, starch and soluble protein. Table 3 showed the methodology followed for biochemical analysis of *Quercus glauca* acorns.

Table 3: Methods applied for biochemical analysis

Particular	Method employed
Total sugar	Phenol-sulphuric acid method (Dubois <i>et al.</i> , 1951)
Total phenol	Folin-Ciocalteu reagent (Malik and Singh, 1980)
Starch	Conversion factor of 0.90 as indicated in (Dubois <i>et al.</i> , 1951).
Soluble proteins	Lowry <i>et al.</i> (1951)

3.2.5.6.1 Total sugar

Extraction of total sugar was made in such a way that one gram of dried sample of seeds was placed in 20-25 ml of boiling ethanol (80 %) for 10 minute and decanted. Another 10-15 ml of boiling ethanol was added to the residue. Thereafter, the two extracted sample filtrate were combined. The final volume was made to 50 ml. The alcoholic extract was then used for the estimation of total sugars while the residue was used for determination of starch. Total sugars in seed samples were estimated by phenol-sulphuric acid method as given by Dubois *et al.* (1951).

3.2.5.6.2 Total phenol

Total phenol of the seed samples were estimated by using Folin-Ciocalteu reagent in alkaline medium as described in Malik and Singh (1980).

3.2.5.6.3 Starch

Starch analysis was made by using the residue taken from sample extraction for sugar analysis (refer section 3.2.5.6.1). Starch content of the sample was estimated by multiplying the glucose content of the sample which was determined by phenol-sulphuric acid method with conversion factor of 0.90 as indicated in Dubois *et al.* (1951).

3.2.5.6.4 Soluble proteins

Soluble proteins were estimated by the method prescribed by Lowry *et al.* (1951).

Experiment 3: Study on the effect of pre-sowing seed treatment on germinability of *Quercus glauca* seeds

3.2.6 Germination study

Pre-sowing treatments are the most common physico-chemical methods used in nurseries to break dormancy and enhance germinability of seeds. In this experiment, the effect of pre-sowing treatments and seed size on germinability of *Quercus glauca* seeds was tested. Freshly collected *Quercus glauca* seeds were classified into three categories, i.e. small (S) medium (M) and large (L) based on their physical appearance and weight. The seven types of pre-sowing treatments were combined with these seed size categories making 21 total number of treatments combinations. Treatments were replicated three times and 25 viable seeds were allocated to each treatment. Germination test was done on a seed germinator at a temperature of $20\pm 3^{\circ}\text{C}$ in the department of Silviculture and Agroforestry. Germination tests were carried out upto 60 consecutive days starting from mid February to April of both testing years of 2014 and 2015.

3.2.6.1 Seed Source

As described in section 3.2.5.1 seeds were collected from *Quercus glauca* forests of Deothal in the month of October 2013 and October 2014.

3.2.6.2 Seed size

The seeds were classified into three groups (small, medium, and large) first by observing its physical appearance and then by weighing each seed on a digital balance and grouping them as small, medium, and large seeds. The mean weight of seed size of the two study years were as follows:

- S₁: Small ($\leq 0.5\text{g}$ in 2014 and $\leq 1.0\text{g}$ in 2015)
 S₂: Medium ($0.6\text{g}-1.0\text{g}$ in 2014 and $1.1\text{g}-1.7\text{g}$ in 2015)
 S₃: Large ($>1.0\text{g}$ in 2014 and $> 1.7\text{g}$ in 2015)

3.2.6.3 Pre-sowing treatments

3.2.6.3.1 Chemical pre-sowing treatments

The following seven pre-sowing treatments were tested in all combinations of the above mentioned seed sizes.

- T₁: Control (without any pre-sowing treatment)
 T₂: Soaking in cold water for 48 hours
 T₃: Soaking in hot water (80°C) for 5 minutes and followed by 48 hour cold water soaking
 T₄: Soaking in $3 \pm 1^{\circ}\text{C}$ cold temperature for 48 hours
 T₅: Soaking in $0 \pm 1^{\circ}\text{C}$ cold temperature for 24 hours
 T₆: Soaking in GA₃ (50ppm) for 24 hours
 T₇: Soaking in GA₃ (100ppm) for 24 hours

3.2.6.3.2 Physical pre-sowing treatments

Three physical pre-sowing treatment and a control in combination of the above mentioned seed sizes were also tested to enable comparison between physical and chemical pre-sowing tests on germination of *Quercus glauca* seeds. The treatments were:

- T₁: Exposed embryo (half a cotyledon containing embryo)
 T₂: Seed coat removed (without seed coat)
 T₃: Seed coat punctured at the base
 T₄: Control (without any physical treatment)

3.2.6.4 Germination study

The following germination parameters were assessed in the study: germination per cent, germination capacity, germination energy, germination value, germination index, and seed moisture content. The formulae used to estimate various germination parameters are described as below:

3.2.6.4.1 Germination per cent

Germination per cent was calculated as the ratio of number of seeds germinated to the total number of seeds sown and expressed in per cent.

3.2.6.4.2 Germination capacity (%)

It is the ratio of the sum of seeds that germinated during the germination period and ungerminated viable seeds to the total number of seed sown and expressed in per cent. Ungerminated viable seeds were identified by immersing exposed embryos of ungerminated seeds in 1 % aqueous solutions of tetrazolium for 24 hours in the dark. The stained embryos were considered as viable.

3.2.6.4.3 Germination energy (%)

Germination energy refers to the sum total of seeds germinated up to the peak and expressed in per cent. The peak period refers a day that has maximum number of germinations.

3.2.6.4.4 Germination value

Germination value, as defined by Czabator (1962), is the product of peak value and means daily germination. Peak value can be calculated as the maximum mean daily germination reached at any time during the germination period (Czabator, 1962). Mean daily germination, on the other hand, is calculated by dividing total number of seeds germinated by total number of days of the test period.

3.2.6.4.5 Germination index

Germination index was calculated by dividing the total number of seeds germinated at the end of the experiment by the time that 50 per cent germination occurred.

3.2.6.5 Biochemical study

In the biochemical analysis, moisture content, total sugar, total phenol, starch and soluble protein for small, medium and large *Quercus glauca* seeds treated with the above mentioned chemical pre-sowing treatments (refer section 3.2.6.3.1) were analyzed.

3.2.6.5.1 Moisture content (%)

Moisture content of seeds is expressed in percentage on fresh weight basis and it is determined by the following formula:

$$\text{Moisture content (\%)} = \frac{\text{Original weight} - \text{Oven dry weight}}{\text{Original weight}} \times 100$$

3.2.6.5.2 Total sugar, total phenol, starch and soluble protein contents

The procedure to assess total sugar, starch, total phenol, and soluble protein are based on the methods discussed in section 3.2.5.6.

3.2.6.6 Seedling growth studies

This study was conducted to see the effect of small, medium and large seeds treated with physical pre-sowing treatments on the growth of *Quercus glauca* seedlings. These treatments were described under section 3.2.6.3. A total of 25 seeds representing each treatment was sown in a root trainer and kept in a shade house for one growing season. Seedling measurements had been taken as described in section 3.2.5.4.

3.2.7 Statistical analysis

Descriptive statistics, scattered plots and histograms were made directly from a spread sheet in window excel 2007. Analysis of variance, correlation coefficients and regression equations were assessed by using Statistical Package for Social Sciences (SPSS) version 16.0 software. The least significant difference at 5 per cent level ($p < 0.05$) was used for testing the significant differences among treatments. The data for both years of investigation were pooled after performing homogeneity test. The heterogeneous data was pooled by the weighed means method as discussed in Nigam and Gupta (1979). Germination parameters, which are described as percentages, were arc-sine transformed before analysis.

Chapter-4

EXPERIMENTAL RESULTS

The results emerging out of the present investigation entitled “**Site characteristics and regeneration studies of bani oak (*Quercus glauca* Thunberg) in Himachal Pradesh**” are presented in this chapter. This study was conducted under *Quercus glauca* bearing forests sites falling in Solan and Sirmour districts of Himachal Pradesh- India and in the Department of Silviculture and Agroforestry during the years of 2013-2015.

Regeneration was the main focus of the study. The first experiment directly or indirectly revolved around natural regeneration, while, the second and the third experiments addressed different aspects of artificial regeneration. In case of natural regeneration, the effect of biotic and abiotic influences on natural regeneration of *Quercus glauca* was studied. Germination of *Quercus glauca* acorns was studied in two experiments. Through these experiments, the influence of stratification, chemical and physical pre-sowing seed treatments and acorn size under open nursery and shaded growing conditions were studied. The results emerging out of the present investigations are described under the following heads and subheads:

Experiment I: Studies on site characteristics and natural regeneration status of *Quercus glauca* forests

4.1 Studies on site characteristics and natural regeneration status of *Quercus glauca* forests

- 4.1.1 Phytosociology of *Quercus glauca* forests
- 4.1.2 Stand characteristics
- 4.1.3 Regeneration assessment
- 4.1.4 Site characteristics
- 4.1.5 Correlation and regression studies

Experiment II: Studies on effect of stratification medium and duration on germination and seedling growth characteristics of *Quercus glauca*

4.2 Studies on effect of stratification media and duration on germination and seedling growth characteristics of *Quercus glauca*

- 4.2.1 Effect of stratification media and stratification duration on germination and seedling growth characteristics of *Quercus glauca* grown under open nursery condition
- 4.2.2 Effect of stratification media and their duration on germination and seedling growth characteristics of *Quercus glauca* grown under shaded conditions
- 4.2.3 Effect of stratification media and stratification duration on nutrient content of soil media and biochemical content of *Quercus glauca* acorns
- 4.2.4 Comparative analysis of open and shaded growing conditions on germination and seedling growth characteristics of *Quercus glauca*

Experiment III: Studies on effect of pre-sowing seed treatments on germinability of *Quercus glauca* seeds

4.3 Studies on effect of pre-sowing seed treatments and acorn size on germinability of *Quercus glauca* acorns

- 4.3.1 Effect of chemical pre-sowing treatments and acorn size on germinability of *Quercus glauca* acorns
- 4.3.2 Effect of physical pre-sowing treatments and acorn size on germinability of *Quercus glauca* acorns
- 4.3.3 Effect of physical pre-sowing treatments and acorn size on seedling growth of *Quercus glauca* under shaded growing condition
- 4.3.4 Effect of chemical pre-sowing treatments and acorn size on biochemical composition of *Quercus glauca* acorns
- 4.3.5 Correlation and regression analysis of germination parameters and biochemical contents of *Quercus glauca* acorns
- 4.3.6 Comparative analysis of chemical and physical pre-sowing treatments

4.1 EXPERIMENT I: STUDIES ON SITE CHARACTERISTICS AND NATURAL REGENERATION STATUS OF *QUERCUS GLAUCA* FORESTS

The study site covered three forest ranges i.e. Solan, Narag and Sarhan, which falls under two adjoining districts- Solan and Sirmour districts of Himachal Pradesh (India). From each

forest range, two *Quercus glauca* bearing forests were selected for data collection. The selected forests were: Shilli (Site I) and Oachghat (Site II) from Solan forest range; Deothal (Site III) and Narag (Site IV) from Narag forest range; and Chakla (Site V) and Tikri (Site VI) from Sarhan forest range. Data on Phytosociology, stand characteristics, regeneration status and site characteristics were collected from these six *Quercus glauca* bearing forests. The data, so obtained, was analysed and presented as below:

4.1.1 Phytosociology of *Quercus glauca* forests

Table 4, 5 and 6 shows recorded trees, shrubs, and herbs under the studied *Quercus glauca* bearing forest sites, respectively. *Quercus glauca* forests in the studied areas were comprised of 131 species out of which 25 were tree species, 45 shrubs and 61 herb species. 24 genus and 19 families were recorded for trees; 39 genus and 25 families for shrubs and 50 genus and 27 families for herbs. Details of phytosociological studies based on parameters such as density (D), basal area (BA), Per cent frequency (F%), relative density (RD), relative basal area (RBA), relative frequency (RF), importance value index (IVI), similarity and species indices for the selected six sites are being presented in Tables 7 to 28.

4.1.1.1 Site I (Shilli, Solan forest range)

Data presented in Tables 7, 8 and 9 indicate that there were nine tree species, twelve shrub species and seventeen species of herbaceous plants were recorded at site I, Shilli, Solan forest range. The upper tree layer was dominated by four species, i.e. *Quercus leucotrichophora*, *Quercus glauca*, *Myrica esculenta* and *Pinus roxburghii* having IVI values of 92.5, 74.8, 44.8 and 43.3, respectively. The minimum IVI value (7.0) was recorded for *Rhododendron arboreum*. Dominant shrub species were *Berberis lycium*, *Caryopteris wallichiana* and *Randia tetrasperma* having IVI values of 56.6, 35.9 and 35.3, respectively (Table 8). The lowest IVI value (8.0) was recorded for *Daphne cannabina*. The herb layer was predominantly occupied by *Digitaria cruciata* having IVI value of 50.7 followed by *Smilax aspera* and *Polystichum squarrosus* having IVI values of 27.5 and 27.2, respectively. *Cissampelos pareira* was the least dominant herb with an IVI of 3.4 (Table 9).

Table 4: Trees observed under different *Quercus glauca* bearing forest sites

Species	Family	Solan range		Narag range		Sarhan range	
		Site I	Site II	Site III	Site IV	Site V	Site VI
<i>Ailanthus excelsa</i>	Simaroubaceae	+	-	-	+	+	-
<i>Albizia spp.</i>	Fabaceae	+	+	-	-	-	-
<i>Bauhinia variegata</i>	Fabaceae	-	+	-	-	-	-
<i>Celtis australis</i>	Cannabaceae	+	+	-	-	-	-
<i>Dalbergia sissoo</i>	Fabaceae	-	+	-	-	-	-
<i>Debregeasia hypoleuca</i>	Urticaceae	-	-	-	-	-	+
<i>Ehretia acuminata</i>	Boraginaceae	-		+		-	+
<i>Ficus palmata</i>	Moraceae	-	+	-	+	-	+
<i>Machilus duthiei</i>	Lauraceae	-	+	-	+	-	+
<i>Manilkara kauki</i>	Sapotaceae	-	-	-	-	-	+
<i>Melia azedarach</i>	Meliaceae	+	-	-	-	-	-
<i>Murraya koenigii</i>	Rutaceae	-	-	-	+	-	-
<i>Myrica esculenta</i>	Myricaceae	+	+	-	+	+	+
<i>Olea paniculata</i>	Oleaceae	-	-	-	-	+	-
<i>Pinus roxburghii</i>	Pinaceae	+	+	-	+	+	+
<i>Pistacia integerrima</i>	Anacardiaceae	-	+	-	-	-	-
<i>Prunus puddum</i>	Rosaceae	-	-	-	-	-	+
<i>Punica granatum</i>	Lythraceae	-	-	+	+	+	+
<i>Pyrus pashia</i>	Rosaceae	-	-	+	+	-	+
<i>Quercus glauca</i>	Fagaceae	+	+	+	+	+	+
<i>Quercus leucotrichophora</i>	Fagaceae	+	-	-	+	+	-
<i>Rhododendron arboretum</i>	Ericaceae	+	-	-	-	-	-
<i>Salix tetrasperma</i>	Salicaceae	-	-	+	-	-	-
<i>Toona ciliata</i>	Meliaceae	-	-	-	-	-	+
<i>Zanthoxylum alatum</i>	Rutaceae	-	-	-	+	-	-
Total		9	10	5	11	7	12

+ Occurrence

- Non-occurrence

Table 5: Shrubs observed under different *Quercus glauca* bearing forest sites

Species	Family	Solan range		Narag range		Sarhan range	
		Site I	Site II	Site III	Site IV	Site V	Site VI
<i>Artemisia spp.</i>	Asteraceae	-	-	+	-	-	-
<i>Barleria cristata</i>	Acanthaceae	-	+	+	-	+	-
<i>Berberis lycium</i>	Berberidaceae	+	-	+	-	+	+
<i>Berchemia floribunda</i>	Rhamnaceae	-	-	-	-	-	+
<i>Callicarpa macrophylla</i>	Verbenaceae	-	-	-	-	+	-
<i>Carissa carandas</i>	Apocynaceae	-	+	-	-	+	+
<i>Coriaria nepalensis</i>	Coriariaceae	-	-	+	-	-	+
<i>Rhus cotinus</i>	Anacardiaceae	-	+	+	-	-	+
<i>Daphne cannabina</i>	Thymelaeaceae	+	-	-	-	-	-
<i>Deutzia staminea</i>	Hydrangeaceae	-	-	+	+	-	+
<i>Elaeagnus umbellata</i>	Elaeagnaceae	-	-	+	-	-	+
<i>Ficus pumila</i>	Moraceae	-	-	+	+	-	+
<i>Flemingia congesta</i>	Fabaceae	-	+	-	-	-	-
<i>Flemingia fruticulosa</i>	Fabaceae	-	+	-	-	-	-
<i>Randia tetrasperma</i>	Rubiaceae	+	+	-	-	+	-
<i>Hypericum oblongifolium</i>	Hypericaceae	-	-	+	-	+	-
<i>Indigofera pulchella</i>	Fabaceae	-	+	-	-	+	+
<i>Inula cappa</i>	Asteraceae	-	-	-	-	+	-
<i>Jasminum dispersum</i>	Oleaceae	+	-	-	-	-	-
<i>Jasminum humile</i>	Oleaceae	-	+	+	-	-	-
<i>Lantana camara</i>	Verbenaceae	-	-	-	-	+	-
<i>Andrachne cordifolia</i>	Phyllanthaceae	+	+	+	-	+	+
<i>Lonicera angustifolia</i>	Caprifoliaceae	-	-	-	-	+	-
<i>Lonicera quinquelocularis</i>	Caprifoliaceae	-	+	-	-	+	-
<i>Meriandra strobilifera</i>	Lamiaceae	-	-	-	-	+	-
<i>Myrsine africana</i>	Primulaceae	+	+	+	+	+	+
<i>Vitis himalayana</i>	Vitaceae	-	-	-	-	+	-
<i>Pavetta indica</i>	Rubiaceae	-	-	-	-	-	+
<i>Prinsepia utilis</i>	Rosaceae	-	-	+	-	-	-
<i>Caryopteris wallichiana</i>	Lamiaceae	+	+	+	-	-	-
<i>Reinwardtia indica</i>	Linaceae	-	-	+	-	-	-
<i>Rhamnus virgatus</i>	Rhamnaceae	-	-	+	-	-	-
<i>Rosa macrophylla</i>	Rosaceae	+	+	-	-	+	-
<i>Rosa moschata</i>	Rosaceae	-	-	+	-	-	+
<i>Rubus ellipticus</i>	Rosaceae	+	-	-	+	-	+
<i>Rubus foliolosus</i>	Rosaceae	-	-	+	-	-	-
<i>Sageretia oppositifolia</i>	Rhamnaceae	+	+	+	+	+	+
<i>Cassia floribunda</i>	Fabaceae	-	-	-	-	+	-
<i>Cassia occidentalis</i>	Fabaceae	-	+	-	-	-	+
<i>Solanum khasianum</i>	Solanaceae	-	-	-	-	+	-
<i>Hamiltonia suaveolens</i>	Rubiaceae	+	-	+	+	+	+
<i>Teucrium royleanum</i>	Lamiaceae	-	+	+	-	-	-
<i>Trachelospermum fragrans</i>	Apocynaceae	-	-	-	-	+	-
<i>Tylophora hirsuta</i>	Apocynaceae	-	-	-	+	-	-
<i>Viburnum cotinifolium</i>	Adoxaceae	+	+	-	+	-	-
Total		12	17	21	8	21	17

+ Occurrence

- Non-occurrence

Table 6: Herbs observed under different *Quercus glauca* bearing forest sites

Species	Family	Solan range		Narag range		Sarhan range	
		Site I	Site II	Site III	Site IV	Site V	Site VI
<i>Achyranthes aspera</i>	Amaranthaceae	+	+	+	-	+	-
<i>Adiantum lunulatum</i>	Pteridaceae	-	-	-	-	-	+
<i>Adiantum incisum</i>	Pteridaceae	-	-	+	-	-	-
<i>Ageratum conyzoides</i>	Asteraceae	-	-	-	-	+	+
<i>Anaphalis busua</i>	Asteraceae	-	-	-	-	+	-
<i>Anisomeles ovata</i>	Lamiaceae	-	-	-	-	+	-
<i>Asparagus officinalis</i>	Asparagaceae	+	-	-	-	+	+
<i>Asplenium dalhousiae</i>	Aspleniaceae	-	-	-	-	-	+
<i>Axonopus fissifolius</i>	Poaceae	+	-	-	-	-	-
<i>Bidens pilosa</i>	Asteraceae	-	+	-	-	+	-
<i>Boenninghausenia albiflora</i>	Rutaceae	+	-	-	-	+	-
<i>Calamagrostis acutiflora</i>	Poaceae	-	-	-	+	-	-
<i>Calamagrostis tacomensis</i>	Poaceae	-	-	+	-	-	-
<i>Carpesium spp.</i>	Asteraceae	-	-	-	-	-	+
<i>Christella dentata</i>	Thelypteridaceae	-	-	-	+	-	-
<i>Cissampelos pareira</i>	Menispermaceae	+	-	-	-	+	-
<i>Clematis spp.</i>	Ranunculaceae	-	+	+	+	-	-
<i>Coniogramme japonica</i>	Pteridaceae	+	-	-	+	-	-
<i>Cuscuta reflexa</i>	Convolvulaceae	-	-	+	-	-	-
<i>Cymbopogon spp.</i>	Poaceae	-	+	-	-	+	-
<i>Desmodium spp.</i>	Fabaceae	+	-	-	-	-	+
<i>Dicliptera bupleuroides</i>	Acanthaceae	-	-	-	-	+	-
<i>Digitaria cruciata</i>	Poaceae	+	+	-	-	-	-
<i>Dioscorea esculenta</i>	Dioscoreaceae	-	-	-	-	-	+
<i>Arundinaria falcata</i>	Poaceae	-	-	-	+	+	-
<i>Dryopteris cochleata</i>	Dryopteridaceae	-	-	-	+	-	+
<i>Equisetum arvense</i>	Equisetaceae	-	-	-	-	-	+
<i>Erigeron annuus</i>	Asteraceae	-	-	+	+	-	-
<i>Galium aparine</i>	Rubiaceae	-	-	-	-	-	+
<i>Galium rotundifolium</i>	Rubiaceae	-	-	-	-	-	+
<i>Geranium pratense</i>	Geraniaceae	-	-	+	-	+	+
<i>Hedera helix</i>	Araliaceae	+	+	+	-	-	+
<i>Plectranthus coetsa</i>	Lamiaceae	-	+	-	+	-	-
<i>Plectranthus gerardianus</i>	Lamiaceae	-	-	+	-	-	-
<i>Lespedeza gerardiana</i>	Fabaceae	-	-	+	-	-	+
<i>Oplismenus compositus</i>	Poaceae	-	-	+	+	+	-
<i>Oplismenus burmanni</i>	Poaceae	+	-	-	-	-	+
<i>Oryzopsis hymenoides</i>	Poaceae	-	-	+	-	-	-
<i>Oxalis spp.</i>	Oxalidaceae	+	-	-	-	-	-
<i>Panicum agrostoides</i>	Poaceae	-	-	-	-	-	+
<i>Panicum depauperatum</i>	Poaceae	+	-	-	-	+	+
<i>Panicum virgatum</i>	Poaceae	-	-	-	+	-	-
<i>Paspalum coryphaeum</i>	Poaceae	-	+	-	-	-	-
<i>Pimpinella diversifolia</i>	Apiaceae	-	-	-	-	+	-
<i>Polystichum discretum</i>	Dryopteridaceae	-	+	-	-	+	-
<i>Polystichum squarrosus</i>	Dryopteridaceae	+	-	-	-	-	-
<i>Pteris vittata</i>	Pteridaceae	-	-	+	-	-	-
<i>Scutellaria scandens</i>	Lamiaceae	-	+	+	+	+	+
<i>Sigesbeckia orientalis</i>	Asteraceae	-	-	+	+	-	-
<i>Smilax aspera</i>	Smilacaceae	+	+	+	+	-	-
<i>Smilax vaginata</i>	Smilacaceae	+	+	-	-	-	-
<i>Strobilanthes glutinosus</i>	Acanthaceae	-	+	-	-	+	-
<i>Strobilanthes atropurpureus</i>	Acanthaceae	-	-	-	+	-	-
<i>Strobilanthes dalhousieanus</i>	Acanthaceae	+	-	+	-	-	-
<i>Thalictrum foliolosum</i>	Ranunculaceae	-	+	+	+	+	-
<i>Thelypteris erubescens</i>	Thelypteridaceae	-	-	-	-	-	+
<i>Urtica spp.</i>	Urticaceae	+	-	-	-	-	-
<i>Viola serpens</i>	Violaceae	-	-	-	-	-	+
<i>Woodfordia floribunda</i>	Lythraceae	-	+	-	-	-	-
<i>Xanthium strumarium</i>	Asteraceae	-	-	+	-	-	-
<i>Zingiber chrysanthum</i>	Zingiberaceae	-	-	+	-	-	-
Total		17	15	20	15	19	20

+ Occurrence
- Non-occurrence

Trees species such as *Quercus leucotrichophora*, *Quercus glauca*, *Pinus roxburghii* and *Myrica esculenta* recorded higher values of density, basal area and frequency. On the basis of density ($N\ ha^{-1}$), the order of dominance was *Quercus leucotrichophora* followed by *Quercus glauca*, *Myrica esculenta* and *Pinus roxburghii*; whereas, on the basis of basal area ($m^2\ ha^{-1}$), the order of dominance was *Quercus leucotrichophora* followed by *Quercus glauca*, *Pinus roxburghii* and *Myrica esculenta* in the descending order, respectively.

Among shrubs, *Berberis lycium* and *Randia tetrasperma* have higher basal area per hectare having values of 3924.0 and 2370.3 $cm^2\ ha^{-1}$, respectively; while *Daphne cannabina* was having the lowest basal area (26.1 $cm^2\ ha^{-1}$). The basal area of *Digitaria cruciata* (4002.1 $cm^2\ ha^{-1}$), *Urtica spp.* (1909.5 $cm^2\ ha^{-1}$), and *Polystichum squarrosus* (1716.7 $cm^2\ ha^{-1}$) was higher than other herbs in the site, whereas, *Oxalis species* was having the lowest basal area (2.3 $cm^2\ ha^{-1}$).

4.1.1.2 Site II (Oachghat, Solan forest range)

A perusal of the data presented in Table 10, 11 and 12 reveal that a total of forty two species were recorded in site II; which included ten tree species, seventeen shrub species and fifteen species of herbs. Based on dominance, *Quercus glauca* was the most persistent species having IVI value of 193.5. *Machilus duthiei* and *Dalbergia sissoo* displayed IVI values of 22.4 and 14.3, respectively. *Albizia spp.*, which has an IVI of 8.8, was the least dominant tree on this site. Shrubs such as *Caryopteris wallichiana*, *Lonicera quinquelocularis* and *Myrsine africana* dominated the middle layer displaying IVI values of 74.8, 35.9 and 31.1, respectively. In the shrub layer the lowest IVI (3.4) was recorded for *Viburnum cotinifolium*. *Digitaria cruciata* and *Paspalum coryphaeum* were dominant herb species having IVI values of 82.7 and 69.9, respectively; whereas *Woodfordia floribunda* was the least dominant herbs (4.7).

The basal area distribution of the site showed that *Quercus glauca* had the highest basal area (26.4 $m^2\ ha^{-1}$) among trees and the minimum basal area was recorded for two trees, *Albizia spp.* and *Ficus palmata* each displaying equal basal area (0.1 $m^2\ ha^{-1}$). Comparison of the basal area of shrubs, data in Table 11 reveals that *Caryopteris wallichiana* had the highest basal area (2533.7 $cm^2\ ha^{-1}$) followed by *Lonicera quinquelocularis* (992.0 $cm^2\ ha^{-1}$) and *Sageretia oppositifolia* (707.7 $cm^2\ ha^{-1}$), while *Jasminum humile* was having the lowest basal area (2.7 $cm^2\ ha^{-1}$). Data on Table 12 indicates that *Digitaria cruciata* and *Paspalum coryphaeum* had higher basal area of 5191.1 and 468.5 $cm^2\ ha^{-1}$, respectively; whereas, *Thalictrum foliolosum* had the lowest basal area (0.6 $cm^2\ ha^{-1}$).

Table 7: Phytosociology of trees at site I (Shilli, Solan forest range)

Species	Density (N ha ⁻¹)	Relative density	Basal area (m ² ha ⁻¹)	Relative basal area	Frequency (%)	Relative frequency	Importance value Index (IVI)
<i>Ailanthus excelsa</i>	8	0.7	0.4	0.9	33.3	5.9	7.5
<i>Albizia spp.</i>	8	0.7	0.4	1.1	33.3	5.9	7.7
<i>Celtis australis</i>	25	2.1	0.4	1.2	33.3	5.9	9.2
<i>Melia azedarach</i>	17	1.4	0.1	0.4	66.7	11.8	13.5
<i>Myrica esculenta</i>	192	16.2	3.9	10.5	100.0	17.6	44.4
<i>Pinus roxburghii</i>	150	12.7	7.0	18.9	66.7	11.8	43.3
<i>Quercus glauca</i>	317	26.8	11.3	30.4	100.0	17.6	74.8
<i>Quercus leucotrichophora</i>	458	38.7	13.4	36.1	100.0	17.6	92.5
<i>Rhododendron arboreum</i>	8	0.7	0.2	0.4	33.3	5.9	7.0
Total	1183	100.0	37.1	100.0	566.7	100.0	300.0

Table 8: Phytosociology of shrubs at site I (Shilli, Solan forest range)

Species	Density (N ha ⁻¹)	Relative density	Basal area (cm ² ha ⁻¹)	Relative basal area	Frequency (%)	Relative frequency	Importance value Index (IVI)
<i>Berberis lycium</i>	164	10.2	3924.0	36.7	73.3	9.7	56.6
<i>Daphne cannabina</i>	53	3.3	26.1	0.2	33.3	4.4	8.0
<i>Randia tetrasperma</i>	84	5.2	2370.3	22.2	60.0	8.0	35.3
<i>Jasminum dispersum</i>	151	9.4	489.7	4.6	53.3	7.1	21.0
<i>Andrachne cordifolia</i>	222	13.8	85.9	0.8	93.3	12.4	27.0
<i>Myrsine africana</i>	274	17.0	105.9	1.0	66.7	8.8	26.8
<i>Caryopteris wallichiana</i>	191	11.9	1144.0	10.7	100.0	13.3	35.9
<i>Rosa macrophylla</i>	53	3.3	219.6	2.1	46.7	6.2	11.6
<i>Rubus ellipticus</i>	140	8.7	1470.1	13.7	53.3	7.1	29.5
<i>Sageretia oppositifolia</i>	50	3.1	42.3	0.4	40.0	5.3	8.8
<i>Hamiltonia suaveolens</i>	175	10.9	422.6	4.0	100.0	13.3	28.1
<i>Viburnum cotinifolium</i>	53	3.3	393.8	3.7	33.3	4.4	11.4
Total	1610	100.0	10694.3	100.0	753.3	100.0	300.0

Table 9: Phytosociology of herbs at site I (Shilli, Solan forest range)

Species	Density (N ha ⁻¹)	Relative density	Basal area (cm ² ha ⁻¹)	Relative basal area	Frequency (%)	Relative frequency	Importance value Index (IVI)
<i>Achyranthes aspera</i>	941	5.6	443.0	3.5	33.3	4.5	13.7
<i>Asparagus officinalis</i>	119	0.7	255.5	2.0	30.0	4.1	6.8
<i>Axonopus fissifolius</i>	1729	10.3	808.6	6.5	33.3	4.5	21.3
<i>Boenninghausenia albiflora</i>	124	0.7	53.2	0.4	33.3	4.5	5.7
<i>Cissampelos pareira</i>	106	0.6	10.9	0.1	20.0	2.7	3.4
<i>Coniogramme japonica</i>	643	3.8	325.7	2.6	33.3	4.5	11.0
<i>Desmodium spp.</i>	779	4.7	185.3	1.5	60.0	8.2	14.3
<i>Digitaria cruciata</i>	2367	14.1	4002.1	32.1	33.3	4.5	50.7
<i>Hedera helix</i>	432	2.6	201.9	1.6	33.3	4.5	8.7
<i>Oplismenus burmanni</i>	1347	8.0	914.4	7.3	33.3	4.5	19.9
<i>Oxalis spp.</i>	1995	11.9	2.3	0.0	56.7	7.7	19.7
<i>Panicum depauperatum</i>	2641	15.8	491.8	3.9	33.3	4.5	24.2
<i>Polystichum squarrosus</i>	725	4.3	1716.7	13.8	66.7	9.1	27.2
<i>Smilax aspera</i>	1241	7.4	804.6	6.4	100.0	13.6	27.5
<i>Smilax vaginata</i>	486	2.9	3.0	0.0	66.7	9.1	12.0
<i>Strobilanthes dalhousieanus</i>	641	3.8	350.8	2.8	33.3	4.5	11.2
<i>Urtica spp.</i>	439	2.6	1909.5	15.3	33.3	4.5	22.5
Total	16755	100.0	12479.1	100.0	733.3	100.0	300.0

Table 10: Phytosociology of trees at site II (Oachghat, Solan forest range)

Species	Density (N ha ⁻¹)	Relative density	Basal area (m ² ha ⁻¹)	Relative basal area	Frequency (%)	Relative frequency	Importance value Index (IVI)
<i>Albizia spp.</i>	8	0.9	0.1	0.2	33.3	7.7	8.8
<i>Bauhinia variegata</i>	17	1.7	0.4	1.4	33.3	7.7	10.8
<i>Celtis australis</i>	8	0.9	0.4	1.3	33.3	7.7	9.8
<i>Dalbergia sissoo</i>	25	2.6	1.2	4.0	33.3	7.7	14.3
<i>Ficus palmata</i>	17	1.7	0.1	0.4	33.3	7.7	9.8
<i>Machilus duthiei</i>	50	5.2	0.6	1.9	66.7	15.4	22.4
<i>Myrica esculenta</i>	8	0.9	0.5	1.8	33.3	7.7	10.3
<i>Pinus roxburghii</i>	8	0.9	0.3	1.0	33.3	7.7	9.6
<i>Pistacia integerrima</i>	17	1.7	0.4	1.2	33.3	7.7	10.7
<i>Quercus glauca</i>	808	83.6	26.4	86.8	100.0	23.1	193.5
Total	966	100.0	30.4	100.0	433.3	100.0	300.0

Table 11: Phytosociology of shrubs at site II (Oachghat, Solan forest range)

Species	Density (N ha ⁻¹)	Relative density	Basal area (cm ² ha ⁻¹)	Relative basal area	Frequency (%)	Relative frequency	Importance value Index (IVI)
<i>Barleria cristata</i>	73	3.5	5.2	0.1	20.0	2.2	5.8
<i>Carissa carandas</i>	82	4.0	206.4	3.3	80.0	8.7	15.9
<i>Rhus cotinus</i>	69	3.3	135.7	2.2	26.7	2.9	8.4
<i>Flemingia congesta</i>	110	5.3	384.0	6.1	46.7	5.1	16.4
<i>Flemingia fruticulosa</i>	29	1.4	360.2	5.7	20.0	2.2	9.3
<i>Randia tetrasperma</i>	84	4.1	31.9	0.5	80.0	8.7	13.3
<i>Indigofera pulchella</i>	147	7.1	535.0	8.5	53.3	5.8	21.4
<i>Jasminum humile</i>	36	1.7	2.7	0.0	33.3	3.6	5.4
<i>Andrachne cordifolia</i>	123	5.9	34.0	0.5	73.3	8.0	14.5
<i>Lonicera quinquelocularis</i>	222	10.7	992.0	15.8	86.7	9.4	35.9
<i>Myrsine africana</i>	331	15.9	269.4	4.3	100.0	10.9	31.1
<i>Caryopteris wallichiana</i>	492	23.7	2533.7	40.2	100.0	10.9	74.8
<i>Rosa macrophylla</i>	37	1.8	34.7	0.6	40.0	4.3	6.7
<i>Sageretia oppositifolia</i>	126	6.1	707.7	11.2	66.7	7.2	24.6
<i>Cassia occidentalis</i>	25	1.2	55.6	0.9	13.3	1.4	3.5
<i>Teucrium royleanum</i>	69	3.3	3.3	0.1	60.0	6.5	9.9
<i>Viburnum cotinifolium</i>	23	1.1	5.2	0.1	20.0	2.2	3.4
Total	2078	100.0	6296.8	100.0	920.0	100.0	300.0

Table 12: Phytosociology of herbs at site II (Oachghat, Solan forest range)

Species	Density (N ha ⁻¹)	Relative density	Basal area (cm ² ha ⁻¹)	Relative basal area	Frequency (%)	Relative frequency	Importance value Index (IVI)
<i>Clematis spp.</i>	111	0.8	5.4	0.0	33.3	5.6	6.5
<i>Achyranthes aspera</i>	216	1.5	142.6	1.3	23.3	4.0	6.7
<i>Bidens pilosa</i>	1067	7.5	175.7	1.6	33.3	5.6	14.7
<i>Cymbopogon spp.</i>	2358	16.5	816.7	7.2	33.3	5.6	29.3
<i>Digitaria cruciata</i>	3659	25.6	5191.1	45.8	66.7	11.3	82.7
<i>Hedera helix</i>	685	4.8	65.1	0.6	33.3	5.6	11.0
<i>Plectranthus coetsa</i>	722	5.0	62.5	0.6	66.7	11.3	16.9
<i>Paspalum coryphaeum</i>	3556	24.8	4468.5	39.4	33.3	5.6	69.9
<i>Polystichum discretum</i>	533	3.7	94.6	0.8	66.7	11.3	15.9
<i>Scutellaria angulosa</i>	322	2.2	177.5	1.6	33.3	5.6	9.5
<i>Smilax vaginata</i>	142	1.0	1.0	0.0	30.0	5.1	6.1
<i>Smilax aspera</i>	350	2.4	22.6	0.2	66.7	11.3	13.9
<i>Thalictrum foliolosum</i>	198	1.4	0.6	0.0	23.3	4.0	5.3
<i>Strobilanthes glutinosus</i>	246	1.7	19.3	0.2	30.0	5.1	7.0
<i>Woodfordia floribunda</i>	147	1.0	91.2	0.8	16.7	2.8	4.7
Total	14312	100.0	11334.4	100.0	590.0	100.0	300.0

4.1.1.3 Site III (Deothal, Narag forest range)

The phytosociological data of site III in Table 13 clearly demonstrates that *Quercus glauca* is the most prominent tree species, as this species displayed the highest values of all the studied traits under investigations. *Quercus glauca* was followed by *Punica granatum* though it remained far behind it. The tree species viz., *Ehretia acuminata*, *Pyrus pashia* and *Salix tetrasperma* displayed almost identical values of most of the investigated traits.

Data in Table 14, which is related to the shrub species at site III (Deothal, Narag forest range) reveals that contrary to tree species this site is represented by good number of shrub species (22 number). At this site, the dominating shrub species recorded were: *Myrsine africana*, *Andrachne cordifolia*, *Sageretia oppositifolia*, *Deutzia staminea*, *Rhus cotinus* and *Berberis lycium*, etc. on the basis of importance values the species followed the order: *Sageretia oppositifolia* > *Myrsine africana* > *Rhus cotinus* > *Berberis lycium* > *Deutzia staminea* > *Andrachne cordifolia* > *Rosa moschata* etc.

On the basis of density ($N\ ha^{-1}$) the most prominent herb species were: *Oplismenus compositus*, *Oryzopsis hymenoides*, *Scutellaria scandens*, *Thalictrum foliolosum*, and *Hedera helix*. However, on the basis of basal area ($cm^2\ ha^{-1}$) the herb species, likes *Oryzopsis hymenoides*, *Xanthium strumarium*, *Calamagrostis tacomensis*, *Lespedeza gerardiana*, and *Oplismenus compositus* were the dominating species and *Thalictrum foliolosum* was the most frequently occurring species (96.7 %). *Oryzopsis hymenoides* was having the clear-cut superiority of IVI than the rest of the herb species occurring in this site (Table 15).

4.1.1.4 Site IV (Narag, Narag forest range)

A perusal of data presented in Table 16 reveals that *Quercus glauca* is the most dominant tree species at site IV having the density of 433 trees per hectare basis. This species is having highest values of density, relative density, basal area and relative basal area. *Quercus glauca* was followed by *Pinus roxburghii* and *Myrica esculenta*, respectively for all these traits. Frequency of occurrence of *Quercus glauca* and *Pyrus pashia* was cent per cent. Likewise, the density, the IVI value of *Quercus glauca* was highest, which was followed by *Pinus roxburghii* and *Pyrus pashia*, respectively.

Table 13: Phytosociology of trees at site III (Deothal, Narag range)

Species	Density (N ha ⁻¹)	Relative density	Basal area (m ² ha ⁻¹)	Relative basal area	Frequency (%)	Relative frequency	Importance value Index (IVI)
<i>Ehretia acuminata</i>	8	2.3	0.1	0.6	33.3	12.5	15.3
<i>Punica granatum</i>	25	6.8	0.2	2.0	66.7	25.0	33.9
<i>Pyrus pashia</i>	8	2.3	0.1	0.7	33.3	12.5	15.5
<i>Quercus glauca</i>	317	86.4	11.3	95.5	100.0	37.5	219.3
<i>Salix tetrasperma</i>	8	2.3	0.1	1.2	33.3	12.5	16.0
Total	366	100.0	11.8	100.0	266.7	100.0	300.0

Table 14: Phytosociology of shrubs at site III (Deothal, Narag range)

Species	Density (N ha ⁻¹)	Relative density	Basal area (cm ² ha ⁻¹)	Relative basal area	Frequency (%)	Relative frequency	Importance value Index (IVI)
<i>Artemisia spp.</i>	53	1.8	113.3	0.9	40.0	2.8	5.5
<i>Barleria cristata</i>	84	2.8	19.1	0.2	66.7	4.6	7.6
<i>Berberis lycium</i>	191	6.4	1152.7	9.4	100.0	6.9	22.7
<i>Coriaria nepalensis</i>	26	0.9	108.4	0.9	13.3	0.9	2.7
<i>Rhus cotinus</i>	278	9.3	1305.4	10.6	100.0	6.9	26.9
<i>Deutzia staminea</i>	251	8.4	835.7	6.8	93.3	6.5	21.7
<i>Elaeagnus umbellata</i>	71	2.4	0.4	0.0	60.0	4.2	6.5
<i>Ficus pumila</i>	74	2.5	10.5	0.1	66.7	4.6	7.2
<i>Hypericum oblongifolium</i>	76	2.5	71.7	0.6	60.0	4.2	7.3
<i>Jasminum humile</i>	47	1.6	129.5	1.1	40.0	2.8	5.4
<i>Andrachne cordifolia</i>	335	11.2	408.1	3.3	86.7	6.0	20.6
<i>Myrsine africana</i>	516	17.3	923.6	7.5	100.0	6.9	31.7
<i>Prinsepia utilis</i>	33	1.1	197.2	1.6	20.0	1.4	4.1
<i>Caryopteris wallichiana</i>	98	3.3	55.7	0.5	86.7	6.0	9.8
<i>Reinwardtia indica</i>	48	1.6	548.7	4.5	33.3	2.3	8.4
<i>Rhamnus virgatus</i>	89	3.0	282.8	2.3	73.3	5.1	10.4
<i>Rosa moschata</i>	145	4.9	1140.2	9.3	73.3	5.1	19.2
<i>Rubus foliolosus</i>	77	2.6	38.9	0.3	66.7	4.6	7.5
<i>Sageretia oppositifolia</i>	280	9.4	4900.5	39.8	86.7	6.0	55.2
<i>Hamiltonia suaveolens</i>	79	2.6	60.1	0.5	73.3	5.1	8.2
<i>Teucrium royleanum</i>	139	4.7	0.5	0.0	100.0	6.9	11.6
Total	2990	100.0	12303.2	100.0	1440.0	100.0	300.0

Table 15: Phytosociology of herbs at site III (Deothal, Narag range)

Species	Density (N ha ⁻¹)	Relative density	Basal area (cm ² ha ⁻¹)	Relative basal area	Frequency (%)	Relative frequency	Importance value Index (IVI)
<i>Achyranthes aspera</i>	444	2.8	335.5	1.7	30.0	3.5	8.0
<i>Adiantum incisum</i>	295	1.9	533.0	2.7	13.3	1.5	6.1
<i>Calamagrostis tacomensis</i>	618	3.9	2051.5	10.5	33.3	3.8	18.2
<i>Clematis spp.</i>	208	1.3	19.8	0.1	33.3	3.8	5.3
<i>Cuscuta reflexa</i>	178	1.1	0.6	0.0	20.0	2.3	3.4
<i>Erigeron annuus</i>	543	3.4	825.1	4.2	33.3	3.8	11.5
<i>Geranium pratense</i>	413	2.6	186.7	1.0	66.7	7.7	11.3
<i>Hedera helix</i>	1180	7.4	194.9	1.0	60.0	6.9	15.4
<i>Plectranthus gerardianus</i>	282	1.8	733.0	3.8	66.7	7.7	13.2
<i>Lespedeza gerardiana</i>	616	3.9	1682.9	8.6	46.7	5.4	17.9
<i>Oplismenus compositus</i>	2653	16.7	1576.0	8.1	50.0	5.8	30.6
<i>Oryzopsis hymenoides</i>	1811	11.4	5120.5	26.2	53.3	6.2	43.8
<i>Pteris vittata</i>	420	2.7	317.3	1.6	33.3	3.8	8.1
<i>Scutellaria scandens</i>	1805	11.4	204.2	1.0	30.0	3.5	15.9
<i>Sigesbeckia orientalis</i>	369	2.3	941.6	4.8	33.3	3.8	11.0
<i>Smilax aspera</i>	632	4.0	476.7	2.4	33.3	3.8	10.3
<i>Strobilanthes dalhousieanus</i>	816	5.1	636.1	3.3	66.7	7.7	16.1
<i>Thalictrum foliolosum</i>	1770	11.2	519.6	2.7	96.7	11.2	25.0
<i>Xanthium strumarium</i>	268	1.7	2277.6	11.7	26.7	3.1	16.4
<i>Zingiber chrysanthum</i>	534	3.4	906.5	4.6	40.0	4.6	12.6
Total	15855	100.0	19538.9	100.0	866.7	100.0	300.0

Phytosociology of shrubs at site IV in Table 17 indicates that *Myrsine africana* was having maximum density, which was followed by *Deutzia staminea*, *Rubus ellipticus*, *Viburnum cotinifolium*, respectively. Maximum basal area, relative basal area as well as importance value index were displayed by *Viburnum cotinifolium*. *Viburnum cotinifolium*, *Myrsine africana* and *Ficus pumila* demonstrated 100 per cent frequency.

It is evidently clear from the data in the Table 18 that maximum density (7778 N ha⁻¹) was of *Panicum virgatum*, which was followed by *Calamagrostis acutiflora* (3516 N ha⁻¹), *Oplismenus compositus* (2412 N ha⁻¹), and *Scutellaria angulosa* (1488 N ha⁻¹), etc. Whereas, maximum basal area (2395 cm² ha⁻¹) was displayed by *Arundinaria falcata*, which was followed by *Erigeron annuus*, *Plectranthus coetsa* and *Oplismenus compositus*, respectively. *Thalictrum foliolosum* was a highly frequent herb species having a frequency of 696.7 %. At this site every second species is that of this species. Importance value index of this species is again highest (53.3), which was followed by *Panicum virgatum* (36.9) *Arundinaria falcata* (33.0) *Oplismenus compositus* (27.6) *Plectranthus coetsa* (25.9) *Calamagrostis acutiflora* (25.3) *Erigeron annuus*, (23.5), etc.

4.1.1.5 Site V (Chakla, Sarhan forest range)

From Table 19 it is evidently clear that *Quercus glauca* dominate the site having the highest values for all traits under investigation. Following *Quercus glauca*, *Punica granatum* and *Quercus leucotrichophora* was having higher density and relative, while *Pinus roxburghii* and *Quercus leucotrichophora* was having higher basal area and relative basal area. Whereas, the frequency and relative frequency of *Pinus roxburghii*, *Punica granatum* and *Quercus leucotrichophora* was the second highest in this site with equal frequency and relative frequency values of 66.7 % and 16.7 %, respectively. In the shrub layer, *Myrsine africana* was having the highest density and relative density, which was followed by *Hamiltonia suaveolens*, *Cassia floribunda*, *Berberis lycium*, *Lonicera quinquelocularis*, etc. The highest basal area (1812.5 cm² ha⁻¹) was recorded by *Carissa carandas*, which was followed by *Berberis lycium* (1148.5 cm² ha⁻¹) and *Myrsine africana* (1147.2 cm² ha⁻¹). The relative basal area of these species was also the highest. The 100 per cent frequency and 6.8 per cent relative frequency was recorded by *Berberis lycium*, *Andrachne cordifolia* and *Myrsine africana*. As displayed in Table

Table 16: Phytosociology of trees at site IV (Narag, Narag forest range)

Species	Density (N ha ⁻¹)	Relative density	Basal area (m ² ha ⁻¹)	Relative basal area	Frequency (%)	Relative frequency	Importance value Index (IVI)
<i>Ailanthus excelsa</i>	17	2.5	0.4	2.3	66.7	11.1	15.9
<i>Ficus palmata</i>	17	2.5	0.4	2.0	33.3	5.6	10.0
<i>Machilus duthiei</i>	8	1.2	0.3	1.5	33.3	5.6	8.3
<i>Myrica esculenta</i>	42	6.2	0.5	2.5	33.3	5.6	14.3
<i>Murraya koenigii</i>	17	2.5	0.4	2.2	33.3	5.6	10.2
<i>Pinus roxburghii</i>	67	9.9	4.2	21.7	66.7	11.1	42.7
<i>Punica granatum</i>	25	3.7	0.2	1.3	66.7	11.1	16.1
<i>Pyrus pashia</i>	33	4.9	0.5	2.7	100.0	16.7	24.3
<i>Quercus glauca</i>	433	64.2	12.1	63.0	100.0	16.7	143.9
<i>Quercus leucotrichophora</i>	8	1.2	0.1	0.5	33.3	5.6	7.3
<i>Zanthoxylum alatum</i>	8	1.2	0.1	0.4	33.3	5.6	7.1
Total	675	100.0	19.2	100.0	600.0	100.0	300.0

Table 17: Phytosociology of shrubs at site IV (Narag, Narag forest range)

Species	Density (N ha ⁻¹)	Relative density	Basal area (cm ² ha ⁻¹)	Relative basal area	Frequency (%)	Relative frequency	Importance value Index (IVI)
<i>Deutzia staminea</i>	232	10.2	903.5	5.0	86.7	13.4	28.6
<i>Ficus pumila</i>	152	6.7	15.3	0.1	100.0	15.5	22.2
<i>Myrsine africana</i>	1057	46.5	3023.4	16.7	100.0	15.5	78.7
<i>Rubus ellipticus</i>	226	9.9	1074.1	5.9	66.7	10.3	26.2
<i>Sageretia oppositifolia</i>	178	7.9	135.6	0.7	80.0	12.4	21.0
<i>Hamiltonia suaveolens</i>	160	7.0	731.0	4.0	73.3	11.3	22.4
<i>Tylophora hirsuta</i>	56	2.5	8.0	0.0	40.0	6.2	8.7
<i>Viburnum cotinifolium</i>	210	9.2	12228.3	67.5	100.0	15.5	92.2
Total	2271	100.0	18119.3	100.0	646.7	100.0	300.0

Table 18: Phytosociology of herbs at site IV (Narag, Narag forest range)

Species	Density (N ha ⁻¹)	Relative density	Basal area (cm ² ha ⁻¹)	Relative basal area	Frequency (%)	Relative frequency	Importance value Index (IVI)
<i>Calamagrostis acutiflora</i>	3516	15.3	707.0	7.5	33.3	2.5	25.3
<i>Christella dentata</i>	525	2.3	399.1	4.2	50.0	3.8	10.3
<i>Clematis</i> spp.	222	1.0	77.0	0.8	33.3	2.5	4.3
<i>Coniogramme japonica</i>	739	3.2	306.9	3.3	56.7	4.3	10.7
<i>Arundinaria falcata</i>	1220	5.3	2394.5	25.4	30.0	2.3	33.0
<i>Dryopteris cochleata</i>	210	0.9	103.0	1.1	26.7	2.0	4.0
<i>Erigeron annuus</i>	1267	5.5	1218.8	12.9	66.7	5.0	23.5
<i>Plectranthus coetsa</i>	1409	6.1	1180.9	12.5	96.7	7.3	25.9
<i>Oplismenus compositus</i>	2412	10.5	1137.0	12.1	66.7	5.0	27.6
<i>Panicum virgatum</i>	7778	33.8	55.0	0.6	33.3	2.5	36.9
<i>Scutellaria angulosa</i>	1488	6.5	759.9	8.1	66.7	5.0	19.5
<i>Sigesbeckia orientalis</i>	445	1.9	739.7	7.9	20.0	1.5	11.3
<i>Smilax aspera</i>	517	2.2	61.5	0.7	40.0	3.0	5.9
<i>Strobilanthes atropurpureus</i>	1008	4.4	277.2	2.9	16.7	1.3	8.6
<i>Thalictrum foliolosum</i>	224	1.0	2.8	0.0	696.7	52.3	53.3
Total	22980	100.0	9420.2	100.0	1333.3	100.0	300.0

20, the three dominant species based on their importance value index were *Myrsine africana* (43.7), *Carissa carandas* (36.6) and *Berberis lycium* (29.8).

Data on Table 21 demonstrates that the density and relative density of herbs at site V was dominated by *Oplismenus compositus*, *Cymbopogon spp.*, *Geranium pratense*, *Panicum depauperatum*, *Bidens pilosa*, *Arundinaria falcate*, etc., respectively in descending order. Whereas, the basal area and relative basal area was recorded higher for *Oplismenus compositus*, *Bidens pilosa*, *Strobilanthes glutinosus*, etc. *Boenninghausenia albiflora* and *Bidens pilosa* had higher frequency and relative frequencies. *Oplismenus compositus* was having the highest (52.3) importance value index, which was followed by *Bidens pilosa* (31.3), *Boenninghausenia albiflora* (26.4), *Thalictrum foliolosum* (21.1), etc.

4.1.1.6 Site VI (Tikri, Sarhan forest range)

The results pertaining to phytosociology of trees in Table 22 shows that at site VI *Quercus glauca* dominated the site for all traits investigated by this study. Following *Quercus glauca*, the density and relative density of *Pinus roxburghii* and *Prunus puddum* was higher than other tree species, while the basal area and relative basal area was recorded higher for *Pinus roxburghii*, although it lags far behind. The second most frequent tree species were *Ehretia acuminata*, *Machilus duthiei* and *Prunus puddum*, having a frequency of 66.7 % each. The order of tree species in their importance value index were: *Quercus glauca* > *Pinus roxburghii* > *Ehretia acuminata* > *Prunus puddum* > *Machilus duthiei*, etc in descending order. As displayed in Table 23, the highest density (308 N ha⁻¹) among shrubs were recorded by *Myrsine africana*, which was followed by *Rhus cotinus*, *Berberis lycium*, *Hamiltonia suaveolens*, *Rubus ellipticus*, *Sageretia oppositifolia*, etc., respectively. Whereas, the highest basal area (2439.7 cm² ha⁻¹) was recorded by *Rhus cotinus*, which was followed by *Sageretia oppositifolia* (1923.1 cm² ha⁻¹), *Berberis lycium* (1529.1 cm² ha⁻¹), *Rubus ellipticus* (1353.9 cm² ha⁻¹), etc., while *Rhus cotinus* and *Myrsine africana* was having a 100 per cent frequency. Based on their importance value index, *Rhus cotinus*, *Berberis lycium*, *Sageretia oppositifolia*, *Rubus ellipticus*, *Myrsine africana*, etc., dominated the shrub layer. On the other hand, the density, relative density, basal area and relative basal area of herbs were dominated by *Panicum agrostoides*, which was followed by *Desmodium spp.*

Table 19: Phytosociology of trees at site V (Chakla, Sarhan forest range)

Species	Density (N ha ⁻¹)	Relative density	Basal area (m ² ha ⁻¹)	Relative basal area	Frequency (%)	Relative frequency	Importance value Index (IVI)
<i>Ailanthus excelsa</i>	17	2.5	0.4	1.1	33.3	8.3	11.9
<i>Myrica esculenta</i>	17	2.5	1.3	3.4	33.3	8.3	14.2
<i>Olea glandulifera</i>	8	1.3	0.5	1.2	33.3	8.3	10.8
<i>Pinus roxburghii</i>	17	2.5	4.3	10.8	66.7	16.7	30.0
<i>Punica granatum</i>	75	11.3	0.8	2.2	66.7	16.7	30.1
<i>Quercus glauca</i>	508	76.3	30.3	77.1	100.0	25.0	178.4
<i>Quercus leucotrichophora</i>	25	3.8	1.7	4.2	66.7	16.7	24.6
Total	667	100.0	39.3	100.0	400.0	100.0	300.0

Table 20: Phytosociology of shrubs at site V (Chakla, Sarhan forest range)

Species	Density (N ha ⁻¹)	Relative density	Basal area (cm ² ha ⁻¹)	Relative basal area	Frequency (%)	Relative frequency	Importance value Index (IVI)
<i>Barleria cristata</i>	115	4.7	68.8	1.0	80.0	5.5	11.1
<i>Berberis lycium</i>	163	6.6	1148.5	16.3	100.0	6.8	29.8
<i>Callicarpa macrophylla</i>	53	2.2	200.5	2.8	86.7	5.9	10.9
<i>Carissa carandas</i>	133	5.4	1812.5	25.7	80.0	5.5	36.6
<i>Randia tetrasperma</i>	53	2.2	36.9	0.5	33.3	2.3	5.0
<i>Hypericum oblongifolium</i>	30	1.2	98.9	1.4	60.0	4.1	6.7
<i>Indigofera pulchella</i>	96	3.9	234.2	3.3	66.7	4.6	11.8
<i>Inula cappa</i>	60	2.4	28.6	0.4	73.3	5.0	7.9
<i>Lantana camara</i>	59	2.4	2.8	0.0	53.3	3.7	6.1
<i>Andrachne cordifolia</i>	145	5.9	239.8	3.4	100.0	6.8	16.1
<i>Lonicera angustifolia</i>	100	4.1	319.3	4.5	40.0	2.7	11.4
<i>Lonicera quinquelocularis</i>	160	6.5	371.8	5.3	100.0	6.8	18.6
<i>Meriandra strobilifera</i>	84	3.4	148.5	2.1	20.0	1.4	6.9
<i>Myrsine africana</i>	506	20.6	1147.2	16.3	100.0	6.8	43.7
<i>Vitis himalayana</i>	43	1.8	37.5	0.5	93.3	6.4	8.7
<i>Rosa macrophylla</i>	56	2.3	253.1	3.6	73.3	5.0	10.9
<i>Sageretia oppositifolia</i>	26	1.1	13.9	0.2	46.7	3.2	4.4
<i>Cassia floribunda</i>	172	7.0	208.0	2.9	13.3	0.9	10.9
<i>Solanum khasianum</i>	90	3.7	114.6	1.6	86.7	5.9	11.2
<i>Hamiltonia suaveolens</i>	195	8.0	71.3	1.0	86.7	5.9	14.9
<i>Trachelospermum fragrans</i>	114	4.6	501.0	7.1	66.7	4.6	16.3
Total	2453	100.0	7057.9	100.0	1460.0	100.0	300.0

Table 21: Phytosociology of herbs at site V (Chakla, Sarhan forest range)

Species	Density (N ha ⁻¹)	Relative density	Basal area (cm ² ha ⁻¹)	Relative basal area	Frequency (%)	Relative frequency	Importance value Index (IVI)
<i>Achyranthes aspera</i>	452	2.8	115.1	0.2	33.3	5.5	8.5
<i>Ageratum conyzoides</i>	408	2.5	11.5	0.0	33.3	5.5	8.0
<i>Anaphalis busua</i>	529	3.2	259.6	0.6	33.3	5.5	9.3
<i>Anisomeles ovata</i>	259	1.6	20.4	0.0	26.7	4.4	6.0
<i>Asparagus officinalis</i>	313	1.9	250.7	0.5	43.3	7.1	9.6
<i>Bidens pilosa</i>	1327	8.1	8255.5	17.7	33.3	5.5	31.3
<i>Boenninghausenia albiflora</i>	650	4.0	5345.0	11.5	66.7	10.9	26.4
<i>Cissampelos pareira</i>	275	1.7	26.1	0.1	30.0	4.9	6.7
<i>Cymbopogon spp.</i>	1842	11.3	978.0	2.1	33.3	5.5	18.8
<i>Dicliptera bupleuroides</i>	861	5.3	4218.2	9.0	33.3	5.5	19.8
<i>Arundinaria falcata</i>	1011	6.2	3053.3	6.5	33.3	5.5	18.2
<i>Geranium pratense</i>	1750	10.7	111.4	0.2	33.3	5.5	16.4
<i>Oplismenus compositus</i>	2862	17.5	13673.5	29.3	33.3	5.5	52.3
<i>Panicum depauperatum</i>	1522	9.3	2108.2	4.5	30.0	4.9	18.8
<i>Pimpinella diversifolia</i>	380	2.3	439.3	0.9	23.3	3.8	7.1
<i>Polystichum discretum</i>	321	2.0	25.2	0.1	33.3	5.5	7.5
<i>Scutellaria angulosa</i>	525	3.2	896.6	1.9	33.3	5.5	10.6
<i>Strobilanthes glutinosus</i>	714	4.4	6785.4	14.5	13.3	2.2	21.1
<i>Thalictrum foliolosum</i>	329	2.0	78.1	0.2	10.0	1.6	3.8
Total	16330	100.0	46651.0	100.0	610.0	100.0	300.0

Table 22: Phytosociology of trees at site VI (Tikri, Sarhan forest range)

Species	Density (N ha⁻¹)	Relative density	Basal area (m² ha⁻¹)	Relative basal area	Frequency (%)	Relative frequency	Importance value Index (IVI)
<i>Debregeasia hypoleuca</i>	8	1.1	0.2	0.5	33.3	5.9	7.5
<i>Ehretia acuminata</i>	17	2.2	0.7	1.8	66.7	11.8	15.8
<i>Ficus palmata</i>	8	1.1	0.1	0.3	33.3	5.9	7.3
<i>Machilus duthiei</i>	17	2.2	0.5	1.2	66.7	11.8	15.2
<i>Manilkara kauki</i>	17	2.2	0.8	2.0	33.3	5.9	10.1
<i>Myrica esculenta</i>	8	1.1	0.4	1.1	33.3	5.9	8.1
<i>Pinus roxburghii</i>	42	5.6	2.0	5.3	33.3	5.9	16.8
<i>Prunus puddum</i>	25	3.4	0.2	0.5	66.7	11.8	15.6
<i>Punica granatum</i>	8	1.1	0.1	0.2	33.3	5.9	7.2
<i>Pyrus pashia</i>	8	1.1	0.2	0.5	33.3	5.9	7.5
<i>Quercus glauca</i>	567	76.4	33.1	86.2	100.0	17.6	180.3
<i>Toona ciliata</i>	17	2.2	0.2	0.4	33.3	5.9	8.5
Total	742	100.0	38.4	100.0	566.7	100.0	300.0

Table 23: Phytosociology of shrubs at site VI (Tikri, Sarhan forest range)

Species	Density (N ha⁻¹)	Relative density	Basal area (cm² ha⁻¹)	Relative basal area	Frequency (%)	Relative frequency	Importance value Index (IVI)
<i>Berberis lycium</i>	272	11.5	1529.1	13.2	93.3	7.5	32.2
<i>Berchemia floribunda</i>	94	4.0	238.9	2.1	60.0	4.8	10.9
<i>Carissa carandas</i>	81	3.4	522.5	4.5	46.7	3.8	11.7
<i>Coriaria nepalensis</i>	44	1.9	134.6	1.2	33.3	2.7	5.7
<i>Rhus cotinus</i>	298	12.5	2439.7	21.1	100.0	8.1	41.7
<i>Deutzia staminea</i>	114	4.8	244.9	2.1	46.7	3.8	10.7
<i>Elaeagnus umbellata</i>	21	0.9	7.2	0.1	73.3	5.9	6.8
<i>Ficus pumila</i>	41	1.7	558.7	4.8	93.3	7.5	14.1
<i>Indigofera pulchella</i>	76	3.2	186.0	1.6	73.3	5.9	10.7
<i>Andrachne cordifolia</i>	149	6.3	154.8	1.3	66.7	5.4	13.0
<i>Myrsine africana</i>	308	13.0	900.7	7.8	100.0	8.1	28.8
<i>Pavetta indica</i>	57	2.4	74.7	0.6	93.3	7.5	10.6
<i>Rosa moschata</i>	41	1.7	949.9	8.2	86.7	7.0	16.9
<i>Rubus ellipticus</i>	242	10.2	1353.9	11.7	86.7	7.0	28.9
<i>Sageretia oppositifolia</i>	216	9.1	1923.1	16.7	66.7	5.4	31.2
<i>Cassia occidentalis</i>	72	3.0	65.2	0.6	40.0	3.2	6.8
<i>Hamiltonia suaveolens</i>	248	10.4	256.3	2.2	80.0	6.5	19.1
Total	2374	100.0	11540.5	100.0	1240.0	100.0	300.0

Table 24: Phytosociology of herbs at site VI (Tikri, Sarhan forest range)

Species	Density (N ha ⁻¹)	Relative density	Basal area (cm ² ha ⁻¹)	Relative basal area	Frequency (%)	Relative frequency	Importance value Index (IVI)
<i>Adiantum lunulatum</i>	198	1.3	22.4	0.2	20.0	3.4	4.9
<i>Ageratum conyzoides</i>	742	4.9	188.8	1.6	26.7	4.5	11.1
<i>Asparagus officinalis</i>	244	1.6	124.8	1.0	16.7	2.8	5.5
<i>Asplenium dalhousiae</i>	186	1.2	14.6	0.1	10.0	1.7	3.1
<i>Carpesium spp.</i>	744	5.0	98.8	0.8	33.3	5.7	11.5
<i>Desmodium spp.</i>	1643	10.9	158.7	1.3	93.3	15.9	28.2
<i>Dioscorea esculenta</i>	234	1.6	1.7	0.0	30.0	5.1	6.7
<i>Dryopteris cochleata</i>	288	1.9	44.3	0.4	16.7	2.8	5.1
<i>Equisetum arvense</i>	148	1.0	0.1	0.0	10.0	1.7	2.7
<i>Galium aparine</i>	862	5.7	6.1	0.1	33.3	5.7	11.5
<i>Galium rotundifolium</i>	628	4.2	24.2	0.2	26.7	4.5	8.9
<i>Geranium pratense</i>	505	3.4	1.6	0.0	30.0	5.1	8.5
<i>Hedera helix</i>	721	4.8	36.9	0.3	26.7	4.5	9.7
<i>Lespedeza gerardiana</i>	282	1.9	64.0	0.5	30.0	5.1	7.5
<i>Oplismenus burmanni</i>	1327	8.8	2206.1	18.5	33.3	5.7	33.0
<i>Panicum agrostoides</i>	4317	28.7	7801.7	65.4	53.3	9.1	103.2
<i>Panicum depauperatum</i>	877	5.8	943.3	7.9	26.7	4.5	18.3
<i>Scutellaria angulosa</i>	372	2.5	128.8	1.1	20.0	3.4	7.0
<i>Thelypteris erubescens</i>	414	2.8	68.3	0.6	33.3	5.7	9.0
<i>Viola serpens</i>	296	2.0	0.9	0.0	16.7	2.8	4.8
Total	15028	100.0	11936.0	100.0	586.7	100.0	300.0

and *Oplismenus burmanni* (Table 24). *Desmodium spp.* and *Panicum agrostoides* were the most frequently occurring herb species in the site while *Panicum agrostoides*, *Oplismenus burmanni* and *Desmodium spp.* dominated the site with importance value of 103.2, 33.0 and 28.2, respectively.

4.1.1.7 Similarity index

Data presented in Table 25 shows that the data pertaining to number of species present in two different forest sites was used to assess their similarities. Similarity index in Table 25 to Table 27 below is presented in per cent. The maximum similarity in tree species was observed between site IV and site V (66.7 %) followed by site IV and site VI (63.6 %), site I and site V (62.5 %). The minimum similarity index was recorded between site I and site III (14.3 %).

Table 25: Similarity index for trees among different *Quercus glauca* bearing forest sites

	Site I	Site II	Site III	Site IV	Site V	Site VI
Site I	100					
Site II	52.6	100				
Site III	14.3	26.7	100			
Site IV	50.0	47.6	50.0	100		
Site V	62.5	35.3	33.3	66.7	100	
Site VI	30.0	47.6	50.0	63.6	44.4	100

Table 26: Similarity index for shrubs among different *Quercus glauca* bearing forest sites

	Site I	Site II	Site III	Site IV	Site V	Site VI
Site I	100.0					
Site II	48.3	100.0				
Site III	36.4	42.1	100.0			
Site IV	50.0	24.0	34.5	100.0		
Site V	42.4	47.4	33.3	20.7	100.0	
Site VI	41.4	41.2	57.9	48.0	36.8	100.0

The data in Table 26 shows that maximum similarity in shrub species was found between site III and site VI (57.9 %) followed by site I and site IV (50 %) and site I and site II (48.3 %), respectively in descending order. Minimum similarity in shrubs, 20.7 %, was recorded between site IV and site V.

It is crystal clear from the data in the Table 27 that the maximum similarity index in herbaceous species was recorded between site II and site V (41.2 %) followed by site III and site IV (40.0 %), site II and site III (34.3 %). Minimum similarity in herbs was found between site IV and site VI (11.8 %).

Table 27: Similarity index for herbs among different *Quercus glauca* bearing forest sites

	Site I	Site II	Site III	Site IV	Site V	Site VI
Site I	100.0					
Site II	31.3	100.0				
Site III	21.6	34.3	100.0			
Site IV	12.5	33.3	40.0	100.0		
Site V	27.8	41.2	25.6	23.5	100.0	
Site VI	27.8	11.8	20.5	11.8	26.3	100.0

4.1.1.8 Species Indices

Data presented in Table 28 shows the Shannon- Weiner diversity index, Margalef's species richness index and Simpson's species dominance index for the trees, shrubs and herb species of the six *Quercus glauca* bearing forest sites. Shannon- Weiner diversity index shows that in general maximum species diversity was for herbs followed by shrubs and trees, respectively. The maximum trees diversity index is recorded at site IV and closely followed by site I. Maximum shrub diversity index is recorded for site V and minimum for site IV, whereas, maximum herb diversity index is displayed at site III. It is also clear from the table that the site at which tree diversity was maximum the herbage diversity was minimum and vice-versa.

Similar to the Shannon- Weiner diversity index, Margalef's species richness index also shows that, in general, richness index is highest for herbs followed by shrubs and trees in the study sites. The site at which the tree Margalef's species richness index is maximum the herb richness index was minimum and vice-versa. It is also clear from Table 28 that maximum Shannon-Weiner diversity index and Margalef's species richness index was displayed at site V. It is also clear from Table 28 Simpson's species dominance index values are maximum for tree species, irrespective of site; whereas, shrub and herb dominance indices didn't followed any definite pattern.

Regeneration status of *Quercus glauca* bearing forests in relation to tree, shrub and herbage density as well as lopping intensity and acorn damage is presented in Table 29. The data in the table reveals that lots of variation exists in seedling and sapling number among the investigated sites. Maximum seedling number is shown at site I, which is closely followed by site II, Site VI, site IV, site III and site V, respectively; whereas, maximum number of saplings i.e. 8750 were recorded at site I, followed by site VI, site III, site II, site IV and site V, respectively. Regeneration per cent and establishment stocking per cent followed the same trend as that of the sapling number. Tree, shrub and herbage density also varied a lot amongst different *Quercus glauca* bearing forest sites. It is also evident from the table that lopping intensity varied among different sites. Damage on acorns and number of viable seeds were also varied a lot at different sites.

Table 28: Species indices of different *Quercus glauca* bearing forest sites

Index	Life form	Site I	Site II	Site III	Site IV	Site V	Site VI
Shannon-Weiner diversity Index	Tree	0.778	0.614	0.407	0.781	0.594	0.697
	Shrub	1.016	1.078	1.197	0.793	1.234	1.159
	Herb	1.154	0.969	1.231	1.077	1.185	1.053
Margalef's species richness index	Trees	1.61	1.89	1.06	2.28	1.37	2.23
	Shrubs	1.93	2.68	3.16	1.16	3.26	2.62
	Herbs	2.57	2.31	3.08	2.14	2.91	2.95
Simpson's species dominance index	Tree	0.2	0.43	0.56	0.27	0.39	0.38
	Shrub	0.11	0.11	0.08	0.2	0.07	0.08
	Herb	0.08	0.16	0.07	0.1	0.08	0.15

Table 29: Regeneration status of *Quercus glauca* bearing forest sites in relation to stand and site characteristics

Life form	Site I	Site II	Site III	Site IV	Site V	Site VI
Seedlings	32251	22417	14500	15750	11500	16334
Saplings	8750	4000	4167	2667	1917	5750
Regeneration %	229.2	109.2	134.2	100.0	71.7	149.2
Establishment stocking %	87.5	40.0	41.7	26.7	14.2	57.5
Trees (N ha⁻¹)	1183	966	366	675	667	742
Shrubs (N ha⁻¹)	1610	2078	2990	2271	2453	2374
Herbs (N ha⁻¹)	16755	14312	15855	22980	16330	15028
Lopping intensity (%)	7.9	65.0	94.7	46.2	45.9	70.6
Insect damage (%)	10	6	3	24	37	22

4.1.2 Stand characteristics

4.1.2.1 Diameter distribution and stand characteristics

Data displayed in Table 30 reveals that the minimum number of diameter classes were recorded in site II that ranged from 10.0-19.9 cm to 30.0-39.9 cm, while the maximum number of diameter classes were recorded in Site V, which contains diameter classes ranging from 10.0-19.9 cm to 70.0-79.9 cm. Other sites contained trees falling within diameter classes in between 10.0-19.9 cm and 60.0-69.9cm.

The number of trees per hectare along diameter classes showed a general decreasing trend from lower diameter classes (10.0-19.9 cm) to higher diameter classes (70.0-79.9 cm) excepting in site III and site V. In site III the diameter class 40.0-49.9 cm has more number of trees per hectare than the diameter class 30.0-39.9 cm and in site V the diameter class 20.0-29.9 cm contained more number of trees per hectare than the diameter class 10.0-19.9 cm. Whereas, in diameter class of 60.0-69.9 cm no tree has been recorded. The highest number of trees per hectare (408) was recorded in site II under the diameter class of 10.0-19.9 cm, while the no tree (0) were recorded in site V for the diameter class 60.0-69.9 cm. Average diameter at breast height and average height also showed variation with diameter classes and sites.

The average crown diameter also showed a general increasing trend with increasing diameter class with minor deviation in site V. The highest average crown diameter (18.5 m) was recorded in site IV for the diameter class 40.0-49.9 cm, while the lowest average crown diameter (2.1 m) was recorded in site VI for the diameter class 10.0-19.9 cm. Similarly, average crown length showed a general increase with increasing diameter classes with the exception of minor deviation in site I and much inconsistency in site VI. The highest average crown length (27 m) was recorded for site III in the diameter class 50.0-59.9 cm and the lowest average crown length (4.1 m) was recorded for site VI in the diameter class of 10.0-19.9 cm.

Both average basal area per hectare and average volume per hectare are results of tree number per hectare and average diameter of each diameter classes. Hence, these values show large variations among diameter classes. Both the largest basal area per hectare ($16.0 \text{ m}^2 \text{ ha}^{-1}$) and the largest volume per hectare ($54.3 \text{ m}^3 \text{ ha}^{-1}$) were recorded for site II under diameter class of

20.0-29.9 cm. On the other hand, the lowest average basal area per hectare ($1.3 \text{ m}^2 \text{ ha}^{-1}$) and the lowest volume per hectare ($3.3 \text{ m}^3 \text{ ha}^{-1}$) were recorded in site I under diameter class 30-39.9 cm and in site V under diameter class 10.0-19.9 cm, respectively.

Table 30: Population structure in relation to growth characteristics of *Quercus glauca* bearing forests of the study sites

Site	Diameter class (cm)	Number (N ha ⁻¹)	Diameter at breast height (cm)	Height (m)	Crown width (m)	Crown length (m)	Basal area (m ² ha ⁻¹)	Volume (m ³ ha ⁻¹)
Site I (Shilli)	Seedlings	2334	-	-	-	-	-	-
	Saplings	1000	-	-	-	-	-	-
	10-19.9	150	13.9	9.5	3.4	5.8	2.3	5.1
	20-29.9	125	24.2	20.5	7.2	14.4	5.7	27.6
	30-39.9	17	31.8	25.5	10.0	19.3	1.3	7.9
	40-49.9	17	41.4	28.5	12.0	19.0	2.2	15.0
	50-59.9	8	51.9	28.0	14.0	16.0	1.8	11.6
Site II (Oachghat)	Seedlings	7917	-	-	-	-	-	-
	Saplings	1000	-	-	-	-	-	-
	10-19.9	408	14.3	9.2	2.5	4.8	6.5	14.1
	20-29.9	333	24.7	14.5	3.9	8.2	16.0	54.3
	30-39.9	67	33.3	16.9	6.8	10.9	5.8	22.9
Site III (Deothal)	Seedlings	2750	-	-	-	-	-	-
	Saplings	667	-	-	-	-	-	-
	10-19.9	200	12.7	8.0	3.3	5.3	2.5	4.7
	20-29.9	67	24.5	10.9	4.1	7.5	3.1	8.0
	30-39.9	17	37.6	16.5	6.0	12.0	1.8	7.1
	40-49.9	25	46.2	27.3	8.7	23.0	4.2	26.8
Site IV (Narag)	50-59.9	8	52.0	30.0	15.0	27.0	1.8	12.4
	Seedlings	5000	-	-	-	-	-	-
	Saplings	1167	-	-	-	-	-	-
	10-19.9	292	13.8	7.5	3.7	4.9	4.4	7.7
	20-29.9	83	22.8	13.5	5.4	9.2	3.4	10.8
	30-39.9	42	33.6	24.0	14.0	17.4	3.7	20.7
Site V (Chakla)	40-49.9	17	45.4	27.5	18.5	20.5	2.7	17.3
	Seedlings	1000	-	-	-	-	-	-
	Saplings	667	-	-	-	-	-	-
	10-19.9	150	12.7	7.4	2.9	4.9	1.9	3.3
	20-29.9	158	24.2	10.7	3.8	7.3	7.3	18.3
	30-39.9	108	35.3	16.5	5.8	11.0	10.6	40.9
	40-49.9	42	43.1	21.0	8.8	13.8	6.1	29.9
	50-59.9	33	56.4	26.5	11.5	16.0	8.3	51.7
	60-69.9	0	0.0	0.0	0.0	0.0	0.0	0.0
Site VI (Tikri)	70-79.9	17	75.3	26.0	10.5	17.0	7.4	45.2
	Seedlings	1667	-	-	-	-	-	-
	Saplings	1250	-	-	-	-	-	-
	10-19.9	208	14.3	6.9	2.1	4.1	3.3	5.4
	20-29.9	142	24.8	16.8	5.4	10.9	6.8	26.8
	30-39.9	117	34.5	16.2	5.8	10.5	10.9	41.4
	40-49.9	67	44.6	17.6	6.3	10.5	10.4	42.9
	50-59.9	25	54.1	23.3	7.7	16.0	5.7	31.4
	60-69.9	8	67.8	30.0	12.0	20.0	3.0	21.1

4.1.2.2 Growth characteristics of *Quercus glauca* and associated species

Graphical depiction of the density, basal area and volume of *Quercus glauca* and associated species in Figure 2 shows that excepting at site I all other sites have quite higher values of all these traits in *Quercus glauca* than the associated species. All of these sites show a lot of variation in density, basal area and volume of both *Quercus glauca* as well as associated species.

4.1.2.3 Effect of lopping/pollarding on the growth of *Quercus glauca*

Illustration of the graphs at Figure 3 shows the variation in growth parameters (density, basal area and volume) of full crown and lopped/ pollarded trees of the study area. The highest density per hectare of full crown and lopped/pollarded trees was recorded in site I and site II, respectively. The highest basal area per hectare and volume per hectare of full crown trees were recorded in site V, while the highest basal area per hectare and volume per hectare of lopped/pollarded trees were recorded in site VI. The lowest density per hectare, basal area per hectare and volume per hectare of unlopped *Quercus glauca* trees were recorded in site III, whereas these values were recorded low in site I for lopped/pollarded *Quercus glauca* trees.

Figure 4 presented the best fit volume equation of unlopped individual trees and it was expressed as $V=0.0005766D^2 - 0.004777D - 0.01248$ ($R^2=0.973$) where V and D are volume and diameter of individual trees. Based on this equation, the loss in volume per tree due to lopping/pollarding is indicated in Figure 5. The average volume of lopped trees was found to be 0.0724 m³ per tree. But this value was expected to be 0.179 m³ per tree without lopping/pollarding. Hence, on average, there is a loss of 0.0724 m³ volume of wood per tree due to lopping/ pollarding.

4.1.3 Regeneration assessment

It is evidently clear from the data presented in Table 31 that in site I there were 13 tree species marking their presence as recruits, unestablished regeneration and/or established regeneration. Out of these tree species, 11 were present as recruits, 9 as unestablished regeneration and 8 as established regenerates. Among recruits, *Cryptolepis buechanani* (4000) showed their dominant presence followed by *Myrica esculenta* (2833), *Celtis australis* (2333),

Quercus leucotrichophora (1250) and *Quercus glauca* (1167). *Myrica esculenta* (3833) and *Pyrus pashia* (1833) displayed maximum number of unestablished and established regenerations, respectively. *Pyrus pashia* produced tallest seedling among the unestablished regenerations followed by *Ailanthus excelsa* and *Albizia spp.*, each displaying equal values. Establishment stocking per cent was recorded high (18.3 %) for *Pyrus pashia*, which was followed by *Myrica esculenta* and *Zanthoxylum alatum*. On the basis of per cent regeneration, the order of the species were: *Myrica esculenta* > *Pyrus pashia* > *Zanthoxylum alatum* > *Quercus leucotrichophora* > *Celtis australis* and *Quercus glauca*, etc.

Data presented in Table 32 reveals that the total number of recruits, unestablished, and established regenerations of site II were 15500, 6917 and 4000, respectively. Ten species were recorded to have one or more of these regeneration types. *Quercus glauca* had the maximum number of recruits (6750), while *Punica granatum* had the maximum number of unestablished regeneration (2750), whereas *Ailanthus excelsa*, *Bauhinia variegata* and *Quercus glauca* equally contributed the maximum number of established regenerations (1000). These species had also the highest (10 %) established stocking per cent. The regeneration per cent was dominantly accounted by *Punica granatum* (27.5 %) followed by *Quercus glauca* (21.7 %) and *Celtis australis* (15 %), respectively.

The data displayed in Table 33 reveals that six tree species have been recorded to have regeneration in site III. *Celtis australis* and *Quercus glauca* were having the maximum recruits (1500), while *Pyrus pashia* had the maximum (3500) unestablished regeneration, which was followed by *Punica granatum* and *Zanthoxylum alatum*. The established regeneration, on the other hand, was occupied by *Punica granatum* (3500) and *Quercus glauca* (667) only. *Punica granatum* had the highest establishment stocking per cent (35.0 %). The order of regeneration per cent in site III were: *Punica granatum* > *Pyrus pashia* > *Quercus glauca* > *Zanthoxylum alatum* > *Celtis australis* > *Melia azedarach*.

The data in Table 34 demonstrates that regenerations of 8 tree species were recorded at site IV. The total number of recruits, unestablished, and established regenerations were 8417, 7333 and 2667, respectively. *Quercus glauca* had the most prolific regenerations that contributed the maximum number of recruits (2167), unestablished (2833) and established (1167)



Plate 1: *Quercus glauca* forest

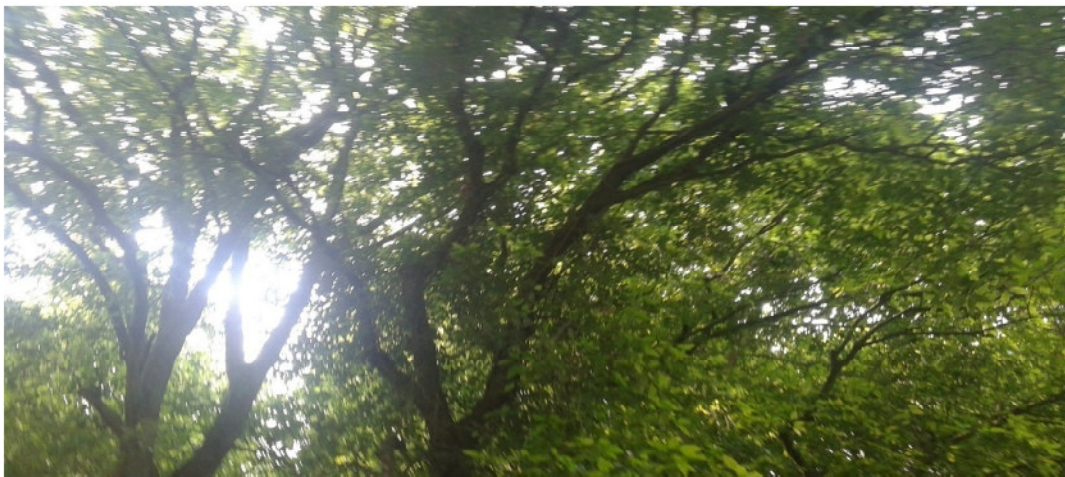


Plate 2: Unlopped *Quercus glauca* trees



Plate 3: Lopped *Quercus glauca* trees

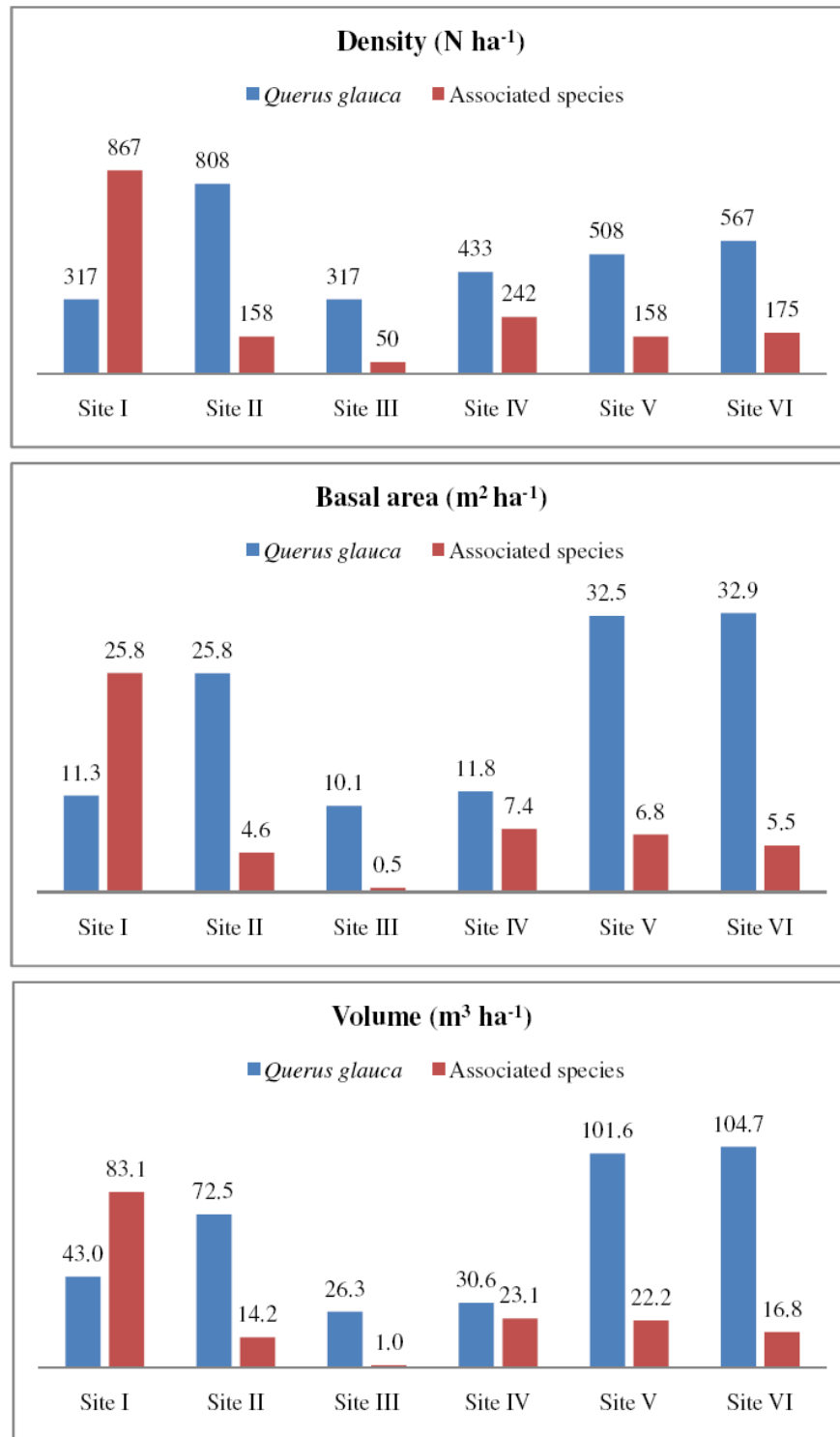


Figure 2: Density, basal area and volume of *Quercus glauca* and associated species

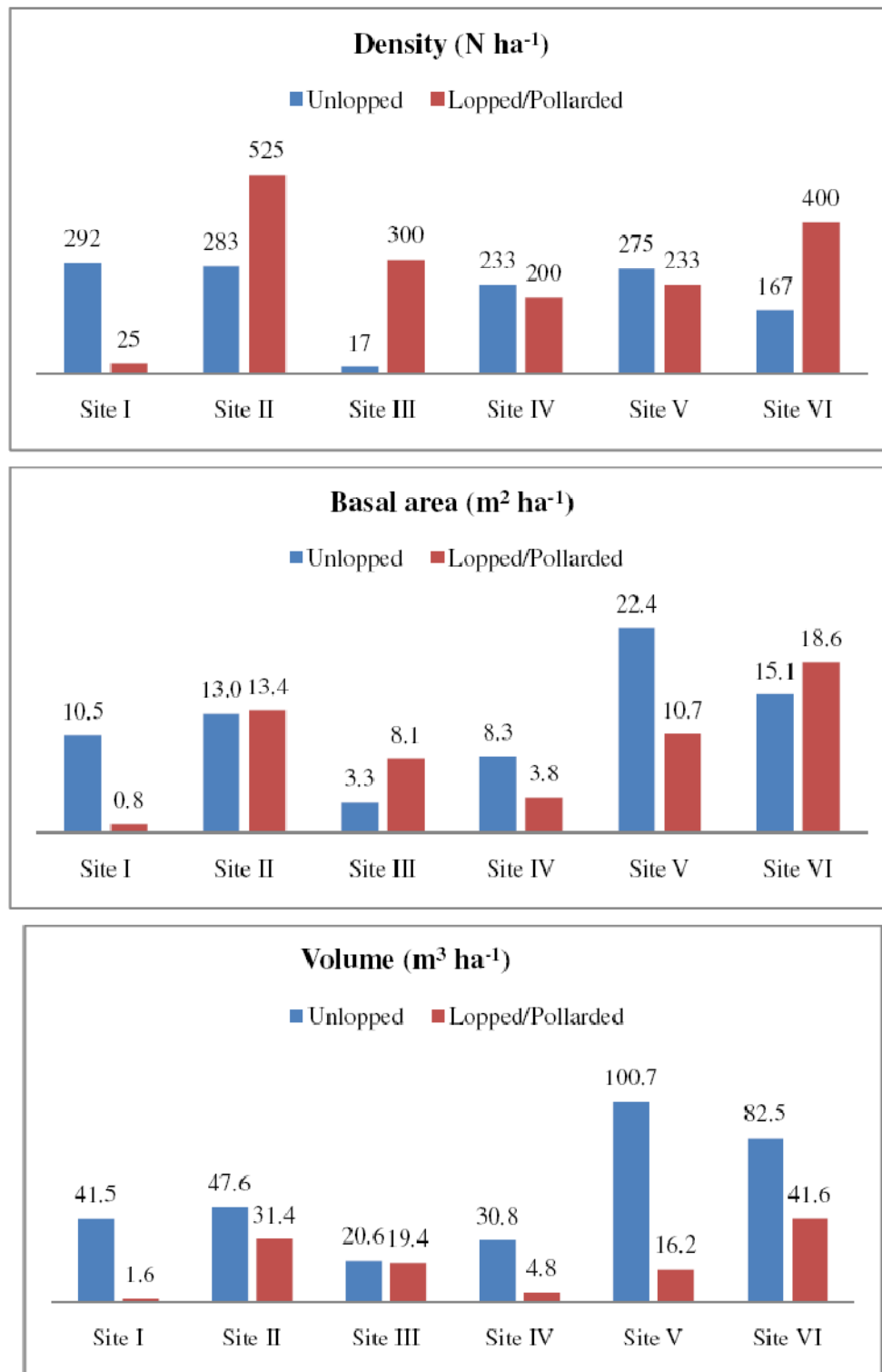


Figure 3: Density, basal area and volume of unlopped and lopped/pollarded trees of *Quercus glauca*

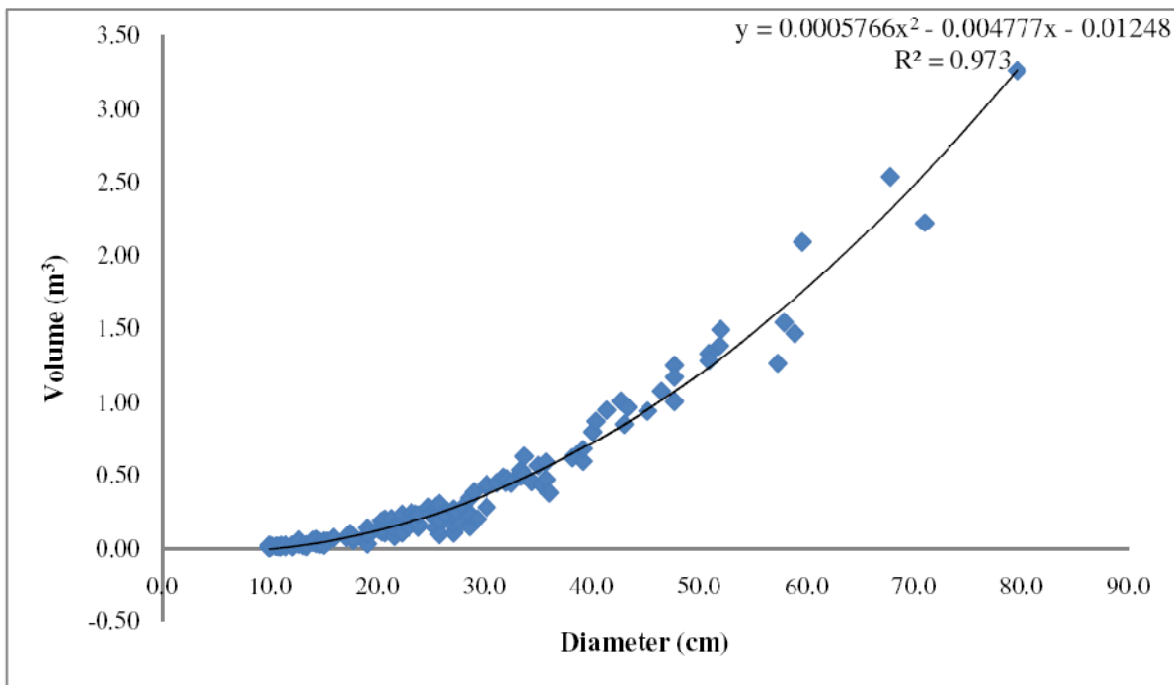


Figure 4: Volume equation of unlopped *Quercus glauca* trees

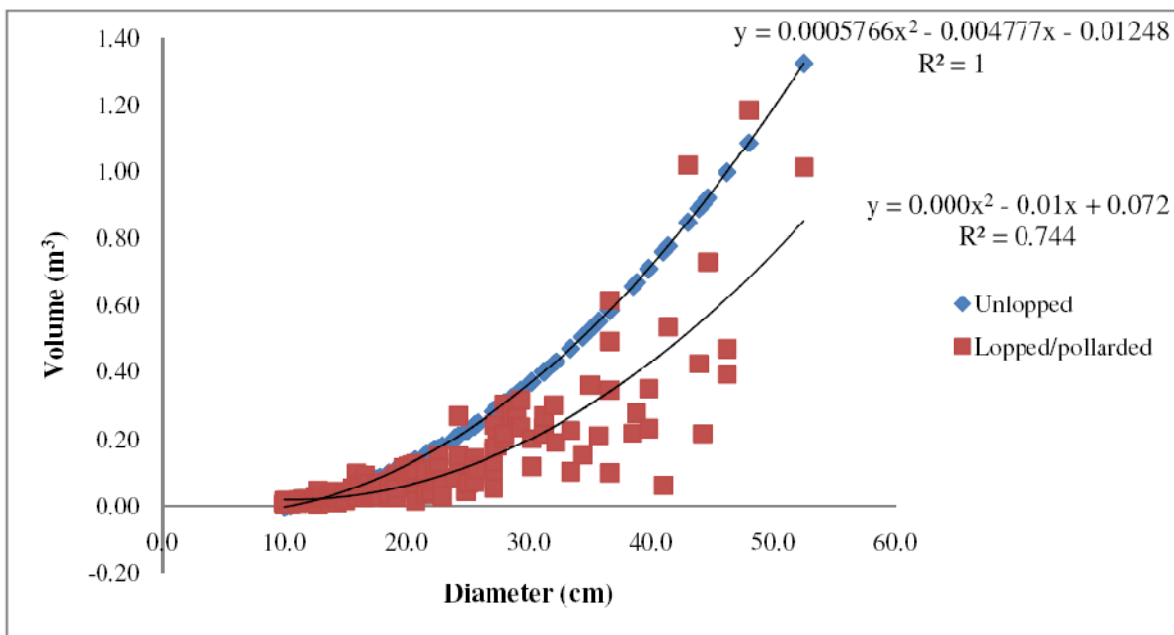


Figure 5: Loss in volume of wood due to lopping/pollarding

regenerates. The site had an establishment stocking per cent of 26.7 % and regeneration per cent of 100 %. *Quercus glauca* had higher establishment stocking per cent (11.7 %) and regeneration per cent (40.0 %) than other species.

At site V (Table 35), there were seven species recorded in the regeneration spectrum of the site. The total number of recruits, unestablished and established regenerations were 6250, 5250 and 1917, respectively. *Glochidion spp.* and *Punica granatum* had maximum number of recruits (1500), while maximum number of unestablished regeneration (2000) and maximum number of established regeneration (750) were recorded by *Punica granatum* and *Machilus duthiei*, respectively. Regeneration of *Quercus glauca* at this site was not satisfactory. The maximum stocking per cent (7.5 %) was recorded for *Machilus duthiei*, whereas, the maximum regeneration per cent (20 %) was recorded for *Punica granatum*.

At site VI ten species made their representations as recruits, unestablished regeneration and/or established regeneration (Table 36). There were a total number of 7167, 9167, and 5750 recruits, unestablished and established regenerations, respectively. The maximum number of recruits (1500) were recorded by *Ficus sarmentosa*, *Machilus duthiei* and *Zanthoxylum alatum*. The maximum number of unestablished (2000) and established (3000) regenerations were recorded for *Zanthoxylum alatum* and *Toona ciliate*, respectively. *Quercus glauca* had no recruits at all but it had 1667 and 1250 unestablished and established regenerate, respectively. Site VI has an establishment stocking per cent of 57.5 %. Out of which, *Toona ciliata* had the maximum (30 % and 35 %) establishment stocking and regeneration per cent, respectively followed by *Quercus glauca*.

4.1.4 Site characteristics

A perusal of data in Table 37 reveals significant differences in soil pH, organic carbon, available potassium and organic matter layer among the study sites. However, differences in moisture content, available nitrogen, available phosphorus and solar influx were insignificant. Considering difference between the two soil depths, soil pH and moisture content were insignificant, while organic carbon, available nitrogen, available phosphorus, and available potassium were found significantly different. The interaction effect of study sites and soil depths on these parameters was found insignificant.

Table 31: Regeneration status of site I (Shilli, Solan forest range)

Species	Recruits (N ha ⁻¹)	Unestablished regeneration (N ha ⁻¹)	Established regeneration (N ha ⁻¹)	Unestablishment height (cm)	Establishment Stocking (%)	Regeneration (%)
<i>Ailanthus excelsa</i>	0	500	0	124.0	0.0	5.0
<i>Albizia spp.</i>	1000	500	500	124.0	5.0	10.0
<i>Celtis australis</i>	2333	1167	1000	78.3	10.0	21.7
<i>Cryptolepis buchanani</i>	4000	0	0	0.0	0.0	0.0
<i>Machilus duthiei</i>	500	0	500	0.0	5.0	5.0
<i>Myrica esculenta</i>	2833	3833	1667	105.0	16.7	55.0
<i>Pistacia integerrima</i>	1000	0	0	0.0	0.0	0.0
<i>Punica granatum</i>	1000	0	0	0.0	0.0	0.0
<i>Pyrus pashia</i>	2000	2667	1833	143.0	18.3	45.0
<i>Quercus glauca</i>	1167	1167	1000	90.0	10.0	21.7
<i>Quercus leucotrichophora</i>	1250	1667	1000	82.0	10.0	26.7
<i>Triadica sebifera</i>	0	1000	0	0.0	0.0	10.0
<i>Zanthoxylum alatum</i>	1000	1667	1250	67.3	12.5	29.2
Total	18083	14167	8750	62.6	87.5	229.2

Table 32: Regeneration status of site II (Oachghat, Solan forest range)

Species	Recruits (N ha ⁻¹)	Unestablished regeneration (N ha ⁻¹)	Established regeneration (N ha ⁻¹)	Unestablishment height (cm)	Establishment Stocking (%)	Regeneration (%)
<i>Acacia spp.</i>	0	500	0	188.0	0.0	5.0
<i>Acer oblongum</i>	0	500	500	106.0	5.0	10.0
<i>Ailanthus excelsa</i>	0	0	1000	0.0	10.0	10.0
<i>Bauhinia variegata</i>	0	0	1000	0.0	10.0	10.0
<i>Celtis australis</i>	1500	1000	500	90.7	5.0	15.0
<i>Cryptolepis buchanani</i>	2000	0	0	0.0	0.0	0.0
<i>Pistacia integerrima</i>	1000	1000	0	174.0	0.0	10.0
<i>Punica granatum</i>	1250	2750	0	182.5	0.0	27.5
<i>Pyrus pashia</i>	3000	0	0	0.0	0.0	0.0
<i>Quercus glauca</i>	6750	1167	1000	133.0	10.0	21.7
Total	15500	6917	4000	87.4	40.0	109.2

Table 33: Regeneration status of site III (Deothal, Narag forest range)

Species	Recruits (N ha ⁻¹)	Unestablished regeneration (N ha ⁻¹)	Established Regeneration (N ha ⁻¹)	Unestablishment height (cm)	Establishment Stocking (%)	Regeneration (%)
<i>Celtis australis</i>	1500	1000	0	110.0	0.0	10.0
<i>Melia azedarach</i>	0	500	0	165.0	0.0	5.0
<i>Punica granatum</i>	1000	1500	3500	139.5	35.0	50.0
<i>Pyrus pashia</i>	0	3500	0	100.0	0.0	35.0
<i>Quercus glauca</i>	1500	1250	667	103.0	6.7	19.2
<i>Zanthoxylum alatum</i>	1250	1500	0	120.0	0.0	15.0
Total	5250	9250	4167	122.9	41.7	134.2

Table 34: Regeneration status of site IV (Narag, Narag forest range)

Species	Recruits (N ha ⁻¹)	Unestablished regeneration (N ha ⁻¹)	Established regeneration (N ha ⁻¹)	Unestablishment height (cm)	Establishment Stocking (%)	Regeneration (%)
<i>Ailanthus excelsa</i>	2000	0	0	0.0	0.0	0.0
<i>Celtis australis</i>	1000	500	0	145.0	0.0	5.0
<i>Ficus palmata</i>	1500	0	0	0.0	0.0	0.0
<i>Machilus duthiei</i>	0	500	0	160.0	0.0	5.0
<i>Myrica esculenta</i>	750	500	500	1.3	5.0	10.0
<i>Punica granatum</i>	0	1500	1000	110.0	10.0	25.0
<i>Pyrus pashia</i>	1000	1500	0	115.0	0.0	15.0
<i>Quercus glauca</i>	2167	2833	1167	114.7	11.7	40.0
Total	8417	7333	2667	80.7	26.7	100.0

Table 35: Regeneration status of site V (Chakla, Sarhan forest range)

Species	Recruits (N ha ⁻¹)	Unestablished regeneration (N ha ⁻¹)	Established regeneration (N ha ⁻¹)	Unestablishment height (cm)	Establishment Stocking (%)	Regeneration (%)
<i>Acer oblongum</i>	750	750	500	108.0	0.0	12.5
<i>Glochidion spp.</i>	1500	0	0	0.0	0.0	0.0
<i>Machilus duthiei</i>	1000	1000	750	142.0	7.5	17.5
<i>Olea paniculata</i>	0	1000	0	117.0	0.0	10.0
<i>Punica granatum</i>	1500	2000	0	160.0	0.0	20.0
<i>Pyrus pashia</i>	1000	0	0	0.0	0.0	0.0
<i>Quercus glauca</i>	500	500	667	166.0	6.7	11.7
Total	6250	5250	1917	99.0	14.2	71.7

Table 36: Regeneration status of site VI (Tikri, Sarhen forest range)

Species	Recruits (N ha ⁻¹)	Unestablished regeneration (N ha ⁻¹)	Established regeneration (N ha ⁻¹)	Unestablishment height (cm)	Establishment Stocking (%)	Regeneration (%)
<i>Ailanthus excelsa</i>	1000	1500	0	60.0	0.0	15.0
<i>Celtis australis</i>	0	1000	0	170.0	0.0	10.0
<i>Ficus sarmentosa</i>	1500	0	0	0.0	0.0	0.0
<i>Machilus duthiei</i>	1500	1000	0	162.0	0.0	10.0
<i>Myrica esculenta</i>	0	0	500	0.0	5.0	5.0
<i>Punica granatum</i>	0	0	1000	0.0	10.0	10.0
<i>Pyrus pashia</i>	1167	1500	0	160.0	0.0	15.0
<i>Quercus glauca</i>	0	1667	1250	93.8	12.5	29.2
<i>Toona ciliata</i>	500	500	3000	134.0	30.0	35.0
<i>Zanthoxylum alatum</i>	1500	2000	0	160.0	0.0	20.0
Total	7167	9167	5750	94.0	57.5	149.2



Plate 4: Recruits of *Quercus glauca*



Plate 5: Unestablished regenerates of *Quercus glauca*

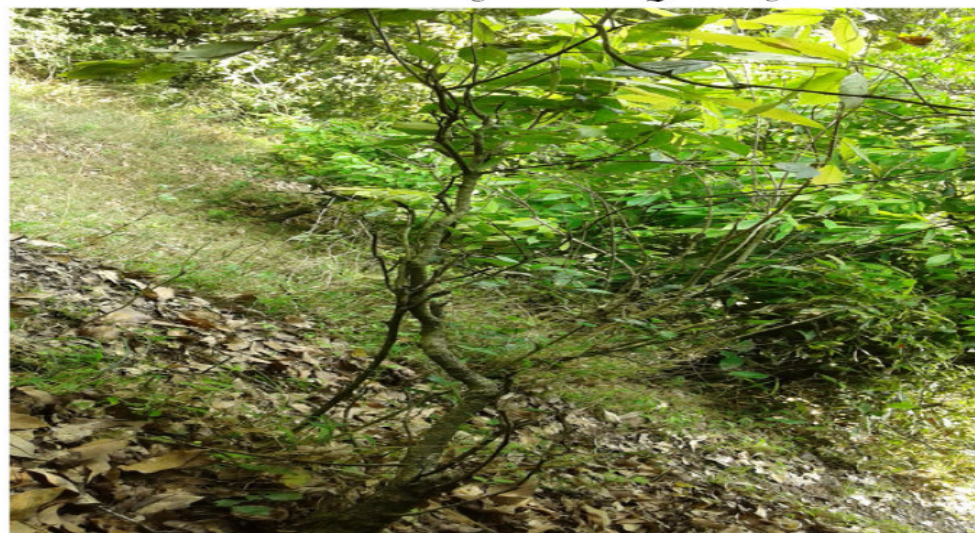


Plate 6: Established regenerations of *Quercus glauca*

In general, pH value was high (6.44) in site III and it was low (4.86) in site IV. Moisture content was recorded high (39.5 %) in site IV and it was low (26.8 %) in site V. The highest organic carbon content (1.46 %) was recorded at sites IV, while lowest organic carbon content (1.29 %) was recorded in site V. Available nitrogen was high (344.5 kg ha⁻¹) in site IV and it was low (254.5 kg ha⁻¹) in site III. The highest (30.2 kg ha⁻¹) and the lowest (19.8 kg ha⁻¹) amount of available phosphorus were recorded in site III and site II, respectively. The highest (231.5 kg ha⁻¹) and the lowest (219.3 kg ha⁻¹) amount of available potassium were recorded in site II and site I, respectively. Organic matter layer was high (1.49 cm) in site IV and it was found low (0.63 cm) in site V. Solar influx was high in site V and it was low in site IV with values of 22.1 % and 12.4 %, respectively. Except soil pH, all values of the measured parameters were found to be significantly higher in the upper soil depth of 0 - 15 cm (D₁) than the lower soil depth of 15 - 30 cm (D₂).

4.1.5 Correlation and Regression studies

In this correlation analysis, the relationship of regeneration of *Quercus glauca* and associated species with different site factors, in general, or site and stand characteristics, in particular, were assessed. The perusal of data in Table 38 reveals that regeneration of *Quercus glauca* was significantly and negatively correlated with soil pH, whereas it had significant and positive relationship with moisture content of the two soil depths. Regeneration of *Quercus glauca* was significantly and negatively correlated with solar influx. The correlation analysis of associated species was not found to be significant in all parameters assessed for site characteristics. The correlation analysis in Table 39 showed the positive and significant relation of *Quercus glauca* regeneration with crown fullness ratio of associated species and crown projection ratios of both *Quercus glauca* and associated tree species. The regeneration of associated species, on the other hand, showed a significant and positive correlation with density, basal area, and volume of associated tree species.

The regression analysis for regeneration of *Quercus glauca* and associated species, as dependent variable, and site and stand characteristics, as independent variable, shows a significant linear relationship between them (Table 40-42). However, most relations showed lower R² values except for moisture content (0-15 and 15-30cm) and solar influx which exhibited a moderately high R² values.

Table 37: Physico-chemical status of different *Quercus glauca* bearing forest sites

Treatment	Soil pH	Moisture content (%)	Organic carbon (%)	Available nitrogen (kg ha ⁻¹)	Available phosphorus (kg ha ⁻¹)	Available potassium (kg ha ⁻¹)	Organic matter layer (cm)	Solar influx (%)
Study Site								
S ₁	5.67	35.0	1.38	313.1	29.5	219.3	1.34	16.3
S ₂	5.82	30.9	1.36	312.0	19.8	231.5	1.43	21.6
S ₃	6.44	29.5	1.32	254.5	30.2	224.5	0.74	21.0
S ₄	4.86	39.5	1.46	344.5	27.2	229.1	1.49	12.4
S ₅	6.00	26.8	1.29	266.8	25.7	222.1	0.63	22.1
S ₆	5.46	36.0	1.44	312.0	27.8	221.3	0.76	17.3
SE _m ±	0.03	3.00	0.04	28.18	3.48	2.17	0.13	4.169
CD _{0.05}	0.10	NS	0.11	NS	NS	6.41	0.41	NS
Soil depth								
D ₁	5.70	34.1	1.75	339.9	32.0	253.3	-	-
D ₂	5.71	31.7	1.00	261.1	21.4	196.0	-	-
SE _m ±	0.02	1.73	0.02	16.27	2.01	1.25	-	-
CD _{0.05}	NS	NS	0.06	48.03	5.93	3.70	-	-

Table 38: Correlation analysis of regeneration of *Quercus glauca* and associated species with site characteristics

		Regeneration		Soil pH		Moisture content		Organic carbon		Available nitrogen		Available phosphorus		Available potassium		Organic matter layer	Solar influx
		<i>Quercus glauca</i>	Associated species	0-15 cm	15-30 cm	0-15cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm		
Regeneration	<i>Quercus glauca</i>	1.00															
	Associated species	-0.07	1.00														
Soil pH	0-15 cm	-0.60**	0.19	1.00													
	15-30 cm	-0.58*	0.16	0.99**	1.00												
Moisture content	0-15 cm	0.87**	0.04	-0.50*	-0.48*	1.00											
	15-30 cm	0.85**	0.15	-0.46	-0.45	0.98**	1.00										
Organic carbon	0-15 cm	0.54*	0.21	-0.57*	-0.59**	0.54*	0.60**	1.00									
	15-30 cm	0.15	-0.40	-0.11	-0.09	-0.03	-0.08	-0.42	1.00								
Available nitrogen	0-15 cm	0.20	-0.04	-0.52*	-0.53*	0.04	0.05	0.41	-0.26	1.00							
	15-30 cm	0.16	-0.22	-0.53*	-0.56*	0.05	0.08	0.48*	-0.11	0.81**	1.00						
Available phosphorus	0-15 cm	0.05	0.30	-0.01	-0.04	0.02	0.05	0.17	0.07	0.35	0.26	1.00					
	15-30 cm	-0.15	0.10	0.05	0.05	-0.10	-0.07	-0.04	-0.05	0.26	0.06	0.54*	1.00				
Available potassium	0-15 cm	0.01	-0.37	0.03	0.05	-0.11	-0.14	-0.17	-0.13	-0.12	-0.14	-0.43	-0.04	1.00			
	15-30 cm	0.26	-0.35	-0.42	-0.42	-0.05	-0.08	0.13	0.12	0.35	0.40	-0.01	-0.30	0.44	1.00		
Organic matter layer		0.45	0.33	-0.50*	-0.50*	0.47*	0.48*	0.46	-0.28	0.19	0.17	-0.02	-0.19	0.23	0.38	1.00	
Solar influx		-0.837**	-0.03	0.43	0.41	-0.95**	-0.92**	-0.42	-0.02	-0.09	-0.09	-0.12	0.10	0.22	0.04	-0.40	1.00

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed).

Table 39: Correlation analysis of regeneration of *Quercus glauca* and associated species with stand characteristics

		Regeneration		Density		Basal area		Volume		Crown fullness ratio		Crown projection ratio		Number of lopped trees	
		<i>Quercus glauca</i>	Associated spp.	<i>Quercus glauca</i>	Associated spp.	<i>Quercus glauca</i>	Associated spp.	<i>Quercus glauca</i>	Associated spp.	<i>Quercus glauca</i>	Associated spp.	<i>Quercus glauca</i>	Associated spp.	<i>Quercus glauca</i>	Associated spp.
Regeneration	<i>Quercus glauca</i>	1													
	Associated spp.	-0.07	1.00												
Density	<i>Quercus glauca</i>	0.08	-0.22	1.00											
	Associated spp.	0.13	0.71**	-0.37	1.00										
Basal area	<i>Quercus glauca</i>	-0.36	-0.33	0.60**	-0.34	1.00									
	Associated spp.	0.05	0.67**	-0.34	0.95**	-0.17	1.00								
Volume	<i>Quercus glauca</i>	-0.40	-0.21	0.35	-0.23	0.91**	-0.06	1.00							
	Associated spp.	0.02	0.64**	-0.29	0.89**	-0.09	0.99**	0.01	1.00						
Crown fullness ratio	<i>Quercus glauca</i>	0.41	-0.19	-0.09	-0.03	-0.21	0.04	-0.27	0.08	1.00					
	Associated spp.	0.60**	0.23	-0.10	0.55*	-0.23	0.47*	-0.22	0.42	0.07	1.00				
Crown projection ratio	<i>Quercus glauca</i>	0.53*	0.32	0.30	0.34	-0.65	0.28	-0.56	0.26	0.68**	0.38	1.00			
	Associated spp.	0.62**	0.10	-0.17	0.37	-0.18	0.33	-0.17	0.31	0.15	0.92**	0.32	1.00		
Number of lopped trees	<i>Quercus glauca</i>	-0.06	-0.34	0.83**	-0.54	0.57*	-0.49	0.28	-0.44	-0.17	-0.16	-0.53	-0.10	1.00	
	Associated spp.	0.10	0.24	-0.12	0.56*	-0.37	0.48*	-0.41	0.43	-0.23	0.22	0.00	0.07	-0.16	1.00

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)



Plate 7: A view of *Quercus glauca* forest floor



Plate 8: *Quercus glauca* forest under the influence of biotic pressure

Table 40: Regression analysis of germination of *Quercus glauca* and site characteristics

No.	Equation*	R ²	SE _m ±	P _{0.05}
1	Y= -17.21X ₁ + 119.5	0.363	11.9	0.008
2	Y= -16.5X ₂ + 115.5	0.335	12.1	0.012
3	Y= 1.71X ₃ + 36.9	0.753	7.4	0.000
4	Y= 1.6X ₄ – 30.1	0.718	7.9	0.000
5	Y= 42.8X ₅ – 53.4	0.289	12.5	0.021
6	Y= -1.8X ₆ + 54.8	0.700	8.1	0.000

* Y represents germination of *Quercus glauca* whereas X₁ = soil pH (0-15 cm), X₂ = soil pH (15-30 cm), X₃ = moisture content (0-15 cm), X₄ = moisture content (15-30 cm), X₅ = organic carbon (0-15 cm) and X₆ = solar influx

Table 41: Regression analysis of germination of *Quercus glauca* and stand characteristics

No.	Equation*	R ²	SE _m ±	P _{0.05}
1	Y= 28.04X ₁ + 5.7	0.355	11.9	0.009
2	Y= 1.15X ₂ – 3.94	0.277	12.7	0.025
3	Y= 0.79X ₃ + 4.31	0.383	11.6	0.006

* Y represents germination of *Quercus glauca*, whereas X₁ = crown fullness ratio of associated species, X₂ = crown projection ratio of *Quercus glauca*, X₃ = crown projection ratio of associated species

Table 42: Regression analysis of germination of associated species and stand characteristics

No.	Equation*	R ²	SE _m ±	P _{0.05}
1	Y= 0.14X ₁ + 25.6	0.503	44.0	0.001
2	Y= 4.3X ₂ + 27.9	0.443	46.6	0.003
3	Y= 1.24X ₃ + 30.3	0.414	47.7	0.004

* Y represents germination of associated species whereas X₁ = density of associated species, X₂ = basal area of associated species and X₃ = volume of associated species represent

4.2 EXPERIMENT II: STUDIES ON EFFECT OF STRATIFICATION MEDIUM AND DURATION ON GERMINATION AND SEEDLING GROWTH CHARACTERISTICS OF *QUERCUS GLAUCA*

The study tested seven stratification media i.e. sand (M₁), farmyard manure (M₂), *Quercus glauca* forest soil (M₃), 1:1 ratio of sand and farmyard manure (M₄), 2:1 ratio of sand and farmyard manure (M₅), 2:2:1 ratio of sand, farmyard and *Quercus glauca* forest soil (M₆) and local soil as a control (M₇). These treatments were tested in combination with three stratification durations i.e. 15 days stratification duration (D₁), 30 days stratification duration

(D₂) and 45 days stratification duration (D₃) and two growing conditions, i.e. open nursery and shaded growing conditions. The results are being presented in Tables 43-49 as below. The results presented hereunder are based on the pooled data of 2014 and 2015 studies and the results of each year studies are annexed.

4.2.1 Effect of stratification media and stratification duration on germination and seedling growth characteristics of *Quercus glauca* grown under open nursery condition

The effect of stratification media had significant effect on germination of acorns grown under open nursery condition (Table 43). However, its effect in all growth parameters studied was not found to be significant. On the other hand, stratification duration significantly affected germination per cent, number of lateral roots, shoot height, number of leaves and leaf area. But, its effect on survival per cent, collar diameter, root length, root-shoot ratio and total biomass was found to be insignificant.

Data presented in Table 43 reveals that maximum germination per cent (51.8 %) was recorded in M₂, which, however remained statistically on at par with values recorded in the treatments M₃ and M₆. Whereas, minimum germination per cent (44.0 %) was recorded in M₇. Though, not-significant the highest (66.9 %) and the lowest (54.3 %) survival per cent were recorded in M₆ and M₂, respectively. Collar diameter was recorded higher (0.29 cm) in M₂, M₄, M₅ and M₆. It was lower (0.27 cm) in M₁ and M₇. The highest root length recorded was 14.7 cm in M₆ and the lowest (13.3 cm) in M₃ and M₇. Number of lateral roots were highest (0.62) in M₄ and the lowest were (0.25) recorded in M₁. Shoot height was tallest (9.3 cm) in M₃ and it was smallest (8.4 cm) in M₆ and M₇. Root-shoot ratio was found to be highest (0.64) in M₆ and it was lowest (0.47) in M₂. The highest number of leaves (2.8) was recorded in M₂ and M₄, while, the lowest number of leaves (2.3) was recorded in M₅. The highest and the lowest leaf area, which were 4.10 cm⁻² and 3.5cm⁻², were recorded in M₂ and M₇, respectively. The highest total biomass (0.4 g) was recorded in M₂, while, the lowest leaf area (0.3 g) was recorded in M₃.

In stratification duration, D₁ had highest values for number of lateral roots (0.67), root-shoot ratio (0.58), leaf area (4.3 cm⁻²) and total biomass (0.35 g). D₂ had highest values for survival per cent (64.2 %), collar diameter (0.29 cm), shoot height (9.3 cm) and number of leaves

(2.9). Whereas, maximum values of germination per cent (49.5 %) and root length (14.3 cm) were recorded in D₃.

4.2.2 Effect of stratification media and stratification duration on germination and seedling growth characteristics of *Quercus glauca* grown under shaded condition

A view of data in Table 44 indicates that germination as well as growth parameters of *Quercus glauca* were not significantly affected by stratification media when they are grown under shaded condition. However, stratification duration exhibited a significant effect on germination per cent as well as growth parameters, likes collar diameter, root length, number of lateral roots, shoot height, number of leaves, and leaf area. In contrary to this, growth parameters like survival per cent, root-shoot ratio, and total biomass didn't showed significant differences among stratification durations.

Though not significant, detail observation of the data in Table 44 shows difference in germination and growth parameters among stratification media. Germination per cent of M₆, for example, was higher (69.3 %) than other growing media, while, M₇ had the lowest (57.6 %) germination per cent. Survival per cent was maximum (98.1 %) in M₇ and it was minimum (90.4 %) in M₆. The maximum collar diameter (0.28 cm) was recorded in M₂, M₄ and M₇, each showing identical values. The values of other stratification media, like M₁, M₃, M₅ and M₆ had lower (0.27 cm) collar diameter. The longest root length (15.8 cm) was recorded in M₆ as M₁ had the smallest root length (14.4 cm). Maximum (0.8) and Minimum (0.41) number of lateral roots were recorded in M₆ and M₅, respectively. Shoot height was tallest (14.5 cm) in M₂ and it was recorded shortest (12.7 cm) in M₄. Maximum (0.43) root-shoot ratio was recorded in M₃ and the minimum (0.31) root-shoot ratio was recorded in M₂. Maximum number of leaves (2.7) was found in M₂; whereas the minimum number of leaves (2.3) was in M₁ and M₃.

The broadest leaf area (9.8 cm⁻²) was recorded in M₇, while the smallest leaf area (8.0 cm⁻²) was recorded in M₁ and M₄. The maximum (0.31 g) and the minimum (0.24 g) total biomass were accumulated in M₄ and M₁, respectively.

Irrespective of the stratification media, 15 days stratification duration gave higher values of survival per cent (97.6 %), collar diameter (0.28 cm), root length (16.1 cm), shoot height

Table 43: Effect of stratification media (M) and stratification duration (D) on germination and seedling growth of *Quercus glauca* grown under open nursery conditions

Treatment	Germination (%)	Survival (%)	Collar diameter (cm)	Root length (cm)	Number of lateral roots	Shoot height (cm)	Root-Soot ratio	Number of leaves	Leaf area (cm ²)	Total biomass (g)
Stratification media										
M ₁	42.0 (44.9)	51.8 (61.6)	0.27	13.4	0.25	8.7	0.61	2.5	3.6	0.34
M ₂	46.0 (51.8)	47.5 (54.3)	0.29	13.8	0.39	8.6	0.47	2.8	4.1	0.40
M ₃	44.6 (49.3)	48.3 (55.7)	0.28	13.3	0.30	9.3	0.52	2.6	3.8	0.30
M ₄	42.3 (45.3)	51.2 (60.5)	0.29	13.8	0.62	8.7	0.60	2.8	3.7	0.35
M ₅	42.0 (44.9)	53.1 (63.9)	0.29	14.2	0.31	9.2	0.56	2.3	3.8	0.32
M ₆	44.3 (48.9)	55.1 (66.9)	0.29	14.7	0.49	8.4	0.64	2.4	3.7	0.32
M ₇	41.5 (44.0)	53.3 (63.9)	0.27	13.3	0.43	8.4	0.59	2.6	3.5	0.31
SE_m±	1.04	1.85	0.01	0.59	0.14	0.38	0.20	0.18	0.26	0.03
CD_{0.05}	2.98	NS	NS	NS	NS	NS	NS	NS	NS	NS
Stratification duration										
D ₁	40.5 (42.3)	49.8 (58.1)	0.28	13.6	0.67	8.9	0.58	2.3	4.3	0.35
D ₂	44.5 (49.2)	53.4 (64.2)	0.29	13.4	0.34	9.3	0.55	2.9	3.6	0.33
D ₃	44.7 (49.5)	51.2 (60.6)	0.28	14.3	0.19	8.1	0.57	2.6	3.2	0.32
SE_m±	0.68	1.21	0.01	0.39	0.09	0.25	0.13	0.12	0.17	0.02
CD_{0.05}	1.95	NS	NS	NS	0.26	0.71	NS	0.34	0.49	NS

Figures in parenthesis are original values. Figures outside parenthesis represent arc-sine transformed values

(14.4 cm) and leaf area (10.3 cm^2), while 30 days stratification duration gave higher values of collar diameter (0.28 cm), number of lateral roots (0.85), root-shoot ratio (0.37), number of leaves (2.8) and total biomass (0.29 g); whereas, 45 days stratification duration resulted in higher germination (66.9 %) and root-shoot ratio (0.37).

The data on the interaction effect of stratification media and stratification duration on germination and seedling growth characteristics of *Quercus glauca* under shaded grown condition accentuated the absence of significant differences among treatment combinations for germination and all growth parameters studied, excepting number of lateral roots in which the maximum (1.72) and minimum (0) significant values were recorded in M_7D_1 and M_1D_3 , respectively (Table 45).

4.2.3 Comparative analysis of open and shaded growing conditions on germination and seedling growth characteristics of *Quercus glauca*

Assessment on the performance of the two growing conditions, open nursery and shaded growing conditions reveals that there is appreciable difference in all parameters, excepting number of leafs per plant (Table 46). Shaded growing condition was superior over open nursery conditions in respect to germination per cent, survival per cent, root length, number of lateral roots, shoot height and leaf area. Considering their average values, germination per cent and survival per cent were 15.3 % and 33 % more in shaded growing conditions than open nursery condition. Root length and shoot height exceeded by 1.3 cm and 4.7 cm respectively. Number of lateral roots was 1.43 times more and leaf area was 2.24 times higher in shaded growing conditions. Whereas, under open nursery condition collar diameter, root-shoot ratio, number of leaves, and total biomass were higher than shaded growing conditions.

4.2.4 Effect of stratification media and stratification duration on nutrient content of soil media and biochemical content of *Quercus glauca* acorns

A look at the Table 47 shows that stratification media had significant effect on the status of available N, P and K. Maximum available N (363.1 kg ha^{-1}) was estimated in farmyard manure (M_2), which was found to be significantly higher than all other stratification media. M_2 was followed by forest soil (M_3), which however remained statistically at par with a 2:2:1 mixture of sand, farmyard manure and forest soil (M_6). Different growing media reported

available N in the order of $M_2 > M_3 > M_6 > M_7 > M_4 > M_1$. The level of available P was again maximum in M_2 (46.6 kg ha^{-1}), which however remained statistically at par with M_3 only. All other stratification media displayed statistically different values among themselves. Similar to the level of available N and P, the maximum level of available K was also found in M_2 , followed by M_3 , M_6 , M_4 , M_5 , M_1 and M_7 , respectively in descending order. All stratification media resulted in statistically different values of available K.

The data presented in the Table 48 demonstrates that different biochemical contents viz., total sugar (%), total phenol (%), starch (%) and soluble protein (%) were significantly influenced by the stratification media and stratification durations.

It is clear from Table 48 that maximum total sugar content were recorded in the acorns kept the forest soil (M_3) stratification media, which however remained statistically at par with farmyard manure (M_2), a 2:2:1 mixture of sand, farmyard manure and forest soil (M_6) and the local soil (M_7) stratification medias. Whereas, the total sugar content recorded in sand (M_1), a 1:1 mixture of sand and farmyard manure (M_4) and a 2:1 mixture of sand and farmyard manure (M_5) also remained statistically alike. Maximum total phenol content (6.2 %) was recorded in M_1 stratification media. Different stratification media displayed different values of total phenol content of *Quercus glauca* acorns, excepting M_3 and M_7 . Similarly, starch content also varied a lot among acorns kept in different stratification media. Stratification medias viz., M_1 , M_4 , M_5 and M_7 displayed statistically identical values. M_2 and M_3 remained statistically identical. Soluble protein content also displayed slight but significant variation among acorns kept in different stratification medias. Maximum (4.4 %) and minimum (3.8 %) soluble protein contents were recorded in M_7 and M_2 and M_3 (both displaying same values).

The level of total sugar content increased with increasing level of the stratification duration, whereas, total phenol contents, starch contents and soluble protein contents declined from D_1 to D_2 and from D_2 to D_3 significantly.

As shown in Table 49, the interaction effect of stratification media and stratification duration on biochemical contents of acorns was significant for total sugar and soluble protein content of acorns. The maximum (10.7 %) and the minimum (7.2 %) total sugar content were

Table 44: Effect of stratification media (M) and stratification duration (D) on germination and seedling growth of *Quercus glauca* grown under shaded conditions

Treatment	Germination (%)	Survival (%)	Collar diameter (cm)	Root length (cm)	Number of lateral roots	Shoot height (cm)	Root-Soot ratio	Number of leaves	Leaf area (cm ²)	Total biomass (g)
Stratification media										
M ₁	51.1 (59.6)	76.9 (90.7)	0.27	14.4	0.50	13.3	0.32	2.3	8.4	0.24
M ₂	53.6 (64.4)	80.8 (93.9)	0.28	15.1	0.47	14.5	0.31	2.7	8.0	0.26
M ₃	55.5 (67.1)	85.0 (97.2)	0.27	15.2	0.48	13.4	0.43	2.3	8.3	0.28
M ₄	51.0 (60.2)	84.4 (96.3)	0.28	14.6	0.57	12.7	0.36	2.5	8.0	0.31
M ₅	49.6 (57.8)	77.6 (91.7)	0.27	14.8	0.41	13.1	0.32	2.6	8.2	0.27
M ₆	57.2 (69.3)	74.8 (90.4)	0.27	15.8	0.80	14.3	0.34	2.4	9.1	0.28
M ₇	49.4 (57.6)	85.7 (98.1)	0.28	15.6	0.74	13.3	0.32	2.4	9.8	0.28
SE_m±	2.49	3.91	0.01	0.96	0.16	0.42	0.05	0.18	0.70	0.03
CD_{0.05}	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Stratification duration										
D ₁	49.2 (57.2)	84.6 (97.6)	0.28	16.1	0.72	14.4	0.29	2.5	10.3	0.28
D ₂	52.8 (62.8)	78.1 (91.3)	0.28	15.6	0.85	13.0	0.37	2.8	8.5	0.29
D ₃	55.5 (66.9)	79.6 (93.3)	0.26	13.5	0.13	13.2	0.37	2.2	6.9	0.25
SE_m±	1.63	2.56	0.00	0.63	0.11	0.28	0.03	0.12	0.46	0.02
CD_{0.05}	4.67	NS	0.01	1.80	0.30	0.79	NS	0.34	1.32	NS

Figures in parenthesis are original values. Figures outside parenthesis represent arc-sine transformed values

recorded in acorns of M₇D₃ and M₁D₁ treatment combinations, respectively. The highest soluble protein contents (4.5 %) were recorded in M₁D₂, M₁D₃, M₇D₁ and M₇D₂ treatment combinations, whereas the lowest soluble protein content (3.6 %) was recorded in acorns of M₃D₁ and M₃D₂ treatment combinations.

Table 45: Interaction effect of stratification media (M) and stratification duration (D) on number of lateral roots of *Quercus glauca* seedlings grown under shaded condition

Stratification Media	Stratification duration		
	D ₁	D ₂	D ₃
M ₁	0.700	0.800	0.000
M ₂	0.683	0.683	0.050
M ₃	0.517	0.683	0.240
M ₄	0.567	0.767	0.367
M ₅	0.167	1.033	0.033
M ₆	0.680	1.600	0.133
M ₇	1.717	0.400	0.100
SE _m ±		0.278	
CD _{0.05}		0.798	

Table 46: Comparative values of germination and seedling growth attributes under open and shaded growing conditions

Parameters	Open growing conditions			Shaded growing conditions		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Germination (%)	44.00	51.80	47.0	57.6	69.3	62.3
Survival (%)	54.30	66.90	61.0	90.4	98.1	94.0
Collar diameter (cm)	0.27	0.29	0.28	0.27	0.28	0.27
Root length (cm)	13.30	14.70	13.8	14.4	15.8	15.1
Number of lateral roots	0.25	0.62	0.40	0.41	0.8	0.57
Shoot height (cm)	8.40	9.30	8.8	12.7	14.5	13.5
Root-Shoot ratio	0.47	0.64	0.57	0.31	0.43	0.34
Number of leaves	2.30	2.80	2.6	2.3	2.7	2.5
Leaf area (cm ²)	3.50	4.10	3.8	8	9.8	8.5
Total biomass (g)	0.30	0.40	0.33	0.24	0.31	0.27



Plate 9: Acorns infested by acorn weevil



Plate10: Healthy *Quercus glauca* acorns

Table 47: Nutrient content of stratification medias

Stratification media	Available nitrogen (kg ha ⁻¹)	Available phosphorus (kg ha ⁻¹)	Available potassium (kg ha ⁻¹)
M ₁	158.2	24.5	142.9
M ₂	363.1	46.6	342.4
M ₃	322.7	44.6	320.0
M ₄	257.8	34.4	231.9
M ₅	246.9	32.9	214.0
M ₆	308.6	37.1	251.7
M ₇	275.6	29.8	189.5
SE _m ±	6.54	0.52	2.45
CD _{0.05}	18.75	1.50	7.01

Table 48: Effect of stratification media and stratification duration on biochemical contents of *Quercus glauca* acorns

Treatment	Total sugar (%)	Total phenol (%)	Starch (%)	Soluble protein (%)
Stratification media				
M ₁	8.1	6.2	35.3	4.3
M ₂	9.4	5.3	33.1	3.8
M ₃	9.7	5.1	31.2	3.8
M ₄	8.8	5.6	36.7	4.2
M ₅	8.5	6.0	35.5	4.3
M ₆	9.5	5.5	30.5	4.2
M ₇	9.3	5.1	33.8	4.4
SE _m ±	0.14	0.07	1.26	0.05
CD _{0.05}	0.41	0.20	3.62	0.14
Stratification duration				
D ₁	8.2	5.9	37.9	4.3
D ₂	9.0	5.5	34.0	4.2
D ₃	9.9	5.2	29.3	4.0
SE _m ±	0.09	0.04	0.83	0.03
CD _{0.05}	0.27	0.13	2.37	0.09

Table 49: Interaction effect of soil media (M) and stratification duration (D) on total sugar and soluble protein contents of *Quercus glauca* acorns

Treatment	Total sugar			Soluble protein		
	D ₁	D ₂	D ₃	D ₁	D ₂	D ₃
M ₁	7.2	7.8	9.3	4.5	4.5	3.9
M ₂	8.3	9.5	10.5	3.9	3.9	3.8
M ₃	9.3	9.6	10.3	4.0	3.6	3.6
M ₄	8.0	8.8	9.6	4.4	4.4	3.9
M ₅	7.8	8.6	9.2	4.4	4.1	4.3
M ₆	9.1	9.7	9.8	4.1	4.4	4.0
M ₇	7.9	9.2	10.7	4.5	4.3	4.5
SE _m ±		0.25			0.08	
CD _{0.05}		0.71			0.24	

4.3 EXPERIMENT III: STUDIES ON EFFECT OF PRE-SOWING SEED TREATMENTS ON GERMINABILITY OF *QUERCUS GLAUCA* ACORNS

4.3.1. Effect of chemical pre-sowing treatments and acorn size on germinability of *Quercus glauca* acorns under laboratory conditions

Seven chemical pre-sowing treatments and three acorn sizes were tested in this experiment. Control or without any treatment (T_1), cold water treatment (T_2), hot water treatment (T_3), cold treatment at 3°C (T_4), cold treatment at 0°C (T_5), 50 ppm GA_3 application (T_6), and 100 ppm GA_3 application (T_7) were considered as chemical pre-sowing treatments. Small (S_1), medium (S_2) and large (S_3) were the three acorn sizes tested. The result presented in Table 50 is based on the pooled data of 2014 and 2015 years.

Almost all chemical pre-sowing treatments applied to break seed dormancy and enhance uniform germinability of *Quercus glauca* acorns had shown better performance than the control (untreated acorns). However, most germination parameters were not significantly different among the tested chemical pre-sowing treatments, excepting germination per cent and germination value. On the other hand, acorn size showed significant difference for all germination parameters with the exception of germination capacity, which is insignificantly different among acorn sizes.

Table 50 indicates that germination per cent was significantly higher in T_7 and it was lower in T_1 with germination per cent of 32.0 % and 22.4 %, respectively. Germination value, which was found significant among treatments, was also recorded highest (0.084) in T_7 and it was recorded lowest (0.05) in T_1 . Although not significant, the highest germination capacity, (82.7 %) was recorded in T_7 , while the lowest (72.0 %) was recorded in T_5 . Germination energy was recorded high (24.4 %) in T_6 and it was lowest (18.7 %) in T_1 . The Highest and the lowest values of germination index were recorded in T_7 and in T_1 with values of 0.22 and 0.162, respectively.

The values of per cent germination, germination capacity, germination energy, germination value and germination index were found to be maximum for biggest sized acorns i.e. S_3 . The significant differences were noticed for all traits, excepting germination capacity.

The interaction effect of chemical pre-sowing treatments and acorn size was found significant for all germination parameters studied. The significantly higher germination per cent (42.7 %) was recorded in a combination of 0 °C cold water treatment and largest acorn size (T₅S₃). Whereas, the significantly lowest germination per cent (18.0 %) was recorded in largest acorn size under control treatment (T₁S₃).

Significantly maximum (86.7 %) and minimum (62.7 %) values of germination capacity were recorded in treatment combinations of T₆S₂ and T₂S₂, respectively. Germination energy was significantly higher (30.7 %) in T₆S₃ and significantly lowest (16.0 %) in T₁S₂ and T₁S₃ treatment combinations, both displaying identical values. Germination value (0.13) was maximum in T₅S₃; whereas (0.037) minimum germination value was recorded in T₁S₂ and T₁S₃. Germination index was also significantly different among the different treatment combinations. Highest value of 0.307 and lowest value of 0.11 were recorded in treatment combinations of T₅S₃ and T₁S₃, respectively.

4.3.2. Effect of physical pre-sowing treatments and acorn size on germinability of *Quercus glauca* acorns under laboratory conditions

In this study, four physical treatments and three acorn sizes had been tested. The four physical treatments were: exposed embryo or half cotyledon (T₁), seed coat removed (T₂), seed coat punctured (T₃) and intact seed coat or a control (T₄) and the three acorn sizes, viz., small (S₁), medium (S₂) and large (S₃). The results presented in this section were based on the pooled data of 2014 and 2015 studies and the results of each year study were annexed.

Physical pre-sowing treatments are inexpensive and efficient way of breaking seed coat dormancy and improve germination of hard coated seeds. Oaks acorns, as a nut, are covered by hard shell which inhibit water permeability and delay germination. Sometimes seed coats may also contain chemicals which inhibit germination. The purpose of this study was to assess efficiency of different physical pre-sowing seed treatments in enhancing germination of *Quercus glauca* acorns and to compare the results with that of chemical pre-sowing seed treatments. The results of the study were presented in Table 51 below.

Table 50: Effect of chemical pre-sowing treatments and acorn size on germination parameters of *Quercus glauca* acorns

Treatment	Germination per cent				Germination capacity				Germination energy				Germination value				Germination index			
	S ₁	S ₂	S ₃	Mean T	S ₁	S ₂	S ₃	Mean T	S ₁	S ₂	S ₃	Mean T	S ₁	S ₂	S ₃	Mean T	S ₁	S ₂	S ₃	Mean T
T₁	33.2 (30.0)	26.0 (19.3)	25.0 (18.0)	28.1 (22.4)	64.9 (82.0)	62.0 (78.0)	56.7 (69.3)	61.2 (76.4)	29.3 (24.0)	23.5 (16.0)	23.5 (16.0)	25.4 (18.7)	0.077	0.037	0.037	0.05	0.24	0.137	0.11	0.162
T₂	30.2 (25.3)	28.8 (23.3)	33.1 (30.0)	30.7 (26.2)	66.9 (84.0)	52.3 (62.7)	67.5 (85.3)	62.2 (77.3)	26.5 (20.0)	25.6 (18.7)	28.3 (22.7)	26.8 (20.4)	0.053	0.053	0.077	0.061	0.183	0.15	0.203	0.179
T₃	28.8 (23.3)	34.0 (31.3)	32.4 (28.7)	31.7 (27.8)	65.0 (82.0)	60.9 (76.0)	68.3 (86.0)	64.7 (81.3)	27.5 (21.3)	29.8 (24.7)	29.8 (24.7)	29.0 (23.6)	0.043	0.077	0.063	0.061	0.157	0.213	0.177	0.182
T₄	30.2 (25.3)	28.4 (22.7)	34.4 (32.0)	31.0 (26.7)	65.9 (83.3)	65.9 (83.3)	64.1 (80.7)	65.3 (82.4)	26.1 (19.3)	26.0 (19.3)	31.4 (27.3)	27.8 (22.0)	0.053	0.047	0.08	0.06	0.177	0.147	0.23	0.184
T₅	27.9 (22.0)	27.0 (20.7)	40.8 (42.7)	31.9 (28.4)	53.2 (64.0)	57.2 (70.7)	64.6 (81.3)	58.3 (72.0)	24.6 (17.3)	26.0 (19.3)	29.5 (24.7)	26.7 (20.4)	0.047	0.043	0.13	0.073	0.16	0.133	0.307	0.2
T₆	26.9 (20.7)	32.4 (28.7)	39.6 (40.7)	33.0 (30.0)	64.2 (77.3)	68.6 (86.7)	64.0 (80.7)	65.6 (81.6)	25.5 (18.7)	29.3 (24.0)	33.5 (30.7)	29.5 (24.4)	0.043	0.08	0.11	0.078	0.153	0.17	0.277	0.2
T₇	32.6 (29.3)	32.8 (29.3)	37.6 (37.3)	34.3 (32.0)	67.6 (85.3)	62.1 (78.0)	67.1 (84.7)	65.6 (82.7)	25.1 (18.0)	29.3 (24.0)	30.5 (26.0)	28.3 (22.7)	0.083	0.073	0.097	0.084	0.217	0.2	0.243	0.22
Mean S	30.0 (25.1)	29.9 (25.0)	34.7 (32.8)		63.9 (79.7)	61.3 (76.5)	64.6 (81.1)		26.4 (19.8)	27.1 (20.9)	29.5 (24.6)		0.057	0.059	0.085		0.184	0.164	0.221	
SE _m ± (T)				0.88				1.85				0.95				0.01				0.01
CD _{0.05} (T)				2.53				NS				NS				0.02				NS
SE _m ± (S)				0.58				1.21				0.62				0				0.01
CD _{0.05} (S)				1.65				NS				1.78				0.01				0.02
SE _m ± (T x S)				1.53				3.2				1.64				0.01				0.02
CD _{0.05} (T x S)				4.37				9.15				4.7				0.03				0.06

Figures in parenthesis are original values. Figures outside parenthesis represent arc-sine transformed values

The effect of physical pre-sowing seed treatments were found significant for all germination parameters tested (Table 51). Except for germination capacity, acorn size had also a significant effect on the tested germination parameters. Detail investigation of the Table point out that germination per cent, germination capacity, germination energy, germination value and germination index were highest in T₁ having values of 99.3 %, 99.6 %, 80.0 %, 0.368 and 1.14, respectively. Minimum values of all of these traits found in the control (T₄) having the values of 42.4 %, 90.9 %, 31.6 %, 0.096 and 0.27, respectively.

Small sized acorns (S₁) gave maximum values of germination per cent (81.5 %), germination energy (64.2 %), germination value (0.293) and germination index (0.83). Though, not significant, higher germination capacity (96.0 %) was recorded in S₃. S₂ had the lowest values for germination per cent (74.7 %), germination capacity (95.3 %), germination value (0.236), and germination index (0.73). S₃ gave the lowest values of germination energy (57.5 %) and germination index (0.73).

The interaction of physical pre-sowing seed treatments and acorn size had shown significant differences only for germination per cent and germination value. The significantly highest (100.0 %) and lowest (42.0 %) germination per cent were recorded in treatment combinations of T₁S₁ and T₄S₂, respectively. The significantly highest (0.387) germination value was recorded in T₁S₂ treatment combination; while the significantly lowest (0.093) germination value was recorded in T₄S₂ and T₄S₃ treatment combinations each displaying equal values. Germination capacity, germination energy and germination index were not significant but their higher values were recorded in the treatment combinations of T₁S₁, T₁S₂ and T₁S₁ with values of 100.0 %, 84.7 % and 1.19, respectively. Lowest values of germination capacity, germination energy and germination index were recorded in treatment combinations of T₄S₁, T₄S₃ and T₄S₃ having values of 90.0 %, 29.3 % and 0.26, respectively.

4.3.3 Effect of physical pre-sowing seed treatments and acorn size on seedling growth of *Quercus glauca* under shaded growing conditions

The data presented in Table 52 shows that physical pre-sowing seed treatment significantly influenced the per cent germination, collar diameter growth and number of leaves of

Table 51: Effect of physical pre-sowing treatments and acorn size on germination parameters of *Quercus glauca* acorns

Treatment	Germination per cent				Germination capacity				Germination energy				Germination value				Germination index			
	S ₁	S ₂	S ₃	Mean T	S ₁	S ₂	S ₃	Mean T	S ₁	S ₂	S ₃	Mean T	S ₁	S ₂	S ₃	Mean T	S ₁	S ₂	S ₃	Mean T
T₁	90.0 (100.0)	87.2 (99.3)	86.1 (98.7)	87.7 (99.3)	90.0 (100.0)	87.2 (99.3)	87.2 (99.3)	88.1 (99.6)	62.4 (78.0)	67.0 (84.7)	61.7 (77.3)	63.7 (80.0)	0.370	0.387	0.347	0.368	1.19	1.11	1.12	1.14
T₂	75.3 (93.3)	65.5 (82.7)	65.4 (82.7)	68.7 (86.2)	79.8 (96.7)	78.7 (96.0)	86.1 (98.7)	81.5 (97.1)	58.0 (72.0)	56.8 (70.0)	52.7 (63.3)	55.9 (68.4)	0.383	0.260	0.277	0.307	1.11	0.99	0.9	1.00
T₃	71.6 (90.0)	59.8 (74.7)	61.5 (77.3)	64.3 (80.7)	78.7 (96.0)	75.8 (94.0)	77.9 (95.3)	77.5 (95.1)	60.2 (75.3)	51.9 (62.0)	50.8 (60.0)	54.3 (65.8)	0.317	0.203	0.260	0.260	0.71	0.56	0.65	0.64
T₄	40.8 (42.7)	40.4 (42.0)	40.8 (42.7)	40.6 (42.4)	71.6 (90.0)	74.4 (92.0)	72.2 (90.7)	72.7 (90.9)	34.0 (31.3)	35.6 (34.0)	32.7 (29.3)	34.1 (31.6)	0.100	0.093	0.093	0.096	0.28	0.27	0.26	0.27
Mean S	69.4 (81.5)	63.2 (74.7)	63.4 (75.3)		80.0 (95.7)	79.0 (95.3)	80.9 (96.0)		53.6 (64.2)	52.8 (62.7)	49.5 (57.5)		0.293	0.236	0.244		0.83	0.73	0.73	
SE_m± (T)				1.06				1.3				1.14				0.01				0.03
CD_{0.05} (T)				3.12				3.82				3.34				0.03				0.09
SE_m± (S)				0.92				1.13				0.99				0.01				0.03
CD_{0.05}(S)				2.7				NS				2.9				0.03				0.07
SE_m± (T x S)				1.84				2.26				1.97				0.02				0.05
CD_{0.05}(T x S)				5.4				NS				NS				0.06				NS

Figures in parenthesis are original values. Figures outside parenthesis represent arc-sine transformed values

Quercus glauca seedlings. Irrespective of the physical pre-sowing seed treatments, acorn sizes significantly influenced the per cent germination, survival (%), collar diameter, shoot height, root-shoot ratio, and number of leaves, leaf area and total biomass production of the seedlings. The two way interactions between physical pre-sowing seed treatments and acorn sizes significantly influenced the per cent survival and collar diameter growth of *Quercus glauca* seedlings (Table 53).

Irrespective of acorn sizes, maximum (86.2 %) germination was recorded in the seed coat puncture (T_3) treatment, which however remained statistically at par with exposed embryo (T_1) only. Minimum (39.8%) germination was displayed by the intact seed coat (T_4) treatment. Collar diameter growth was maximum (0.343 cm) in T_3 , which was found to be significantly at par with T_2 . The treatments viz., T_1 and T_2 remained statistically alike. The number of leaves remained statistically different among physical pre-sowing seed treatments, which follow the order: $T_1 > T_2 > T_3 > T_4$.

Irrespective of the physical pre-sowing treatments, different parameters displayed significantly maximum values of the traits, viz., per cent germination, survival (%), collar diameter, shoot height, root-shoot ration, number of leaves, leaf area and total biomass in largest sized acorns (S_3) over small sized acorns (S_1). In general, S_1 and S_2 remained statistically identical for most of these traits.

There were no significant differences in germination and most growth parameters by the interaction of physical pre-sowing seed treatment and acorn sizes. Survival per cent and collar diameter showed significant differences among combinations of physical pre-sowing seed treatments and acorn sizes. Detail observation of data in Table 53 indicates that the significantly highest (100.0 %) and lowest (79.7 %) survival per cent were recorded in treatment combinations of T_2S_3 and T_2S_1 , respectively. The significantly highest collar diameter (0.4 cm) was recorded in treatment combinations of T_3S_3 , while significantly the lowest collar diameter (0.247 cm) was recorded in treatment combinations of T_1S_1 .

Table 52: Effects of physical pre-sowing seed treatments and acorn size on germinability and seedling growth characteristics of *Quercus glauca* under shaded growing conditions

Treatment	Germination (%)	Survival (%)	Collar diameter (cm)	Root length (cm)	Number of lateral roots	Shoot height (cm)	Root-Shoot ratio	Number of leaves	Leaf area (cm ²)	Total biomass (g)
Physical pre-sowing treatment										
T ₁	62.2(77.3)	72.5(90.3)	0.306	17.0	0.49	13.0	0.461	4.1	14.5	0.608
T ₂	57.7(70.8)	79.3(92.3)	0.319	17.1	0.45	12.9	0.468	4.8	12.8	0.593
T ₃	69.9(86.2)	71.5(88.9)	0.343	16.7	0.73	13.1	0.468	4.2	14.7	0.569
T ₄	39.1(39.8)	76.3(93.5)	0.312	16.6	0.40	12.2	0.474	3.8	13.7	0.577
SE_m±	2.36	2.17	0.01	0.67	0.11	0.42	0.02	0.17	0.64	0.04
CD_{0.05}	6.95	NS	0.03	NS	NS	NS	NS	0.51	NS	NS
Acorn size										
S ₁	53.3(63.6)	68.6(86.0)	0.282	15.8	0.43	10.3	0.403	3.7	10.4	0.368
S ₂	57.2(68.7)	77.0(93.7)	0.331	17.6	0.59	13.6	0.484	4.5	14.2	0.631
S ₃	61.1(73.3)	79.1(94.1)	0.348	17.2	0.53	14.5	0.517	4.5	17.2	0.762
SE_m±	2.04	1.88	0.01	0.58	0.10	0.36	0.02	0.15	0.55	0.03
CD_{0.05}	6.02	5.54	0.02	NS	NS	1.07	0.06	0.44	1.63	0.09

Figures in parenthesis are original values. Figures outside parenthesis represent arc-sine transformed values

Table 53: Effects of physical pre-sowing seed treatments and acorn size on growth of *Quercus glauca* seedlings under shaded growing conditions

Treatments	Survival per cent			Collar diameter		
	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃
T ₁	67.9 (85.6)	73.2 (91.4)	76.4 (94.0)	0.247	0.33	0.34
T ₂	63.4 (79.7)	84.5 (97.4)	90.0(100.0)	0.277	0.327	0.353
T ₃	67.7 (85.1)	75.8 (93.5)	71.1 (88.0)	0.3	0.33	0.4
T ₄	75.4 (93.5)	74.4 (92.5)	79.0 (94.4)	0.303	0.337	0.297
SE _m ±		3.75			0.02	
CD _{0.05}		11.07			0.05	

Figures in parenthesis are original values. Figures outside parenthesis represent arc-sine transformed values

4.3.4 Effect of chemical pre-sowing treatments and acorn size on biochemical composition of *Quercus glauca* acorns

Unlike physical pre-sowing treatments, chemical pre-sowing treatments were expected to modify the biochemical composition of acorns in the process of breaking seed dormancy and enhancing their germinability. Thus, it became essential to assess the biochemical composition of acorns from each pre-sowing treatment and find out their correlation with germination parameters. There are various biochemical compounds that acorns may contain. However, moisture content, total sugar, total phenol, starch and soluble protein were addressed in this study. Results of the investigation were presented on Tables 54 and 55.

The results in Table 54 reveals that moisture content and total phenol content of acorns were significantly affected by the type of pre-sowing treatments. Acorn sizes had significant effect in all the evaluated biochemical contents of acorns. From Table 54 it is evident that soaking acorns in cold water (T₂) had the highest moisture content of 45.2 % followed by hot water treatment (T₃), which is having moisture content of 45.1 %. The least moisture content (30.2 %) was recorded in the control (T₁). Total sugar was recorded highest (9.9 %) in T₇ and the lowest (9.4 %) in T₁. Acorns of the control treatment (T₁) and those treated with 0°C cold temperature (T₅) had the highest total phenol content having values of 6.0 % and 5.9 %, respectively. While, acorns treated with hot water (T₃) had the lowest (3.5 %) total phenol contents. Starch was recorded highest (36.9 %) in T₁ and it was lowest (36.5 %) in T₆ and T₇,

each displaying equal values. Acorns in T₁, T₂ and T₃ had the highest (4.9 %) content of soluble protein and acorns in T₇ had the lowest (4.4 %) content of soluble protein.

Considering biochemical content of different acorn sizes, there was a general trend of increasing in biochemical content with increase in acorn size. Thus, S₃ had higher moisture content (42.7 %), total sugar (10.3 %), total phenol (5.2 %), starch (37.4 %) and soluble protein (4.9 %) than S₁ and S₂.

The interaction effect of chemical pre-sowing treatments and acorn sizes had significant differences in total sugar and total phenol contents of acorns (Table 55). Total sugar was significantly highest (11.4 %) in the interaction of 0°C temperature application and large sized acorns (T₅S₃), whereas, the lowest was (8.3 %) in the treatment combinations of T₁S₃ and T₇S₁, each displaying equal values. The significantly highest total phenol content (6.1 %) was recorded in T₁S₂ and the lowest total phenol content (3.3 %) was recorded in T₃S₁ and T₃S₂ treatment combinations, each displaying equal values.

4.3.5. Correlation and regression analysis of germination parameters and biochemical content of *Quercus glauca* acorns

The correlation between germination parameters and biochemical content of *Quercus glauca* acorns was presented in Table 56 below. The correlation Table illustrated three types of correlations: correlation of one germination parameter with other germination parameters, correlation of one germination parameter with biochemical contents of acorns and correlation of one biochemical with other biochemical content of acorns.

Considering correlation of germination parameters to one another, it indicated that germination per cent and germination index were significantly correlated with all other germination parameters. In addition to germination per cent and germination index, germination energy was also correlated with germination value. Correlation of germination parameters with biochemical content of acorns reveals that it is only moisture content, total sugar and starch that had significant correlation with germination parameters.

Table 54: Average effect of chemical pre-sowing treatments and acorn size on biochemical content of *Quercus glauca* acorns

Treatment	Moisture content (%)	Total sugar (%)	Total phenol (%)	Starch (%)	Soluble protein (%)
Chemical pre-sowing treatment					
T ₁	30.2	9.5	6.0	36.9	4.9
T ₂	45.2	9.6	4.6	36.8	4.9
T ₃	45.1	9.7	3.5	36.8	4.9
T ₄	40.4	9.7	5.3	36.8	4.6
T ₅	38.2	9.8	5.9	36.6	4.7
T ₆	44.1	9.8	4.9	36.5	4.5
T ₇	43.7	9.9	5.1	36.5	4.4
SE _m ±	0.70	0.10	0.07	0.23	0.10
CD _{0.05}	2.00	NS	0.20	NS	NS
Acorn size					
S ₁	38.6	9.2	4.9	35.9	4.5
S ₂	41.7	9.6	5.0	36.7	4.7
S ₃	42.7	10.3	5.2	37.4	4.9
SE _m ±	0.46	0.06	0.05	0.15	0.10
CD _{0.05}	1.31	0.18	0.13	0.43	0.30

Table 55: Interaction effects of physical pre-sowing seed treatments and acorn size on biochemical content of *Quercus glauca* acorns

Treatment	Total sugar			Total phenol		
	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃
T ₁	9.2	10.9	8.3	6.0	6.1	6.0
T ₂	9.2	9.0	10.7	4.8	4.3	4.8
T ₃	9.7	9.0	10.2	3.3	3.3	3.8
T ₄	9.9	8.9	10.3	5.1	5.4	5.5
T ₅	8.8	9.1	11.4	5.6	6.0	6.0
T ₆	9.4	9.1	11.0	4.5	4.8	5.5
T ₇	8.3	11.0	10.4	5.2	4.9	5.1
SE _m ±		0.17			0.12	
CD _{0.05}		0.48			0.35	

Moisture content had a significantly positive correlation with germination per cent, germination energy and germination value. Excepting for germination capacity, total sugar was significantly correlated with all germination parameters, whereas starch had significant correlation with germination per cent. Total sugar was found to have significant correlation with starch contents of acorns. Total phenol content was found to have significantly negatively

Table 56: Correlation of germination attributes with biochemical contents of *Quercus glauca* acorns

	Germination per cent	Germination capacity	Germination energy	Germination value	Germination index	Moisture content	Total sugar	Total phenol	Starch	Soluble protein
Germination per cent	1.00									
Germination capacity	0.29*	1.00								
Germination energy	0.73**	0.22	1.00							
Germination value	0.93**	0.22	0.59**	1.00						
Germination index	0.94**	0.28*	0.66**	0.88**	1.00					
Moisture content	0.36**	0.18	0.33**	0.30*	0.24	1.00				
Total sugar	0.52**	0.23	0.43**	0.44**	0.46**	0.2	1.00			
Total phenol	0.01	-0.10	-0.14	0.09	0.08	-0.59**	0.08	1.00		
Starch	0.25*	0.04	0.20	0.22	0.17	0.15	0.30*	0.09	1.00	
Soluble protein	0.00	0.01	0.04	-0.08	-0.09	-0.05	0.12	0.04	0.32*	1

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

correlation with moisture content. Starch showed significant correlation with total sugar and soluble protein.

The simple regression analysis of germination parameters, as dependent variable, and biochemical content of acorns, as independent variable, showed the presence of significant linear relationship, although their R^2 values were low (Table 57).

4.3.6 Comparative analysis of chemical and physical pre-sowing treatments

The mechanism of breaking seed dormancy by chemical and physical pre-sowing seed treatments is different. Chemical pre-sowing seed treatments involve some hormonal activities that activate cell division or dilute chemical inhibitors involved. Whereas, physical pre-sowing seed treatments creates favourable condition for water to imbibe in to the embryo or completely remove seed coat and its effects from the seed. Hence, the effectiveness of the type of pre-sowing seed treatment depends on the type of dormancy the seed has. Generally, chemical pre-sowing seed treatments are effective in breaking endogenous seed dormancies while physical pre-sowing seed treatments are effective in breaking exogenous seed dormancies.

Table 57: Regression equation of germination parameters and biochemical content of acorns

No.	Equation*	R^2	$SE_{m\pm}$	$P_{0.05}$
1	$Y_1 = 0.48X_1 + 8.1$	0.13	6.99	0.00
2	$Y_2 = 0.3X_1 + 9.41$	0.11	4.90	0.01
3	$Y_3 = 0.002X_1 + 0.005$	0.09	0.03	0.02
4	$Y_1 = 4.08X_2 - 11.98$	0.27	6.42	0.00
5	$Y_2 = 2.33X_2 - 0.87$	0.18	4.69	0.00
6	$Y_3 = 0.013X_2 - 0.061$	0.19	0.03	0.00
7	$Y_4 = 0.028X_2 - 0.087$	0.22	0.05	0.00
8	$Y_1 = 2.15X_3 - 51.4$	0.06	7.26	0.04

* Y_1 represents germination per cent, whereas Y_2 = germination energy, Y_3 = germination value, Y_4 = germination index, X_1 = moisture content, X_2 = total sugar and X_3 = starch content

Data in Table 58 illustrates that the minimum, maximum and average values of physical pre-sowing seed treatments were much higher than chemical pre-sowing seed treatments. By

comparing their average values, germination per cent, germination capacity and germination energy were 49.5 %, 16.6 % and 39.7 % more in physical pre-sowing seed treatments than chemical pre-sowing seed treatments. Germination value and germination index were also 3.7 and 4 times more in physical pre-sowing seed treatments than chemical pre-sowing seed treatments.

Table 58: Comparative analysis of germination parameters of chemical and physical pre-sowing seed treatments

Germination parameters	Chemical pre-sowing treatment			Physical pre-sowing treatment		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Germination per cent	22.4	32.0	27.7	42.4	99.3	77.2
Germination capacity	72.0	82.7	79.1	90.9	99.6	95.7
Germination energy	18.7	24.4	21.7	31.6	80.0	61.4
Germination value	0.05	0.085	0.07	0.098	0.368	0.26
Germination index	0.16	0.22	0.19	0.271	1.14	0.76

Chapter-5

DISCUSSION

In this chapter, the results coming out of the present study entitled “**Site characteristics and regeneration studies of bani oak (*Quercus glauca* Thunberg) in Himachal Pradesh**” have been discussed in detail. The most likely causes and effects, underlining principles and patterns, the resulting predictions, facts and evidences, both supporting and contradicting previous works on the same or related species are being presented and discussed in order to draw proper interpretation and conclusion under the following headings:

- 5:1 Phytosociological study
- 5:2 Site and stand characteristics
- 5:3 Natural regeneration assessments
- 5:4 Stratification studies
- 5:5 Germination studies

5:1 PHYTOSOCIOLOGICAL STUDIES

Phytosociological studies are broad in scope that encompasses one or more ecosystems, communities, populations or species. Its ultimate goal is to understand ecosystem structure and functions, species composition of plant communities, population interaction and dynamics, distribution and classification of a species. The phytosociology study in this paper emphasized on the interaction of *Quercus glauca* with its biotic and abiotic surrounding that had a potential influence on its distribution, growth and reproduction.

The floristic composition of the studied areas indicated presence of 25 tree species belonging to 24 genera and 19 families; 45 shrub species belonging to 39 genera and 25 families; 61 herbaceous species from 50 genera and 27 families (Table 4-6). Higher number of tree species were recorded in site VI and species number was quite low in site III. Site III and site V are rich in number of shrub species, while site III and site VI have maximum number of herbaceous species (Table 59). Species richness, which indicates number of plant species of an area (Table 28), showed highest tree, shrub and herb species richness are

recorded at site IV, site V and site III, respectively. Species richness is more for herbs, followed by shrubs and trees, respectively. The results were in line with Pant and Sharma (2007), who reported herbs to be more species rich than shrubs and trees.

Table 59: Total number of trees, shrubs and herbs recorded in *Quercus glauca* bearing forest sites

Form	Number	Solan Forest Range		Narag Forest Range		Sarhan Forest Range	
		Site I	Site II	Site III	Site IV	Site V	Site VI
Trees	Species	9	10	5	11	7	12
	Genera	8	10	5	10	6	12
	Families	8	8	5	9	6	10
Shrubs	Species	12	17	21	8	21	17
	Genera	12	16	21	8	20	17
	Families	10	13	16	8	16	13
Herbs	Species	17	15	20	15	19	20
	Genera	16	14	20	15	19	18
	Families	13	10	13	9	12	14

Various research reports indicated that abiotic factors including topography, elevation, soil, rainfall, and other climatic condition to influence plant communities of an area (Colins and Carson, 2004, Cerny *et al.* 2013). However, tree density was found to determine species richness of the study sites. With increasing tree density, species richness of trees increases up to some limiting point and thereafter it declines. The situation is more like self-thinning rule of Yoda *et al.* (1963), in which they presented that self thinning will not occur until some critical level is not reached. Up to this critical density level, all trees have a chance to grow thereby tree species richness continues to increase. After critical density level, tree species starts to die, which reduces tree species richness. Critical density level was usually associated to crown closure (Yoda *et al.*, 1963). Beyond crown closure, non competent trees, mainly of shade intolerant tree species, start to die due to sever competition from upper canopy trees and lower shade tolerant trees (Chapman *et al.*, 2006). In case of *Quercus glauca* forests, this critical density level was found to be about 675 trees per hectare (Figure 6).

On the other hand, species richness of shrubs and herbs decreases with increasing tree density and it starts to increase after tree species richness reached its maximum and begin to

decline. However, species richness of shrubs and herbs is increasing up to certain critical density level and starts to decline thereafter (Figure 6). In case of *Quercus glauca* forests, this critical density level, which limits species richness of shrubs and herbs, is about 740 trees per hectare. Species richness of shrubs and herbs is obviously higher in open conditions due to sufficient availability of light, moisture and other resources, which are necessary for their growth. However, with increasing tree density, species richness of shrubs and herbs start to decline due to competition in upper canopy trees. With sufficiently high tree density (crown closure), some dominant and co-dominant trees start to die; which opens a room for fast growing shrubs and herbs to fill the gap (Dodson *et al.*, 2008, Roberts and Gilliam, 1995, Gomez-Rey *et al.*, 2013). Human interference, i.e. disturbance, is also one of the reasons to hasten this process. Negi *et al.* (2008) reported higher species richness in disturbed forest sites than protected forests. Any logging activity in densely populated *Quercus glauca* stands will reduce species richness of trees; on the other hand, it will increase species richness of shrub and herbaceous plants. Anitha *et al.* (2009) also reported that low disturbance had certain advantage in improving species richness and biodiversity.

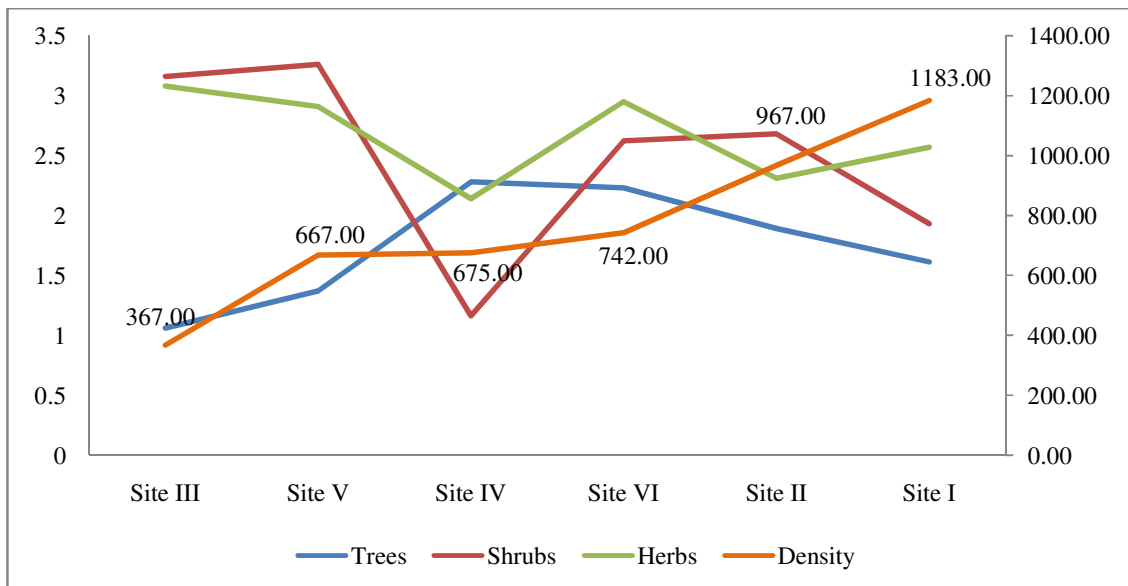


Figure 6: Relation between tree density and species richness of trees, shrubs and herbs

The structure of *Quercus glauca* bearing forests clearly classified into three vegetation layers, i.e. upper layer (trees), middle layer (shrubs) and the lower layer (herbs/grasses). Importance value index (IVI), which represents the relative dominance of a species in a community, is used to describe the dominant of trees, shrubs and herbaceous species of each study site.

Considering the density of trees (Table 60), site I was the densest site with a density of 1183 trees per hectare followed by site II (967 trees ha⁻¹), site VI (742 trees ha⁻¹), site IV (675 trees ha⁻¹), site V (667 trees ha⁻¹) and site III (367 trees ha⁻¹). All these *Quercus glauca* forests are naturally regenerated. However, differences in tree densities were associated to the age of the forest as well as disturbance level imposed in these sites. Better protection by forest department was provided in site I. Site II is a private forest and had better protection than other sites. Site III on the contrary, showed sever destruction of the forest sites that exhibited fragmentation in the form of *Quercus glauca* forests interrupted by bushes; and devoid of visible tree species.

The basal area of trees at site V (39.3 m² ha⁻¹) and site VI (38.4 m² ha⁻¹) was higher than other sites (Table 60). Site I, site II and site IV follow site V and site VI with basal area values of 37.1 m² ha⁻¹, 30.4 m² ha⁻¹, and 19.2 m² ha⁻¹, respectively. Site III had the lowest value of basal area (11.8 m² ha⁻¹). In contrast to their moderate tree density, the higher basal area of site V and site VI was due to the presence of old bigger sized diameter trees of *Quercus glauca*. Chapman *et al.* (2006) also reported increase in tree density and basal area with increase in forest age. The highest density and basal area of shrubs were observed in site III and site IV; whereas the highest density and basal area of herbs were observed in site IV and site III. The frequency distribution of trees, shrubs and herbs were recorded higher in site IV, site V and site IV, respectively. The density of shrubs was significantly influenced by disturbance level of the sites, where the disturbance favouring higher shrub density. Whereas, density of herbs was mainly influenced by crown cover although disturbance and other site factors seem to have effect on their density. Higher number of herbs was recorded in shaded (high crown covered) sites. Basal area of trees varies with age of the stand; whereas, basal area of shrubs and herbs is more related to the availability of light and other site conditions. Per cent frequency (abundance) of trees, shrubs and herbs are also linked to disturbance.

Table 60: Density, basal area and frequency of trees, shrubs and herbs at the study sites

Parameter	Life form	Site I	Site II	Site III	Site IV	Site V	Site VI
Density (Nha ⁻¹)	Trees	1183	967	367	675	667	742
	Shrubs	1610	2078	2990	2272	2453	2372
	Herbs	16755	14313	15855	22979	16330	15030
Basal area (m ² ha ⁻¹)	Trees	37.1	30.4	11.8	19.2	39.3	38.4
Basal area (cm ² ha ⁻¹)	Shrubs	10694.3	6296.8	12303.2	18119.3	7057.9	11540.5
	Herbs	12479.1	11334.4	19538.9	9420.2	46651	11936
Frequency (%)	Trees	566.7	433.3	266.7	600	400	566.7
	Shrubs	753.3	920	1440	646.7	1460	1240
	Herbs	733.3	590	866.7	1333.3	610	586.7

There is a general decreasing trend of shrub density with increasing tree density (Figure 7). The density of herbs increase with tree density up to tree density level of 675 trees ha⁻¹, then after it starts to decline. The shrub density at site VI and herb density at site IV were higher which can be owed to favorable site conditions, mainly high soil water content of the sites. There are reports that signify the importance of abiotic factors that equally influence the structure and composition of a forest as that of biotic factors (Colins and Carson, 2004, Cerny *et al.*, 2013).

The basal area of shrubs in the study area showed an increase while basal area of herbs decreased and vice-versa (Figure 8). Site II, which registered low basal area of shrubs and herbs was an exception to this trend. This may be due to the relatively higher density of trees at this site and differences in the management practices of the sites.

A perusal of data in the Table 7 to Table 24 revealed that *Quercus glauca* was the dominant species at all the study sites, excepting for site I. In site I, *Quercus leucotrichophora* was the dominant tree species followed by *Quercus glauca*, *Myrica esculenta* and *Pinus roxburghii* having IVI values of 92.5, 74.8, 44.4 and 43.3, respectively. The presence of woody debris of *Pinus roxburghii* at this site coupled with its high basal area indicated that it is in its senescence stage. Decline of *Pinus roxburghii* opened a room for *Myrica esculenta* and other species to flourish at the site. The higher basal area of *Quercus glauca* than *Quercus leucotrichophora* indicated that it was a dominant species at the site and lost its dominance over time.

In site II, *Quercus glauca* was a dominant species followed by *Machilus duthiei* and *Dalbergia sissoo*. These species had IVI values of 193.5, 22.4 and 14.3, respectively. Likewise, site III was dominated by *Quercus glauca*, *Punica granatum* and *Salix tetrasperma* having IVI values of 219.3, 33.9 and 16.0, respectively. Site III is the largest *Quercus glauca* forest among the studied sites stretched for 3-5 kilometers along gullies and gorges. However, it is the most disturbed one and having large swap of the forest became devoid of *Quercus glauca* and converted into some sort of shrub land. The phytosociology assessment also revealed the process of conversion of the forest in to shrub land. The lowest number of tree species as well as the lowest density and basal area of trees were recorded at this site. Tree density and basal area were reported to decline with increasing disturbance (Pokhriyal *et al.*, 2012). Site IV, V and VI were dominated by *Quercus glauca* having IVI values of 143.9, 178.4 and 180.3, respectively. *Pinus roxburghii* was the second dominant species at site IV and VI, while it was the third dominant species at site V next to *Punica garnatum*.

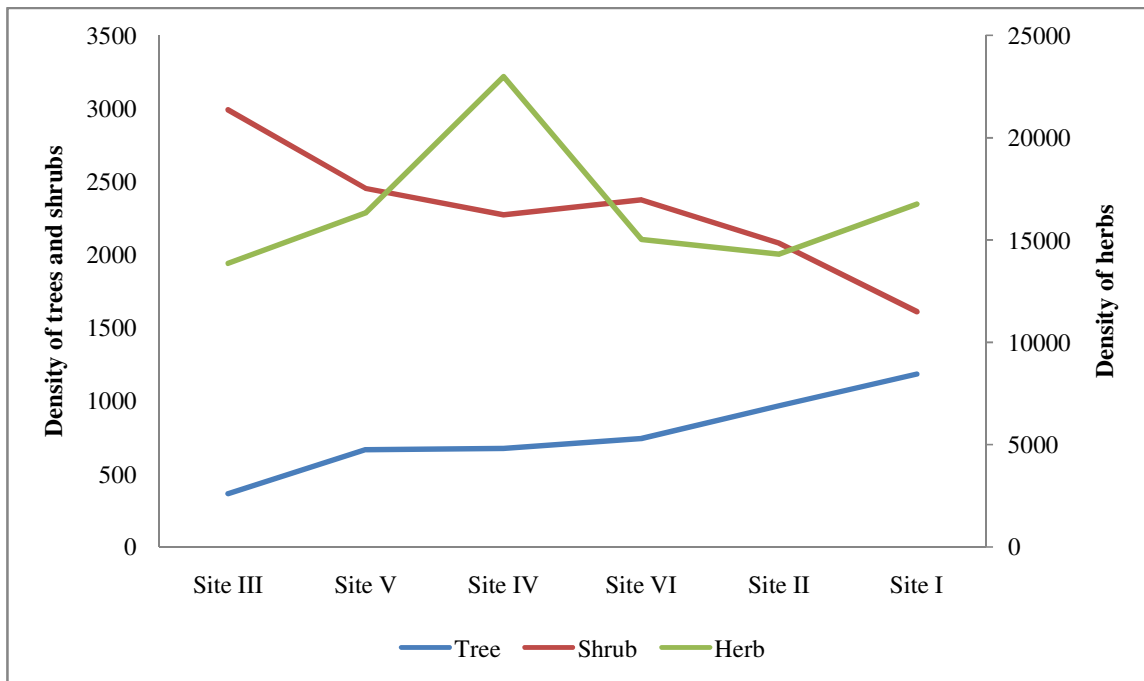


Figure 7: Density ($N\ ha^{-1}$) of trees, shrubs and herbs in the study areas

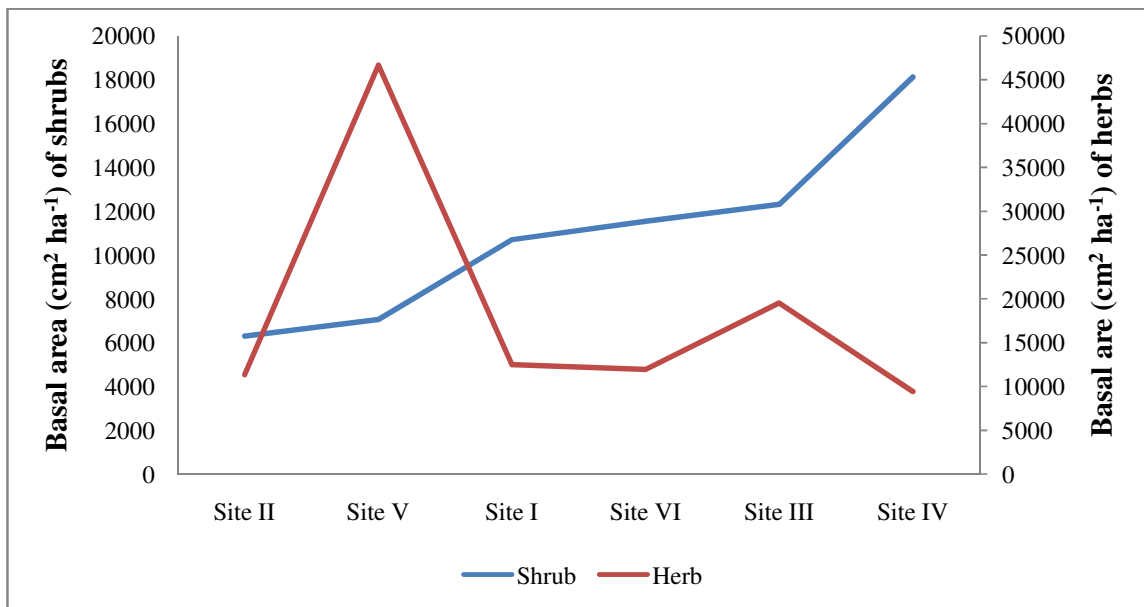


Figure 8: Relationship between basal area of shrubs and herbs at study sites

The IVI values of *Pinus roxburghii* in sites VI, V and VI were 42.7, 30.0 and 16.8, respectively. *Punica granatum*, the second dominant species at site V had an IVI value of 30.1. *Pyrus pashia* at site IV and *Ehretia accuminata* at site VI were the third dominant species having IVI values of 24.3 and 15.8, respectively.

Among the shrub species, *Myrsine africana* and *Sageretia filiformis* were universal species that occurred at all the sites, although their dominance was very low. *Berberis lycium* at site I, *Caryopteris wallichiana* at site II, *Sageretia oppositifolia* at site III, *Viburnum cotinifolium* and *Myrsine africana* at site IV, *Myrsine africana* and *Carissa carandas* at site V, and *Rhus cotinus* and *Berberis lycium* at site VI were the dominant shrub species. Among herbs, *Scutellaria scandens* was present at all sites, excepting one. *Digitaria cruciata*, *Digitaria cruciata* and *Paspalum coryphaeum*, *Oryzopsis hymenoides* and *Oplismenus compositus*, *Thalictrum foliolosum*, *Oplismenus compositus*, and *Panicum agrostoides* were the dominant herbaceous species at site I, site II, site III, site IV, site V and site VI, respectively. The behaviour of each shrub and herb species to dominate an area greatly varies in response to several biological and ecological influences. Based on Simpson's dominance index, trees were more dominant at site III, shrubs at site IV and herbs at site II (Table 28)

The similarity index in Tables 25-27 illustrated that maximum similarities (66.7%) in trees were observed between site IV and site V, between site IV and site VI (63.6%) and between site I and site V (62.5%). The least similarity in trees was observed between site I and site III (14.3%). Maximum similarity (57.9 %) in shrubs was between site III and site VI followed by site I and site VI (50.0 %). The minimum similarity in shrubs, which is 20.7 %, was recorded between site IV and site V. In case of herbaceous species, maximum similarity (41.2 %) was recorded between site II and site V. The minimum similarity in herbs (11.8 %) was recorded between site II and VI and between site IV and site VI, each displaying equal values.

It was observed that the per cent similarity values were higher in trees followed by shrubs and herbs, respectively. This might be due to the higher number of species recorded for herbs and shrubs than trees. With increasing number of species at a site there is a tendency of decrease in per cent similarity index that might be associated to the increase in number of species that may not be common to the sites under consideration. Higher similarities between two vegetations can be attributed to the presence of some species with wider ecological range as well as similarities in their ecological and edaphic conditions

(Bharali *et al.* 2011, Ito *et al.* 2007). Proximity between two sites may have higher similarity index either due to the absence of abrupt environmental gradient, which restricted growth of a species or high probability of transfer of genetic material from one site to the other (Suyal *et al.*, 2010).

As depicted in Figure 9, tree species diversity was generally lower than shrub and herb diversity. It was only in site IV that tree diversity was more close and comparable with shrub diversity. This might be associated with the presence of unlopped trees with high crown width that inhibit availability of sufficient light on forest floor for the growth of shrubs and herbs. The maximum crown width (18.5 m) the highest average crown width (10.4 m) and the lowest solar influx in forest floor (12.4 %) were recorded at site IV. Several research reports emphasized on the relation between available light in forest floor and understory species diversity and regeneration (Lochhead and Comeau, 2012, Dech *et al.*, 2008 and Sagar *et al.*, 2008). It can also be observed that with the increase in diversity of trees, shrubs and herbaceous diversity tend to decrease. Despite high diversity of trees, diversity of shrubs remained high at site VI. It might be due to the presence of favourable site factors, including light and high soil moisture that maintained higher tree and shrub diversity at the same time (Pausas and Austin, 2001). The highest light influx on forest floor (22 %) and higher moisture content (36 %) were recorded at this site. On the other hand, higher herbage diversity in site I and site IV together with higher tree diversity may be due to higher moisture content and low light condition that favours trees and herbs to maintain their diversity at the same time.

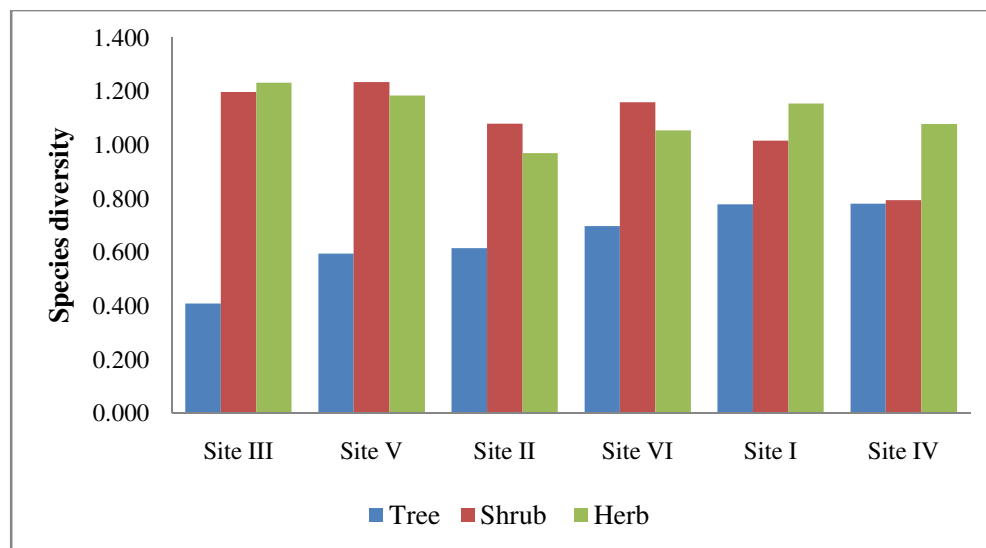


Figure 9: Diversity of trees, shrubs and herbs at the study sites

Regeneration of a species is influenced by the presence of viable germplasm. Existing trees in the forest site, long-ranged seed dispersion or buried seed bank may serve as source of germplasm for regeneration. Usually, seed trees and seed bank have high contribution to natural regeneration (Higo *et al.*, 1995). Data in Table 62 revealed that the maximum contribution of seed trees and seed bank to the natural regeneration was at site IV (87.5 %) and site II (60.0 %), respectively. The contribution of these seed sources to the natural regeneration of site I, site III and site V was almost comparable. On the other hand, existing seed trees in the forest sites may not guarantee regeneration success. Ten tree species, including *Pinus roxburghii* were recorded in the study forest sites; however, they failed to register their regeneration. This indicates the assertion that species based regeneration management is important to achieve successful regeneration and species composition of a site (Duncan and Chapman, 2003).

Competition between the already established vegetation and emerging seedlings for space, moisture, soil nutrients and light are common features of the microenvironment. The data pertaining to regeneration status of *Quercus glauca* bearing forests in relation to stand and site characteristics showed that natural regeneration, in general, tend to increase with increase in tree density; whereas, it tend to decrease with increase in shrub and herb density as well as lopping intensity (Table 29).

The ratio of seedlings and saplings per individual tree is one measure of regeneration (Bisht *et al.*, 2013.). Data in Table 30 showed that the amount of seedlings and saplings per individual *Quercus glauca* tree was the highest (11.5) at site IV, which was followed by site II, site III and site I with values of 9.8, 8.7 and 7.4 seedlings per tree, respectively. Site VI and site V had 2.9 and 2.0 seedlings per individual tree, respectively. The lower values at site V and site VI indicated the considerable effect of grazing in these sites. Although the site is severely disturbed, Site III has better seedling number per tree, which may be due thick bush cover that might have protected seedlings from grazing. On the other hand, number of saplings per *Quercus glauca* tree is very much low ranging from 1.2 saplings per tree at site II to 3.2 saplings per tree at site I. The high density of *Quercus glauca* trees in site II and its low density in site I are the reason for these differences. However, it can be presumed that sapling density in all the study sites is very low. Similarly, regeneration per cent of *Quercus glauca* per seed tree is very low, ranging from 0.02 % at site V to 0.09 % at site IV. This is also an indication of unsatisfactory regeneration of the species. Bisht *et al.* (2013) also

reported a 0.05 and 0.02 seedling and sapling densities per individual *Quercus semecarpifolia* tree, respectively.

5:2 SITE AND STAND CHARACTERISTICS

The study on site characteristics of *Quercus glauca* bearing forests of Himachal Pradesh revealed the presence of significant differences among the study sites with respect to soil pH, organic carbon, available potassium and organic matter layer. However, differences in their soil moisture content, available nitrogen, available phosphorus and solar influx found to be insignificant (Table 37).

Soil pH was found to be in the range of 4.86 to 6.44, the minimum and maximum values of soil pH were recorded in site IV and site III, respectively. High organic matter layer from large crown trees at site IV coupled with better soil moisture could be a reason for lower pH of site IV. Forest degradation in site III might be a reason for its high soil pH. These results are in line with the findings of Cerny *et al.* (2013), who reported minimum, maximum and average pH value of 4.13, 6.08, 4.68, respectively in *Quercus mongolica* and *Lindera obtusiloba* forests of Korea. Jina *et al.* (2009) also reported a pH value of 5.5-6.5 in *Quercus leucotrichophora* and *Pinus roxburghii* forests of central Himalaya. Gonzalez *et al.* (2012) too found high soil pH in open forest stands and low soil pH in mixed forests and grasslands.

Soil moisture content didn't vary amongst the studied sites and soil depths. The minimum and maximum soil moisture content i.e. 26.8 % and 39.5 %, were recorded in site V and site IV, respectively. The presence of high organic matter layer as well as high crown cover (less solar influx to forest floor) may have played a role in maintaining high moisture content of the soil in site IV. The role of shading and organic matter content on maintaining soil moisture was also highlighted by Welander and Ottosson, (2000) and Davis *et al.* (1999).

Organic carbon content, which ranged from 1.29 % to 1.46 %, was found significantly different amongst the studied sites. The availability high organic matter layer and better soil moisture in site IV may have improved organic matter decomposition and soil nutrients release. Andivia *et al.* (2012) also reported the importance of litter fall in improving soil fertility and its dependence on rainfall, soil moisture and total crown surface. The higher amount of available nitrogen (344.5 kg ha^{-1}) was also found on the same site, where organic carbon content was high. Thus, the same reason can be deduced for the variation in nitrogen content. The minimum (19.8 %) and maximum (30.2 %) values of available phosphorus were

recorded at Site II and site III, respectively. These values were recorded in highly contrasting sites. The highest value of available phosphorus was recorded by the site which was dominated by shrubs and herbs, while the lower value was recorded by the site where tree density and organic matter layer were higher. On the other hand, Site I and site II contained the lowest and the highest content of available potassium. While working in central Himalaya, Srivastava (2010) reported that available phosphorus was independent on soil organic matter. He found high amount of available phosphorous in pine forests; whereas high amount of organic matter, organic carbon, available nitrogen and soil moisture were found in oak forests. Kumar (2012) also reported the high amount of available potassium and available phosphorus in *Pinus gerardiana* forests of Kinnaur district and associated it to the presences of parent materials like granite, gneiss, mica, etc.

Significantly maximum (1.49 cm) and minimum (0.63 cm) soil organic matter layer were recorded in site IV and site V, respectively. Although the density of trees between the two sites was comparable (Table 29), the difference in organic matter layer might be as a result of the level of forest protection on these sites. Although it was not significantly different amongst the studied sites, solar influx varied between 12.4 % and 22.1 % and these extreme values were recorded in site IV and site V, respectively. The main reason for this illumination difference was effect of lopping. Both sites had comparable density of trees and similar intensity of lopping. However, lopping at site IV left bigger trees untouched that helped for the accumulation of organic layer. This is also evident from the crown data given in Table 30. Site IV had a maximum of 18.4 meter crown width while this value for site V was 11.5 meter. Excepting soil pH, all values of the measured parameters were found higher in the upper soil depth of 0 - 15 cm (D_1) than the lower soil depth of 15 - 30 cm (D_2). These results are in line with the findings of Lanker (2007), who also reported decreasing soil moisture, organic carbon, available nitrogen, and available phosphorous with increasing soil depth. However, soil pH and available phosphorus increased with increasing soil depth.

Receptivity of seed bed refers availability of favourable conditions on the ground for acorn germination and subsequent growth and establishment of *Quercus glauca* seedling. Soil moisture, organic matter layer and fertility of the site are some of the important factors that determine seed bed receptivity. Regeneration of *Quercus glauca* (Tables 31- 36) has been found to increasing with increase in soil moisture content, organic carbon, available nitrogen and organic matter layer (Table 37). Some deviations from this general trend were observed

at site I and site V in reference to available nitrogen and at site I and site II with reference to organic matter layer; which might be due to other biotic and abiotic factors. On the other hand, *Quercus glauca* regenerations were found to decrease with increase in soil pH, available phosphorus and available light on the forest floor/solar influx. Some deviations to this general trend were observed at site III with reference to soil pH, site II and site V with reference to available phosphorus and at site II and site VI with reference to solar influx. These variations can be attributed to disturbance in the forest ecosystems and other site conditions. Available potassium has been found to have no clear relationship with *Quercus glauca* regeneration (Table 38).

Usually, stand characteristics refers tree diameter classes and their variations in tree diameter, height, basal area, volume distributions and other crown parameters. In this particular study, measurements were made in all trees that have 10 cm or more diameter at breast height (dbh) to characterize *Quercus glauca* bearing forests of the studied sites. Diameter classes were defined as 10.00-19.9cm, 20-29.9cm, 30.39.9cm, etc. with a diameter class interval of 9.9 cm. The maximum diameter class of 30.0-39.9 cm was recorded in site II, while the maximum diameter class of 70.0-79.9 cm was recorded in site V. Based on the relationship of diameter and age, it can be conceived that site II was the youngest and site V was the oldest forest stands (Loewenstein *et al.*, 2000). Number of trees per diameter class was found to decrease from lower to higher diameter class (Figure 10) and best fit with an exponential equation of $y = 519.6e^{-0.86x}$, where y is number of trees and x is diameter class.

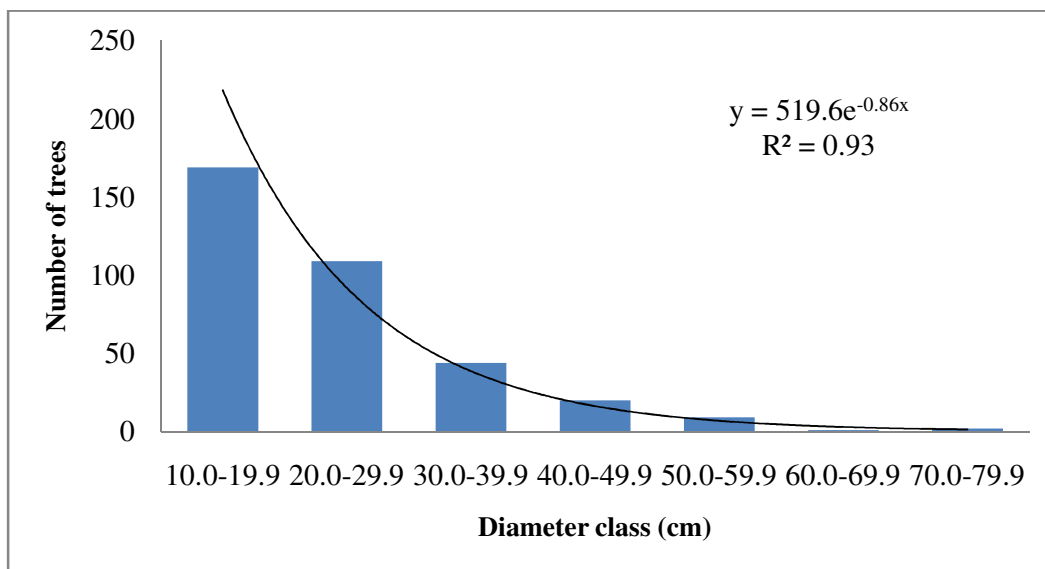


Figure 10: Number of *Quercus glauca* trees along diameter class

Data pertaining to growth parameters under different diameter classes indicated that number of trees decreased with increasing diameter class attaining a reversed 'J' shape (Table 30). Whereas, diameter, height, crown width and crown length showed an increasing trend with increase in diameter classes. Maximum number of trees (408.3 trees ha⁻¹) was recorded in site II for diameter class 10.0-19.9 cm; while no tree (0 trees ha⁻¹) were recorded in site V for 60.0-69.9 cm diameter class. Non-representation of this diameter class could be due to selective logging in the course of its lifetime. High number of trees in the 10.0-19.9 cm diameter class at site II indicated towards prevalence of better growing conditions that supported this young forest stand.

Highest tree height (30 m) was recorded in diameter class of 50.0-59.9 cm at site III and in a diameter class of 60.0-69.9 cm at site VI, whereas, minimum height (6.9 cm) was recorded in a diameter class of 10.0-19.9 cm at site VI. In all study sites, height was affected by lopping and pollarding activities (Table 61). Highest lopping intensity (94.7 %), as recorded at study site III, affected tree height of all diameter classes excepting 50-59.9 cm diameter class. Similarly, at study site VI lopping has resulted in minimum tree heights. On the other hand, site I at which the lopping intensity was minimum (7.9 %), in general, displayed higher tree height across all the diameter classes.

Table 61: Effect of lopping on average height (m) of trees along diameter classes

Diameter class (cm)	Lopping intensity (%)					
	7.9	65.0	94.7	46.2	45.9	70.6
	Site I	Site II	Site III	Site IV	Site V	Site VI
10-19.9	9.5	9.2	8	7.5	7.4	6.9
20-29.9	20.5	14.5	10.9	13.5	10.7	16.8
30-39.9	25.5	16.9	16.5	24	16.5	16.2
40-49.9	28.5	-	27.3	27.5	21	17.6
50-59.9	28	-	30	-	26.5	23.3
60-69.9	-	-	-	-	-	30
70-79.9	-	-	-	-	26	-

Maximum basal area and volume i.e. 16 m² ha⁻¹ and 54 m³ ha⁻¹, respectively were recorded in site II for the diameter class 20.0-29.9 cm. Whereas, minimum basal area (1.3 m² ha⁻¹) was recorded in site I for the diameter class 30.0-39.9 cm; while the minimum volume (3.3 m³ ha⁻¹) was recorded in site V for diameter class 10.0-19.9 cm. The trend in basal area and volume along diameter class are not consistent. Basal area and volume on per hectare basis were concentrated in the mid diameter classes and this characteristics is taken as an

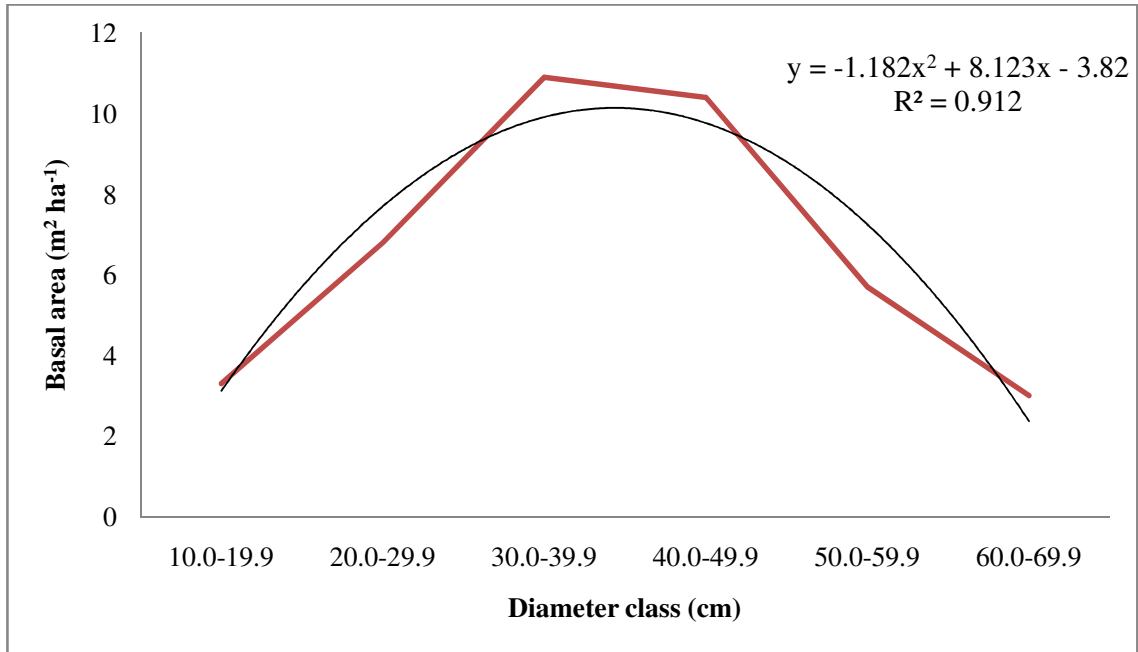


Figure 11: Basal area of site VI as a good indicator of normality of a forest

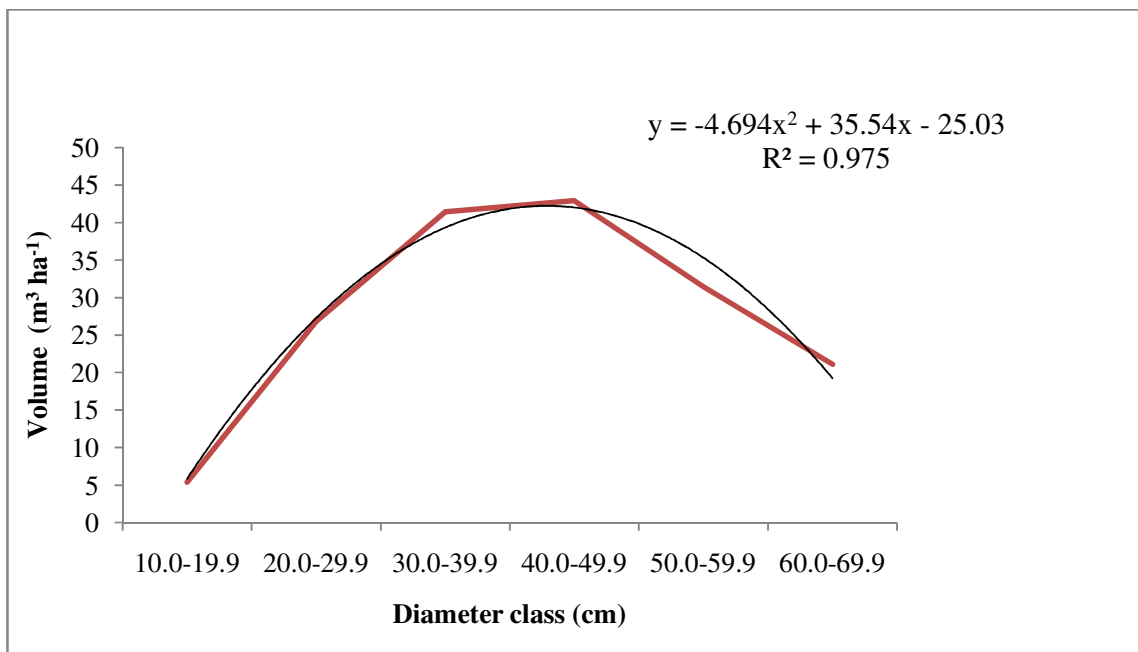


Figure 12: Volume of site VI reflecting normality of the forest site

indicator for normality of a forest (Babic *et al.*, 2010; Loewenstein *et al.*, 2000). However, most sites didn't showed this characteristic, excepting site II and site VI. In contrast to higher human interference, Site VI showed some sort of normality of the forest (Figure 11 and 12). This might be due to uniform lopping activities in all the diameter classes (Table 61).

Based on data in Figure 2, maximum density of *Quercus glauca* was recorded in site II while its maximum basal area and volume was recorded in site V and VI. This can be due to the fact that site II was a young stand that embraced high number of trees, whereas site V and site VI were old stands that had higher basal area and volume than the younger stands. Density, basal area and volume of associated species were high in site I because of the dominance of associated species than *Quercus glauca* (Table 7). Site III contained the least density, basal area and volume of both *Quercus glauca* and associated species. Human disturbance could be the reason for this. Pokhriyal *et al.* (2012) also reported the decline in tree density and basal area with increasing disturbance.

Lopping was another factor that influenced the growth of *Quercus glauca*. As observed in Figure 3, maximum number of trees lopped were found in site II followed by site VI and site III. Whereas, minimum number of lopped trees were found in site I. However, if lopping intensity taken into account, higher intensity of lopping was observed in site III, site VI and site II with respective lopping intensity of 94.7 %, 70.6 % and 65.0 %, respectively. Moderate lopping intensity was recorded in site IV and site V in which 46.2 % and 45.9 % of trees lopped, respectively. Whereas, lowest lopping intensities (7.9 %) was recorded in site I. Maximum basal area and volume of lopped trees were recorded in site II and site VI. Higher number of trees lopped in site II and the bigger diameter trees lopped in site VI inflated the basal area and volume of lopped trees in these sites. Thapa and Chapman (2010) also reported the higher intensity of lopping in 10.0-30.0cm diameter class trees than very young or very old trees. Figures 4 and 5 evidenced the loss of 0.0724 m³ volume of wood in every lopped tree. Figure 13 below shows the total volume of wood lost per hectare in the study sites. Maximum wood loss (38 m³) occurred in site II, which was followed by site VI and site III having values of 29 m³ and 21.7 m³ of wood loss per hectare, respectively. The minimum wood loss (1.8 m³ ha⁻¹) occurred in site I.

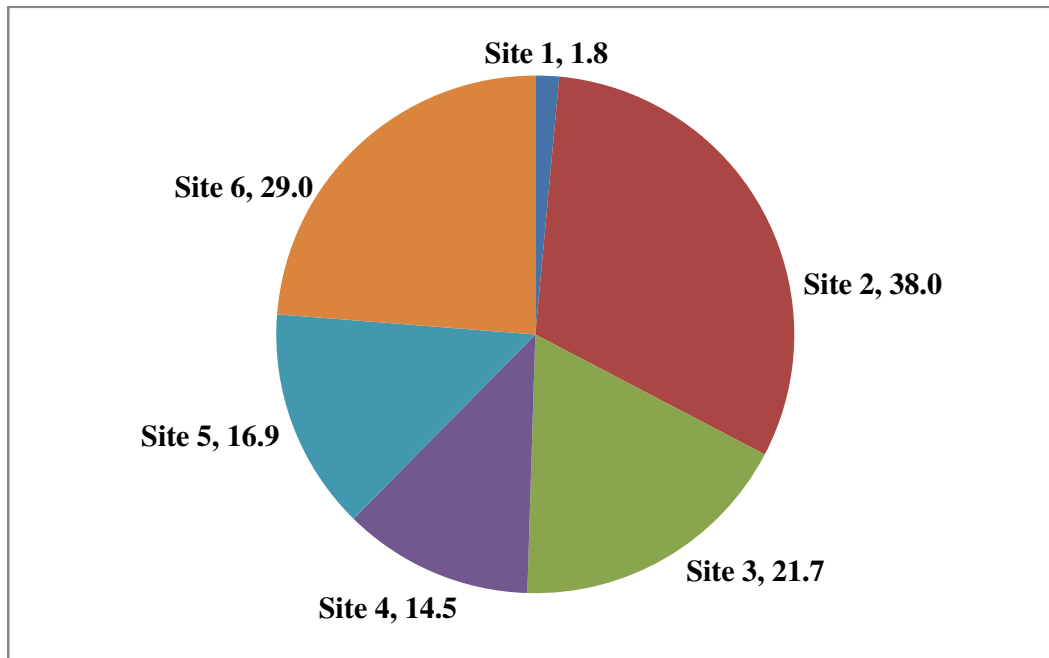


Figure 13: Loss of volume of wood (m³ ha⁻¹) in the study sites

Finally, the effect of site and stand characteristics on natural regeneration of *Quercus glauca* and associated species was assessed thorough correlation and regression analysis. The result in Table 38 revealed that soil pH in 0-15 cm and 15-30 cm soil depths as well as solar influx had a significant and negative correlation with regenerations of *Quercus glauca*. However, soil moisture content in a soil depth of 0-15 cm and 15-30cm and soil organic carbon at the upper soil depth (0-15 cm) had a significant and positive correlation with regenerations of *Quercus glauca*. The simple linear regression analysis of these variables as independent variable and regeneration of *Quercus glauca* as dependent variable was presented in Table 40. The results in the Table demonstrated that the ability of these site factors to explain regeneration dynamics of the species was very low, except for soil moisture content and solar influx. The linear function presented for moisture content of 0-15cm, as independent variable, can explain 75% of the variation in natural regeneration of *Quercus glauca*; while the linear regression equation presented for solar influx, as independent variable, explained 70 % of variation in regenerations.

Table 39 displayed that regenerations of *Quercus glauca* had a positive and significant correlation with crown fullness ratio of associated species, crown projection ratio of *Quercus glauca* and crown projection ratio of associated species. Regeneration of associated species was positively and significantly correlated with density, basal area and

volume of associated species. The simple linear regression analysis in Table 41 and Table 42 showed that small amount of the regeneration dynamics can be explained with the help of linear regression equations.

5:3 NATURAL REGENERATION ASSESSMENTS

It can be inferred from the Tables 31-36 that highest number of recruits (18083), unestablished (14167) and established (8750.0) regenerations were recorded in site I. Establishment stocking per cent and regeneration per cent were also the highest in site I having values of 87.5 % and 229.2 %, respectively. The recruits, unestablished and established regenerations of site I was dominated by *Cryptolepis buchanani*, *Myrica esculenta* and *Pyrus pashia*, respectively. These species are known for their shade tolerance and forming close association with *Quercus* and *Pinus* species (Hussain *et al.*, 2008, Tayung and Saikia, 2003, Bhatt *et al.*, 2000). The death of prominent *Pinus roxburghii* trees also allowed these species to proliferate at the site. The site was also better protected, especially from grazing, browsing and also had minimum lopping intensity (7.9 %). In contrast to their dominance, the regeneration status of *Quercus glauca* and *Quercus leucotrichophora* was moderate. The result partially supports regeneration problem of the genus as also reported by several workers in the past (McCreary 2009, Shrestha, 2003, Rajwar *et al.*, 1999).

The recruit and unestablished regeneration of site II was occupied by *Quercus glauca* and *Punica granatum*, respectively. Established regeneration was also high for *Ailanthus excelsa*, *Bauhinia variegata* and *Quercus glauca*. However, the first two species had no recruits and unestablished regenerations may be due to shading effect. Although it has the highest number of recruits, the regeneration performance *Quercus glauca* was much similar to site I. Higher density of trees in site I and site II may not have effect on recruits of *Quercus* species, however light was an essential requirement for further growth and establishment of the species (Welandar and Ottosson, 1998 & 2000). Higo *et al.* (1995) also reported that the dominant tree, *Quercus serrata*, had the lowest (2.8 %) regeneration per cent and he concluded the species was in the process of succession, losing its dominance to more shade tolerant species.

Site III was the most disturbed site that had a direct effect in stand structure, species composition and regeneration of the site. The lowest tree density and the lowest tree species richness was recorded in site III and its effect was reflected on the regeneration. Few number

of tree species were accounted for their regeneration. The lowest number of recruits were observed at this site, while its established regenerations were occupied by only two tree species i.e. *Punica granatum* and *Quercus glauca*. Both the low number of recruits and the absence of established regeneration for most species were as a result of competition effect. Highest density of shrubs was recorded in site III and the density of herbs was also high. Davis *et al.* (1999) also reported that herbaceous competition significantly affected the growth, survival, and photosynthesis of oak seedlings.

The highest number of recruits, unestablished and established regenerations in site IV was attributed to *Quercus glauca*. The highest regeneration and stocking per cent was also accounted by *Quercus glauca*. The site was characterized by its low tree density, high crown shading, and high moisture, high organic matter, organic carbon and available nitrogen contents. The site was also protected forest that entertains lowest intensity of grazing. Thus, it can be presumed that these site conditions may play an important role for the prolific regeneration of *Quercus glauca*. Fernandez (2008) reported the importance of available soil nutrients in the forest to predict site quality and its productivity. Welander and Ottosson (2000) also reported the influence of light, water and nutrients on seedlings growth of *Quercus robur*. However, Royse *et al.* (2010) and Major *et al.* (2013) reported high litter depth and soil fertility leads to high seedling mortality and less natural regeneration of oak species. On the other hand, Shrestha (2003) reported that lack of sufficient natural regeneration of *Q. semecarpifolia* was due to anthropogenic effect and it didn't have clear relationships with soil factors.

The lowest establishment stocking per cent and regeneration per cent were recorded in site V. The performance of *Quercus glauca* regeneration was also the lowest at all the study sites. Site V was more or less similar to site III. Human interference was very high; few trees species were accounted for their regeneration; most trees had no established regenerations. The site was also characterized by highest light radiation available on the forest floor and lowest soil moisture content, organic carbon, and organic matter layer. These factors coupled with the presence of several old age *Quercus glauca* trees might affect regenerations of all the species growing at the sites.

Ficus sarmentosa, *Machilus duthiei* and *Zanthoxylum alatum* had the highest recruits in site VI, while the highest unestablished and established regenerations were recorded for *Zanthoxylum alatum* and *Toona ciliata*, respectively. Establishment stocking per cent and regeneration per cent was

also high for *Toona ciliata*. *Quercus glauca*, on the other hand, had a moderate establishment stocking per cent and regeneration per cent. Establishment stocking per cent and regeneration per cent was also the second highest record from all the study sites. Like site III and site V, much of the species failed to establish at site VI. The higher number of tree species in the first phase of regeneration (recruits) and absence of established regeneration might indicate the progressive disturbance level of the site. The high soil moisture content, the moderate soil nutrient content and the low light intensity on the forest floor indicated that disturbance was moderate as compared to site III and site V. Moderate disturbance has been reported to have a positive relationship with regeneration of oak specie (Thadani and Ashton, 1995).

In general, regeneration of *Quercus glauca* in all the study sites were low, ranging from 11.7 % in site V to 40 % in site IV. Evidenced from low regeneration per cent of highly disturbed sites, anthropogenic factors might be a reason for lack of regeneration in the study sites. In addition to anthropogenic effects, biotic pressure from fungus, insects, birds and mammals were the reason for the lack of regeneration in most oak forests (Gribko, 1995, Riccardi, 2004). The maximum recruits and unestablished regeneration as well as highest regeneration per cent were recorded from site IV. Better regeneration potential of site IV can be associated to its moderate disturbance, better soil fertility and high crown width and higher shade (Table 30 and Table 37). Site VI, had better established seedlings and establishment stocking per cent. This site was presumed to be in transition from less disturbed site into highly disturbed site. The total absence of recruits and less number of unestablished seedlings of *Quercus glauca* might support this proposition. The low regeneration per cent was recorded at site V and site III, which is evidently an impact of sever disturbance on regeneration potential of *Quercus glauca*.

There were a total of 22 species recorded to have regenerations in one or more of the study sites. About half of these species had restricted occurrence and their contribution to the total regeneration and establishment stocking per cent was quite low. In addition to *Quercus glauca*, *Punica granatum* and *Pyrus pashia* had a universal occurrence. Thus, their contribution to the total germination per cent was quite high. The contribution of *Quercus glauca* and *Punica granatum* to the total establishment stocking per cent was also high. In contrast to its limited occurrence, the contribution of *Toona ciliata* to regeneration and establishment stocking per cents was also high (Table 62).

5:4 STRATIFICATION STUDIES

Stratification media have been found to have a significant effect on germination of acorns under open nursery condition (Table 43). Farm yard manure (M₂) had the highest germination per cent (51.8 %) followed by forest soil (M₃) and a 2:2:1 mixture of sand, farmyard manure and forest soil (M₆) with 49.3% and 48.9 % germination per centages, respectively. The lowest germination per cent (44.0 %) was recorded in the control (M₇). In our study, germination per cent was higher in nutrient rich stratification media i.e. M₂, M₃ and M₆ (Table 37). In contrary to this result, high regeneration and seedling emergence was recorded by nutrient poor soil media (Dolor, 2011, Pahla *et al.*, 2014).

Germination converts the nutrition available in the seed into usable products during cell initiation, differentiation and elongation processes. Nutrient contents of the surrounding environment were not expected to have a direct impact on germination. Thus, the high germination potential of nutrient rich soils might be related to its high moisture holding capacity and high amount of microorganisms available which have an impact on germination (Araujo *et al.*, 2009, Wall, 2005, Hanapi *et al.*, 2014, Jalaluddin and Hamid, 2011).

Apart from germination per cent, stratification media had no significant effect on the growth of *Quercus glauca* seedlings. This can be mainly due to the fact that *Quercus glauca* seedlings had grown under homogeneous growing environment. Thus, there was no extended effect of stratification media on seedlings grown under these uniform conditions after germination.

Stratification duration, on the other hand, had significant effect on both germination and growth of seedlings. Fifteen days stratification duration (D₁) gave maximum values of number of lateral roots (0.67) and root-shoot ratio (0.58). Whereas, thirty days stratification duration (D₂) gave the maximum values of shoot height (9.3 cm) and number of leaves (2.9); while forty five days stratification duration (D₃) had the highest germination per cent (49.5 %). Similarly, Drake and Ewing (1997) also reported that six weeks stratification duration had significant effect on germination of several native Washington plant species and germination weaken on twelve's weeks of stratification. The importance of moderate stratification period on germination and seedling growth was reported by various authors (Fetouh and Hassan, 2014, Ghasemi and Khosh-Khui, 2007). However, Pandey and Tamta (2013) reported 10 to 20 days stratification duration to be better for enhancing germination of *Quercus serrata* and *Quercus semecarpifolia*.

Table 62: Natural regeneration of tree species, their occurrence and contribution to the total regeneration and establishment stocking per cents of the study areas

Sr. No.	Spp.	Site I		Site II		Site III		Site IV		Site V		Site VI		ES %	R %
		Seed tree	Seed bank	Seed tree	Seed bank	Seed tree	Seed bank	Seed tree	Seed bank	Seed tree	Seed bank	Seed tree	Seed bank		
1	<i>Acacia spp</i>				X									0.0	5.0
2	<i>Acer oblongum</i>				X						X			5.0	22.5
3	<i>Ailanthus excelsa</i>	X			X			X					X	10.0	30.0
4	<i>Albizia spp</i>	X												5.0	10.0
5	<i>Bauhinia variegata</i>			X										10.0	10.0
6	<i>Celtis australis</i>	X		X			X		X				X	15.0	61.7
7	<i>Cryptolepis buchanani</i>		X		X									0.0	0.0
8	<i>Ficus foveolata</i>												X	0.0	0.0
9	<i>Ficus palmata</i>							X						0.0	0.0
10	<i>Glochidion spp.</i>										X			0.0	0.0
11	<i>Machilus duthei</i>		X					X			X	X		12.5	37.5
12	<i>Melia azedarach</i>						X							0.0	5.0
13	<i>Myrica esculenta</i>	X						X				X		26.7	70.0
14	<i>Olea glandulifera</i>									X				0.0	10.0
15	<i>Pistacia integerrima</i>		X	X										0.0	10.0
16	<i>Punica granatum</i>		X		X	X		X		X		X		55.0	132.5
17	<i>Pyrus pashia</i>		X		X	X		X			X	X		18.4	110.0
18	<i>Quercus glauca</i>	X		X		X		X		X		X		57.5	143.3
19	<i>Quercus leucotrichophora</i>	X												10.0	26.7
20	<i>Sapium sebiferum</i>		X											0.0	10.0
21	<i>Toona ciliata</i>											X		30.0	35.0
22	<i>Zanthoxylum alatum</i>	X					X						X	12.5	64.2
	Contribution (%)	53.8	46.2	40.0	60.0	50.0	50.0	87.5	12.5	42.9	57.1	60.0	40.0		

Stratification duration had significant effect on germination and growth of *Quercus glauca* seedlings grown under shaded growing conditions (Table 44). Fifteen days stratification duration (D₁) had significantly higher values of root length (16.1 cm), shoot height (14.4 cm) and leaf area (10.3 cm²). Whereas, 30 days stratification duration (D₂) had significantly higher values of number of lateral roots (0.85) and number of leaves (2.8), while, 45 days stratification duration (D₃) had significantly higher germination per cent (66.9 %) than D₁ and D₂. In contrary to this result, Fetouh and Hassan (2014) reported higher root, shoot, leaf, and vigor index of *Magnolia grandiflora* seedlings under 60 to 90 days stratification durations treatment.

Appreciable differences were observed in germination and seedling growth characteristics of open and shaded growing conditions. The result of this study revealed that higher germination and better initial growth of *Quercus glauca* seedlings was recorded under shaded growing condition than open nursery conditions (Figure 14 and 15). Germination per cent as well as survival per centage of *Quercus glauca* was better under shaded growing condition than open nursery environment (Table 46). This clearly indicates towards shade loving nature of this species. Higher root length, number of lateral roots, shoot height and leaf area were also recorded in shaded growing condition than open nursery conditions. Whereas, collar diameter, root-shoot ratio, number of leaves and total biomass were higher under open growing conditions with respective advantages of 0.1 cm, 0.23, 0.1 and 0.06 g over shaded growing conditions.

Moisture and light condition were the two most important factors that influence germination and growth under the two growing conditions. The availability of constant and sufficient moisture under shaded growing condition enhanced germination and survival by reducing desiccation which otherwise might have affected young seedlings. However, moderate light conditions affected the growth and morphology of above ground parts under shaded conditions. Shoots became thin, long and low in biomass, while, leafs became few in number with sufficiently large leaf area to capture intermittent light that passed through shades. Our results are in agreement with the findings of Gottshalk (1985), who reported higher (80 %) height growth of red oak and black oak under shaded growth conditions treatment, while diameter and root-shoot ratio decreased with increase in shading. Similarly, Muick (1991) also reported better emergence and survival of blue oak and coast live oak under 50 % shaded field conditions than open conditions. While, Welander and Ottosson (1998, 2000) reported initial

growth of oak seedlings was not affected by low light condition, but proper growth of oak seedlings would be achieved by increasing light intensity after one year.

The assessment of biochemical changes of *Quercus glauca* acorns in different stratification media after 15, 30 and 45 days of stratification period were found significant for both stratification media and stratification durations (Table 48). The highest total sugar content (9.7 %) was recorded in forest soil (M₃) followed by a 2:2:1 mix of sand, farmyard manure and forest soil (M₆) and farmyard manure (M₂), respectively. The maximum total phenol (6.2 %) as recorded in the sand media (M₁), while the minimum total phenol content (5.1 %) was recorded in forest soil media (M₃) and the control (M₇). The maximum (36.7 %) and minimum (30.5 %) values of starch contents were recorded in a 1:1 mixture of sand and farmyard manure (M₄) and a 2:2:1 mixture of sand, farmyard manure and forest soil (M₆), respectively. Soluble protein was high (4.4 %) in the control (M₇) and it was low (3.8 %) in farmyard manure (M₂) and forest soil (M₃). Differences in biochemical content of acorns among the three stratification durations indicated that the 45 days stratification duration had the highest total sugar content (9.9 %), while the 15 days stratification duration had the highest total phenol (5.9 %), starch (37.9 %) and soluble protein (4.3 %) contents.

General observation in the biochemical content of *Quercus glauca* acorns indicated existence of close relationship between biochemical content and germination of acorns. Various authors reported that biochemical content of seeds changed as a result of metabolic activities during germination (Andarwulan *et al.*, 1999, Alencar *et al.*, 2012). Hence, the observed differences might be linked to the process of germination during stratification periods. Thus, it can be inferred that higher contents of total sugar and the lower contents of starch and soluble protein in stratification media that had better germination might be the result of metabolic activities during germination. Initial stages of metabolic activities convert polysaccharides into simple sugar and proteins into free amino acids that give energy for the newly produced cells. The same reason might hold true for the higher content of total sugar and lower content of starch and soluble protein in the stratification duration of 45 days.

The amount of total phenol, on the other hand, didn't appear to be related to germination. Rather, the high moisture holding capacity of nutrient rich soils and the control, which was more

or less clayey, might have induced leaching of phenols from acorns. Thus, total phenol was recorded low in nutrient rich soils as well as the 45 days stratification treatment. Contrary to this, Alencar *et al.* (2012) reported that total sugar content of *Cereus jamacaru* increased with germination, whereas, starch showed increase up to the fifth day after imbibitions and tend to decrease at latter stages. Malik and Shamet (2009) also reported increases in total sugar content of *Pinus gerardiana* up to three months of cold storage and decreased thereafter. Protein compounds were also reported to decrease with increase in germination. Satayanarayana *et al.*, (2011) reported reduction of soluble protein content of *Sterculia urens* seeds with increase in germination time. Andarwulan *et al.*, (1999) also reported increased total phenol content during germination.

5:5 GERMINATION STUDIES

The main objective of conducting germination tests was to assess the potential of chemical and physical pre-sowing treatments on breaking exogenous and/or endogenous seed dormancies, so as to realize high and uniform germination of acorns in a shortest possible period of time. Categorization of acorns as small, medium and large had helped to realize influence of seed morphology on germination of acorns. Chemical and physical pre-sowing and seed sizes had significant influence on germination of *Quercus glauca* acorns.

The seven chemical pre-sowing treatments, control, cold and hot water treatment, 3⁰C and 0⁰C cold temperature, and 50 ppm and 100 ppm GA₃ applications had significant effect on germination per cent and germination values of *Quercus glauca* acorns (Table 50). Higher values of germination traits under all pre-sowing treatments over the control, excepting germination capacity, indicated that application of chemical pre-sowing treatments is essential to improve germination of *Quercus glauca* acorns. Among the tested pre-sowing treatments application of GA₃ showed better performance of all germination parameters, while application of 100 ppm GA₃ was found to be superior than 50 ppm GA₃ application.

Different studies reported the importance of pre-sowing seed treatments on enhancing germination of different tree species. Soaking acorns in cold water has shown improvements in the germination of *Quercus rubra* and other species (Struve, 1998, Doody and Oreilly, 2008, Brand and Rivo, 1999). Hot water treatments were found effective in enhancing germination of

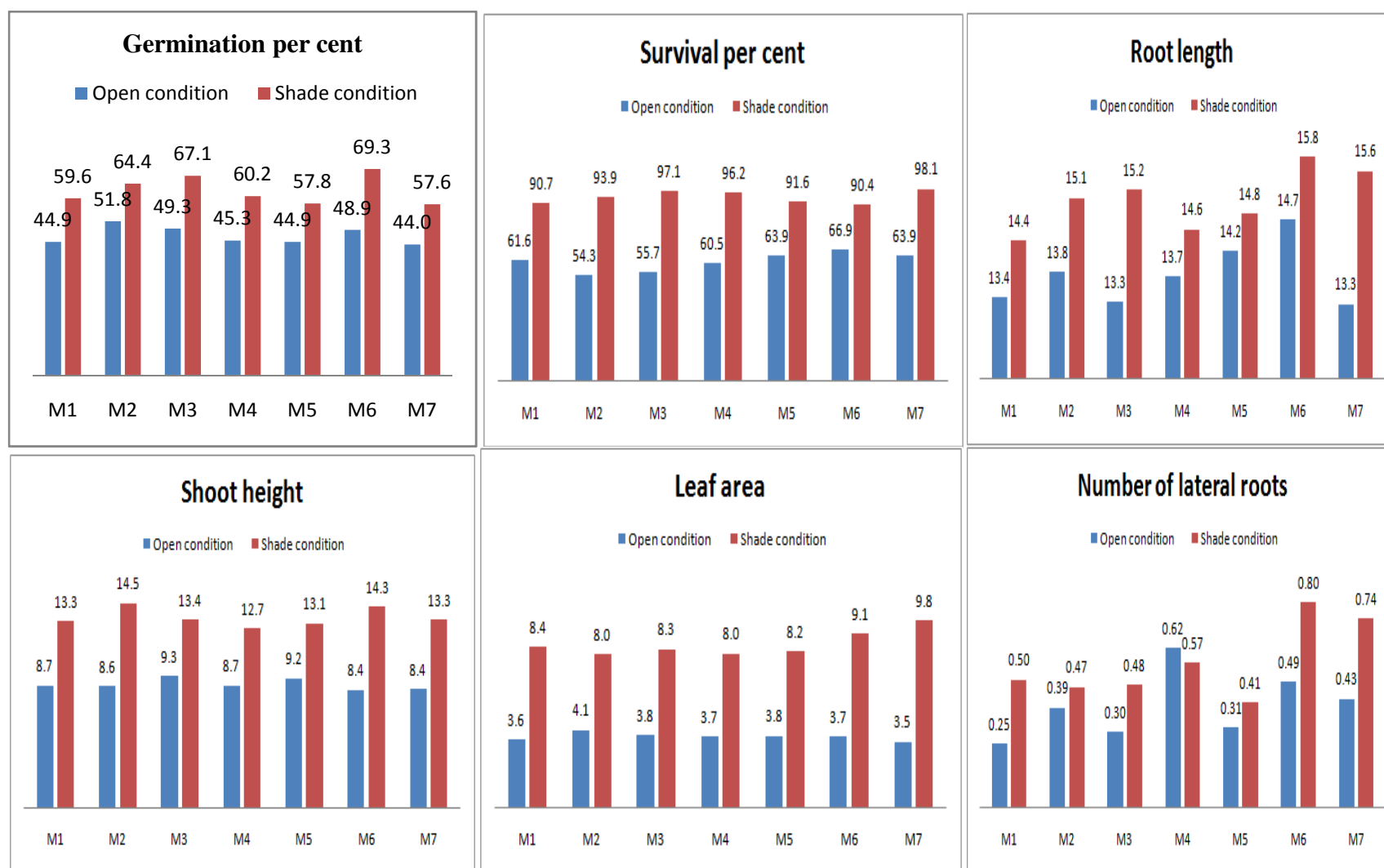


Figure 14: Comparison in germination, survival, root length, shoot height, leaf area, and number of lateral roots between seedlings grown under open and shaded conditions

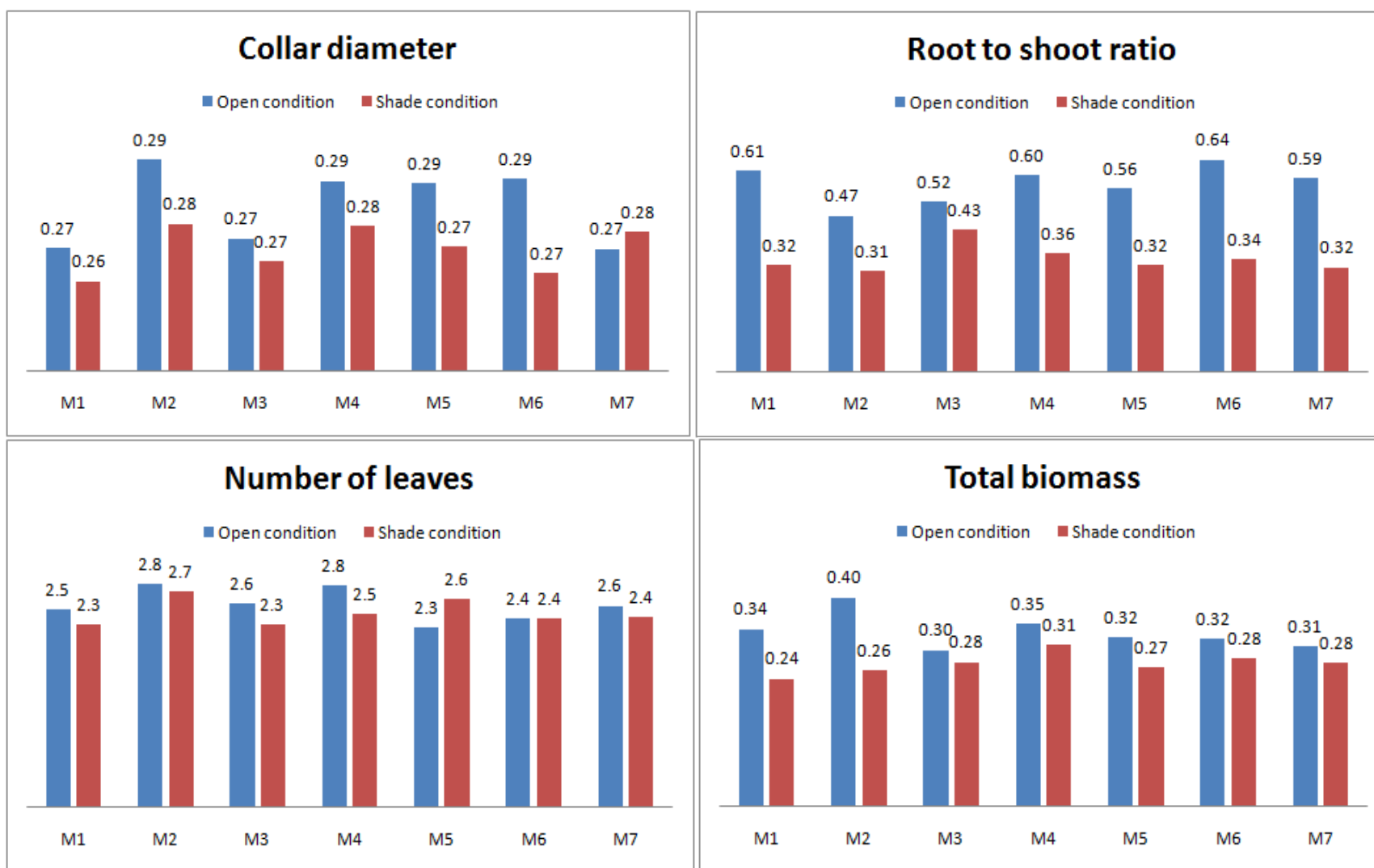


Figure 15: Comparison in collar diameter, root to shoot ratio, number of leaves and total biomass between seedlings grown in open and shaded condition.

seeds, which have hard seed coat (Cervantes *et al.* 1996, Ren and Tao 2004). Application of GA₃ as a pre-sowing treatment was reported to have a beneficial effect on the germination of various *Quercus* as well as other species (Ghasemi and Khosh-Khui, 2007; Ghildiyal *et al.*, 2009; Caliskan *et al.*, 2012). Importance of physical pre-sowing treatments was also reported by Zulfiqar *et al.* (2015) and Purohit *et al.* (2009).

Response of GA₃ application as a pre-sowing treatment to enhance germination of seeds will vary based on the amount of chemical applied and the type of species used (Adams *et al.*, 2010). However, some studies indicated application of higher concentration of GA₃ may improve germination per cent with higher per centage than the value presented here. Adams *et al.* (2010), for instance obtained higher germination per cent of *Quercus pagoda* with application of 300 ppm concentration of GA₃. Caliskan *et al.* (2012) had reported a 100% germination of *Ficus carica* by applying 500 ppm and 1000 ppm concentration of GA₃. Hence, more work is required to optimize the concentration of GA₃ treatments for germination of *Quercus glauca* acorns.

Excepting for germination capacity, seed size had a significant effect on all germination parameters. The data in Table 50 indicated that larger sized acorns had higher germination performance over small and medium sized acorns. This might be due to the higher amount of food reserves accumulated in larger acorns and to its higher moisture content. The results obtained in this study are in line with other germination studies that found higher germination potential of larger acorns (Suresha, 2007, Navarro and Guitian, 2003 and Tilki, 2010). However, the effect of seed size on germination varies from species to species (Lommasson, 1986; Landergott *et al.*, 2012). All germination parameters were also significantly affected by the interaction of chemical pre-sowing seed treatments and seed size.

The effectiveness of physical pre-sowing treatments in improving germination was highlighted by various authors. Zulfiqar *et al.* (2015) had found a 100% germination of *Quercus glauca* in scarified acorns and it performed better than stratified acorns. Scarified acorns of *Quercus glauca* and *Quercus leucotrichophora* had a 94.4 % and 82.7 % of germination, respectively (Purohit *et al.*, 2009). Struve (1998) tested effect of seed conditioning of red oaks and the treatment strained pericarp to split which resulted in germination completeness and uniformity.

Physical pre-sowing treatments such as exposed embryo (T₁), seed coat removed (T₂), seed coat punctured (T₃) and intact seed coat, which is a control, (T₄) were tested for their effectiveness on germination of *Quercus glauca* acorns. All the tested physical pre-sowing seed treatments had significant differences in all germination parameters (Table 51). All physical pre-sowing treatments, by far, had better germination, completeness and uniformity than the control. Exposed embryo had the highest values and the control had the lowest values of all germination parameters. The result was a clear indication that not only seed coat but also the hard cotyledon had some adverse effect on germination of *Quercus glauca* acorns. Seed coat removal performs better than seed coat punctures and this might be due to better imbibitions of water to embryo.

Acorn size had also a significant effect on all germination parameters, excepting for germination capacity. In contrast to results of chemical pre-sowing treatment, smaller acorns in the physical pre-sowing treatment showed better performance than medium and larger acorns. This might be due to the higher resilience of large acorns to perform in unfavorable conditions (restricted water permeability due to hard seed coat) and speedy desiccation of small acorns in unfavorable conditions (Bonfil, 1998). Under natural condition small acorns compensated their limited nutrition content by hastening regeneration and establish itself to the existing environment (Lommasson, 1986; Landergott *et al.*, 2012). The interaction effect of physical pre-sowing treatment and seed size had a significant effect on germination per cent and germination value only.

The effect of physical pre-sowing treatment on germination and seedling growth under shaded growing condition had shown significant difference for germination per cent, collar diameter and number of leaves. Under laboratory condition, germination per cent was high for exposed embryo (T₁). In contrast to this result, germination per cent became high for seed coat puncture (T₃) treatment under nursery conditions. This difference might be as a result of moisture stress under nursery conditions in which water loss was comparatively high due to evaporation and soil infiltration. In such conditions exposed embryo may not get consistent moisture for its proper germination. On the other hand, punctured acorns that have high capacity to hold moisture inside the seed coat might be able to escape the water stress conditions.

The other difference between laboratory and nursery conditions were effect of seed size on germination per cent. Under nursery conditions, larger sized acorns germinate better than small and medium sized acorns, which may be due to their resilience to such stress and their higher moisture contents. With the exception of root length and number of lateral roots, all growth parameters were found significantly different among seed sizes. Larger acorns had significantly higher values for all parameters, excepting root length and lateral roots, which were insignificant. The higher nutrition content of larger acorns, which is useful for early growth of seedlings, might be the reason for this difference. These results are in line with studies of various workers viz., Bonfil, 1998; Gunaga and Vasudeva, 2011; Tiliki, 2010. The interaction effect of physical pre-sowing treatments and seed size was insignificant for all growth parameters, except survival per cent and collar diameter.

Seed germination is the process of mobilization of their biochemical contents by hydrolytic enzymes and utilization of hydrolysis products for growth and respiration (Fu *et al.*, 2005; Soltani *et al.*, 2006; Pritchard *et al.*, 2002). It was discussed that biochemical content of acorns might have effect on germination and early growth of seedlings. Unlike physical pre-sowing seed treatments, chemical pre-sowing seed treatments are expected to change chemical composition of acorns and thereby breaking seed dormancy. Biochemical contents are also expected to vary with seed size.

Results of the investigation in Table 54 indicated that moisture content and total phenol contents also varied significantly among chemical pre-sowing treatments. Treatments with high germination per cent had shown high moisture content and low total phenol. Reduction in total phenol with increasing moisture content indicates towards effectiveness of these treatments in lowering the level of phenols. However, Andarwulan *et al.* (1999) reported an increase in total phenolics during germination of *Pangium edule* seeds. The effect of chemical pre-sowing seed treatments on total sugar, starch and soluble protein content was found insignificant. This might be due to the fact that 24 to 48 hours treatment applications might not be sufficient to induce significant metabolic activities that had the ability to change the biochemical content of the hard coated *Quercus glauca* acorns. In contrast to this, fast germinating seeds of *Cereus jamacarus* showed changes in their biochemical content in two days after imbibitions (Alencar *et al.*, 2012). Variation in germination per cent among chemical pre-sowing seed treatments might be related

to their initial moisture content rather than biochemical changes. Connor and Sowa (2004) reported germination of *Quercus alba* and *Quercus pagoda* to be dependent on initial moisture content of acorns. Ozbingol and Oreilly, (2005) reported initial moisture content to influence germination of oak species.

On the other hand, all the measured biochemical content showed significant variation among the three seed sizes. Larger seed had the highest moisture content, total sugar, total phenol, starch and soluble protein contents. These results are in line with the finding of Venudevan and Srimathi (2013).

Correlation of germination with biochemical content of acorns in Table 56 indicated that moisture content of acorns was significantly correlated with germination per cent, germination energy and germination value. Excepting for germination capacity, total sugar had significant correlation with all other germination parameters. Starch had a significant correlation with germination per cent only. Total phenol and soluble protein was found to have no correlation with germination parameters. The correlation between germination and moisture content is due to the role of water in facilitating metabolic activities of acorns and enhancing germination. The importance of water in enhancing germination is well reported by Ozbingol and Oreilly (2005). The result of biochemical contents of acorns presented in Table 54 revealed that higher content of total sugar and lower content of starch in 50 ppm GA₃ application (T₆) and 100 ppm GA₃ application (T₇) that had higher germination per cent. In general, total sugar increases with germination, while starch decreases with increase in germination due to its conversion to simple sugar (Alencar *et al.*, 2012). The regression analysis of germination parameters and biochemical contents of acorns presented in Table 57 suggested that only 6-27 % of variations in germinations can be attributed to moisture content, total sugar and starch content of acorns.

The comparison between chemical and physical pre-sowing seed treatments at Figure 16 showed that physical pre-sowing seed treatments have better performance of all germination related traits than chemical pre-sowing seed treatments. In comparison with their average values (Table 58) germination per cent was nearly 50 % more in physical pre-sowing seed treatments. Germination capacity and germination energy were more in physical pre-sowing seed treatments by 16.6 % and 39.7 %, respectively. Germination value and germination index were 3.7 times

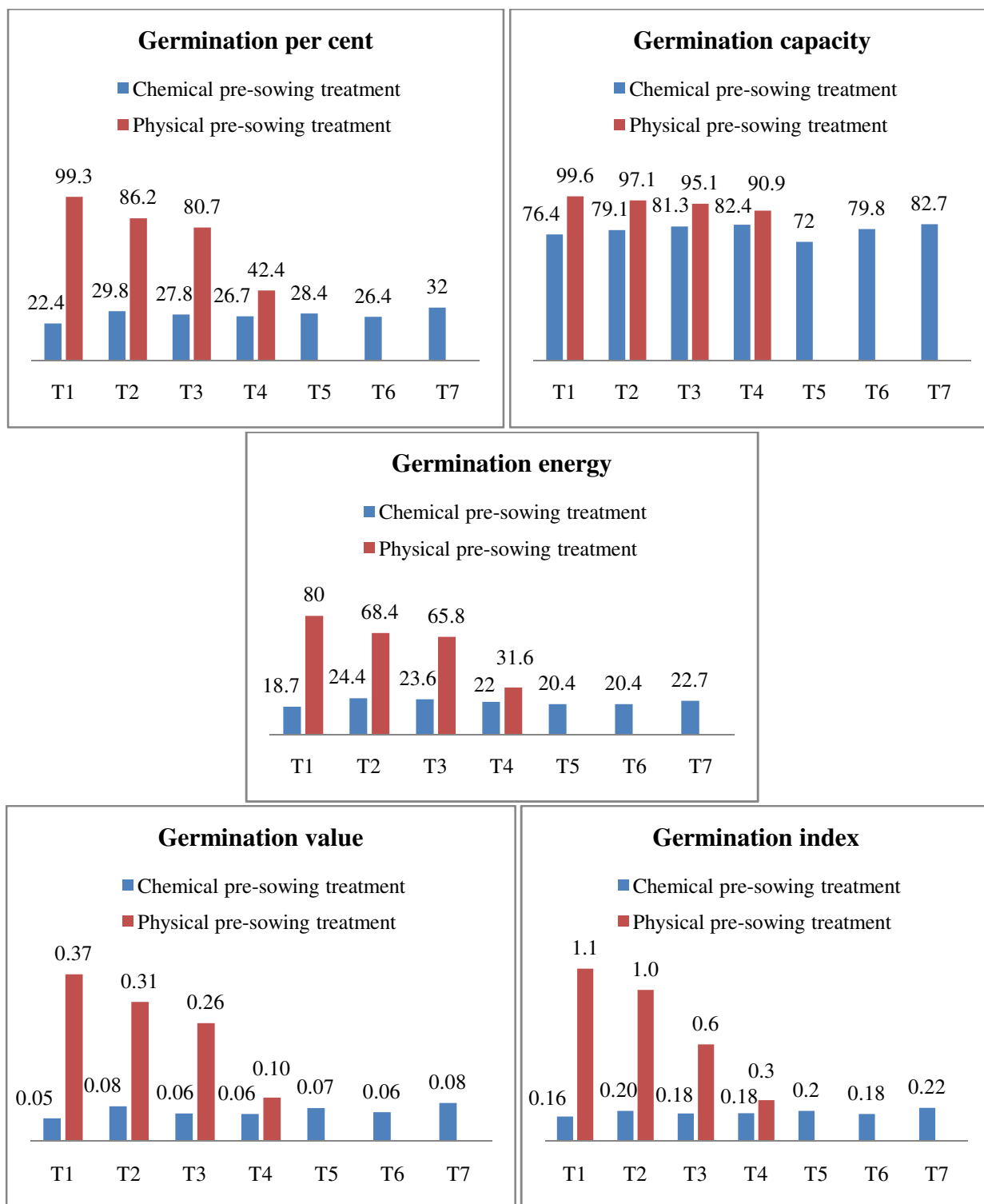


Figure 16: Differences in germination parameters between chemical and physical pre-sowing seed treatments

and 4 times more in physical pre-sowing seed treatments than chemical pre-sowing seed treatments.

Although both treatments were conducted under laboratory condition and homogenous environment, the variation recorded between them was very high. The main reason for this may be that physical pre-sowing treatments facilitated water imbibitions into the seed, which stimulated many acorns to germinate in short period of time . Higher germination capacity in physical pre-sowing treatments can be attributed to reduced desiccation of acorns as result of quick and uniform germination of majority of the acorns. Germination energy, germination value and germination index combines both number of acorns germinated and time taken to germinate. Germination energy and germination value indicated that more acorns germinated in physical pre-sowing seed treatments up to the peak. Germination index also indicate that the high number of acorns germinated under physical pre-sowing seed treatments within the time that took 50% of acorns to germinate. Thus, it can be inferred that physical pre-sowing seed treatments are more efficient over chemical pre-sowing seed treatments with reference to germination speed as well as germination per cent.

Chapter-6

SUMMARY AND CONCLUSION

The study entitled “**Site characteristics and regeneration studies of bani oak (*Quercus glauca* Thunberg) in Himachal Pradesh**” encompasses three experiments, which were exclusively dealt with natural regeneration, stratification and Pre-sowing seed treatments. Experiment I was conducted at Solan, Oachghat, Deothat, Narag, Chakla and Tikri forest sites of Solan, Nareg and Sarhan forest ranges (HP, India). A 20m × 20m plot for trees, 5m × 5m sub-plot for shrubs, 1m × 1m sub-sub-plot for herbs and 2m × 2m sub-plots for regeneration assessment were used. Data related to phytosociology, stand characteristics, site characteristics and natural regenerations were collected, analyzed and interpreted based on standard laboratory and statistical procedures. Experiment II had been conducted in the nursery area of Department of Silviculture and Agroforestry under open nursery and shaded growing conditions. Seven stratification media and three stratification durations were tested and factorial RBD design was used in the experiment. Data related to germination, seedling growth, nutrient content of stratification media and biochemical contents of stratified acorns were collected, analyzed and interpreted based on standard laboratory and statistical procedures. Experiment III, which was solely conducted under laboratory conditions, tested seven chemical and four physical pre-sowing treatments in combination with three acorn sizes. CRD design was applied and data related to germination and biochemical content of chemically treated acorns were collected, analyzed and interpreted based on standard laboratory and statistical procedures. Seedling growth study was conducted under shaded growing conditions. The results of these experiments are summarized as follows:

- ❖ The floristic composition of the sites showed the presence of 25 tree species, 45 shrub species and 61 herbages. Maximum number of trees (12) were recorded at site VI, while maximum number of shrubs (21) were recorded at site II and site V. Maximum number of herbaceous species (20) were recorded at site III and site VI.
- ❖ It has been found that disturbance, in the form of lopping, pollarding, and selective logging, favours growth of herbs and shrubs while it discourages growth of tree species.

- ❖ Species richness was found to be associated with tree density; thereby a tree density of 675 for trees and a tree density of 740 for shrubs and herbs were critical density levels that influenced species richness of these life forms.
- ❖ *Quercus glauca* was a dominant tree species in all the study sites, excepting site I, whereas dominance of shrubs and herbs varied from site to site.
- ❖ Based on the similarity index, maximum similarity (66.7%) for trees was observed between site IV and site V, while maximum similarity (57.9 %) for shrubs was observed between site III and site VI. Maximum similarity (41.2 %) for herbs was recorded between site II and site V.
- ❖ Shannon- Weiner diversity index showed that on average tree diversity was lower (0.65) than that of shrubs (1.08) and herbs (1.11). Shannon- Weiner species diversity was higher (1.00) at site V. Margalef's species richness index showed that maximum tree richness (2.28) was recorded at site IV, while maximum shrub (3.26) and herb (3.08) species richness was recorded at site V and site III, respectively. Simpson's species dominance index indicated that tree were more dominant (0.56) at site III. Whereas, shrubs (0.11) were more dominant at site I and site II, while herbs (0.16) were dominant at site II.
- ❖ Natural regeneration in general increases with tree density, while it decreases with increase in shrub and herb density. The number of seedlings per individual *Quercus glauca* tree was found to be higher (11.5) at site IV and the number of saplings per individual *Quercus glauca* tree was found to be higher (3.2) at site I.
- ❖ Soil pH in the study sites were found to be in the range of 4.86 to 6.44. The maximum soil pH was recorded at site III, while the minimum soil pH was recorded at site IV. The minimum (26.8 %) and maximum (39.5 %) soil moisture content, on the other hand, was recorded at site V and site IV, respectively. Site IV was found to be better in site conditions with high soil moisture (39.5 %), organic carbon content (1.46 %), available nitrogen (344.4 kg ha⁻¹) and organic matter layer (1.49 cm). The lowest soil pH (4.86) and solar influx (12.4 %) were also recorded at this site. The maximum available phosphorus (30.2 kg ha⁻¹), available potassium (231.5 kg ha⁻¹) and solar influx (22.1 %) were recorded at site III, site II and site V respectively.
- ❖ Regeneration of *Quercus glauca* increased with increase in soil moisture content, organic carbon, available nitrogen and organic matter layer, whereas, it was decreasing with increase in soil pH, available phosphorus and solar influx.

- ❖ Based on their diameter classes, site II having maximum diameter class of 30.0-39.9cm was a younger stand, while site V having maximum diameter class of 70.0-79.9 was an old growth stand. Excepting number of trees, diameter at breast height, height, crown width, crown height, basal area and volume tend to increase with increase in diameter classes. Number of trees per diameter classes was more or less normally distributed along diameter classes, whereas, basal area and volume were normally distributed at site II and site VI only.
- ❖ Lopping had been found to affect growth of *Quercus glauca* trees. Maximum number of lopped trees (525 trees ha⁻¹) and maximum loss in volume wood due to lopping (38 m³ ha⁻¹) was at site II, while maximum lopping intensity (94.6 %) was recorded at site III.
- ❖ Regeneration of *Quercus glauca* was found to have a negative but significant correlation with soil pH and solar influx, while it had a significant and positive correlation with soil moisture content and soil organic carbon. It was also found to have a significant and positive correlation with crown projection ratio of *Quercus glauca* and associated species as well as crown fullness ratio of associated species. Regeneration of associated species was also having a significant and positive correlation with density, basal area and volume of associated tree species. The regression analysis indicated that regeneration dynamics was best explained by soil moisture and solar influx with probability of more than 70%.
- ❖ Among the study sites, site I was having the highest natural regeneration per cent (229.2 %) and establishment stocking per cent (87.5 %). However, the highest natural regeneration of *Quercus glauca* (40 %) and establishment stocking (12.5 %) was recorded at site V and site VI, respectively. Maximum number of *Quercus glauca* seedlings (7917 N ha⁻¹) and saplings (1250 N ha⁻¹) were also recorded at site II and site VI, respectively. The lowest regenerations of *Quercus glauca* (11.7 %) and associated species (71.7 %) were recorded at site V, which was related to site conditions and anthropogenic effects.
- ❖ Regeneration of 22 species were recorded from all the study sites, out of which regenerations of 15 species derived from seed trees in the site and regeneration of 7 species derived from soil seed bank. Ten trees, which are present in the sites, failed to account for their regenerations.
- ❖ Stratification media was having a significant effect on germination, but not on growth characteristics of *Quercus glauca* seedlings which were grown under open nursery

conditions. Farmyard manure had the highest germination (51.8 %), while the control had the lowest (44.0 %) germination response. Stratification media didn't significantly affected germination and growth characteristics of *Quercus glauca* seedlings grown under shaded conditions. However, germination of acorns was found to be better in farm yard manure, which might be due to better moisture content and microbial activities.

- ❖ Stratification duration had significant effect on germination and growth of *Quercus glauca* seedlings under both growing conditions. Germination and seedling growth was found to be better under shaded growing conditions than open nursery conditions. Fifteen days and thirty days stratification durations had better seedling growth performance, while forty five days stratification duration had better acorn germination. In general, treatments with higher germination percent were having higher total sugar and lower starch and soluble protein contents in their acorns. The negative relation of phenol contents of acorns with germination might be due to high moisture content of nutrient rich soil media.
- ❖ Chemical pre-sowing treatments as well as seed size were having a significant effect on germination of *Quercus glauca* acorns. The highest germination of acorns was recorded for 100 ppm GA₃ pre-sowing treatment (34.3 %) and larger sized acorns (34.7 %). These treatments had also higher values for other germination parameters. Considering, the physical pre-sowing treatments, exposed embryo and smaller acorns were having higher germination per cent, which was found to be 87.7 % and 69.4 %, respectively. In general, physical pre-sowing treatments had higher performance over chemical pre-sowing treatments in all germination parameters. On the other hand, germination and seedling growth characteristics under shaded growing conditions was found to be higher in seed coat puncture treatment and larger sized acorns.

CONCLUSION

1. *Quercus glauca* attained better natural regeneration at sites where its main tree associates were *Machilus duthiei*, *Dalbergia sissoo*, *Bauhinia variegata*, *Pinus roxburghii*, *Pyrus pashia* and *Myrica esculenta*. In shrub layer its main associates were *Caryopteris wallichiana*, *Lonicera quinquelocularis*, *Myrsine africana*, *Viburnum cotinifolium* and *Deutzia staminea*. In herbs layer the major species were *Digitaria cruciata*, *Paspalum coryphaeum*, *Cymbopogon spp*, *Thalictrum foliolosum*,

Panicum virgatum and *Arundinaria falcate*. Therefore, these species should be favoured in the *Quercus glauca* bearing forests for its sustenance.

2. Natural regenerations of *Quercus glauca* was better on the sites showed higher values of Shannon-Weiner diversity index, but lower values of Margalef's species richness and Simpson's species dominance indices.
3. Natural regeneration of *Quercus glauca* was found to be positively related to moisture and organic carbon contents of the soil layer but negatively related to soil pH, lopping intensity, insect damage and solar influx.
4. Stratification of seeds in farmyard manure (FYM) for 45 days durations is recommended for better germination response.
5. The nursery seedling of *Quercus glauca* should be raised in shaded growing conditions for getting better germination response and survival initially but shade should be removed latter on for getting better quality nursery stock.
6. Larger sized acorns of *Quercus glauca* should be punctured at the base for getting better germination and quality planting stock.
7. Physical pre-sowing treatments should be preferred over chemical pre-sowing treatments.

Chapter-7

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Title of Thesis : “Site characteristics and regeneration studies of bani oak (*Quercus glauca* Thunberg) in Himachal Pradesh”
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ABSTRACT

The study was carried out at *Quercus glauca* bearing forests of Solan, Nareg and Sarhan forest ranges of Himachal Pradesh, India during the year 2013-2015. Six forest sites viz.: Solan, Oachghat, Deothal, Narag, Chakla and Tikri were non randomly selected to assess effects of phytosociology, stand characteristics and site conditions in natural regeneration of the species as well as effects of stratification media, stratification duration, acorn size and pre-sowing treatments on germination and growth characteristics *Quercus glauca* seedlings. Data collection, analysis and interpretation were conducted based on standard field, laboratory and statistical procedures.

Stand structure, species composition, site characteristics and status of natural regeneration varied a lot in the study sites. Natural regeneration of *Quercus glauca* was better at Oachghat and Narag forest sites, in which major tree associates were *Machilus duthiei*, *Dalbergia sissoo*, *Bauhinia variegata*, *Pinus roxburghii*, *Pyrus pashia* and *Myrica esculenta*. Natural regeneration of *Quercus glauca* was positively related to soil moisture content, organic carbon and organic matter layer and it was negatively related to soil pH and solar influx. In general, natural regeneration increased with increase in tree density but it decreased with increase in shrub and herb density. In the stratification trial, highest germination of acorns were recorded under farmyard manure media (51.8 %) and 45 days stratification duration (49.5%). Shaded growing conditions had been found better in germination, survival and seedling growth characteristics than open nursery conditions. Germination was higher in nutrient rich stratification media. Total sugar content was increasing, whereas, starch and soluble protein content of acorns was decreasing with increase in germination. Application of 100 ppm GA₃ treatment and exposed embryo had higher germination for chemical and physical pre-sowing treatments under laboratory conditions, respectively. Physical pre-sowing treatments had also better performance in germination than chemical pre-sowing treatments. The study concluded that maintaining tree density and plant associates that enhanced natural regeneration of *Quercus glauca* should be preserved for the sustenance of the species. The use physical pre-sowing treatments in combination of shaded growing conditions should be encouraged for artificial reproduction of the species

Signature of the Major Advisor

Signature of the Student

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APPENDIX –I

Meteorological data

Month	Rainfall(mm)	Temperature ⁰ C		Relative humidity (%)
		Maximum	Minimum	
January 2014	63.0	17.6	2.6	56
February 2014	107.8	17.3	4.1	65
March 2014	180.0	21.1	7.9	53
April 2014	57.6	26.3	10.4	52
May 2014	15.2	30.0	14.4	57
June 2014	101.8	32.6	17.8	58
July 2014	361.0	28.1	19.2	76
August 2014	83.8	28.8	18.6	72
September 2014	129.4	27.9	16.1	71
October 2014	15.7	25.7	10.3	60
November 2014	0.0	23.6	5.7	49
December 2014	75.6	19.7	2.4	58
January 2015	49.4	17.1	2.6	63
February 2015	67.0	19.6	5.7	59
March 2015	213.6	21.4	7.8	58
April 2015	71.8	25.4	11.9	58
May 2015	16.1	31.3	15.7	45

Source: Meteorological observatory, Department of Environmental Science, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan (HP)

APPENDIX –II

Effect of stratification media (M) and stratification duration (D) on germination and seedling growth of *Quercus glauca* grown under open nursery conditions (Year1)

Treatment	Germination (%)	Survival (%)	Collar diameter (cm)	Root length (cm)	Number of lateral roots	Shoot height (cm)	Root to Soot ratio	Number of leaves	Leaf area (cm ²)	Total biomass (g)
Stratification media										
M ₁	42.8 (46.2)	34.4 (32.4)	0.246	10.8	0.100	7.8	0.609	0.9	1.9	0.179
M ₂	47.2 (53.8)	27.5 (22.2)	0.280	13.4	0.033	7.4	0.450	1.7	2.4	0.328
M ₃	45.9 (51.6)	29.5 (24.9)	0.260	11.2	0.022	8.8	0.503	1.7	2.2	0.194
M ₄	45.1 (50.2)	37.7 (37.7)	0.276	11.3	0.167	8.6	0.578	1.8	2.3	0.223
M ₅	42.5 (45.8)	39.3 (41.3)	0.283	12.8	0.256	8.8	0.572	1.0	2.1	0.224
M ₆	45.1 (50.2)	39.6 (41.3)	0.288	13.1	0.433	7.7	0.712	1.4	2.3	0.253
M ₇	42.5 (45.8)	37.9 (38.5)	0.259	12.9	0.422	7.3	0.649	1.9	2.0	0.242
SE _m ±	1.58	2.95	0.01	0.89	0.10	0.73	0.07	0.31	0.24	0.04
CD _{0.05}	NS	8.47	NS	NS	0.29	NS	NS	NS	NS	NS
Stratification duration										
D ₁	41.2 (43.4)	31.9 (28.9)	0.253	12.9	0.295	7.6	0.647	1.0	2.0	0.202
D ₂	45.1 (50.1)	39.2 (40.7)	0.282	12.1	0.176	8.9	0.553	2.0	2.4	0.239
D ₃	47.1 (53.7)	34.3 (32.5)	0.276	11.6	0.143	7.6	0.546	1.6	2.1	0.263
SE _m ±	1.04	1.93	0.01	0.58	0.07	0.47	0.05	0.20	0.16	0.03
CD _{0.05}	2.97	5.54	0.02	NS	NS	NS	NS	0.58	NS	NS

Figures in parenthesis are original values. Figures outside parenthesis represent arc-sine transformed values

APPENDIX –III

Interaction effect of stratification media (M) and stratification duration (D) on germination and seedling growth of *Quercus glauca* grown under open nursery conditions (Year1)

Treatment	Number of lateral roots			Number of leaves		
	D ₁	D ₂	D ₃	D ₁	D ₂	D ₃
M ₁	0.000	0.133	0.167	0.3	1.1	1.3
M ₂	0.000	0.100	0.000	2.4	0.6	1.9
M ₃	0.000	0.000	0.067	0.7	1.9	2.6
M ₄	0.100	0.300	0.100	1.2	3.6	0.6
M ₅	0.767	0.000	0.000	0.2	2.0	0.8
M ₆	0.467	0.167	0.667	0.7	2.0	1.6
M ₇	0.733	0.533	0.000	1.1	2.4	2.2
SE _m ±		0.17			0.53	
CD _{0.05}		0.50			1.53	

APPENDIX –IV

Effect of stratification media (M) and stratification duration (D) on germination and seedling growth of *Quercus glauca* grown under open nursery conditions (Year2)

Treatment	Germination (%)	Survival (%)	Collar diameter (cm)	Root length (cm)	Number of lateral roots	Shoot height (cm)	Root to Soot ratio	Number of leaves	Leaf area (cm ⁻²)	Total biomass (g)
Stratification media										
M ₁	41.2 (43.6)	78.4 (90.9)	0.298	16.0	0.4	9.6	0.609	4.1	5.2	0.499
M ₂	44.9 (49.8)	72.7 (86.4)	0.310	14.2	0.8	9.8	0.497	4.0	5.7	0.471
M ₃	43.3 (47.1)	75.3 (86.5)	0.289	15.4	0.6	9.9	0.532	3.5	5.4	0.403
M ₄	39.3 (40.4)	70.3 (83.3)	0.303	16.2	1.1	8.8	0.620	3.9	5.1	0.474
M ₅	41.5 (44.0)	73.7 (86.5)	0.294	15.6	0.4	9.6	0.541	3.6	5.4	0.422
M ₆	43.6 (47.6)	78.3 (92.6)	0.292	16.4	0.5	9.1	0.578	3.4	5.2	0.388
M ₇	40.4 (42.2)	74.6 (89.3)	0.285	13.6	0.4	9.6	0.540	3.2	4.9	0.370
SE _m ±	1.34	5.19	0.01	0.83	0.26	0.39	0.04	0.28	0.46	0.04
CD _{0.05}	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Stratification duration										
D ₁	39.8 (41.1)	75.9 (87.3)	0.312	14.3	1.0	10.3	0.521	3.6	6.6	0.508
D ₂	44.0 (48.4)	74.6 (87.6)	0.288	14.8	0.5	9.7	0.554	3.8	4.9	0.420
D ₃	42.3 (45.3)	73.8 (88.8)	0.288	17.0	0.2	8.5	0.603	3.6	4.3	0.370
SE _m ±	0.88	3.40	0.01	0.55	0.17	0.25	0.02	0.18	0.30	0.03
CD _{0.05}	2.51	NS	0.02	1.57	0.49	0.73	NS	NS	0.86	0.08

Figures in parenthesis are original values. Figures outside parenthesis represent arc-sine transformed values

APPENDIX –V

Effect of stratification media (M) and stratification duration (D) on germination and seedling growth of *Quercus glauca* grown under shaded conditions (Year 1)

Treatment	Germination (%)	Survival (%)	Collar diameter (cm)	Root length (cm)	Number of lateral roots	Shoot height (cm)	Root to Shoot ratio	Number of leaves	Leaf area (cm ²)	Total biomass (g)
Stratification media										
M ₁	53.3 (63.6)	90.0(100.0)	0.277	9.6	0.9	11.4	0.360	2.4	5.7	0.243
M ₂	55.9 (67.1)	87.9 (98.9)	0.299	12.9	0.9	12.4	0.380	3.1	5.6	0.279
M ₃	56.2 (67.6)	90.0 (100.0)	0.282	12.5	0.9	11.4	0.354	2.5	5.5	0.277
M ₄	55.3 (67.1)	90.0 (100.0)	0.294	12.9	1.0	10.9	0.393	2.8	6.5	0.279
M ₅	54.3 (64.4)	90.0 (100.0)	0.296	12.3	0.8	10.6	0.386	2.8	5.6	0.274
M ₆	54.4 (65.3)	88.1 (99.1)	0.283	13.5	1.3	12.0	0.420	2.4	6.8	0.294
M ₇	53.9 (64.0)	90.0 (100.0)	0.286	13.3	1.4	11.1	0.383	2.7	6.0	0.272
SE _m ±	3.61	1.02	0.01	1.13	0.32	0.59	0.032	0.30	0.77	0.02
CD _{0.05}	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Stratification duration										
D ₁	53.6 (63.8)	89.1 (99.5)	0.286	13.5	1.3	11.4	0.342	2.6	7.0	0.255
D ₂	54.5 (65.5)	89.1 (99.6)	0.301	13.5	1.5	11.8	0.358	3.1	7.1	0.326
D ₃	56.1 (67.4)	90.0 (100.0)	0.277	10.4	0.2	10.9	0.448	2.3	3.8	0.241
SE _m ±	2.36	0.67	0.005	0.739	0.21	0.39	0.021	0.20	0.50	0.01
CD _{0.05}	NS	NS	0.02	2.12	0.60	NS	0.06	0.57	1.45	0.04

Figures in parenthesis are original values. Figures outside parenthesis represent arc-sine transformed values

APPENDIX –VI

Effect of stratification media (M) and stratification duration (D) on germination and seedling growth of *Quercus glauca* grown under shaded conditions (Year 2)

Treatment	Germination (%)	Survival (%)	Collar diameter (cm)	Root length (cm)	Number of lateral roots	Shoot height (cm)	Root to Shoot ratio	Number of leaves	Leaf area (cm ²)	Total biomass (g)
Stratification media										
M₁	50.0 (55.6)	72.1 (81.5)	0.250	19.1	0.111	15.1	0.288	2.3	11.1	0.245
M₂	51.9 (61.8)	79.9 (88.9)	0.258	17.3	0.000	16.6	0.237	2.4	10.5	0.240
M₃	56.8 (66.7)	84.9 (94.4)	0.255	17.9	0.037	15.4	0.504	2.1	11.1	0.275
M₄	46.9 (53.3)	83.8 (92.6)	0.261	16.2	0.111	14.6	0.328	2.1	9.6	0.341
M₅	45.5 (51.1)	73.2 (83.3)	0.249	17.3	0.056	15.6	0.263	2.5	10.8	0.257
M₆	62.5 (73.3)	69.1 (81.7)	0.248	18.0	0.296	16.5	0.265	2.4	11.4	0.271
M₇	45.7 (51.1)	86.0 (96.3)	0.267	17.8	0.056	15.5	0.251	2.1	13.5	0.279
SE_m±	4.30	6.17	0.01	1.53	0.11	0.76	0.09	0.21	1.07	0.05
CD_{0.05}	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Stratification duration										
D₁	45.3 (50.7)	85.1 (95.6)	0.270	18.7	0.103	17.3	0.237	2.4	13.6	0.308
D₂	51.8 (60.0)	74.0 (82.9)	0.248	17.6	0.167	14.1	0.385	2.4	9.8	0.246
D₃	56.9 (66.3)	76.2 (86.6)	0.248	16.7	0.016	15.4	0.294	2.0	10.0	0.264
SE_m±	2.82	4.04	0.01	1.0	0.07	0.50	0.06	0.14	0.70	0.03
CD_{0.05}	8.08	NS	0.02	NS	NS	1.43	NS	NS	2.01	NS

Figures in parenthesis are original values. Figures outside parenthesis represent arc-sine transformed values

APPENDIX –VII

Nutrient content of stratification medias (Year 1)

Stratification media	Available nitrogen (kg ha ⁻¹)	Available phosphorus (kg ha ⁻¹)	Available potassium (kg ha ⁻¹)
M ₁	173.2	25.5	149.4
M ₂	410.6	48.7	365.6
M ₃	320.6	45.2	321.3
M ₄	239.0	30.5	252.5
M ₅	222.3	28.6	231.1
M ₆	332.1	34.1	291.1
M ₇	268.3	30.6	198.9
SE _m ±	10.65	0.77	3.24
CD _{0.05}	30.56	2.21	9.30

APPENDIX –VIII

Nutrient content of stratification medias (Year 1)

Stratification media	Available nitrogen (kg ha ⁻¹)	Available phosphorus (kg ha ⁻¹)	Available potassium (kg ha ⁻¹)
M ₁	143.2	23.4	136.3
M ₂	315.6	44.4	319.2
M ₃	324.8	44.0	318.7
M ₄	276.7	38.2	211.3
M ₅	271.4	37.3	196.8
M ₆	285.0	40.0	212.3
M ₇	282.9	28.9	180.2
SE _m ±	6.10	0.65	2.84
CD _{0.05}	17.49	1.86	8.15

APPENDIX –IX

Effect of stratification media and stratification duration on biochemical content of *Quercus glauca* acorns (Year 1)

Treatment	Total sugar (%)	Total phenol (%)	Starch (%)	Soluble protein (%)
Stratification media				
M ₁	8.0	6.9	30.8	4.4
M ₂	8.9	6.1	34.9	3.6
M ₃	9.5	6.0	29.7	3.4
M ₄	8.9	6.6	34.3	3.8
M ₅	8.0	6.8	34.6	4.1
M ₆	9.1	6.4	28.3	3.9
M ₇	8.6	6.0	30.3	4.1
SE _m ±	0.14	0.11	1.92	0.07
CD _{0.05}	0.39	0.30	NS	0.21
Stratification duration				
D ₁	8.1	6.7	34.7	3.8
D ₂	8.7	6.4	32.7	3.9
D ₃	9.4	6.1	28.2	4.0
SE _m ±	0.09	0.07	1.26	0.05
CD _{0.05}	0.26	0.20	3.61	0.14

APPENDIX –X

Interaction effect of stratification media and stratification duration on biochemical content of *Quercus glauca* acorns (Year 1)

Treatment	Total sugar			Soluble protein		
	D ₁	D ₂	D ₃	D ₁	D ₂	D ₃
M ₁	7.0	8.1	9.1	4.1	4.6	4.6
M ₂	8.1	8.7	9.9	3.4	3.6	3.7
M ₃	9.4	9.4	9.6	3.4	3.2	3.5
M ₄	8.3	9.0	9.3	3.3	4.1	4.2
M ₅	7.3	8.3	8.5	4.1	4.0	4.2
M ₆	8.5	9.4	9.5	4.0	4.4	3.4
M ₇	7.9	8.2	9.6	4.2	3.8	4.2
SE _m ±		0.24			0.13	
CD _{0.05}		0.68			0.37	

APPENDIX –XI

Effect of stratification media and stratification duration on biochemical content of *Quercus glauca* acorns (Year 2)

Treatment	Total sugar (%)	Total phenol (%)	Starch (%)	Soluble protein (%)
Stratification media				
M ₁	8.1	5.4	39.8	4.2
M ₂	9.9	4.5	31.2	4.1
M ₃	10.0	4.3	32.7	4.1
M ₄	8.7	4.6	39.2	4.6
M ₅	9.0	5.1	36.4	4.4
M ₆	9.9	4.6	32.8	4.4
M ₇	9.9	4.2	37.2	4.7
SE _m ±	0.24	0.05	1.37	0.05
CD _{0.05}	0.69	0.15	3.93	0.14
Stratification duration				
D ₁	8.3	5.0	41.1	4.2
D ₂	9.3	4.7	35.2	4.4
D ₃	10.4	4.4	30.5	4.5
SE _m ±	0.16	0.04	0.90	0.03
CD _{0.05}	0.45	0.10	2.57	0.10

APPENDIX –XII

Interaction effect of stratification media and stratification duration on biochemical content of *Quercus glauca* acorns (Year 2)

Treatment	Total phenol (%)			Starch (%)			Soluble protein (%)		
	D ₁	D ₂	D ₃	D ₁	D ₂	D ₃	D ₁	D ₂	D ₃
M ₁	5.7	5.5	5.0	40.9	40.7	38.0	3.8	4.4	4.3
M ₂	4.9	4.4	4.4	34.6	31.8	27.3	4.1	4.2	4.1
M ₃	4.5	4.2	4.1	41.0	30.3	26.8	3.9	4.1	4.4
M ₄	5.1	4.5	4.1	41.0	39.1	37.3	4.6	4.7	4.7
M ₅	5.6	5.1	4.7	44.5	39.9	24.7	4.4	4.2	4.5
M ₆	4.8	4.8	4.4	43.9	27.5	26.9	4.0	4.4	4.8
M ₇	4.6	4.1	4.0	41.8	37.2	32.7	4.7	4.7	4.7
SE _m ±		0.09			2.37			0.09	
CD _{0.05}		0.26			6.81			0.25	

APPENDIX –XIII

Effect of chemical pre-sowing treatments and acorn size on germination parameters of *Quercus galuca* acorns (Year 1)

Treatment	Germination per cent				Germination capacity				Germination energy				Germination value				Germination index			
	S ₁	S ₂	S ₃	Mean T	S ₁	S ₂	S ₃	Mean T	S ₁	S ₂	S ₃	Mean T	S ₁	S ₂	S ₃	Mean T	S ₁	S ₂	S ₃	Mean T
T₁	31.1 (26.7)	27.5 (21.3)	26.5 (20.0)	28.3 (22.7)	65.4 (82.7)	63.5 (80.0)	63.4 (80.0)	64.1 (80.9)	31.1 (26.7)	22.5 (14.7)	24.6 (17.3)	26.0 (19.6)	0.067	0.043	0.037	0.049	0.23	0.14	0.123	0.164
T₂	31.1 (26.7)	31.9 (28.0)	30.2 (25.3)	31.1 (26.7)	63.5 (80.0)	66.5 (84.0)	62.6 (78.7)	64.2 (80.9)	27.5 (21.3)	28.4 (22.7)	29.3 (24.0)	28.4 (22.7)	0.057	0.067	0.047	0.057	0.223	0.19	0.15	0.188
T₃	31.1 (26.7)	28.4 (22.7)	30.2 (25.3)	29.9 (24.9)	63.4 (80.0)	50.1 (58.7)	65.0 (81.3)	59.5 (73.3)	29.3 (24.0)	27.5 (21.3)	28.4 (22.7)	28.4 (22.7)	0.053	0.033	0.053	0.047	0.19	0.167	0.14	0.166
T₄	27.5 (21.3)	30.2 (25.3)	29.3 (24.0)	29.0 (23.6)	65.5 (82.7)	65.4 (82.7)	63.5 (80.0)	64.8 (81.8)	24.6 (17.3)	27.4 (21.3)	26.5 (20.0)	26.2 (19.6)	0.043	0.053	0.053	0.05	0.17	0.17	0.177	0.172
T₅	28.4 (22.7)	27.4 (21.3)	30.1 (25.3)	28.6 (23.1)	44.6 (49.3)	55.6 (68.0)	58.9 (73.3)	53.0 (63.6)	23.6 (16.0)	26.5 (20.0)	26.4 (20.0)	25.5 (18.7)	0.047	0.04	0.053	0.047	0.19	0.153	0.143	0.162
T₆	29.3 (24.0)	31.9 (28.0)	32.8 (29.3)	31.3 (27.1)	70.4 (88.0)	68.6 (86.7)	65.5 (82.7)	68.2 (85.8)	26.5 (20.0)	28.4 (22.7)	30.1 (25.3)	28.3 (22.7)	0.05	0.07	0.063	0.061	0.193	0.177	0.197	0.189
T₇	31.1 (26.7)	31.8 (28.0)	32.8 (29.3)	31.9 (28.0)	78.4 (96.0)	71.8 (89.3)	76.6 (92.0)	75.6 (92.4)	27.5 (21.3)	29.3 (24.0)	28.3 (22.7)	28.4 (22.7)	0.067	0.067	0.073	0.069	0.203	0.223	0.207	0.211
Mean S	29.9 (25.0)	29.9 (25.0)	30.3 (25.5)		64.5 (79.8)	63.1 (78.5)	65.1 (81.1)		27.1 (21.0)	27.1 (21.0)	27.7 (21.7)		0.055	0.053	0.054		0.2	0.174	0.162	
SE_m± (T)				0.77				1.64				0.8				0.01				0.01
CD_{0.05} (T)				2.21				4.7				2.28				NS				0.03
SE_m± (S)				0.51				1.07				0.52				0.01				0.01
CD_{0.05}(S)				NS				NS				NS				NS				0.02
SE_m± (T x S)				1.34				2.84				1.38				0.01				0.02
CD_{0.05}(T x S)				NS				8.14				3.96				NS				NS

Figures in parenthesis are original values. Figures outside parenthesis represent arc-sine transformed values

APPENDIX –XIV

Effect of chemical pre-sowing treatments and acorn size on germination parameters of *Quercus galuca* acorns (Year 2)

Treatment	Germination per cent				Germination capacity				Germination energy				Germination value				Germination index			
	S ₁	S ₂	S ₃	Mean T	S ₁	S ₂	S ₃	Mean T	S ₁	S ₂	S ₃	Mean T	S ₁	S ₂	S ₃	Mean T	S ₁	S ₂	S ₃	Mean T
T ₁	35.2 (33.3)	24.4 (17.3)	23.5 (16.0)	27.7 (22.2)	64.6 (81.3)	60.9 (76.0)	50.3 (58.7)	58.6 (72.0)	27.4 (21.3)	24.4 (17.3)	22.2 (14.7)	24.7 (17.8)	0.087	0.027	0.03	0.048	0.243	0.127	0.1	0.157
T ₂	29.3 (24.0)	25.4 (18.7)	35.9 (34.7)	30.2 (25.8)	73.4 (88.0)	40.0 (41.3)	73.9 (92.0)	62.4 (73.8)	25.4 (18.7)	22.5 (14.7)	27.2 (21.3)	25.0 (18.2)	0.05	0.033	0.1	0.061	0.143	0.107	0.253	0.168
T ₃	26.3 (20.0)	39.2 (40.0)	34.4 (32.0)	33.3 (30.7)	67.5 (84.0)	77.7 (93.3)	72.3 (90.7)	72.5 (89.3)	25.4 (18.7)	31.9 (28.0)	31.1 (26.7)	29.4 (24.4)	0.037	0.123	0.07	0.077	0.127	0.26	0.217	0.201
T ₄	32.8 (29.3)	26.5 (20.0)	39.1 (40.0)	32.8 (29.8)	66.4 (84.0)	66.5 (84.0)	65.5 (81.3)	66.1 (83.1)	27.5 (21.3)	24.5 (17.3)	35.9 (34.7)	29.3 (24.4)	0.063	0.037	0.107	0.069	0.19	0.127	0.283	0.2
T ₅	27.4 (21.3)	26.5 (20.0)	50.7 (60.0)	34.9 (33.8)	63.4 (78.7)	58.9 (73.3)	74.7 (89.3)	65.7 (80.4)	25.5 (18.7)	25.5 (18.7)	32.1 (29.3)	27.7 (22.2)	0.04	0.043	0.2	0.094	0.13	0.12	0.477	0.242
T ₆	24.4 (17.3)	32.8 (29.3)	46.1 (52.0)	34.4 (32.9)	59.9 (66.7)	68.8 (86.7)	62.6 (78.7)	63.8 (77.3)	24.4 (17.3)	30.2 (25.3)	36.7 (36.0)	30.4 (26.2)	0.037	0.087	0.16	0.094	0.11	0.163	0.36	0.211
T ₇	34.0 (32.0)	33.4 (30.7)	42.3 (45.3)	36.6 (36.0)	60.0 (74.7)	54.7 (66.7)	61.8 (77.3)	58.8 (72.9)	22.5 (14.7)	29.1 (24.0)	32.6 (29.3)	28.1 (22.7)	0.097	0.08	0.12	0.099	0.223	0.167	0.283	0.224
Mean S	29.9 (25.3)	29.7 (25.1)	38.9 (40.0)		65.0 (79.6)	61.1 (74.5)	65.8 (81.1)		25.4 (18.7)	26.9 (20.8)	31.1 (27.4)		0.059	0.061	0.112		0.167	0.153	0.282	
SE _m ± (T)				1.59				3.51				1.59				0.01				0.02
CD _{0.05} (T)				4.54				NS				NS				0.03				NS
SE _m ± (S)				1.04				2.3				1.04				0.01				0.01
CD _{0.05} (S)				2.97				NS				2.97				0.02				0.04
SE _m ± (T x S)				2.75				6.08				2.75				0.02				0.04
CD _{0.05} (T x S)				7.87				17.41				NS				0.06				0.10

Figures in parenthesis are original values. Figures outside parenthesis represent arc-sine transformed values

APPENDIX –XV

Effect of physical pre-sowing treatments and acorn size on germination parameters of *Quercus galuca* acorns (Year 1)

Treatment	Germination per cent				Germination capacity				Germination energy				Germination value				Germination index			
	S ₁	S ₂	S ₃	Mean T	S ₁	S ₂	S ₃	Mean T	S ₁	S ₂	S ₃	Mean T	S ₁	S ₂	S ₃	Mean T	S ₁	S ₂	S ₃	Mean T
T ₁	90.0 (100.0)	90.0 (100.0)	84.4 (97.3)	88.0 (99.1)	90.0 (100.0)	90.0 (100.0)	86.1 (98.7)	88.6 (99.6)	55.1 (66.7)	65.6(8 2.7)	59.4(7 3.3)	60.0(7 4.2)	0.37	0.37	0.324	0.355	1.004	0.989	0.842	0.945
T ₂	76.8 (94.7)	68.8 (86.7)	65.9 (82.7)	70.5 (88.0)	78.4 (96.0)	76.8 (94.7)	86.1 (98.7)	80.4 (96.4)	58.9 (73.3)	56.6 (69.3)	54.1 (65.3)	56.5 (69.3)	0.421	0.289	0.276	0.329	1	0.975	0.871	0.949
T ₃	73.9 (92.0)	57.2 (70.7)	62.5 (78.7)	64.5 (80.4)	82.3 (97.3)	76.8 (94.7)	75.2 (93.3)	78.1 (95.1)	60.0 (74.7)	49.2 (57.3)	52.4 (62.7)	53.8 (64.9)	0.307	0.21	0.264	0.26	0.69	0.526	0.748	0.655
T ₄	40.0 (41.3)	38.4 (38.7)	40.0 (41.3)	39.4 (40.4)	67.6 (85.3)	84.5 (97.3)	71.0 (89.3)	74.3 (90.7)	33.6 (30.7)	32.7 (29.3)	33.5 (30.7)	33.3 (30.2)	0.11	0.086	0.092	0.096	0.256	0.25	0.248	0.251
Mean S	70.1 (82.0)	63.5 (74.0)	63.2 (75.0)		79.6 (94.7)	82.0 (96.7)	79.6 (95.0)		51.9 (61.3)	51.0 (59.7)	49.8 (58.0)		0.302	0.239	0.239		0.738	0.685	0.677	
SE _m ± (T)				1.43				1.56				1.9				0.02				0.02
CD _{0.05} (T)				4.2				4.58				5.58				0.04				0.07
SE _m ± (S)				1.24				1.35				1.65				0.01				0.02
CD _{0.05} (S)				3.64				NS				NS				0.04				NS
SE _m ± (T x S)				2.48				2.7				3.29				0.03				0.04
CD _{0.05} (T x S)				7.28				7.94				NS				NS				0.12

Figures in parenthesis are original values. Figures outside parenthesis represent arc-sine transformed values

APPENDIX –XVI

Effect of physical pre-sowing treatments and acorn size on germination parameters of *Quercus galuca* acorns (Year 2)

Treatment	Germination per cent				Germination capacity				Germination energy				Germination value				Germination index			
	S ₁	S ₂	S ₃	Mean T	S ₁	S ₂	S ₃	Mean T	S ₁	S ₂	S ₃	Mean T	S ₁	S ₂	S ₃	Mean T	S ₁	S ₂	S ₃	Mean T
T ₁	90.0 (100.0)	86.0 (98.7)	90.0 (100.0)	88.5 (99.6)	90.0 (100.0)	86.1 (98.7)	90.0 (100.0)	88.6 (99.6)	71.5 (89.3)	68.9 (86.7)	64.6 (81.3)	68.3 (85.8)	0.367	0.4	0.367	0.378	1.377	1.23	1.4	1.336
T ₂	73.9 (92.0)	62.6 (78.7)	65.6 (82.7)	67.4 (84.4)	84.5 (97.3)	82.3 (97.3)	86.1 (98.7)	84.3 (97.8)	57.2 (70.7)	57.2 (70.7)	51.5 (61.3)	55.3 (67.6)	0.343	0.237	0.273	0.284	1.223	1.007	0.927	1.052
T ₃	69.9 (88.0)	62.5 (78.7)	60.7 (76.0)	64.4 (80.9)	76.8 (94.7)	75.2 (93.3)	84.5 (97.3)	78.8 (95.1)	60.8 (76.0)	54.9 (66.7)	49.2 (57.3)	55.0 (66.7)	0.323	0.207	0.253	0.261	0.733	0.597	0.55	0.627
T ₄	41.5 (44.0)	42.3 (45.3)	41.5 (44.0)	41.8 (44.4)	76.8 (94.7)	69.6 (86.7)	73.9 (92.0)	73.4 (91.1)	34.3 (32.0)	38.4 (38.7)	31.8 (28.0)	34.9 (32.9)	0.1	0.103	0.1	0.101	0.317	0.293	0.263	0.291
Mean S	68.8 (81.0)	63.3 (75.3)	64.4 (75.7)		82.0 (96.7)	78.3 (94.0)	83.6 (97.0)		56.0 (67.0)	54.8 (65.7)	49.3 (57.0)		0.283	0.237	0.248		0.913	0.782	0.785	
SE _m ± (T)				1.14				2				1.42				0.02				0.06
CD _{0.05} (T)				3.36				5.88				4.16				0.05				0.16
SE _m ± (S)				0.99				1.73				1.23				0.02				0.05
CD _{0.05} (S)				2.91				NS				3.6				NS				NS
SE _m ± (T x S)				1.98				3.47				2.45				0.03				0.1
CD _{0.05} (T x S)				5.82				NS				NS				NS				NS

Figures in parenthesis are original values. Figures outside parenthesis represent arc-sine transformed values

APPENDIX –XVII

Effects of physical pre-sowing seed treatments and acorn size on germinability and seedling growth characteristics of *Quercus galuca* under shaded growing condition (Year 1)

Treatment	Germination (%)	Survival (%)	Collar diameter (cm)	Root length (cm)	Number of lateral roots	Shoot height (cm)	Root to Soot ratio	Number of leaves	Leaf area (cm²)	Total biomass (g)
Physical pre-sowing treatment										
T₁	68.8 (86.2)	66.0 (82.7)	0.320	15.1	0.181	11.2	0.562	4.0	14.8	0.522
T₂	58.2 (71.6)	81.0 (93.0)	0.306	15.5	0.222	11.0	0.583	4.7	13.7	0.523
T₃	76.5 (92.9)	82.7 (97.1)	0.351	15.6	0.722	11.0	0.558	3.9	16.2	0.460
T₄	33.0 (30.2)	85.8 (97.8)	0.337	15.2	0.000	9.7	0.650	3.6	13.2	0.498
SE_m±	2.385	2.015	0.015	1.209	0.126	0.582	0.038	0.369	1.088	0.051
CD_{0.05}	7.041	5.947	NS	NS	0.372	NS	NS	NS	NS	NS
Seed size										
S₁	56.1 (66.3)	75.2 (88.7)	0.287	13.8	0.167	9.1	0.455	3.3	10.9	0.286
S₂	59.8 (72.7)	81.3 (94.4)	0.334	15.7	0.292	11.2	0.619	4.2	14.9	0.516
S₃	61.5 (71.7)	80.1 (94.8)	0.364	16.6	0.386	11.9	0.691	4.6	17.7	0.701
SE_m±	2.066	1.745	0.013	1.047	0.109	0.504	0.033	0.319	0.942	0.044
CD_{0.05}	NS	NS	0.038	NS	NS	1.487	0.096	0.942	2.782	0.130

Figures in parenthesis are original values. Figures outside parenthesis represent arc-sine transformed values

APPENDIX –XVIII

Interaction effects of physical pre-sowing seed treatments and acorn size on germinability and seedling growth characteristics of *Quercus galuca* under shaded growing condition (Year 1)

Treatment	Survival (%)			Number of lateral roots		
	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃
T ₁	61.8 (77.5)	65.8 (82.8)	70.4 (88.0)	0.0	0.0	0.5
T ₂	63.3 (78.9)	90.0 (100.0)	90.0 (100.0)	0.0	0.0	0.7
T ₃	85.9 (98.6)	86.0 (98.6)	76.2 (94.2)	0.7	1.2	0.3
T ₄	90.0 (100.0)	83.4 (96.3)	84.1 (97.0)	0.0	0.0	0.0
SE _m ±	3.490			0.218		
CD _{0.05}	10.301			0.645		

Figures in parenthesis are original values. Figures outside parenthesis represent arc-sine transformed values

APPENDIX –XIX

Effects of physical pre-sowing seed treatments and acorn size on germinability and seedling growth characteristics of *Quercus galuca* under shaded growing condition (Year 2)

Treatment	Germination (%)	Survival (%)	Collar diameter (cm)	Root length (cm)	Number of lateral roots	Shoot height (cm)	Root to Shoot ratio	Number of leaves	Leaf area (cm ²)	Total biomass (g)
Physical pre-sowing treatment										
T ₁	57.8 (68.4)	87.1 (97.9)	0.291	18.8	0.794	14.8	0.359	4.2	14.3	0.694
T ₂	58.8 (70.0)	80.0 (91.7)	0.333	18.7	0.676	14.8	0.352	4.9	12.0	0.661
T ₃	66.4 (79.6)	67.1 (80.6)	0.338	17.9	0.740	15.1	0.382	4.4	13.1	0.678
T ₄	44.6 (49.3)	72.0 (89.2)	0.288	18.0	0.808	14.8	0.302	4.1	14.3	0.657
SE _m ±	4.091	3.989	0.008	0.614	0.190	0.432	0.027	0.174	0.401	0.039
CD _{0.05}	12.077	11.775	0.024	NS	NS	NS	NS	0.513	1.184	NS
Seed size										
S ₁	51.4 (60.8)	69.3 (83.2)	0.278	17.7	0.694	11.6	0.352	4.0	10.0	0.448
S ₂	56.4 (64.7)	79.1 (93.0)	0.330	19.5	0.888	16.0	0.352	4.9	13.6	0.747
S ₃	62.9 (75.0)	81.3 (93.4)	0.329	17.9	0.682	17.1	0.343	4.3	16.7	0.822
SE _m ±	3.543	3.454	0.007	0.531	0.165	0.374	0.024	0.151	0.347	0.034
CD _{0.05}	NS	10.197	0.021	NS	NS	1.103	NS	0.445	1.026	0.101

Figures in parenthesis are original values. Figures outside parenthesis represent arc-sine transformed values

APPENDIX –XX

Interaction effects of physical pre-sowing seed treatments and acorn size on germinability and seedling growth characteristics of *Quercus galuca* under shaded growing condition (Year 2)

Treatment	Collar diameter (cm)			Root length (cm)		
	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃
T ₁	0.247	0.323	0.303	19.2	19.4	18.0
T ₂	0.303	0.347	0.350	18.7	19.3	18.1
T ₃	0.287	0.337	0.390	14.1	19.8	19.7
T ₄	0.277	0.313	0.273	18.9	19.5	15.7
SE _m ±		0.014			1.063	
CD _{0.05}		0.042			3.137	

APPENDIX –XXI

Effect of chemical pre-sowing treatments and acorn size on biochemical content of *Quercus galuca* acorns (Year 1)

Treatment	Moisture content (%)	Total sugar (%)	Total phenol (%)	Starch (%)	Soluble protein (%)
Chemical pre-sowing treatment					
T ₁	29.6	9.2	4.8	36.8	4.1
T ₂	45.3	8.6	4.3	36.5	4.5
T ₃	45.0	8.6	2.6	35.7	4.6
T ₄	41.5	8.5	6.2	38.0	3.7
T ₅	36.8	9.1	8.3	36.0	3.8
T ₆	43.4	9.0	3.7	36.5	4.2
T ₇	43.1	9.5	3.7	36.8	4.3
SE _m ±	1.18	0.14	0.11	0.34	0.33
CD _{0.05}	3.39	0.41	0.31	0.97	NS
Seed size					
S ₁	38.5	8.2	4.5	36.2	4.1
S ₂	41.3	9.3	4.7	36.5	4.1
S ₃	42.2	9.4	5.2	37.2	4.3
SE _m ±	0.78	0.09	0.07	0.22	0.22
CD _{0.05}	2.22	0.27	0.20	0.63	NS

APPENDIX –XXII

Interaction effect of chemical pre-sowing treatments and acorn size on biochemical content of *Quercus galuca* acorns (Year 1)

Treatment	Total sugar			Total phenol		
	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃
T ₁	9.1	11.0	7.5	4.8	4.8	4.9
T ₂	7.9	8.4	9.7	4.5	3.7	4.8
T ₃	8.2	9.0	8.7	2.3	2.7	3.0
T ₄	8.4	8.5	8.7	5.7	6.2	6.6
T ₅	7.9	8.4	11.1	7.8	8.4	8.7
T ₆	8.1	8.6	10.3	2.9	3.7	4.7
T ₇	7.6	11.1	9.9	3.7	3.4	3.8
SE _m ±		0.25			0.19	
CD _{0.05}		0.70			0.54	

APPENDIX –XXIII

Effect of chemical pre-sowing treatments and acorn size on biochemical content of *Quercus galuca* acorns (Year 2)

Treatment	Moisture content (%)	Total sugar (%)	Total phenol (%)	Starch (%)	Soluble protein (%)
Chemical pre-sowing treatment					
T ₁	30.8	9.8	7.3	36.9	5.8
T ₂	45.1	10.6	5.0	37.0	5.3
T ₃	45.2	10.7	4.3	37.8	5.1
T ₄	39.4	10.8	4.5	35.6	5.5
T ₅	39.5	10.4	3.4	37.2	5.5
T ₆	44.8	10.6	6.1	36.6	4.9
T ₇	44.2	10.3	6.4	36.2	4.5
SE _m ±	0.69	0.14	0.07	0.38	0.06
CD _{0.05}	1.98	0.39	0.19	1.09	0.17
Seed size					
S ₁	38.7	10.3	5.3	35.6	4.9
S ₂	42.0	9.9	5.2	37.0	5.3
S ₃	43.1	11.2	5.3	37.7	5.5
SE _m ±	0.45	0.09	0.04	0.25	0.04
CD _{0.05}	1.30	0.26	NS	0.72	0.11

APPENDIX –XXIV

Interaction effect of chemical pre-sowing treatments and acorn size on biochemical content of *Quercus galuca* acorns (Year 2)

Treatment	Moisture content			Total sugar			Total phenol			Soluble protein		
	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃	S ₁	S ₂	S ₃
T₁	30.2	31.1	31.2	9.4	10.9	9.1	7.2	7.4	7.2	5.3	5.4	6.7
T₂	43.4	45.5	46.4	10.5	9.6	11.7	5.2	4.9	4.9	5.4	5.6	5.0
T₃	44.5	45.0	46.0	11.2	9.0	11.8	4.3	4.0	4.5	4.6	5.4	5.3
T₄	35.1	40.1	43.0	11.3	9.4	11.8	4.6	4.5	4.5	5.4	5.3	5.6
T₅	33.4	43.1	42.0	9.7	9.8	11.7	3.3	3.6	3.4	5.3	5.8	5.3
T₆	43.1	44.5	46.9	10.8	9.5	11.6	6.1	5.9	6.3	3.9	4.8	5.9
T₇	41.3	45.0	46.3	9.0	10.9	10.9	6.6	6.4	6.2	4.5	4.6	4.4
SE_m±		1.20			0.24			0.11			0.11	
CD_{0.05}		3.43			0.68			0.33			0.30	

APPENDIX –XXV

Mean comparison of germination and seedling growth parameters for stratification durations by Tukey's Honestly Significant Difference test

Stratification duration	Germination percent	Survival per cent	Collar diameter (cm)	Root length (cm)	Number of lateral roots	Shoot height (cm)	Root-shoot ratio	Number of leaves	Leaf area (cm ²)	Total biomass (g)
15	49.7 ^b	77.9	0.29	14.9	0.71 ^a	11.7 ^a	0.43	2.4 ^b	7.3 ^a	0.31
30	56.0 ^a	77.7	0.29	14.5	0.62 ^a	11.2 ^{ab}	0.46	2.8 ^a	6.1 ^b	0.31
45	58.2 ^a	77.0	0.28	13.9	0.17 ^b	10.6 ^b	0.47	2.4 ^b	5.1 ^c	0.28
HSD_{0.05}	0.00	0.91	0.34	0.17	0.00	0.01	0.54	0.00	0.00	0.35
SE_m±	1.97	2.1	0.01	0.53	0.10	0.31	0.03	0.13	0.36	0.02

Figures with the same symbol are not significantly different

APPENDIX –XXVI

Mean square analyses of germination and growth parameters for different growing conditions, stratification media, stratification durations and their interactions

Source	<i>df</i>	Germination %	Survival %	Collar diameter	Root length	No. lateral roots	Shoot height	Root- Shoot ratio	Leaf number	Leaf area	Total biomass
Growing condition (G)	1	7344.8**	34463.4**	0.00**	51.3**	0.9*	709.0**	1.6**	0.32	731.2**	0.11**
Stratification media (M)	6	240.1*	87.0	0.00	3.3	0.3	1.6	0.02	0.35	1.3	0.01
Stratification duration (D)	2	803.3**	9.7	0.00	9.5	3.4**	11.1**	0.01	2.56**	54.1**	0.01
G x M	6	36.7	194.8	0.00	1.6	0.08	3.3	0.03	0.25	2.9	0.01
G x D	2	38.9	400.7*	0.00	33.8**	0.95*	9.0*	0.04	1.14*	14.3**	0.00
M X D	12	146.8	108.7	0.00	2.6	0.26	2.1	0.03*	0.63*	2.8	0.01
G x M x D	12	143.2	59.5	0.00	2.7	0.38	2.0	0.01	0.30	3.8	0.01
Error	84	81.2	94.3	0.00	5.8	0.20	2.1	0.02	0.32	2.7	0.01
Mean		54.7	77.5	0.28	14.4	0.5	11.1	0.5	2.5	6.1	0.3
Standard deviation		13.0	19.4	0.02	2.4	0.5	2.8	0.2	0.6	3.1	0.1
SE _m ±		1.2	1.7	0.0	0.2	0.0	0.3	0.0	0.1	0.3	0.0

* Significant at the 0.05 level (2-tailed)

** Significant at the 0.01 level (2-tailed)

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