PAN
ARCHIVES OF ACOUSTICS
Vol. 38, No. 3, pp. 389–395 (2013)

DOI: 10.2478/aoa-2013-0046

Road Traffic Noise Attenuation by Vegetation Belts at Some Sites in the Tarai Region of India

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(*received March 18, 2013; accepted July 12, 2013*)

Noise measurements have been carried out at eleven different sites located in three prominent cities of the Tarai region of India to evaluate the effectiveness of vegetation belts in reducing traffic noise along the roadsides. Attenuation per doubling of distance has been computed for each site and excess attenuation at different 1/3 octave frequencies has been estimated. The average excess attenuation is found to be approximately 15 dB over the low frequencies (200 Hz to 500 Hz) and between 15 dB to 20 dB over the high frequencies (8 kHz to 12.5 kHz). Over the critical middle frequencies (1–4 kHz), the average excess attenuation (between 10–15 dB) though not as high, is still significant, with a number of sites showing an excess attenuation of 15 dB or more at 1 kHz. The results indicate that sufficiently dense vegetation belts along the roadsides may prove as effective noise barriers and significant attenuation may be achieved over the critical middle frequencies (1–4 kHz).

Keywords: noise, attenuation, traffic, frequency, vegetation belt, Tarai.

1. Introduction

Land, in most cities, is a scarce resource due to which houses and buildings are generally built quite close to the road. As a result, the population living/working along the roadsides is often exposed to noise levels that are significantly greater than the prescribed standards. Thus, there is a need of taking ameliorative measures for reducing noise levels along the roadsides. Providing noise barriers along the roadsides is a typical measure adopted worldwide in this regard. Though noise barriers may be made of different kinds of construction materials, thick plantations along the roadsides are a relatively inexpensive and aesthetically more pleasing alternative. As a result, a number of authors (Cook, Van Haverbeke, 1971; Aylor, 1972; Linskens *et al.*, 1976; Carlson *et al.*, 1977; Martens, 1980; Bullen, Fricke, 1982; Price *et al.*, 1988; Huddart, 1990; Kumar *et al.*, 1998; Fang, Ling, 2003; Tyagi *et al.*, 2006; Maleki *et al.*, 2010) across the world have focused their attention on the attenuation of road traffic noise by vegetation belts.

However, there is little in common in these studies in terms of the measurement procedures used or the results obtained. Consequently, there is a considerable divergence of opinion on the effectiveness of vegetation as a noise barrier. In the Indian context, surprisingly, very few noteworthy attempts (Kumar *et al.*, 1998; Pal *et al.*, 2000; Tyagi *et al.*, 2006; Pathak *et al.*, 2008; Garg *et al.*, 2012) have been made to investigate the role of vegetation in the attenuation of traffic noise. It is pertinent here to mention that the potential of vegetation belts in reducing road side noise levels remains unexploited in the Indian context despite the fact that many plant species in India do not shed the foliage throughout the year quite unlike the plant species in the temperate regions of the world. In their earlier studies Kumar *et al.* (1998) and Tyagi *et al.* (2006) have reported in the context of Delhi that vegetation belts could play a significant role in attenuating roadside noise levels due to road traffic. The present study is a continuation of their efforts to assess the effectiveness of vegetation in reducing road traffic noise levels in the Indian context by obtaining the sound attenuation spectrum of vegetation at some sites located in the Tarai region of India.

2. Methodology

In the present study, field experiments were conducted to evaluate the performance of vegetation barriers in reducing noise levels along the roadsides at eleven sites located in Dehradun, Pantnagar, and Haridwar, which are some of the prominent cities of the Tarai region in India. Each of the sites chosen had straight and level roads, carrying freely flowing traffic with average speed of ≥40 km/hour. The traffic consisted of two wheelers, autos, cars, jeeps, buses, light and heavy commercial vehicles. The depth of vegetation belt at each site was approximately 15 m. Generally, at all the sites, the vegetation belt started at 1–1.5 meters from the edge of the road. Most of the sites were dominated mainly by shrub type of vegetation interspersed with some trees. The details of species composition at each site are provided in Appendix. As these were natural vegetation belts, their height was variable but was 2 meters or more at most of the sites. Each site had an optical density such that a vegetation belt of 15 m thickness provided zero visibility across it at least up to a height of 2–3 meters. This criterion of selecting vegetation belt was based on ISO9613-2 A.1 according to which the foliage of trees and shrubs provides a small amount of attenuation but only if it is sufficiently dense to completely block the view along the propagation path, i.e. when it is impossible to see a short distance through the foliage.

For making the noise measurements, two type-I SVAN 945 sound level meters with the facility of integration, spectrum analysis, and data logging in real time were used. The equipment was mounted on tripod stands at a height of 1.5 m above the ground level on either side (front and rear) of the belt, close to the vegetation stand. The equipment in the front side was placed at 1.0 m from the kerbside of the road, approximately at a distance of 5.0 m from the centreline of the road (Fig. 1). No buildings were present in the vicinity of the measurement sites. The noise levels at all the sites were measured on calm and clear sunny days. The meteorological data (temperature and humidity) corresponding to each site is given in Appendix.

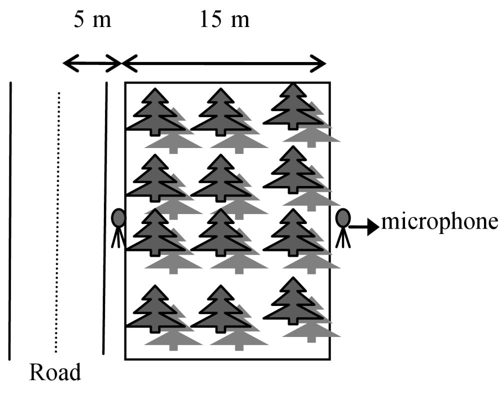

Fig. 1. Schematic diagram of the experimental set-up.

At each site, traffic noise measurements were made for a period of 30 minutes at the sampling rate of one observation/second. During each observation, the instrument recorded noise levels (in a linear mode) at different 1/3 octave frequencies (in the range of 40 Hz to 20000 Hz) as well as the A-weighted noise levels. This means that the instrument recorded time sequences consisting of 1800 values of noise levels at each 1/3 octave frequency along with the time sequence of A-weighted noise levels. The clocks of both pieces of the equipment were synchronized, so that they recorded the same sound signal. The data recorded at each site was downloaded with the help of RS 232 cable and analyzed using SVANPC interface software.

Noise attenuation at each site was evaluated from the time sequence plots of noise levels in the front and rear sides of the vegetation belt. A typical time series plot of A-weighted noise levels in the front and rear side of a vegetation belt is presented in Fig. 2. In the time sequence plots of noise levels at each site, there were time instants when noise levels in front of the noise barrier were at their background levels. At these time instants it is improper to compute attenuation since the background noise levels in the front and rear sides of the vegetation barrier would be approximately the same.

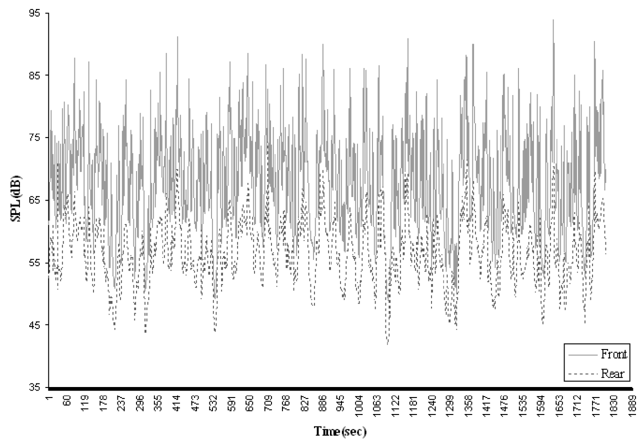

Fig. 2. A-weighted noise levels in the front and rear side of the vegetation belt.

A closer examination of the time series plots of the noise levels at each site revealed that the noise levels at the rear side of the noise barrier were a bit higher than or comparable in magnitude to the levels at the front side at some discrete time instants. This aberration, in fact, might have been due to extraneous factors such as chirping of birds near the microphone at the rear side of the noise barrier during the quiet sampling intervals. For this reason, noise attenuation for each site was recomputed by considering only those time instants when noise events occurred. The noise events at each site were identified on the basis of noise levels exceeding L_1 and L_{10} values of the time series respectively. While L_1 is the value that is exceeded only 1% of the time in the data, L_{10} is the value that is exceeded 10% of the time. Noise levels exceeding these values were considered as noise events in the context of the present study.

At the discrete time instants when noise events occurred, noise attenuation of overall A-weighted noise levels was computed for each site. For this purpose, A-weighted noise levels in the rear side of the barrier were subtracted from the corresponding levels at the front side at the time instants of occurrence of the noise events identified on the basis of L_1/L_{10} levels. This gave the overall attenuation of noise achieved by the barrier.

A similar approach was adopted to evaluate average overall noise attenuation at each 1/3 octave frequency at time instants of occurrence of noise events identified on the basis of L_1 levels. However, since noise also attenuates due to geometrical divergence (distance effect) and atmospheric absorption, excess attenuation at each 1/3 octave frequency was computed by applying appropriate corrections in order to assess the effectiveness of the barrier at each site. Excess attenuation is defined as the attenuation which is not accounted for by geometrical divergence and atmospheric absorption. In the present study, the correction for attenuation by geometrical divergence was applied by considering the moving live traffic as a line source, i.e. by considering the attenuation due to divergence to be proportional to 1/distance (Huddart, 1990). Atmospheric attenuation at each frequency for given conditions of temperature and relative humidity were computed following the calculation procedure given in ISO9613-1 (1992).

3. Results and discussion

Attenuation results of overall A-weighted noise levels identified on the basis of L_1/L_{10} levels at different sites are presented in Table 1. It can be seen that attenuation of A-weighted noise events identified on the basis of L_{10} levels varies from about 10 dBA to about 21 dBA at different sites. Attenuation of noise events identified on the basis of L_1 levels is found to vary between 13 dBA to 26 dBA.

To compare these results with those obtained by Huddart (1990), attenuation per doubling of distance (dd) was computed for each site using the following equation (Huddart, 1990):

$$L_p = L_x - k \log(r_p/r_x), \tag{1}$$

where L_p is the noise level in dB at a distance r_p from the source, L_x is the noise level in dB at a distance r_x from the source, and k is a constant which is dependent on ground and vegetation characteristics.

While Huddart (1990) reports a variation of $5.4L_{10}$ dBA to $9.3L_{10}$ dBA in the attenuation per doubling of distance (dd) over seven different sites, attenuation per doubling of distance in the present study (Table 2) is found to vary between $5.1L_{10}$ dBA to $10.9L_{10}$ dBA over eleven different sites. Out of these, five sites have the attenuation/dd of $9L_{10}$ dBA or more. In the study by Huddart (1990), only one of the sites (site-4) has the attenuation/dd of $9L_{10}$ dBA or more.

Table 1. Attenuation of A-weighted noise levels for noise events identified on the basis of L_1/L_{10} levels.

S.No.	Name of experimental site	Attenuation of A-weighted noise levels for noise events based on L_{50}, L_{10} and L_1		
		L_{50} dBA±s.d. [dBA]	L_{10} dBA±s.d. [dBA]	L_1 dBA±s.d. [dBA]
1	Site-1 (Lachhiwala, Dehradun)	10.5±3.9	12.8±3.66	13.7±2.96
2	Site-2 (near Saung River, Dehradun)	7.3±4.8	13.1±3.47	16.4±2.40
3	Site-3 (Laltapar, Dehradun)	7.9±3.8	10.1±2.86	14.8±2.60
4	Site-4 (near Limekiln site, Dehradun)	11.5±4.3	15.6±3.60	17.2±4.32
5	Site-5 (Raiwala, Dehradun)	14.6±4.2	18.7±3.12	22±1.92
6	Site-6 (Doiwala, Dehradun)	11.2±3.0	13.8±2.64	15.6±3.43
7	Site-7 (Patharchatta, Pantnagar)	11.3±5.9	18.5±4.48	24±3.44
8	Site-8 (Tanda, Pantnagar)	11.9±5.4	18.7±4.54	22.8±3.07
9	Site-9 (Saptarishi Ashram, Haridwar)	15.5±4.6	19.9±4.39	23.5±4.86
10	Site-10 (Bhadrabad Road, Haridwar)	10.5±4.3	14.6±4.30	16.6±5.56
11	Site-11 (GK University, Haridwar)	15.8±4.7	21.7±3.16	26.1±2.78

Note: L_{50} dBA, L_{10} dBA, and L_1 dBA are the average attenuation of the A-weighted noise levels computed for the noise events identified on the basis of L_{50}, L_{10}, and L_1 levels respectively in the front side of the vegetation belt during the measurement period.

Table 2. Attenuation per doubling of distance.

Site name	Attenuation/dd L_{50} dBA	Attenuation/dd L_{10} dBA	Attenuation/dd L_1 dBA
Site-1 (Lachhiwala, Dehradun)	5.2	6.4	6.85
Site-2 (near Saung River, Dehradun)	3.6	6.55	8.2
Site-3 (Laltapar, Dehradun)	3.9	5.05	7.4
Site-4 (near Limekiln site, Dehradun)	5.8	7.8	8.6
Site-5 (Raiwala, Dehradun)	7.3	9.35	11
Site-6 (Doiwala, Dehradun)	5.6	6.9	7.8
Site-7 (Patharchatta, Pantnagar)	5.6	9.25	12
Site-8 (Tanda, Pantnagar)	5.9	9.35	11.4
Site-9 (Saptarishi Ashram, Haridwar)	7.7	9.95	11.75
Site-10 (Bhadrabad Road, Haridwar)	5.3	7.3	8.3
Site-11 (GK University, Haridwar)	7.9	10.85	13.05

Note: L_{50} dBA, L_{10} dBA, and L_1 dBA are the average attenuation of the A-weighted noise levels computed for the noise events identified on the basis of L_{50}, L_{10}, and L_1 levels respectively in the front side of the vegetation belt during the measurement period.

Figures 3–5 represent the excess attenuation at different 1/3 octave frequencies for various sites in the present study. It may be seen that not only have the vegetation belts differed from each other in terms of the magnitude of attenuation, they have also shown variations in terms of their spectral behavior in reducing the noise levels. Nevertheless, certain inferences may be drawn with a reasonable degree of confidence regarding the attenuation behavior of the vegetation belts.

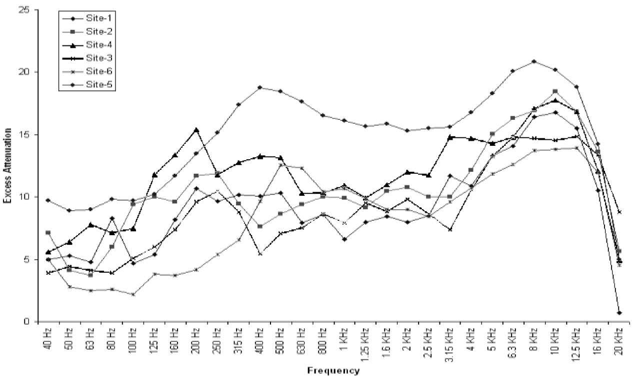

Fig. 3. Excess attenuation at different 1/3 octave frequencies at vegetation belt sites in Dehradun.

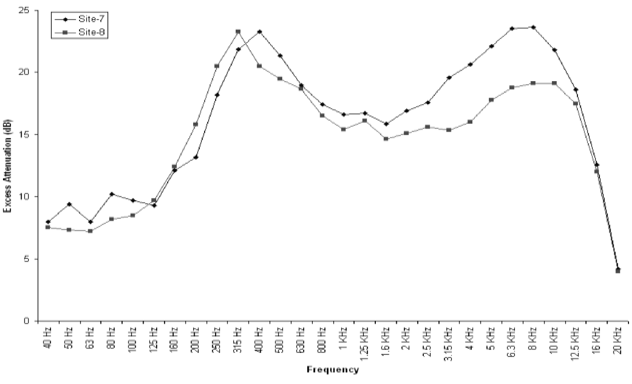

Fig. 4. Excess attenuation at different 1/3 octave frequencies at vegetation belt sites in Pantnagar.

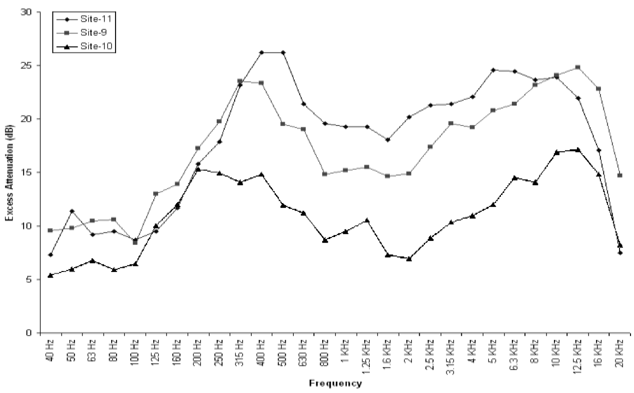

Fig. 5. Excess attenuation at different 1/3 octave frequencies at vegetation belt sites in Haridwar.

A close examination of the attenuation plots reveals that a peak in attenuation exists in the low frequency region in the range of 200 Hz to 500 Hz in the case of most vegetation belts. Similar peaks in attenuation at low frequencies have been reported by Aylor (1972), Carlson *et al.* (1977), and Martens (1981). The peak attenuation at low frequencies is due to interaction of the sound field with the ground. Attenuation as a result of this interaction between the sound waves and the ground surface is termed "the ground effect" (Attenborough 1988). Bullen and Fricke (1982), however, suggest that vegetation might reduce the benefit of the ground effect since the phases of the sound waves arriving at a point in the rear side of the vegetation belt would be random and as such the interference effects caused by the ground are destroyed. Huddart

(1990), on the other hand, suggests that soft porous ground surfaces are the best attenuators of sound over low frequencies and that the vegetation plays an important role in supplying a deep covering of plant debris which, together with the development of the plant root system, maintains a soft porous surface necessary for good ground absorption of sound. In the context of the present study, a significant low frequency peak in attenuation, varying from 12dB to more than 20 dB, is observed at almost all the sites. This indicates that vegetation does not reduce the benefit of the ground effect over low frequencies.

With regards to attenuation over the middle frequencies, most vegetation belts in the present study are found to cause a reasonable degree of attenuation though it may not be as high as the attenuation achieved over the low (200 Hz to 500 Hz) and high frequencies (8 kHz to 12.5 kHz). From Figs. 3–5, it is inferred that a minimum excess attenuation in the middle frequencies exists in the range of 1 kHz to 2 kHz. Martens (1981) reports a similar result and suggests the existence of an acoustic window from 1000 Hz to 2000 Hz for some species. Scattering by trunks and branches of vegetation seems to be an important mechanism of attenuation at middle frequencies. Aylor (1972) suggested that attenuation predicted by the scattering theory agreed well with field observations when

$$\frac{2\pi\, a}{\lambda} \geq 1,$$

where a – the radius of a trunk, λ – wavelength of the sound.

This implies that a trunk/branch diameter of $\sim$11 cm or more is required for scattering sound at 1000 Hz. The trunk/branch/twig diameters of vegetation at different sites in the present study were highly variable. However, most sites in the present study were dominated by the shrub type vegetation. In such vegetation, a trunk/branch diameter of 11 cm would generally lie in the extreme right of the size distribution of trunk/branches and as such the frequency of occurrence of trunks/branches with the diameter of 11 cm would be comparatively lower than trunks/branches of smaller diameters. Scattering of sound by trunks/branches of the shrub type of vegetation in the vicinity of 1000 Hz, therefore, is not as pronounced as it is at higher frequencies for which trunk/branches of a smaller diameter are required. The scattering by trunks/branches/twigs, therefore, is a plausible explanation for the observed attenuation behaviour at the middle and high frequencies. The minimum excess attenuation observed over the middle frequencies (1 kHz to 2 kHz) is found to vary from 6 dB to approximately 15 dB in the cases of some sites.

Another important result obtained regarding attenuation of sound by vegetation belts in the present study is the peak observed over high frequencies in the range of 8 kHz to 12.5 kHz. Though most studies report the maximum attenuation at high frequencies, there exist some variations regarding the frequency intervals in which such peaks are observed. In this respect, the results of the present study are quite close to some of the earlier studies (Aylor, 1972b; Yamada *et al.*, 1977; Linskens, 1976). Whereas Aylor (1972b) reports the high frequency peak attenuation at a frequency of 10 kHz, Yamada *et al.* (1977) observed the maximum attenuation at 8 kHz. The authenticity of their observation, however, is affected by the fact that they did not study the attenuation behavior in the entire audible spectrum. While Aylor (1972b) studied excess attenuation in the frequency range of 100 Hz to 10000 Hz, Yamada *et al.* (1977) observed excess attenuation in the range of 125 Hz to 8000 Hz. Linskens (1976), on the other hand, studied excess attenuation in the frequency range of 125 Hz to 16000 Hz and reported high frequency peak attenuation in the frequency range of 8000 Hz to 12500 Hz, which is similar to the results obtained in the present study. Other authors such as Huddart (1990) report the high frequency maximum in the range of 3000 Hz to 7000 Hz. Studies (Martens, 1980) have indicated that foliage is primarily responsible in attenuating sound at high frequencies and that the frequency of peak attenuation is influenced by foliage characteristics. Sites in the present study had mainly the shrub type of vegetation with variable leaf sizes. Figures 3–5 reveal that the high frequency (8 kHz to 12.5 kHz) peak attenuation is found to vary from less than 15 dB to more than 20 dB at different sites.

Figure 6 represents the average excess attenuation of all the eleven sites in the present study. The average excess attenuation at the low frequency peak due to the ground effect is approximately 15 dB. Though a dip is observed over the middle frequencies, excess attenuation is still significant (between 10 dB and 15 dB) enough. The average excess attenuation is found to be the maximum (between 15 dB and 20 dB) in the high frequency range (8 kHz to 12.5 kHz), owing to scattering and absorption by vegetation. Further, it can also be seen that there exists a variability in the atten-

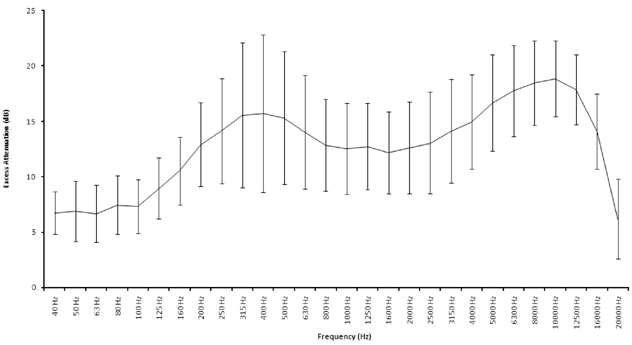

Fig. 6. Excess attenuation based upon the average taken from all the eleven sites with standard deviations represented as vertical error bars.

uation behavior of vegetation belts. Whereas the low frequency attenuation may have been influenced by the variation in the physical properties of the ground surface, the variation over the middle and high frequencies may have been due to the variation in the vegetation belt characteristics such as species composition, dominance, and density. The variability observed in the results, however, provides a sufficient basis for future research to investigate the effect of the factors mentioned above on excess attenuation.

4. Conclusions

The results of the present study indicate that sufficiently dense vegetation belts along the roadsides may prove as effective noise barriers and significant attenuation may be achieved even over the critical middle frequencies (1–4 kHz) if further research is conducted to evaluate contributions of individual plant species towards traffic noise attenuation. It is worthwhile here to mention that an excess attenuation of 15 dB or more is observed at 1 kHz for a number of sites in the context of the present study. Attenuation performance of vegetation belts in the low frequency range (200–500 Hz) and over the high frequency range (8–12.5 kHz) is found to be even better. The perceived benefits of vegetation barriers, in fact, are much more than merely reducing the noise levels. The aesthetic aspect provided by the vegetation barriers has a positive effect on human psychology, which is quite crucial for reducing the annoyance caused by exposure to the road traffic noise. Reduction of annoyance due to noise is very important since annoyance affects the psychological and hence the physiological health of human beings adversely. An additional benefit of vegetation belts along the roadsides is that the foliage cover of the vegetation provides surface for the aerosol particles to settle, thus mitigating the effect of air pollutants as well.

Appendix

Site number	Height of veg. belt	Temp.	RH	Species composition – type of vegetation
Site-1, Dehradun	9 ft	39°C	17%	Mallotus *phillipensis*, Cordia *dichotoma*, Morus *alba*, Adina *cordifolia*, Diospyros *tomentosa*, Azadirachta *indica*, Angoeissus *latifollia*, Symplocos *crataegeides*, Helicteres *isora*, Adhatoda *vassica*, Callicarpa *macrophyola*, Nerium *indicum*
Site-2, Dehradun	10 ft	39°C	18%	Adhatoda *vassica*, Mallotus *phillipensis*, Murraya *koeniggi*, Indigoferra *heterantha*, Arundo *donax*, Bauhinia *variegate*, Celtus *tetrandra*
Site-3 Dehradun	5–7 ft	27°C	26%	Lantana *camara*, Syzygium *cumini*, Thysanolena *agrostis*
Site-4, Dehradun	10–12 ft	27° C	26%	Broussonetia *papyrifera*, Lagerstroemia *parviflora*, Holarrhena *antidysenterica*, Mallotus *phillipensis*, Eulalliopsis *binata*, Themada *arundinacea*, Nerium *indicum*, Solanum *verbascifolium*, Murraya *kceniggi*
Site-5, Dehradun	12 ft	39°C	17%	Mallotus *phillipensis*, Lantana *camara*, Celtus *tetrandra*, Fiscus *racemosa*, Trema *orientalis*, Achyranthes *aspera*, Cryptolepis *buchanani*, Hiptage *bengalensis*, Saccharum *spontaneum*
Site-6, Dehradun	9 ft	39°C	18%	Mallotus *phillipensis*, Bauhinia *variegate*, Cryptolepis *buchanani*, Schleichera *oleosa*, Millettia *auriculata*, Saccharum *spontaneum*, Murraya *kceniggi*
Site-7, Pantnagar	10–12 ft	25° C	26%	Sal, Haplophragma *adenophyllum*, Adhatada *vassica*, Celtis *tetranda*, Bridelia *retusa*, Ehretia *laevis*, Litsea *glutinesa*, Bombax *ceiba*
Site-8, Pantnagar	14 ft	25°C	26%	Bauhinia *variegate*, Haloptelea *integrifolia*, Cassia *fistula*, Ehretia *laevis*, Coculus *laurifolius*, Mallotus *phillipensis*, Litsea *glutinesa*
Site-9, Haridwar	10 ft	40°C	16%	Moringa *oleifera*, Morus *alba*, Litsea *glutinesa*, Melia *azedarach*, Celastrus *paniculata*, Cuscuta *reflaxa*, Mangifera *indica*, Symplocos *crataegeides*
Site-10, Haridwar	6–7 ft	40°C	16%	Themeda *arundinacea*, Saccharum *spontaneum*, Cannabis *sativa*
Site-11, Hardwar	10 ft	40°C	16%	Themeda *arundinacea*, Lantana, Eulaliopsis *binata*, Cynadon *dactylon*, Vetiveria *zizanioides*

Acknowledgments

Two of the authors, Krishan Kumar and Vikrant Tyagi, would like thank the University Grants Commission, Government of India, for providing the financial assistance for carrying out this study.

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