CHAPTER 7

SUMMARY
APTI is an empirical relation which evaluates the tolerance level of plant species towards air pollution by considering leaf biochemical parameters such as total chlorophyll content (T), ascorbic acid content (A), leaf extract pH, and relative water content (RWC). It has been used in studies like green belt development, traffic noise reduction and pollution mitigation along roadsides and around industries. It is a method to screen out the tolerant species from the sensitive ones. The information generated under the proposed study will be helpful in preparing plans for future plantations along such highways. The objective of this research is to contribute to vital suggestions which can be incorporated into a well planned green belt design along the National Highway 5. The suggested tolerant plant species can be grown along the highway to act as a filter for air pollutants emanating from increased traffic flow to the state and the sensitive plant species can be used as biomonitors. This study is also important because no extensive research has been carried out in temperate zones of the country and not much literature is available on the impact of altitude on APTI.

The present investigation entitled “Air Pollution tolerance of temperate woody vegetation growing along the National Highway - No. 5 from Solan to Shimla, Himachal Pradesh” was conducted at Himalayan Forest Research Institute, Panthaghati (Shimla) and Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni (Solan) during 2013–2015.

The study was conducted along the stretch of National Highway 5 from Solan, the Mushroom city of India to the capital of Himachal Pradesh (Shimla) covering various small towns and villages in a span of 45 kilometres. The entire highway was divided into three sections based on altitude and the study was conducted mainly during three seasons (winter, summer and monsoon); however spring season was also considered in some species. Six main species selected for the investigation include: Quercus leucotrichophora, Rubus ellipticus, Hypericum oblongifolium, Debregeasia saeneb, Punica granatum and Grevillea robusta. Three horizontal distances were considered: 0-5 m, 5-10 m and >100 m (control). Factorial ANOVA was performed to know the effect of species and its interaction with other factors such as altitude, distance and season on different plant biochemical (RWC, T, A and pH) parameters as well as physical factors like leaf dust accumulation. An ethnobotanical survey was also undertaken to enlist various uses of the commonly
occurring species. The species with maximum uses was *Punica granatum*. The study indicated that the commonly growing species are still used by the local communities residing along this stretch of highway; though with problems like rapid development and climate change, certain species have become vulnerable as their distribution pattern is adversely affected. The rural communities still use medicinal herbs for the treatment of common health problems and there is an urgent need of detailed investigation and documentation of indigenous knowledge which has been an integral part of lives of such people and has been verbally passed from one generation to another. Moreover conservation and cultivation of medicinal plants can help the villagers to earn their livelihood to some extent.

The effect of species as well as its interactions (2-way, 3-way and 4-way) with other three factors *viz.*, altitude (3 levels), distance (3 levels) and season (3 and 4 levels) was studied. For three species (*Quercus leucotrichophora*, *Rubus ellipticus* and *Debregeasia saeneb*), data (four biochemical parameters, APTI and dust accumulation) were collected for all the four seasons. In these cases the total number of treatment combinations was 108 for each parameter. For all the six species, data regarding the four biochemical parameters and APTI were collected in three seasons (without considering spring season) and in that case the total number of treatment combinations was 162 for each parameter. The data recorded were analyzed by ANOVA (factorial). Wherever the treatment effects were found significant (significant F-value), Bonferroni multiple comparison test was carried out to know which treatment (main effects/interactions) were significant among themselves.

### 7.1. RELATIVE WATER CONTENT (RWC)

Relative water content was found to vary significantly with different species. Maximum RWC was observed for *Hypericum oblongifolium* (83.27%), followed by *Debregeasia saeneb* (82.57%), *Punica granatum* (80.31%), *Grevillea robusta* (76.67%), *Rubus ellipticus* (66.15%) and *Quercus leucotrichophora* (65.33%). Highest RWC was recorded during monsoon season in five species, thus indicating that RWC is influenced by the seasons; however, there was no significant effect of altitude on the RWC content; however *Hypericum oblongifolium* registered maximum RWC (85.32%) in the altitudinal section 1, while the minimum value
was observed in *Rubus ellipticus* (63.76%) in altitudinal section 3. Distance from the highway also had a significant effect on RWC content. At >100 m distance, RWC was observed to be highest in all the species except *Rubus ellipticus* and *Grevillea robusta*. For *Grevillea robusta*, significant difference was observed in RWC of species growing at distance 0-5 m and 5-10 m when compared with RWC of species present at >100 m distance from the highway. Since *Rubus ellipticus* and *Grevillea robusta* were able to maintain high RWC content at sites which were close to the highway, they behaved as tolerant species, while the other species behaved as sensitive ones. *Hypericum oblongifolium* registered maximum RWC (84.83%) at >100 m distance, while minimum RWC was observed for *Quercus leucotrichophora* (64.79%) at 0-5 m distance. The species × distance × season interaction was also found to significantly affect RWC. Maximum RWC was recorded for *Debregeasia saeneb* (87.11%) at >100 m distance in summer season, while minimum RWC was observed for *Quercus leucotrichophora* (62.39%) at >100 m distance from the highway in summer season. RWC was found to be highest during monsoon season in all the species studied, irrespective of distance from highway. The species × distance × altitude and species × altitude × season interactions had no significant effect on RWC.

Upon considering the spring season, it was noticed that species had a significant effect on RWC at p<0.05 and it was observed that for *Quercus leucotrichophora* and *Rubus ellipticus*, the RWC values were not significantly different. Maximum RWC was observed for *Debregeasia saeneb* (81.68%) followed by *Rubus ellipticus* (67.18%) and *Quercus leucotrichophora* (66.42%). The seasonal variation in RWC of species growing was analyzed and it was observed that the interaction of species × season also had a significant effect on RWC. *Debregeasia saeneb* registered maximum RWC (85.23%) during summer season, while minimum RWC was observed for *Quercus leucotrichophora* (63.55%) during summer season. The species × distance, species × altitude, species × distance × season, species × altitude × season and species × distance × altitude interactions did not have a significant effect on RWC.

7.2. TOTAL CHLOROPHYLL CONTENT (T)
The present study showed that the total chlorophyll content varied significantly in all species (p<0.05). The highest concentration was observed for *Rubus ellipticus* (2.85 mg/g), followed by *Quercus leucotrichophora* (2.64 mg/g), *Punica granatum* (2.39 mg/g), *Grevillea robusta* (2.15 mg/g), *Debregeasia saeneb* (2.13 mg/g) and *Hypericum oblongifolium* (2.00 mg/g). During different seasons, the values were noticed to be significantly different in all the species (p<0.05). Highest total chlorophyll content was observed for *Quercus leucotrichophora* (3.01 mg/g) during monsoon season, while the lowest concentration was observed for *Hypericum oblongifolium* (1.76 mg/g) during summer season. Total chlorophyll content was not influenced significantly by altitude; however the highest concentration was observed for *Rubus ellipticus* (3.04 mg/g) in the altitudinal section 1 and the lowest concentration was recorded for *Hypericum oblongifolium* (1.86 mg/g) in the altitudinal section 3. The chlorophyll concentration was significantly affected by distance from the highway. With an increase in distance from the highway, its concentration was found to increase for *Quercus leucotrichophora*, *Debregeasia saeneb*, *Punica granatum* and *Hypericum oblongifolium*, while it was found to follow a reverse trend for *Grevillea robusta*. There was an increase in the concentration of total chlorophyll content with increasing proximity to the highway in *Grevillea robusta*. Thus, it can be regarded as a tolerant plant species with respect to this parameter. From the analysis of distance-wise seasonal variation of species growing along the National Highway 5, it was observed that the interaction of species × distance × season had a significant effect on total chlorophyll content. *Rubus ellipticus* registered highest total chlorophyll content (3.23 mg/g) at the distance 0-5 m in monsoon season, while the least value was recorded for *Hypericum oblongifolium* (1.72 mg/g) at the distance >100 m from the highway in summer season. The species × distance × altitude and species × altitude × season did not have any significant effect on the concentration.

When the spring season was considered, total chlorophyll content was found to be significantly different in all the three species. *Rubus ellipticus* registered the highest value (2.96 mg/g), followed by *Quercus leucotrichophora* (2.71 mg/g) and *Debregeasia saeneb* (2.08 mg/g). Total chlorophyll content was observed to vary significantly at different species × season interactions; however, it did not significantly vary in different seasons in *Debregeasia saeneb*. The highest
concentration was observed for *Rubus ellipticus* (3.27 mg/g) during spring season, while the least concentration was recorded for *Debregeasia saeneb* (1.94 mg/g) during spring season. Species × altitude interaction had a significant effect on total chlorophyll content. For *Quercus leucotrichophora*, the altitude effect was non-significant. The concentration was found to decrease with the increase in altitude in case of all the three species. The highest value was observed for *Rubus ellipticus* (3.17 mg/g) in the altitudinal section 1, while least value was observed for *Debregeasia saeneb* (1.90 mg/g) in the altitudinal section 3. The species × distance interaction did not have any significant effect on total chlorophyll content. The species × distance × season interaction had a significant effect on total chlorophyll content. Highest total chlorophyll content was observed for *Rubus ellipticus* (3.48 mg/g) at >100 m distance in spring season, while the least concentration was recorded for *Debregeasia saeneb* (1.82 mg/g) at >100 m distance from the highway in spring season. The species × altitude × distance interaction effects were non-significant.

7.3. LEAF EXTRACT pH

Leaf extract pH was found to vary significantly with different species (p<0.05). Highest pH value was observed in *Debregeasia saeneb* (7.77), followed by *Quercus leucotrichophora* (5.84), *Grevillea robusta* (5.80), *Rubus ellipticus* (5.62) and *Punica granatum* (5.35); while the lowest pH was recorded for *Hypericum oblongifolium* (4.45). Since *Debregeasia saeneb* exhibited pH in the alkaline range, it can be considered the most tolerant plant species, while leaf extract pH of *Hypericum oblongifolium* was observed to be most acidic among all the species studied and thus was the most sensitive plant species with respect to this parameter. Leaf extract pH did not vary significantly in different seasons in all the six species; however, highest pH was recorded for *Debregeasia saeneb* (8.32) during winter season, while the lowest was observed for *Hypericum oblongifolium* (4.43) during winter season. Leaf extract pH was found to be non-significant for species × altitude interactions. The species × distance interaction also had no significant effect on pH. The three way interactions viz. species × distance × altitude, species × distance × season and species × altitude × season also had no significant effect on leaf extract pH.
Upon considering spring season, it was observed that species had a significant effect (p<0.05) on leaf extract pH; however the value was not significantly different for Quercus leucotrichophora and Rubus ellipticus. Debregeasia saeneb registered highest pH value (7.65), followed by Quercus leucotrichophora (5.79) and Rubus ellipticus (5.59). Season did not significantly affect leaf extract pH; however, the highest pH was observed for Debregeasia saeneb (8.16) during monsoon season, while the lowest value was observed for Rubus ellipticus (5.50) during spring season. The distance from highway and altitude did not significantly affect this parameter. The species × distance × season, species × altitude × season and species × distance × altitude interactions were also not found to significantly affect pH.

7.4. ASCORBIC ACID (A)

Ascorbic acid, a natural antioxidant in plants has been shown to play an important role in pollution tolerance. Species effect was found to have be significant for ascorbic acid content (p<0.05). The highest concentration was observed for Grevillea robusta (6.51 mg/g), followed by Rubus ellipticus (4.20 mg/g), Quercus leucotrichophora (3.73 mg/g), Punica granatum (3.71 mg/g), Hypericum oblongifolium (3.24 mg/g) and Debregeasia saeneb (2.29 mg/g). Ascorbic acid was found to significantly vary with seasons in all the six species (p<0.05). Maximum concentration was recorded for Grevillea robusta (7.35 mg/g) during winter season, while the minimum concentration was observed for Debregeasia saeneb (1.70 mg/g) during monsoon season. Ascorbic acid concentrations were found to be highest in winter season in all the species. The species × altitude interaction revealed that though, ascorbic acid content was found to increase with the increase in altitude for all the six species, the differences were non-significant. Maximum concentration was recorded for Grevillea robusta (7.00 mg/g) in the altitudinal section 3, while minimum concentration was observed for Debregeasia saeneb (1.97 mg/g) in the altitudinal section 1.

Ascorbic acid was found to significantly vary with distance from the highway in all the six species. Grevillea robusta registered maximum concentration (7.68 mg/g) at 0-5 m distance, while the minimum concentration was observed for Debregeasia saeneb (2.04 mg/g) at >100 m distance from the highway. Grevillea robusta, Debregeasia saeneb and Quercus leucotrichophora showed highest concentrations at 0-5 m distance and there was an increase in ascorbic acid
concentration with increasing proximity to the highway, thus indicating that these species exhibited a tolerant behaviour with respect to this parameter. *Punica granatum* registered the highest concentration at >100 m distance from the highway, thus indicating its sensitive behaviour with respect to ascorbic acid content. Ascorbic acid concentrations in *Rubus ellipticus* and *Hypericum oblongifolium* were not found to be significantly affected with distance from the highway. The species × distance × season interaction was also found to have a significant effect on ascorbic acid content. Maximum concentration was recorded for *Grevillea robusta* (7.86 mg/g) at 0-5 m distance in summer season, while the minimum concentration was recorded for *Debregeasia saeneb* (1.39 mg/g) at >100 m distance in monsoon season. The interaction effects of species × altitude × season and species × distance × altitude were found to be non-significant for ascorbic acid content.

Analysis of data collected during all the four seasons for the three growing species revealed that species had a significant effect on ascorbic acid content at p<0.05 and the concentrations were noticed to be significantly different in all the three species. *Rubus ellipticus* registered the highest value (4.34 mg/g), followed by *Quercus leucotrichophora* (3.73 mg/g) and *Debregeasia saeneb* (2.43 mg/g). Ascorbic acid content was found to be significantly different in all the three species when different seasons were considered. For *Quercus leucotrichophora*, the value of ascorbic acid content at different seasons was not significantly different. Maximum value was recorded for *Rubus ellipticus* (5.08 mg/g) during winter season, while the minimum was observed for *Debregeasia saeneb* (1.70 mg/g) during monsoon season. The species × distance × season interaction also had a significant effect on the concentration of this parameter. *Rubus ellipticus* recorded maximum ascorbic acid content (5.18 mg/g) at >100 m distance during summer season, while *Debregeasia saeneb* recorded the minimum content (1.39 mg/g) at >100 m distance from the highway in monsoon season. The species × distance and species × altitude interactions had no-significant effect on ascorbic acid content. Likewise the three way interaction of species × altitude × season and species × distance × altitude also did not have any significant effect on ascorbic acid content.
7.5. LEAF DUST ACCUMULATION

Dust content was found to be significantly different in all the three species (p<0.05). Maximum dust content was accumulated by *Debregeasia saeneb* (0.060 g/m²), followed by *Rubus ellipticus* (0.055 g/m²) and *Quercus leucotrichophora* (0.041 g/m²). Higher amount of dust accumulation by *Debregeasia saeneb* and *Rubus ellipticus* may be attributed to the fact that both these species have rough leaf surfaces, while *Quercus leucotrichophora* is found to have a smooth leaf surface. Moreover, *Debregeasia saeneb* has a large leaf surface area. Dust content was found to vary significantly in all the three species in different seasons and at different distances from the highway. It was noticed to be significantly lower in all the three species during monsoon season. Maximum dust accumulation was recorded for *Debregeasia saeneb* (0.078 g/m²) during summer season, while the minimum dust accumulation amount was recorded for *Quercus leucotrichophora* (0.023 g/m²) during monsoon season. Despite of relatively high traffic count during monsoon season, the dust accumulation recorded in this season was significantly lower when compared to other seasons. This indicates washout of dust particles during monsoon season. On the other hand, summer season had highest traffic count and so was the amount of dust accumulated.

A significant positive correlation of dust was observed for pH and ascorbic acid content; whereas for total chlorophyll content, the correlation was found to be significantly negative (p<0.01). The negative relation between dust and total chlorophyll content implies that an increase in dust content decreases the chlorophyll concentration in plants. The correlation between dust and APTI was also observed to be positive and highly significant (p<0.01).

7.6. AIR POLLUTION TOLERANCE INDEX (APTI)

APTI was found to vary significantly (p<0.05) with species. It was observed to be significantly different in *Rubus ellipticus, Punica granatum, Quercus leucotrichophora* and *Grevillea robusta*. Highest APTI was observed for *Grevillea robusta* (12.89), followed by *Punica granatum* (10.87), *Debregeasia saeneb* (10.50), *Hypericum oblongifolium* (10.43), *Rubus ellipticus* (10.18) and *Quercus leucotrichophora* (9.68). All the six species were sensitive to air pollution. These plants can thus be recommended for bio monitoring as they can serve as early
indicators of air pollution. Season × species interaction had a significant effect on APTI (p<0.05). Highest APTI was recorded for *Grevillea robusta* (13.34) during winter season, while the lowest value was observed for *Rubus ellipticus* (8.99) during monsoon season. All the six species were sensitive to air pollution during all the seasons. APTI was found to vary significantly with distance from the highway in *Grevillea robusta* when compared to the remaining five species. Highest APTI was recorded for *Grevillea robusta* (14.09) at 0-5 m distance, while the least value was observed for *Quercus leucotrichophora* (9.64) at >100 m distance from the highway. All the six species were sensitive to air pollution at all distances under consideration.

At different altitudes, APTI value was not significantly different in all the six species; however, it was found to increase with an increase in altitude for *Quercus leucotrichophora*, *Grevillea robusta* and *Rubus ellipticus*, while a reverse trend was noted for *Hypericum oblongifolium* and *Punica granatum*. Highest APTI was noted for *Grevillea robusta* (12.97) in the altitudinal section 3, while the least was observed for *Quercus leucotrichophora* (9.67) in the altitudinal section 1. All the six species were sensitive to air pollution in all the altitudinal sections under consideration. APTI was not found to be significantly different in the species × distance × altitude and species × altitude × season interactions (p<0.05); however, the species × distance × season interaction had a significant effect on APTI (p<0.05). Highest APTI was recorded for *Grevillea robusta* (14.46) at 0-5 m distance in monsoon season, while the least was observed for *Rubus ellipticus* (8.42) at >100 m distance from the highway in monsoon season. All the six species were sensitive to air pollution at all distances under consideration in all the seasons.

Upon considering the spring season, APTI was observed to be significantly different for different species (p<0.05). APTI in case of *Rubus ellipticus* (10.44) was observed to be significantly higher than *Quercus leucotrichophora* (9.81), while the APTI value was not significantly different when compared to that *Debregeasia saeneb* (10.42). In this case also, all the three species were sensitive to air pollution. APTI was observed to be significantly different in species × season interaction (p<0.05). Highest APTI was noted for *Rubus ellipticus* (11.19) during spring season, while the lowest value was recorded for *Rubus ellipticus* (8.99) during monsoon season. All the three species were sensitive to air pollution during
all the seasons. Species × distance and species × altitude interactions were found to have no significant effect on APTI. The three way interaction of species × distance × season had non-significant effect on APTI (p<0.05). Likewise the species × altitude × season and species × altitude × distance interactions also did not have any significant effect on APTI. A significant positive correlation of APTI was observed with all the biochemical parameters.

All the species registered APTI values in the sensitive range and *Grevillea robusta* recorded the highest APTI value (12.89) among the selected plant species. These species can be used as bioindicators of air pollution and thus, can be used in air pollution management strategies. Since *Grevillea robusta* showed tolerant behaviour when individual biochemical parameters (relative water content, total chlorophyll content and ascorbic acid content) were estimated, it can be recommended for plantation. *Quercus leucotrichophora* can serve as early indicator of air pollution. When the native species are considered, *Punica granatum* (10.87) can be suggested for plantation. *Grevillea robusta* and *Punica granatum* are the best plant species among trees. Moreover, *Punica granatum* has many ethnobotanical uses too, which if grown by the local communities, can help to sustain their livelihood. *Debregeasia saeneb* is the best plant species among shrubs which can be recommended for green belt development. However, when the spring season is considered, *Rubus ellipticus* may also be suggested for green belt development. Maximum dust content was accumulated on *Debregeasia saeneb*, followed by *Rubus ellipticus*. *Debregeasia saeneb* and *Rubus ellipticus* are the most commonly growing plant species along this stretch of highway which scavenge dust particles. These species can be recommended for plantation as they can serve as a buffer by accumulating large amounts of dust.