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Inline Plantation of Virginia Mallow (*Sida hermaphrodita* R.) as Biological Acoustic Screen

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1. Introduction

Rzeszów branch of General Directorate for National Roads and Motorways directed to Voivodship Inspectorate of Environmental Protection (VIEP) in Rzeszów materials concerning, conducted in 2005 by AGH University of Mining and Metallurgy – Department of Mechanics and Vibroacoustics, measurement of general traffic. Prepared by VIEP in Rzeszów elaboration "State of environment in Podkarpackie Voivodship in 2005" [10] contains, among others, data concerning measurements of traffic related noise level in vicinity of national roads of Podkarpackie Voivodship. Its results point on its significant tiresomeness along investigated roads. Allowable noise level was exceeded in each of chosen measurement sections. Level of noise considered to be allowable for house and multi-family building developments with services and homestead areas was assumed at 60 dB for daytime and 50 dB for a nighttime. One of the chosen measurement points, significant when aspect of environment protection is taken into consideration, was located by national road 28 in Krasiczyn. Equivalent noise level L_{Aeq} was 64.5 dB, traffic volume was 195 vehicles per hour (heavy good vehicles in number of 25 per hour, making up 13.0%), weighted mean speed of vehicles was 73.5 km·h^{-1}.

In summary of mentioned above publication, it was stated that main factor affecting degradation of acoustic climate of the environment i.e. increase of noise level leading to high and very high tiresomeness, is traffic. Reason for expansion of traffic noise in environment is mainly successively increasing number of vehicles on roads accompanied by insufficient reorganization and modernisation of roads and communication routes. Such development of tendencies concerning changes of environment quality in most of monitored towns of Podkarpackie Voivodship creates a necessity of undertaking appropriate, optimal and effective repair actions, being a part of, dictated by economical and structural feasibility, long-term policy on environment noise protection.

The tools used in the environmental monitoring play an important role in the context of sustainable development assuming preservation of the environment status for the living of future generations [8].

2. Materials and methods

In order to conduct research, field experiment, located in Przemyśl County, on area of Pogórze Przemyskie Landscape Park, was established. Experimental plots sown with Virginia mallow (*Sida hermaphrodita* Rusby) formed roadside green belt, 15 m in width and 360 m long, on the right side of county road 2085 R Krasiczyn – Korytniki. This belt was divided by means of narrow technological paths into two parts characterizing with various spacing of plant rows: plot 1 where spacing between rows of plants was 0.75 m and plot 2 where spacing between the rows was 0.5 m. When compared to the road, which was above the surrounding area, particular experimental fields were at different level. Difference between the road level and plots 1 and 2 was 0.5–0.6 m and 2.0–2.5 m respectively. The experiment was founded on the soil of the following granulometric content: sand (2.0–0.1 mm) – 30%, dust (0.01–0.02 mm) – 35%, floatable matter (<0.02 mm) – 35%. According to the soil form division into granulometric groups and subgroups, according to the regulation BN-78/9180 – 11 [1] it is light dusty clay. The humus content in the soil amounted to 2.30%. The contents of assailable forms of primary mineral components, in mg per 100 g of soil, was correspondingly: P – 13.6; K – 22.2; Mg – 8.4 and pH profile was 7.4. In the first year of the research, the experiment was fertilised with ammonium niter (N 34%), mono superphosphate (P 19%) and potassium sulfate (K 50%) in the proportions of N:P:K = 158:88:116 = 1.8:1:1.3. Nitrogen was introduced in 2 doses.

Experimental plots were sown in spring, and research cycle started when plants were 2 years old.

Subject of conducted research, on equivalent acoustic pressure level (L_{Aeq}) along measurement profiles, was distribution of this indicator, while model sound (communication noise) was its object.

Measurements of equivalent acoustic pressure level along, set perpendicularly to biological road screen, measurement profiles had experimental character, and registered traffic noise was used as a model sound. Source of the sound was set at the edge of the road at height of 0.5 m. Sound intensity level emitted by the source, measured at height of 0.5 m and distance of 1m from it, was adjusted to 90 dB.

For purpose of this research, experimental plot – roadside belt of vegetation, which was meant to fulfill function of biological road screen, was used. Four measurement profiles were set:

- profile A for open space, where additionally approx. 15 m high trees were growing along the road;
- profile B for plot where distance between rows was 0.75 m, and where additionally approx. 15 m high trees were growing along the road;
- profile C for plot where distance between rows was 0.75 m;
- profile D for plot where distance between rows was 0.5 m.

Figure 1 provides a schematic layout of the experiment plot.

Within each of the profiles, three, crosswise to road axis, measurement sections were set. Measurements were conducted at four distances from the road's edge: 7 m – before the screen, 15 m – in a middle of the screen, 22 m – directly beyond the screen and 35 m – 13 m beyond the screen. For each of these distances and each of the profiles, measurements at three various heights above ground level were done: two constants: 0.5 m and 4 m and one variable, depending on plants height in particular growth stage. Measurements were taken every 30–40 days, from March to October.

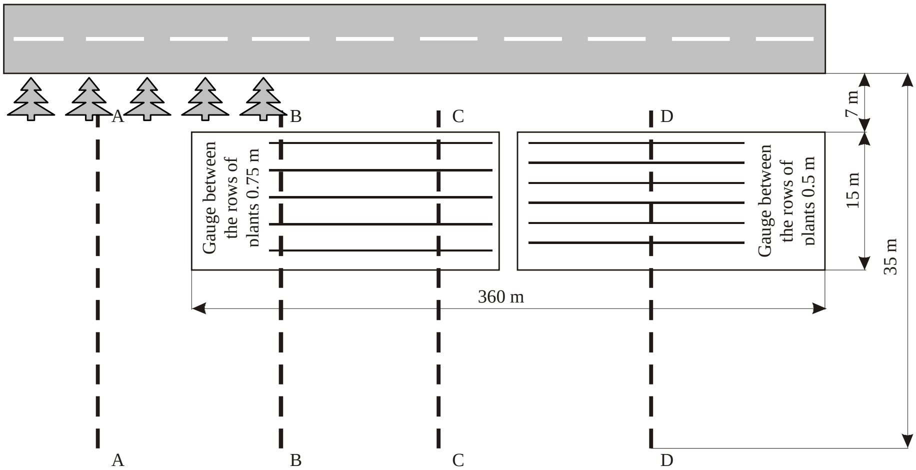

Fig. 1. Schematic layout of the experiment plots
Rys. 1. Schemat pola doświadczalnego

Measurements of noise immission and of equivalent acoustic pressure level along the measurement profiles were conducted by means of class 1 SVAN 912 AE meter set, in which microphone cable (10 m), preamplifier, standard microphone 1/2", anti-wind cover, stand, calibrator (1000 Hz, 114 dB) and measuring tape were included. For measurements of equivalent acoustic pressure level along profiles perpendicular to biological screen, additional, handheld support extending to 2.0 m, was utilized. Meter used for research meets Polish and international norms for class 1 meters (IEC 651, IEC 804) and is approved by Central Office of Measures.

During taking measurements following settings of the meter were used:

- measurements of acoustic background: time of measuring elementary signal of 1 min., correction characteristic A, FAST time constant, measuring range 110 dB, integration time 1/2 s;
- measurements of equivalent acoustic pressure level along measurement profiles, running perpendicularly to biological screen, in consecutive stages of their growth: time of measuring elementary signal of 5 s, correction characteristic A, FAST time constant, measuring range 110 dB, integration time 1/2 s.

After each measurement, calibration of measuring line was conducted by means of calibration measurement (calibration coefficient was calculated in relation to reference level, measuring range 114 dB).

All measurements of equivalent acoustic pressure level along measurement profiles were conducted within two years, during various phases of Virginia mallow growth, every 30–40 days, from the beginning of March, before the plants vegetation started, to October, after vegetation had stopped and leaves had been dropped. In March, variable measurement height, depending on plants height, was based on height of previous years stems, which were not harvested first year after experimental field was established.

3. Results and discussion

In town of Krasiczyn, on the county road by side of which field experiment was established (road Krasiczyn – Korytniki), indicator determining level of environment noise pollution i.e. equivalent acoustic pressure level (L_{Aeq}) during the daytime in summer was:

- for a weekday 57.2 dB (background 33.7 dB),
- for a weekend 56.8 dB (background 35.0 dB).

Noise by Krasiczyn – Korytniki road was noise of average arduousness, when subjective scale of noise arduousness perception was applied. While, when scale of acoustic comfort is taken into consideration, these were average acoustic conditions.

Analysis of research results on equivalent acoustic pressure level along measurement profiles shows that noise suppression by Virginia mallow screen was observed from May to October. In order to determine effectiveness of in line plantations of Virginia mallow used as acoustic screen, calculations of noise reduction (tab. 1), in conformity to PN-ISO 10847 norm [9], were conducted. As the reference, measurement profile A was chosen. Highest noise reduction was observed at measuring height of 0.5 m and distances of 22 and 35 m from its source. Moreover, highest changes of sound level, compared to measurement profile A, were observed for measurement profile C.

Table. 1. Range of noise suppression of Virginia mallow biological screen in measurement profiles B, C, D in reference to measuring profile A
Tabela 1. Zakres tłumienia hałasu przez ekran biologiczny ze ślazowca pensylwańskiego w profilach pomiarowych B, C, D w odniesieniu do profilu pomiarowego A

	Profile B [dB]		Profile C [dB]		Profile D [dB]	
	range	mean	range	mean	range	mean
At measuring height of 0.5 m						
15 m from the noise source	0.3–3.6	1.98	0.5–9.2	3.84	0.8–8.1	4.25
22 m from the noise source	4.3–9.4	6.4	0.7–12.6	4.91	0.3–12.5	4.9
35 m from the noise source	0.3–9.1	4.97	1.4–13.4	5.04	0.4–11.1	5.45
At measuring height equal to average height of plants						
15 m from the noise source	0.04–5,3	2.44	0.2–6.6	2.67	0.9–7.1	3.71
22 m from the noise source	0.1–6.0	3.07	0.9–7.7	4.31	3.4–8.5	5.6
35 m from the noise source	0.1–5.8	2.44	0.6–11.2	4.37	2.5–9.5	5.66
At measuring height of 4.0 m						
15 m from the noise source	0.1–5.7	2.27	0.3–3.5	2.22	1.1–7.0	3.7
22 m from the noise source	0.4–6.7	2.79	0.7–6.4	3.19	2.2–8.7	4.39
35 m from the noise source	2.4–8.3	4.48	1.5–11.2	4.98	1.71–10.4	6.21

Source: Authors own research

Statistical analysis of results of value of equivalent acoustic pressure level (L_{Aeq}) measurements was conducted by means of STATISTICA 6.0 programme. Distribution of sound level along measurement profiles A, B, C and D was analysed, and measurements were taken at different heights. Statistical analysis was done separately for each of measurement days. Conducted triple factor variance analysis showed significant influence of all factors (measurement profile, distance from noise source, height at which measurements were taken) as well as their interactions. Additionally, Tukey's test comparing measurement profiles (at significance level α = 0.05) was conducted (fig. 2) (where: I – first year of the study, II – second year of the study). No statistically significant differences between all measurement profiles were noted, for readings taken on: March(I), April(I), May(I), October(I), March(II), May(II), July(II), September(II), October(II). While for ones taken on June(I), July(I), August(I), September(I), April(II), August(I), statistically significant differences were recorded for profiles A and C. In most cases no statistically significant differences were noted between measurement profiles B and/or D and measurement profile A. Figure 3 graphically presents chosen approximated and real sound pressure level changes along the measurement profiles for the results of measurements carried out at the phase of full growth of plants (august (II), height of plant 3.2 m).

a)

Profile	y	1
D	64.5	****
B	65.8	****
C	66.5	****
A	67.2	****

b)

Profile	y	1
A	65.6	****
D	65.8	****
C	66.1	****
B	66.6	****

c)

Profile	y	1
B	61.6	****
C	61.7	****
D	62.7	****
A	65.0	****

d)

Profile	y	1	2
C	62.7	****	
B	62.9	****	
D	63.5	****	****
A	67.8		****

Fig. 2. Tukey's test comparing profiles at 0.05 significance level, conducted for measurements results obtained: a) March(I); b) April(I); c) May(I); d) June(I) where: I – first year of the study, II – second year of the study
Source: Authors own research
Rys. 2. Test Tukeya porównujący profile na poziomie istotności 0,05, przeprowadzony dla wyników pomiarów uzyskanych: a) marzec(I); b) kwiecień(I); c) maj(I); d) czerwiec(I)
gdzie: (I) – pierwszy rok badań, (II) – drugi rok badań
Źródło: badania własne

e)

Profile	y	1	2
C	58.4	****	
B	62.1	****	****
D	62.5	****	****
A	65.9		****

f)

Profile	y	1	2
C	58.3889	****	
D	60.2472	****	****
B	60.9333	****	****
A	64.1278		****

g)

Profile	y	1	2
C	63.1667	****	
D	64.9861	****	
B	65.3333	****	****
A	69.5889		****

h)

Profile	y	1
A	64.9528	****
C	65.7778	****
D	66.1944	****
B	66.4000	****

i)

Profile	y	1
C	61.6694	****
D	61.8917	****
B	63.5444	****
A	66.3083	****

j)

Profile	y	1	2
C	60.2917	****	
B	61.2750	****	
D	62.5861	****	****
A	66.3306		****

k)

Profile	y	1
C	62.4111	****
D	63.3083	****
B	63.4583	****
A	66.1389	****

l)

Profile	y	1	2
D	60.7861	****	
C	61.067	****	
B	61.972	****	
A	66.994		****

Fig. 2. cont.; e) July(I); f) August(I); g) September(I); h) October(I); i) March(II); j) April(II); k) May(II); l) June(II)
where: I – first year of the study, II – second year of the study
Source: Authors own research
Rys. 2. cd; e) lipiec(I); f) sierpień(I); g) wrzesień(I); h) październik(I); i) marzec(II); j) kwiecień(II); k) maj(II); l) czerwiec(II)
gdzie: (I) – pierwszy rok badań, (II) – drugi rok badań
Źródło: badania własne

m)

Profile	y	1
D	64.4361	****
C	64.8000	****
B	66.5194	****
A	68.4000	****

n)

Profile	y	1	2
C	60.2694	****	
D	61.3306	****	****
B	62.4806	****	****
A	65.4361		****

o)

Profile	y	1
C	64.4028	****
D	66.5833	****
A	68.0444	****
B	68.5361	****

p)

Profile	y	1
D	61.3889	****
C	62.0306	****
B	65.8833	****
A	66.0222	****

Fig. 2. cont.; m) July(II); n) August(II); o) September(II); p) October(I) where: I – first year of the study, II – second year of the study
Source: Authors own research
Rys. 2. cd; m) lipiec(II); n) sierpień(II); o) wrzesień(II); p) październik(II) gdzie: (I) – pierwszy rok badań, (II) – drugi rok badań
Źródło: badania własne

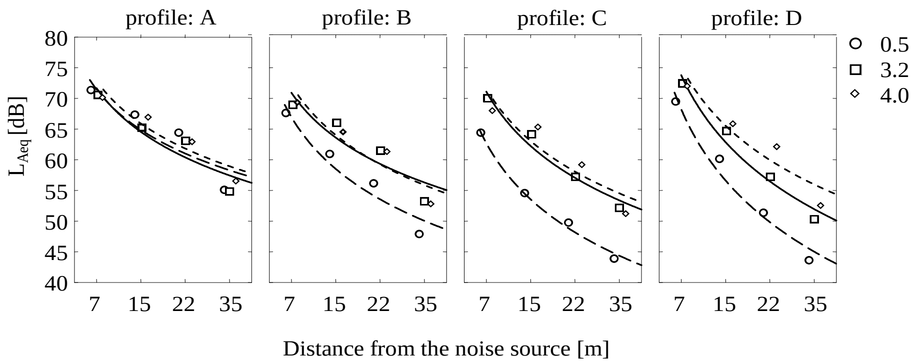

Fig. 3. Chosen approximated and real the sound pressure level changes along the measurement profiles for the results of measurements carried out at the phase of full growth of plants (august(II), height of plant 3.2 m, background noise 32.9 dB, δ = 0.40 dB); *Source: Authors own research*
Rys. 3. Wybrane rzeczywiste i aproksymowane zmiany poziomu ciśnienia akustycznego wzdłuż profili pomiarowych dla wyników pomiarów prowadzonych w fazie pełnego rozwoju roślin (sierpień(II), wysokość roślin 3,2 m, tło akustyczne 39,2 dB, δ = 0,40 dB); *Źródło: badania własne*

Statistically significant differences between measurement profile C and measurement profile A were observed in first year of the study, for measurements taken from July to October, which was a period when Virginia mallow plants reached height of 3 m and were densely leaved. While in second year of the study, on some of measurement days (during same period) no statistically significant differences were noted.

Reports found in literature prove that plants can be used with success in noise suppression. High and wide enough belt of natural vegetation may reduce level of traffic noise [11]. Results of investigations of Kalansuriy and other researchers [4] show that traffic noise of higher frequency (above 4 kHz) is in great degree moderated by plant barrier practically without suppressing low frequencies (bellow 100 Hz). It must be noted that level of sound suppression is directly proportional to the width of plant barrier. On average, plant barrier caused 4 dB noise reduction, what corresponds to 40% reduction of acoustic energy use.

Obtained results correspond with results presented by other authors. Ozer and others [7] stated that, originating from high traffic volume routes, communication noise, especially in big cities, should be reduced by means of planting proper species of plants along cities' main routes. These authors, while investigating traffic noise suppression by pine forest (Pinus sylvestris L. and Populus nigra L.), noted noise reduction from 2.4 to 9.3 dB, when compared with control open space. Hoser and Nowakowski [3] quote example of natural plant screen in Spain, which caused noise reduction from 80 to 65–70 dB, and cite experiments conducted in Pakistan, which show, that natural plant screens can cause 8 dB noise reduction. Such natural plant screens are recommended there as a method of traffic noise suppression. Significant influence of leaves cover on plant screens effectiveness, and 40–60% reduction of noise suppression caused by defoliation, were noted. These authors attempted to evaluate reduction of traffic noise caused by plants in Warsaw area. Research project was based on four natural screens and one technical screen. It was noted that utilization of plant screens may yield similar noise suppression effects as use of technical screens, if between protected area and source of noise there is plant belt of enough width. Moreover, conclusion that technical screens are more effective than plant screens, but only when there is not enough space between protected area and source of noise, was proposed. According to Makarewicz [5] even narrow line of plants e.g. row of single trees has some noise reduction properties. Vegetation of low, measured in dB, "efficiency" shields source of noise and causes change of its spectrum shape by means of dispersion and absorption of high frequencies. Noise in which these parts of spectrum (squeals and creaks) are eliminated is less bothersome. Same vegetation lowers, by means of sound dispersion, pace in which sound level increases and decreases, what also moderates noise unpleasantness. According to this author, plant screens creation is justified only when norms are exceeded no more than 5 dB. Research conducted by various scientists shows that vegetation characterizes with ability to suppress medium frequencies best (500 Hz), that is the range where most of traffic noise energy is accumulated, what favours utilization of plants as acoustic screen [2].

Length of traffic noise acoustic wave is about 0.3 m, and is greater than most of sizes of elements of vegetation. Therefore, significant diffraction of wave emitted by car is observed. For frequencies below 1000 Hz length of wave is greater than 0.3 m, what makes dispersion phenomenon insignificant. For these frequencies, suppression is influenced by ground absorption, which is greater in case of green areas, while for frequencies above 1000 Hz phenomenon of sound dispersion dominates [5, 6]. Therefore, plant screen fulfils its role within whole acoustic spectrum [2].

4. Summary and conclusions

The answer to question, if use of biological acoustic screens is justified, must always be given with respect to particular situation that is dealt with. One shall remember about ecological effectiveness which does not require obtaining absolute effect leading to achieving values of sound level regarded as allowable. In many cases, benefit in form of lowering noise level from very tiresome to acceptable levels of moderate tiresomeness is vital.

Relying on analysis of research results following conclusions can be stated:

1. Pollution of environment with traffic noise, not exceeding threshold values of noise level as well as allowable daytime noise level in environment, for both weekdays and weekends was 57.2 dB and 56.8 dB respectively.

2. Results of research concerning use of Virginia mallow as biological acoustic screen along communication routes, show that most effective noise suppression, by means of above mentioned plant screen, was observed at measurement height of 0.5 m, from May to October. Greatest noise reduction, reaching 13.4 dB, was noted for measurement profile C, 35 m from source of noise. Whereas, at the same distance from the source and same measurement height, mean noise suppression for measurement profiles B, C and D was 4.97 dB, 5,04 dB and 5,45 respectively.
3. It should be noted that leafless vegetation (October) suppressed noise to significantly lesser degree, 3.57 dB for measurement profile C and 35 m from the noise source. In analogous measurement points, noise reduction for measurement profiles C and D was 2.1 dB and 0.4 dB respectively.

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Pasowe nasadzenia ślazowca pensylwańskiego (*Sida hermaphrodita* R.) jako biologiczny ekran akustyczny

Streszczenie

Głównym czynnikiem pogarszania się jakości klimatu akustycznego środowiska, tj. wzrostu hałasu do poziomów dużej i bardzo dużej uciążliwości, jest komunikacja drogowa. Niezbędne staje się podjęcie adekwatnych, optymalnych i skutecznych działań naprawczych – w zakresie ochrony środowiska przed hałasem komunikacyjnym. W pracy przedstawiono wyniki pomiarów równoważnego poziomu ciśnienia akustycznego wzdłuż profili pomiarowych wyznaczonych prostopadle do biologicznego ekranu drogowego, który stanowiły pasowe nasadzenia ślazowca pensylwańskiego o szerokości ok. 15 m i długości 360 m. Pas zieleni składał się z dwóch działek, różniących się rozstawem między rzędami roślin: działka 1 o rozstawie między rzędami roślin 0,75 m i działka druga o rozstawie między rzędami roślin 0,5 m. Działki doświadczalne znajdowały się na różnym poziomie w odniesieniu do płaszczyzny jezdni (droga powyżej otaczającego poziomu terenu). Różnica poziomu drogi w stosunku do działki 1 wynosiła ok. 0,5–0,6 m, a w stosunku do działki 2 ok. 2,0–2,5 m. Wyznaczono cztery różne profile pomiarowe, pomiary prowadzono w czterech odległościach od krawędzi jezdni: 7 m – przed ekranem,15 m – w środku ekranu, 22 m – bezpośrednio za ekranem i 35 m – 13 m za ekranem. Dla każdej z tych odległości, dla danego profilu wykonano pomiary na trzech różnych wysokościach od powierzchni terenu: 2 stałych 0,5 m i 4 m oraz jednej zmiennej, zależnej od wysokości roślin w danej fazie wzrostu. Pomiary wykonywano od marca do listopada, co 30–40 dni. Przedmiotem badań w pomiarach równoważnego poziomu ciśnienia akustycznego (L_{Aeq}) wzdłuż profili pomiarowych był rozkład tego wskaźnika, obiektem badań był dźwięk wzorcowy (hałas komunikacyjny). Badania prowadzono w różnych fazach wzrostu roślin.

Analiza wyników badań równoważnego poziomu ciśnienia akustycznego (L_{Aeq}) wzdłuż profili pomiarowych wskazuje na tłumienie hałasu przez ekran ze ślazowca pensylwańskiego od maja do października. W celu określenia efektywności pasowych nasadzeń ślazowca pensylwańskiego jako ekranu akustycz-

nego dokonano obliczeń redukcji hałasu. Jako referencyjny przyjęto profil pomiarowy bez nasadzeń roślinności. Najwyższe redukcje hałasu, stwierdzono na wysokości pomiarowej 0,5 m, w odległościach pomiarowych 22 i 35 m od źródła hałasu.

Analiza statystyczna uzyskanych wyników badań wykazała na tłumienie hałasu przez ekran ze ślazowca pensylwańskiego, w pełnej fazie wzrostu roślin, na wysokości pomiarowej 0,5 m, w odległości 22 m od źródła hałasu. Doniesienia literaturowe dowodzą, że ekrany roślinne mogą być z powodzeniem wykorzystywane do redukcji hałasu. Odpowiednio wysoki, szeroki i gęsty pas naturalnej roślinności może zmniejszyć poziom hałasu komunikacyjnego.