

## AN INVESTIGATION OF THE NOISE ABSORPTION POTENTIAL OF A SIX SELECTED GRASS SPECIES

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**ABSTRACT.** Grass has a high leaf density and requires minimum space to grow. This experiment was designed to determine the sound absorption behaviour of six grass species (*Zoysia matrella* (L) Merr., *Stenotaphrum dimidiatum*(L.) Brongn, *Panicum repens* (L.), *Eleusine indica* (L.) Gaertn., *Axonopus compressus* (Sw) P. Beauv, and *Ischaemum sp.*) for their possible use as noise screens. The sound absorption of each morphological leaf structure was studied. For Sound Absorption Coefficients (SAC) ( $\alpha$ ) studies, the reverberation room method under ISO 345:2003 standards was followed. A B&K dodecahedron Omni-directional speaker, power amplifier, and 2250L handheld analyser were used for reverberation time and RT<sub>60</sub> measurements. Microscopic images of grass leaves were analysed using ImageJ software. This study revealed that grasses with the highest and lowest SAC for higher noise frequencies (> 1500 Hz) are *S. dimidiatum* Brongn and *A. compressus*, respectively. The SAC of *S. dimidiatum* Brongn positively correlated with noise frequency. In general, the correlation of SAC ( $\alpha$ ) with noise frequency ( $f$ ) is in the form of  $\log_{10}\alpha = a_1\log_{10}f + b_1$  where  $a_1$  and  $b_1$  are grass type-dependent constants. The morphological parameters like total leaf area, total sample area, plant height, and sample dry weight strongly

correlated with the SAC. But leaf thickness, length, width, surface area, and the weight of the sample poorly correlated with SAC in the frequency range.

**Keywords:** Grass; Sound Absorption Coefficient; Morphological Characteristics; Correlations.

### INTRODUCTION

Environmental noise pollution threatens the health (Berglund *et al.*, 1995; Fong and Johnston, 2000) and well-being of humans and other living beings. Noise levels can be reduced through dampening (Sagartzazua *et al.*, 2007). Noise barriers and absorption materials are often used to attenuate acoustic energy.

Sound barriers work through mechanisms of reflection, scattering, and absorption (Dobson and Ryan, 2000). They convert acoustic energy to heat due to the medium's friction or viscosity. Absorption depends on the properties of the medium and the frequency of the sound waves.

In literature, many studies have investigated the ability of plants to absorb sound energy through different

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ways. In 1981, Martens and Michelsen conducted an experiment using four plant species (*Ligustrum Hegelianism*, *Betula Verrucosa*, *Corylus Evelina*). Another experiment was done by Horoshenkov *et al.* (2013) using the equivalent fluid model for sound propagation in porous media in the frequency range of 50–1200 Hz. In 1977 S. Yamada (Watanabe and Yamada, 1996) proposed a theoretical model to calculate the sound energy absorption of leaves. In 2010, Wong *et al.* proved that vertical greenery systems could absorb sound energy and reduce sound levels. Kang *et al.* (2013) conducted a series of measurements to examine the sound absorption coefficients of vegetation and bedding plants using a reverberation room method (Smyrnova *et al.*, 2010).

This study investigates the sound absorptive characteristics of six grass species (*Figure 1*) commonly available in Sri Lanka for their potential application as noise barriers. Some of these species are used for landscaping worldwide.

## MATERIALS AND METHODS

### Sound absorption coefficient (SAC)

The average sound absorptive coefficient ( $\alpha$ ) in an enclosure with different sound-absorbent materials is defined as

$$\alpha = \frac{\sum_i \alpha_i S_i}{\sum_i S_i} = \frac{A}{S} \quad (1)$$

where  $A$  represents the total effective absorptive area, and  $S$  is the total spatial area.  $\alpha_i$  and  $S_i$  are the relevant values for different absorbent materials in the enclosure.

W.C. Sabine, in the late 1890s, derived a relationship to calculate  $RT_{60}$  in terms of room volume ( $V$ ) and total effective absorption area ( $A$ ), which is given in equation (2) (Hughes *et al.*, 2015).

$$RT_{60} = \frac{0.161 V}{A} \quad (2)$$

If the  $RT_{60}$  values for an enclosure without a sample are  $T_1$  and  $T_2$ , equations (1) and (2) can be extended to calculate the sample average SAC.

$$\frac{1}{T_1} = \frac{\sum_i \alpha_i S_i}{0.161 V}$$

$$\frac{1}{T_2} = \frac{\sum_i \alpha_i S_i + \alpha_1 S_1}{0.161 V} \quad (3)$$

$$\alpha_1 = \frac{0.161 V}{S_1} \left( \frac{1}{T_1} - \frac{1}{T_2} \right)$$

In this study, equation (3) was used to calculate the sound absorption coefficient of grass species by measuring the reverberation time where  $S_i$  is the total sample area.

Six grass species, *Zoysia matrella*(L) Merr., *Stenotaphrum dimidiatum*(L.) Brongn, *Panicum repens*(L.), *Eleusine indica*(L.) Gaertn., *Axonopus compressus* (Sw) P. Beauv, and *Ischaemum sp.* were selected for the study.

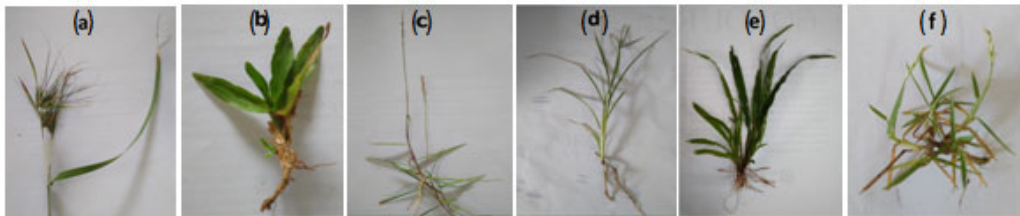
The primary considerations in selecting these plants were their acoustic interactions, availability, high potential growth under tropical climates, and manageability in challenging environments. Naturally grown plants collected from the field were used for the experiment (*Fig. 2a*). Herbarium specimens were prepared from the National Herbarium, Peradeniya, Sri Lanka, for identification purposes.

The reverberation room method (Asdrubali *et al.*, 2014; Hughes *et al.*, 2015; Smyrnova *et al.*, 2010; ISO 345:2003) is described under ISO 345 standards (ISO 345:2003) and is widely accepted for testing

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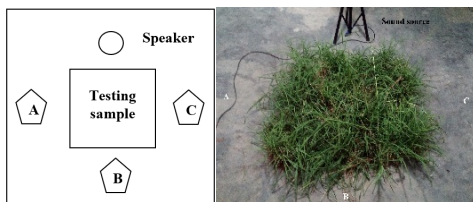
large samples and calculating random incidence absorption coefficients (Prisutova *et al.*, 2014) (Fig. 2b). Per the standards, the minimum recommended volume of the standardised reverberation room, 200 m<sup>3</sup>, and the surface area of the test specimen between 10 m<sup>2</sup> and 12 m<sup>2</sup> were utilised. The testing room used in this study was cuboidal shaped with an approximate volume of 60 m<sup>3</sup> and a total internal surface area of 102 m<sup>2</sup>

covered by four brick walls. The total diffuser area and the room length were 16 m<sup>2</sup> and 7.1 m, respectively (Rasa, 2016; del Rey *et al.*, 2017). The relative surface area of the reverberation room, the diffuser area ratio to the total interior room area, is 0.157 and follows the given standards. All the sample areas of the tested specimens were between 3.1-3.6 m<sup>2</sup> and agreed with the standards.



**Figure 1 - (a) *Z. matrella*, (b) *S. dimidiatum* (L) Brongn., (c) *P. repens*, (d) *E. indica* (L) Gaertn., (e) *A. compressus* (Sw) P. Beauv. (f) *Ischaemum* sp.**

Each species' healthy and densely grown naturally grasses were used to prepare the testing samples. The grasses selected from the monoculture were uprooted with minimal damage and transported immediately in sealed bags to the laboratory. Then root soil was carefully washed away, and the grasses devoid of extra moisture were placed within a 1.4 × 1.4 m<sup>2</sup> area to be used as the testing sample. Three samples from each of the six species grown in three different environments were used for the experiment.



**Figure 2 - (a) The experimental setup speaker and sound analyser locations A, B and C; (b) Testing sample in the centre of the reverberation room.**

A type 2250L B&K handheld sound analyser with reverberation time software

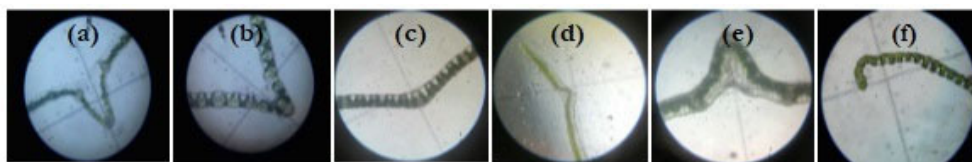
(BZ 7227), Dodecahedron Omni Directional B&K speaker (makes 360 degrees sound), an internal sound generator with a B&K Power amplifier, and a 16 Megapixel camera were the primary equipment used in the study. The testing sample was placed in the middle of the reverberation room. The handheld analyser was fixed on a tripod and set 1 m away from the plant samples and 1 m from the ground to reduce the effects. The reverberation room temperature and humidity were monitored using a Kestrel 4500 pocket weather tracker. Readings showed that weather conditions were not significantly different and unlikely to affect the experiments. A Dodecahedron Omni Directional speaker was positioned 1 m away from the sample.

Pink noise (Wong *et al.*, 2010), which contained an equal energy output for all octave bands between 800 Hz-3150 Hz, was generated by the power amplifier used in the experiment. Corresponding RT<sub>30</sub> values for 1/3 octaves of the input frequency range were monitored for 1 min using the sound analyser with the reverberation time software (BZ 7227). Measurements were repeated for

three analyser locations, A, B, and C, as illustrated in Fig. 2. Each measurement was repeated ten times. The standard reverberation time  $RT_{60}$  needed to determine SAC was calculated by multiplying the  $RT_{30}$  by two (del Rey *et al.*, 2017). By repeating the procedure,  $T_1$  and  $T_2$  were obtained without and with the fresh samples, respectively. The total leaf area  $S_l$  of the sample was estimated by using Image-J software. From a birds-eye view, images of the adaxial surface of three portions of the  $10 \times 10 \text{ cm}^2$  area of the sample (Fig. 3) were examined, and the average value was taken.



**Figure 3 - A portion of a sample ( $10 \times 10 \text{ cm}^2$ ) and the leaves glued on paper to calculate the leaf area of the sample**



**Figure 4 - Microscopic images of the leaves. (a) *Z. matrella*, (b) *S. dimidiatum*(L)Brongn, (c) *P. repens*, (d) *E. indica* (L) Gaertn., (e) *A. compressus* (Sw) P. Beauv, (f) *Ischaemum* sp.**

## RESULTS AND DISCUSSION

Ninety measurements were used for each plant sample. SAC were calculated using equation (03). The changes in  $RT_{30}$  and SAC with each selected grass species frequency is shown in Fig. 5(a) and 5(b), respectively.

For lower frequencies ( $< 1600 \text{ Hz}$ ), random variations of reverberation time and SAC could be observed, implying that noise absorption behaviour was not uniform at lower frequencies for these

Morphological characteristics such as the thickness of a leaf and nature (length of epidermal hairs) were examined at the microscopic level using a light microscope at high power ( $10 \times 40$ ). Fig. 4 illustrates the sample images taken by the camera. The adaxial area of a leaf sample area and total leaf area were obtained by analysing camera images. The sample area (the sample's upper surface area) was calculated using a birds-eye view image of the sample. The total leaf area of the sample was measured manually by considering both sides of the leaf. A meter ruler and a vernier calliper were used for measuring the plant height, width, and leaf length of samples. The net and dry weights of the sample were measured using an electronic scale. SPSS software was used for all statistical analyses. The non-linear regression method was used to find the best correlations between SAC and frequency. R squared values and the significant values (p-values) were obtained for regression models to choose the best model.

grass species.  $RT_{30}$  decreased sharply with increasing frequencies up to 1.5 kHz, and then it decreased gradually. The SAC was highest in *S. dimidiatum* for frequencies above 1500 Hz. However, it was the lowest in frequencies less than 1 kHz. *A. compressus* was the lowest sound absorptive grass species for noise frequencies higher than 1500 Hz. *Ischaemum* sp. had the lowest  $RT_{30}$  values over the frequency range. The

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difference in  $RT_{30}$  between *Ischaemum sp.* decreases from 800 Hz to 2500 Hz.

The highest and lowest differences are 1.12 s (800 Hz) and 0.50 s (2500 Hz).

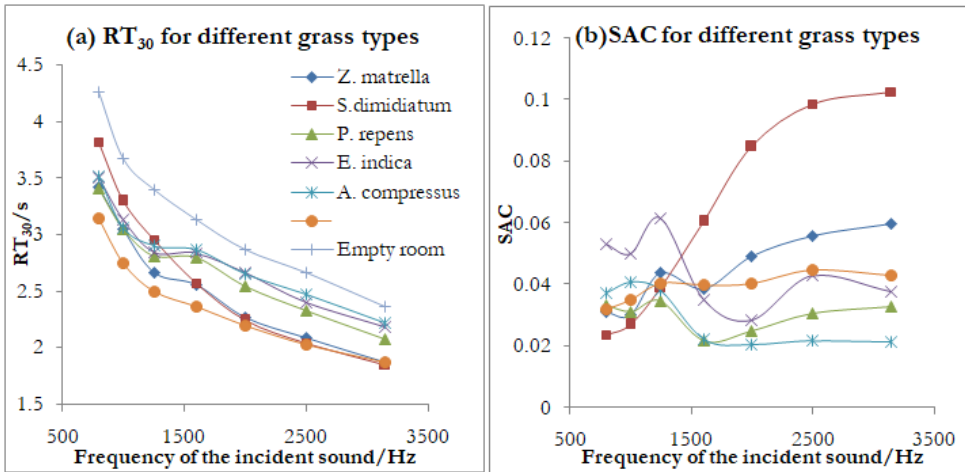


Figure 5 - Changes in (a)  $RT_{30}$  and (b) SAC of the six grass species with the frequency

Table 1 - Averaged  $RT_{30}$  and SAC values of the six grass species with their standard deviations given in the brackets for the tested frequency range

Details	Averaged $RT_{30}/s$	Averaged SAC
<i>Z. matrella</i>	2.56 (0.54)	0.04 (0.001)
<i>S. dimidiatum</i> Brongn	2.68 (0.71)	0.06 (0.001)
<i>P. repens</i>	2.72 (0.45)	0.03 (0.001)
<i>E. indica</i>	2.80 (0.44)	0.04 (0.001)
<i>A. compressus</i>	2.81 (0.42)	0.03 (0.001)
<i>Ischaemum sp.</i>	2.41 (0.44)	0.04 (0.001)

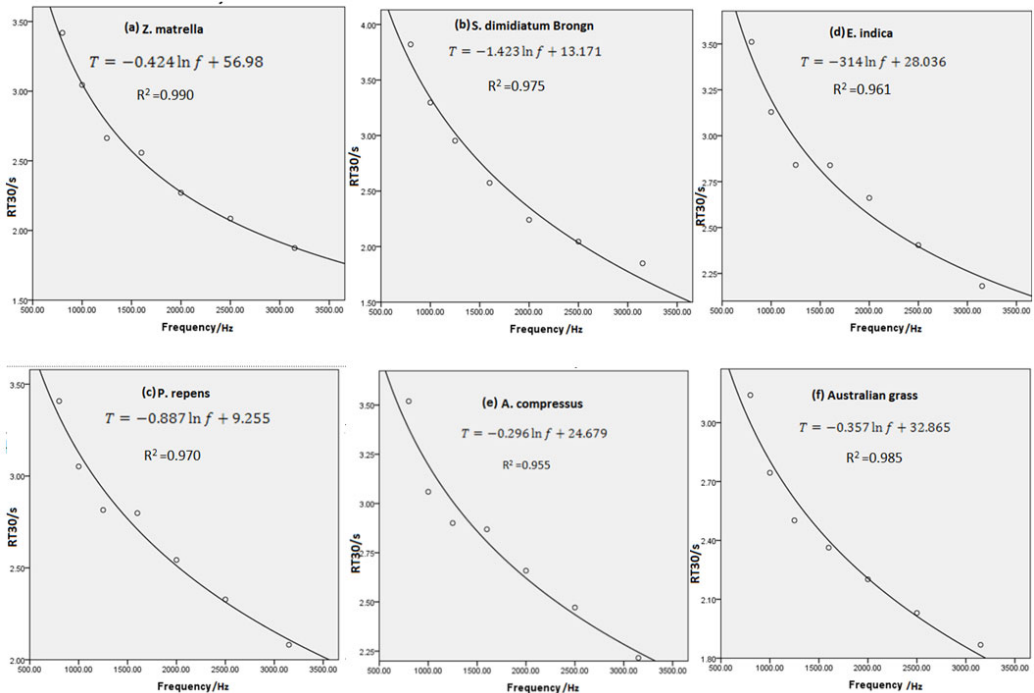
The averaged  $RT_{30}$  and SAC values for the tested frequency range with their standard deviations for six grass species are shown in Table 1. *A. compressus* had the highest averaged  $RT_{30}$  values. The plants with the highest and lowest averaged SAC values were *S. dimidiatum* Brongn and *A. compressus*, respectively. The SAC of *S. dimidiatum* Brongn increased significantly with increasing frequencies from 1500 Hz to 3150 Hz. *S. dimidiatum* Brongn spreads uniformly over the soil surface and grows very compactly, minimising leaf

height variation. These features could be responsible for the highly correlated absorption properties of noise frequencies. *Z. matrella* and *P. repens* show the same SAC behaviour with increased frequencies. The averaged  $RT_{30}$  value of all tested grass types was between 2.41 to 2.81, and the average SAC was between 0.03 and 0.06. In a study by J. Kang *et al.* (2013), the SAC of Buxes and Holly are in the range of 0-0.2 for a similar frequency range. A significant increase in SAC values are seen from 1600 Hz, according to a study

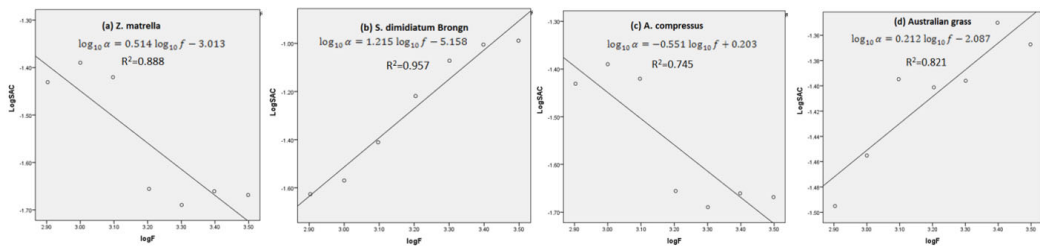
by Yang, Kang, and Cheal (2013). This study showed a similar variation in *S. dimidiatum* Brongn, *Z. matrella* and *P. repens*.

The possible correlation between  $RT_{30}$  and frequencies was statistically tested, and the corresponding R squared values and p-values were obtained using regression analysis. Most of the fitted

functions, except *S. dimidiatum* Brongn and *Ischaemum* sp., were natural logarithmic functions. To make a similar pattern for all plant types, the  $RT_{30}$  values for the two deviated plant types were also fitted for natural logarithmic functions. All the adjusted R squared values of each fitted curve were higher than 0.94, as shown in Fig. 6.



**Figure 6 - Fitted curves for  $RT_{30}$  with the frequency of the incident sound wave for six grass species (a) *Z. matrella*, (b) *S. dimidiatum*(L)Brongn, (c) *P. repens*, (d) *E. indica*, (L) Gaertn., (e) *A. compressus* (Sw) P. Beauv, (f) *Ischaemum* sp**



**Figure 7 - Fitted curves for SAC with the frequency for grass species (a) *Z. matrella*, (b) *S. dimidiatum*(L)Brongn, (c) *P. repens*, (d) *E. indica* (L) Gaertn., (e) *A. compressus* (Sw) P. Beauv, (f) *Ischaemum* sp**

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All the mathematical models obtained using SPSS are in the form of  $RT_{30} = a_1 \ln f + b_1$ , where  $a_1$  and  $b_1$  are grass type-dependent constants. A significant value has a p less than 0.05. The fitted lines for SAC with powerful R squared values are shown in Fig. 7.

The four data sets fit logarithmic equations, but the trend patterns differ. *A. compressus* has a decreasing trend pattern, and the other three grass species have increasing trend patterns.

*P. repens*, *E. indica* have random variations. Smyrnova *et al.* (2010) have previously taken growing and decaying SAC vs frequency graphs for different plant types. The results of both studies are similar.

The SAC of *S. dimidiatum* Brongn positively correlated with noise frequency ( $R^2=0.95$ ), but *Z. matrella*, *Ischaemum* sp., and *A. compressus* reasonably relate. The correlation of SAC ( $\alpha$ ) with frequency ( $p < 0.05$ ) is in the form of  $\log_{10}\alpha = a_2 \log_{10}f + b_2$  where  $a_2$  and  $b_2$  are grass type-dependent constants, and  $f$  is the noise frequency. The above stimulating noise absorption behaviours were further studied by analysing their morphological nature. The parameters studied were leaf thickness, leaf area, leaf length, leaf width, hair length, plant height, total and dry weight of the sample, total leaf area, and sample area. Table 2 shows the averaged values obtained by ten measurements of each parameter.

Table 3 gives the coefficients of determinations (R squared values) for the studied parameters. This study suggests that the acoustic behaviour of plants in different frequencies is diverse. For noise frequencies of 800 Hz and

1250 Hz, the most impactful morphological parameter is the total leaf area. The sample area affects SAC parameters for 800 Hz and 1250 Hz. At 1600 Hz, the height of the sample is the main determiner. There was a significant effect on SAC in the range of 1600 Hz-3150 Hz due to the plant height. According to Table 3, the thickness of a leaf and surface area, length of a leaf, sample weight, and leaf width did not alter SAC throughout the range of frequencies. Fig. 8 illustrates the highly correlated variables for noise absorption under different frequencies.

The length of the hairs (trichomes) was measured for each plant variety using microscopic images and ImageJ software. *Zoysia matrella*, *Ischaemum* sp., *Axonophus*, and *Panicum repens* had a few hairs at the leaf bottoms. The hair lengths were 3.2 mm, 0.73 mm, 3.24 mm, and 0.24 mm, respectively. Only *Stenotaphrum dimidiatum* (L) Brongn and *Eleusine indica* had trichomes on the upper leaf surface. The length of the hairs was 0.39 mm and 4.18 mm, respectively.

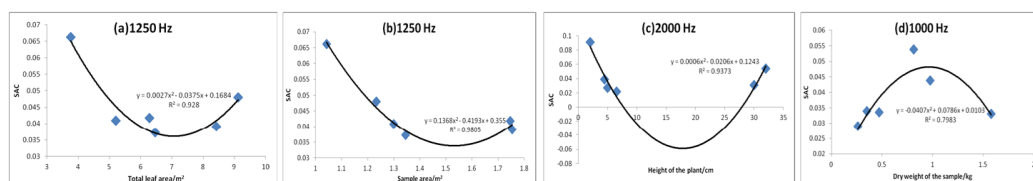
Though the hair densities on the leaf's upper body were  $5 \text{ cm}^{-2}$  and  $10 \text{ cm}^{-2}$ , the hair density varied greatly from plant to plant. The maturity and soil conditions were mainly affected by hair density. *Stenotaphrum dimidiatum* (L) Brongn and *Axonophus* had hairs on the leaves' edges, and the length of the hairs was about 0.7 mm. The linear hair density of both plant varieties was about 13 hairs per one centimetre. There were no branched hairs on the selected plant varieties.

**Table 2 - Measured morphological parameters of leaves**

Scientific Name	Morphological/Anatomical features (Mean)									
	Leaf thickness (10 <sup>-3</sup> mm)	Hair length (mm)	Leaf area (cm <sup>2</sup> )	Leaf length (10 <sup>-1</sup> mm)	Leaf width (mm)	Plant height (10 <sup>-1</sup> mm)	Sample weight (kg)	Dry sample weight (kg)	Sample area (m <sup>2</sup> )	Total leaf area (m <sup>2</sup> )
<i>Zoysia matrella</i>	86.95	0.00	2.09	2.0	0.0	0	0.50	0.58	0.37	0.12
<i>Stenotaphrum dimidiatum(L) Brongn</i>	103.33	0.39	0.03	0.5	0.0	2	0.21	0.26	0.75	0.28
<i>Panicum repens</i>	49.29	0.00	0.02	0.9	0.0	5	0.09	0.47	0.35	0.46
<i>Eleusine indica</i>	109.70	0.18	0.78	6.0	0.0	0	0.67	0.81	0.04	0.76
<i>Axonopus compressus</i>	90.58	0.00	0.32	8.2	0.0	0.5	0.32	0.98	0.30	0.20
<i>Ischaemum sp.</i>	49.31	0.00	0.29	2.3	2.0	4.5	9.03	0.35	4.21	8.42

**Table 3 - R-squared values for each parameter and SACs**

	R squared values (coefficient of determination) for SACs						
	800	1000	1250	1600	2000	2500	3150
Frequency/Hz							
Leaf thickness	0.17	0.06	0.24	0.04	0.11	0.06	0.09
Leaf surface area	0.13	0.20	0.13	0.07	0.10	0.11	0.12
Length of a leaf	0.49	0.58	0.52	0.11	0.14	0.10	0.12
Width of a leaf	0.25	0.08	0.42	0.11	0.17	0.16	0.17
Total leaf area	0.89	0.90	0.93	0.05	0.16	0.07	0.11
Sample area	0.88	0.73	0.98	0.50	0.37	0.35	0.30
Plant Height	0.74	0.68	0.68	0.83	0.94	0.90	0.93
Sample Weight	0.25	0.36	0.18	0.01	0.09	0.05	0.10
Dry weight of the sample	0.70	0.80	0.25	0.50	0.63	0.54	0.59



**Figure 8 - The best-fitted curves under respective frequencies, (a) SAC vs total leaf area, (b) SAC vs sample area, (c) SAC vs plant height, (d) SAC vs dry weight of the sample.**



## CONCLUSIONS

*S. dimidiatum* had the highest SAC values for frequencies above 1500 Hz and is recommended for higher frequency noise absorption. For lower frequencies (< 1500 Hz), the noise absorption capability of *E. indica* was significant. *A. compressus* showed the lowest SAC for higher noise frequencies (> 1600 Hz) and the highest RT<sub>30</sub> over the considered frequency range. The characteristic variation pattern of reverberation time RT<sub>30</sub> with sound frequency was similar for all tested grass types at higher frequencies (> 1600 Hz). For lower frequencies (< 1600 Hz), random variations of reverberation time and SAC with noise frequency were observed.

Morphological parameters like total leaf area, total sample area, plant height, and sample dry weight strongly correlated with the SAC. But the leaf thickness, length, width, surface area, and sample weight poorly correlated with SAC for the entire range of frequencies. The SAC for the frequency range of 1600 Hz-3150 Hz depended on the plant's height. The total leaf area was not affected by SAC at higher frequencies (1600 Hz-3150 Hz). Epidermal hairs, categorised in many ways like unicellular, cellular, single branches, multi branches, etc., played different roles in noise absorption. However, there were no branched hairs on the selected plant varieties. If a leaf contained longer trichomes, water molecules were deposited and percolated through them creating an extra dragging force against their vibrations. It was

disturbed by the insertion of sound waves through the cuticles into the leaf which decreased sound absorption. Since the sound waves move back and forth, it was easy to move a thin leaf. Therefore, thin plant leaves showed high SACs. More studies on the structures of epidermal hairs are needed to understand the acoustic behaviour of plant leaves.

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