ASEAN
Journal of Scientific and Technological Reports
Online ISSN:2773-8752

Research article

Reduction of Sound Pressure Levels with Noise Barriers Containing Agricultural Residues: Case Study

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Citation:
Tinnam, P.; Yodpijit, N.; Junsupasen, S.; Sappakittipakorn, M.; Jongprasithporn, M. Reduction of sound pressure levels with noise barriers containing agricultural residues: Case study. *ASEAN J. Sci. Tech. Report.* **2025**, *28*(3), e257762. https://doi.org/10.55164/ajstr.v28i3.257762.

Article history:
Received: February 5, 2025
Revised: May 5, 2025
Accepted: May 12, 2025
Available online: May 31, 2025

Abstract: Over the past decade, PM 2.5 pollution has become an increasingly serious environmental concern in Thailand, with one of its primary sources being the open burning of agricultural residues, particularly sugarcane residues. To mitigate this issue, it is essential to develop alternative applications for sugarcane leaves that eliminate the need for burning. This study investigates a sustainable approach by incorporating sugarcane leaves into producing noise insulation mortar boards. The research aims to assess these boards' acoustic performance through a combination of laboratory experiments and field testing. Employing the Design of Experiments (DOE) methodology, mortar samples were prepared with sugarcane leaf content at 2%, 4%, 6%, 8%, and 10% by cement weight to identify the optimal mixture. Analysis of variance (ANOVA) indicated that the sugarcane leaf content had a statistically significant effect on sound pressure level reduction at a 95% confidence level. Both laboratory and field results demonstrated that the 4% sugarcane leaf mixture yielded the highest performance, achieving noise reductions of 20.6 dBA and 23 dBA, respectively. These findings confirm that mortar boards reinforced with sugarcane leaves effectively reduce noise and offer a viable solution for repurposing agricultural residues. This approach contributes to noise pollution mitigation and addresses environmental concerns related to the open burning of biomass.

Keywords: Agricultural residues; noise insulation; sugarcane leaves; ANOVA

1. Introduction

PM 2.5 is a pollution problem that has affected the environment in Thailand for the past ten years. Burning waste material after sugarcane harvest is a long-standing practice of Thailand's farmers as it can be disposed of quickly and cheaply. Burning sugarcane generates high heat, causing rapid combustion and higher dust vaporization in the air at 2,250 meters and drifting up to 16 kilometers [1]. Sugarcane is one of Thailand's most important cash crops, growing mainly in northeastern and central areas. Each year, a large amount of produce is released to the market. In 2019, Thailand's sugarcane plantations exceeded 78,600 square kilometers, yielding more than 130 million tons [2]. As a result of this output, more than 22 million tons of harvest waste were generated [3]. Currently, there is an inclination to use agricultural residues materials in various production industries due to their main strengths: being cheap and environmentally friendly. Studies have shown that many types of agricultural residue materials are used in the production of sheets to study their properties in various applications, such as thermal protection properties of various fiber crops [4-6], sound control properties from hemp fibers, kenaf fibers, coconut fiber, reed grating, cork, reeds, straw bale [5-7]. Many researchers have studied the physical and structural characteristics of concrete mixed with various natural fibers, including coconut fiber [8-11], corn fiber [12], and bamboo fiber [13]. Regarding noise insulation, sound control properties from concrete mixed with date palm were studied [14]. Concrete with straw fibers has a better sound absorption ability than unmixed materials [15]. Corncob concrete has good sound absorption capabilities in the low-frequency range [16]. From comparing the sound-absorbing properties of concrete with a mixture of 5 substitute materials, it was found that corn cob slit perches with a thickness of 40 mm have the best sound absorption capacity [17]. The review results show the research on developing soundproofing materials using agricultural residues as an ingredient. Most studies focus on sound absorption properties, unlike this research, which focuses on sound transmission protection properties. The literature review [5-7,14,16-17] revealed that most research on the development of soundproofing materials using agricultural residues as a component has focused on sound absorption properties. In contrast, this study emphasizes the characteristics of sound transmission loss. Burning agricultural residues, particularly sugarcane leaves, significantly contributes to PM2.5 pollution in Thailand. This study addresses the urgent need to reduce such practices by developing sound insulation boards incorporating sugarcane leaves, thus providing a practical and environmentally beneficial alternative to waste disposal.

The major goal of this study is to develop and evaluate sound insulation boards made from agricultural residues, specifically sugarcane leaves, as a practical and sustainable solution for industrial noise mitigation. This approach also reduces air pollution, improves waste management, and promotes environmentally friendly building materials. The environmental implications of inappropriate waste disposal methodologies necessitate innovative solutions. Consequently, this research proposes the development of sound insulation panels fabricated from mortar composite incorporating sugarcane leaf waste. This approach serves the dual purpose of waste valorization and potentially mitigating the prevalent practice of agricultural residue incineration, thereby reducing particulate matter emissions and atmospheric pollution. Our methodology employed laboratory-scale prototype development utilizing design of experiments (DOE) principles and Analysis of Variance (ANOVA) for statistical validation. Subsequently, the fabricated panels were implemented in a field environment to evaluate their acoustic attenuation performance through insertion loss measurements, comparing empirical results with theoretical predictions from the laboratory phase.

2. Materials and Methods

2.1 Design of experiments to produce prototype sound insulation boards for laboratory testing

The design of experiments methodology was employed to fabricate sound insulation panels from mortar-sugarcane leaf composite materials. The independent variable in this study was the proportion of sugarcane leaf content, while the dependent variable was the sound transmission loss, measured as reduced sound pressure level. Before the primary investigation, preliminary trials were conducted to determine the maximum proportion of sugarcane leaf material to maintain structural integrity in the composite panels. Results from these preliminary experiments, testing 16%, 13%, and 10% sugarcane leaf content relative to cement weight, demonstrated that specimens with 16% and 13% leaf content failed to achieve adequate structural stability. Consequently, the maximum sugarcane leaf dosage was established at 10%, with subsequent experimental formulations decremented at 2% intervals. The mortar composition ratios utilized in this study are presented in Table 1.

Table 1. Proportion of mortar mixing

Proportion of sugarcane leaves by cement weight (%)	Item weight (kg)			
	Cement	Sand	Water	Sugarcane leave
0	2.880	6.480	1.728	0
2	2.880	6.480	1.728	0.058
4	2.880	6.480	1.728	0.115
6	2.880	6.480	1.728	0.173
8	2.880	6.480	1.728	0.230
10	2.880	6.480	1.728	0.288

The sugarcane leaves used in this research are post-harvest sugarcane leaves from Suphan Buri province, located in central Thailand. The sugarcane leaves are collected, cleaned, dried, and cut into 10-20 mm lengths before being mixed with mortar. This study employed a Portland cement-based mortar mixed by weight at a cement-to-sand ratio of 1:2.25 and a water-to-cement ratio of 0.6. This mix proportion was selected because it falls within the standard range for general-purpose mortar and was verified through preliminary trials to ensure sufficient strength and workability. All samples were subjected to 28 days of air-dried curing before testing to allow for proper hydration and material stabilization. Samples of prepared sugarcane leaves and an insulation plate sample are shown in Figure 1 (a) and (b), respectively.

The acoustic performance evaluation was conducted utilizing a custom-designed sound pressure testing chamber with a dual-compartment configuration, as illustrated in Figure 2. The apparatus consists of a source chamber and a receiving chamber separated by a test aperture where specimens are mounted. Figure 2(a) depicts the interior of the testing cabinet with the positioning of the sound source (on the left) and microphones (on the right) for precise sound pressure level measurements. In contrast, Figure 2(b) demonstrates the installation methodology of the sugarcane-cement composite insulation panel. The specimen was securely affixed between the chambers using hinged mounting brackets to ensure proper sealing and eliminate acoustic leakage. During the experimental procedure, broadband noise was generated in the source chamber, and the sound transmission loss through the test specimen was measured via calibrated microphones in both chambers. This experimental setup complies with standard measurement protocols for determining building materials' sound transmission class (STC), allowing for systematic quantification of the acoustic insulation properties of the fabricated bio-composite panels.

Figure 1. Samples of prepared sugarcane leaves(a) and insulation plate(b)

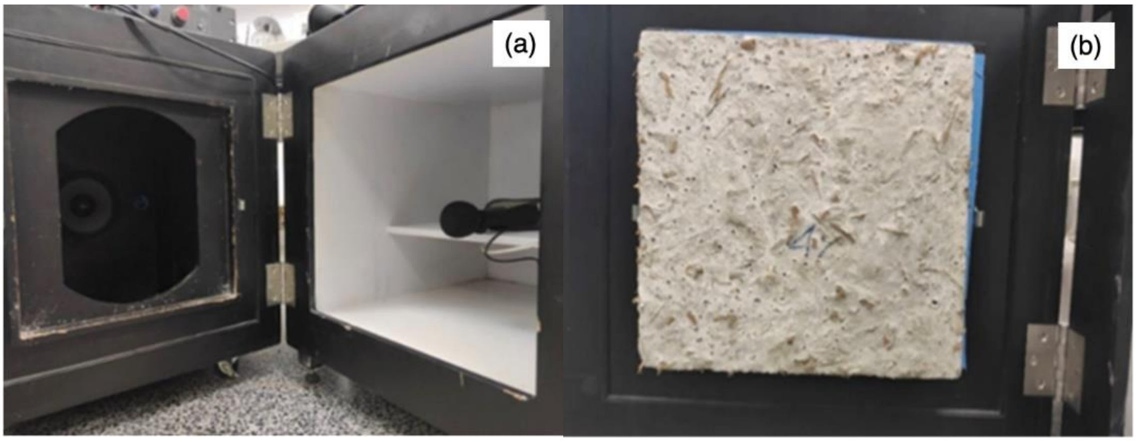

Figure 2. Sound pressure testing cabinet(a) and sample insulation plate during installation(b)

Figure 3. Sound Pressure Meter (Brüel & Kjær model 2270)

Brüel & Kjær model 2270, a noise measurement instrument shown in Figure 3, was used to measure sound pressure levels in the 200-20,000 Hz frequency range in both laboratory and field testing. This measuring device is calibrated in compliance with the IEC 61672-1 standard [18].

2.2 Design of experiments for field testing

2.2.1 Noise survey

The initial field testing phase was conducted at a block brick manufacturing facility, as illustrated in Figure 4, in Suphan Buri province, Thailand. Following site selection, researchers surveyed sound pressure levels, specifically along three sides of the factory perimeter, that generated significant noise pollution affecting the surrounding community. These critical areas were designated as Position A, B, and C, as shown in Figure 5, each representing different boundary interfaces between the industrial operation and neighboring residential zones. Subsequently, after comprehensive acoustic analysis, only the side exhibiting the highest sound pressure levels was selected for intervention. This identified location became the installation site for noise barriers constructed using the developed sugarcane leaf-incorporating mortar plates. This strategic implementation allowed researchers to evaluate the bio-composite barriers' maximum potential noise reduction capability under the most challenging real-world conditions.

Figure 4. Example of a machine used in the production of brick blocks

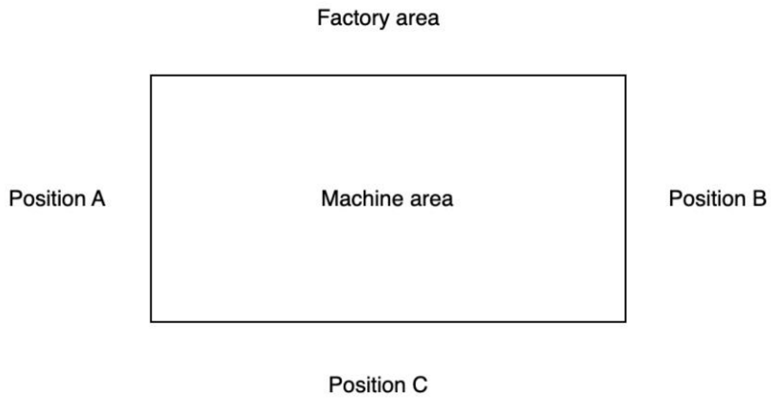

Figure 5. Position A, B, and C

2.2.2 Design and installation of noise barrier

The sample soundproof wall, a size 15 meters wide and 3 meters high, was designed and constructed from mortar mixed with sugarcane leaves and was installed in position C, as shown in Figure 6, where the sound pressure level was initially measured and found to have the highest sound pressure level to test for insertion loss. The barrier was located 3 meters from the noise source (block brick machine), as shown in Figure 7. The method for measuring in this work is a direct insertion loss measurement based on ISO 10847:1997 [19], which involves measuring the sound pressure in the same area before and after the sound barrier's installation. The sound pressure meter was positioned 5 meters away from the barrier and 1.5 meters above the ground, and the fabrication and installation of the noise barrier were illustrated in Figure 8 [20-22]. The production and installation of the noise barrier are shown in Figure 8. The findings on the mortar plate tests in the laboratory revealed that incorporating sugarcane leaves, at 2-10% by weight, resulted in a greater reduction in sound pressure levels compared to plates without sugarcane leaves. Among the tested variations, the 4% sugarcane leaf addition achieved the most significant reduction of 20.6 dBA. Based on these preliminary results, the researcher selected the 4% sugarcane leaf mixture for further testing in this field testing. Previous studies indicated that sound reflections from building ceilings and diffraction over the upper edge of partition walls are recognized transmission paths that can markedly degrade barrier performance. Ceiling reflections have been shown to lower indoor barrier insertion loss [23]. A 3-meter-high wall constructed from sugarcane leaves was strategically positioned to minimize diffraction by increasing the vertical obstruction to sound waves. In addition, an absorptive ceiling treatment using mineral wool was specified to reduce sound reflections from the ceiling surface, which is known to lower indoor barrier insertion loss. Together, these measures were intended to enhance the acoustic performance of the barrier by mitigating both ceiling reflections and diffraction-induced sound transmission, thereby improving the overall noise reduction within the enclosed space.

Figure 6. Production soundproof plate(a) and installation soundproof wall(b)

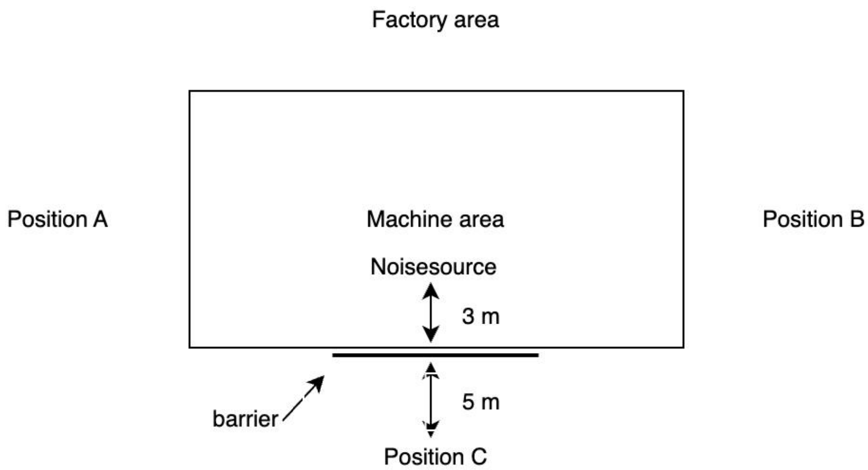

Figure 7. Position and distance for sound measurement (top view)

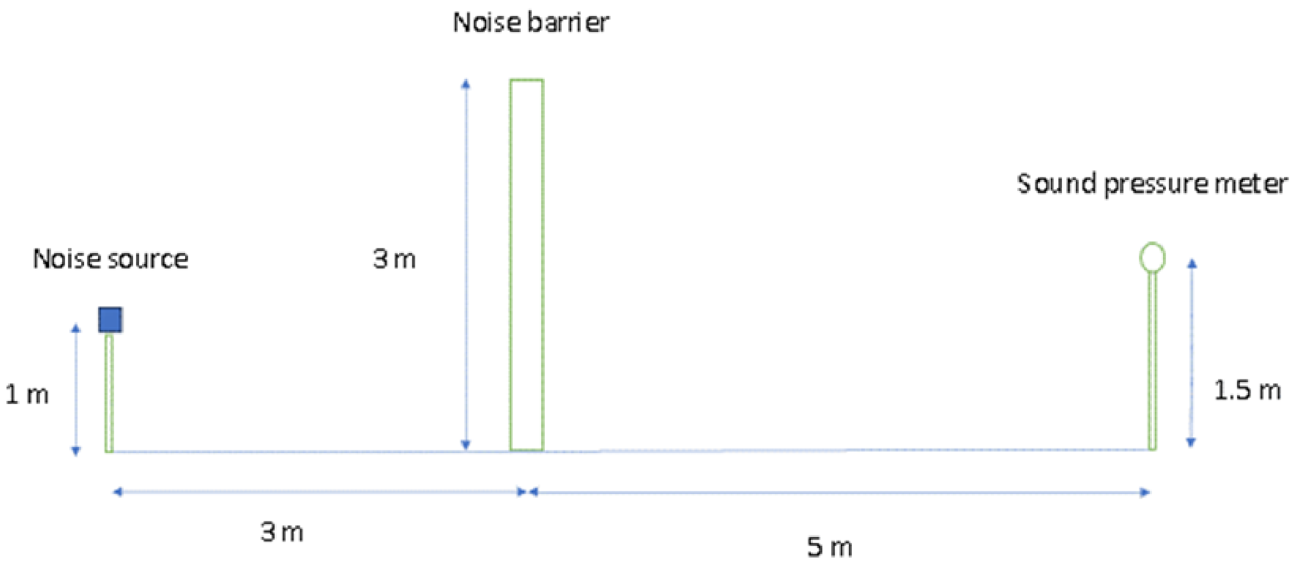

Figure 8. Position and distance for sound measurement (side view)

3. Results and Discussion

3.1 Sound pressure reduction test results and statistical analysis

The results of the laboratory sound reduction ability test are shown in Table 2.

Table 2. Test results of sound pressure reduction of sample insulation plates

Sample	Reduction of sound pressure levels at various sugarcane leaf proportions (dBA)					
	0%	2%	4%	6%	8%	10%
Sample 1	10.22	19.95	20.40	15.50	17.53	17.03
Sample 2	10.03	19.59	20.76	15.89	17.36	16.51
Sample 3	10.35	17.91	20.64	16.01	16.98	16.26
Average	10.20 ± 0.16	19.15 ± 1.09	20.60 ± 0.18	15.80 ± 0.27	17.29 ± 0.28	16.60 ± 0.39

The table shows that adding sugarcane leaves to insulation plates generally improves sound pressure reduction, with the best performance observed at a 4% proportion (average of 20.6 dBA reduction). Increasing the sugarcane leaf proportion beyond 4% decreases sound insulation effectiveness, although it remains better than the baseline (0% sugarcane leaves). There is some variation in performance between the three samples tested, but the overall trend holds. Data analysis was carried out using the Minitab program version 19. The data were analyzed for variance by determining a significance level of 0.05. The results are summarized as shown in Table 3.

Table 3. Statistics analysis results

Source	DF	Adj SS	Adj MS	F-Value	P-Value
% Sugarcane leaves	5	193.735	38.7470	150.01	0.000
Error	12	3.100	0.2583		
Total	17	196.835			

From the ANOVA, a P-value of 0.000 less than the 0.05 significant level indicates that the main hypothesis is rejected, so it can be concluded that the proportion of sugarcane leaves affects the ability to reduce the sound pressure level at a significant level of 0.05.

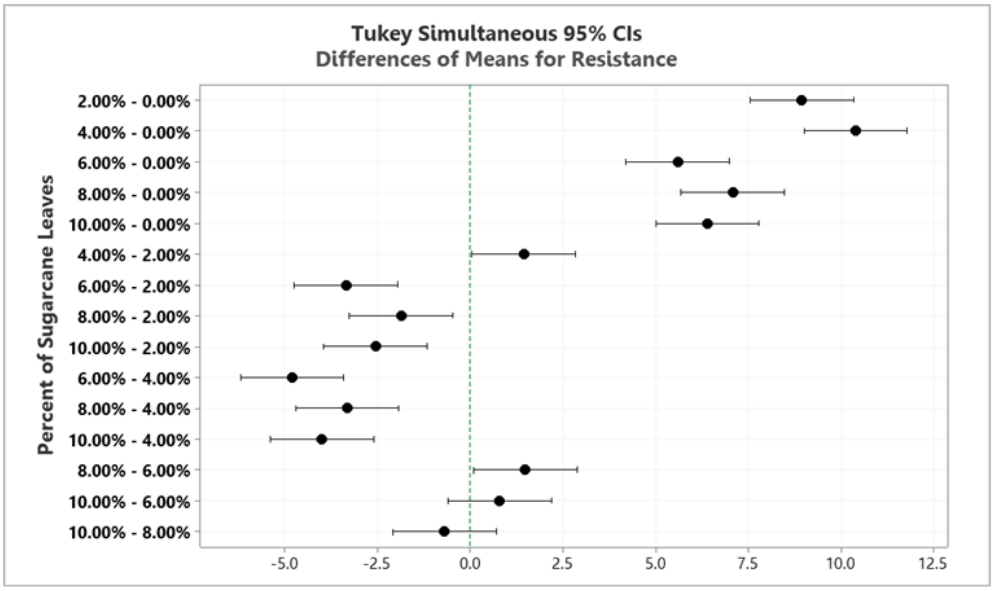

Figure 9. Comparison of Tukey Simultaneous 95%

The results of Tukey Simultaneous 95% CIs showed that the ability to decrease sound pressure level of the proportion of sugarcane leaves between (6%,10%) and (8%, 10%) are not significantly different, and all of the other pairs are significantly different as shown in Figure 9.

According to the test results, there is a difference in soundproofing properties between mortar without sugarcane leaves and sugarcane leaf blend, likely because sugarcane leaves increase pores in the mortar, which is similar to the other studies [14, 24], which concluded from the study of the sound-regulating properties of corn- crop mixing in concrete.

3.2 Preliminary sound pressure measurement results

The results of measuring sound pressure levels in the factory area at frequencies between 12.5-16000 Hz and A-Weighting at 3 positions (A, B, and C) are illustrated in Figure 10.

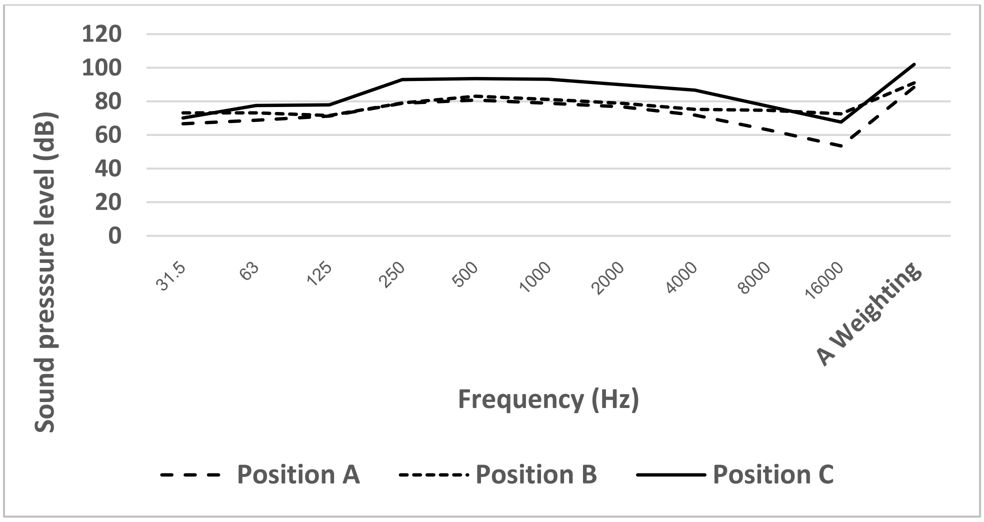

Figure 10. Sound pressure measurement results at positions A, B, and C

Sound pressure measurements in all three predetermined areas showed that the maximum sound pressure levels were measured within the frequency range of approximately 500 Hz. Sound pressure levels tend to decrease as frequency increases. A-Weighting showed that the position C region had the highest level, approximately 102 dBA, which the researcher selected to install a noise barrier.

3.3 Sound pressure measurement results after installing noise barrier

The results of the sound pressure measurement at 1/3 octave in the frequency range of 31.5-16000 Hz at position C before and after the installation of the noise barrier are shown in Figure 11. In addition, insertion loss (IL) represents the reduction in sound pressure achieved by the barrier, calculated by subtracting the sound pressure level measured after installation from the level measured before.

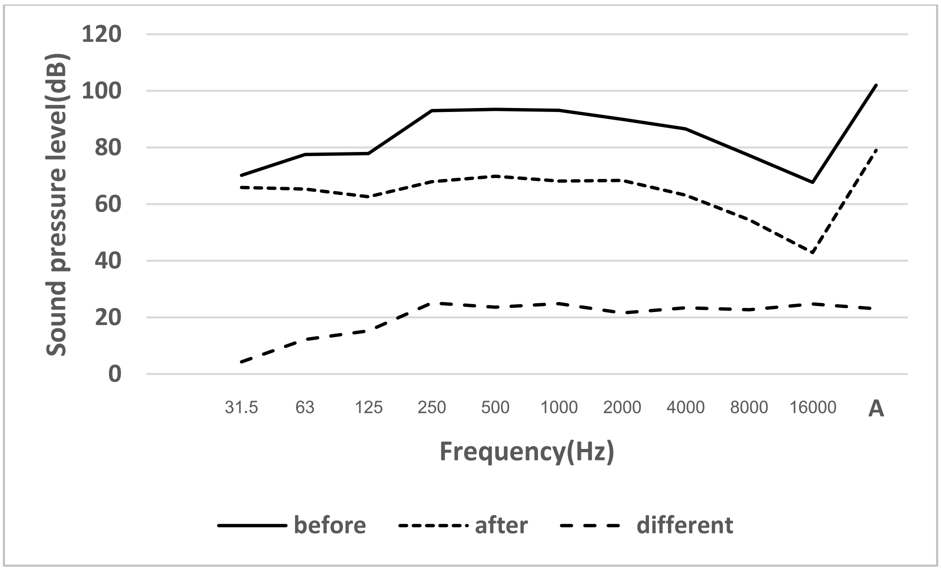

Figure 11. Sound pressure level measurement results before and after the installation of the barrier

Figure 11 shows that in the low-frequency range, the insertion loss (IL) value is small and tends to increase to the frequency level of 250 Hz. When the frequency level is greater, the IL value is relatively stable or slightly reduced, similar to the other studies [20-21], which found that IL values are high in the range of 250-8000 Hz. Similar to corn cob and sunflower stalk [25], sugarcane leaves, when incorporated, improve the sound-absorbing properties of cement-based composites. The developed sound insulation boards offer a practical and sustainable solution for industrial noise mitigation by effectively utilizing agricultural residues, such as sugarcane leaves. This approach contributes to improved waste management and reduced reliance on conventional building materials and has the potential to lower air pollution associated with open burning or improper disposal of agricultural residues. Although the experimental formulation incorporated only 4% sugarcane leaves by weight, scaling up production for industrial applications could significantly enhance the cumulative environmental benefits by promoting large-scale waste valorization and minimizing the negative impacts of traditional disposal practices. As shown in Table 4, the developed sugarcane leaf insulation panels achieved a sound pressure reduction of 20.6 dBA, outperforming lightweight concrete panels, which recorded 11.9 dBA, and demonstrating comparable performance to commercially available acrylic panels (17.35–18.26 dBA). These results highlight the potential of sugarcane leaf panels as a cost-effective and environmentally friendly alternative for industrial noise reduction applications. From an economic perspective, utilizing agricultural residues in the production of insulation boards significantly reduces raw material costs, making the product a financially viable option for manufacturers. Additionally, this approach creates value for agricultural by-products, offering potential income streams for farmers and thereby supporting economic sustainability in parallel with environmental benefits.

Table 4. Test results of the ability to reduce the sound pressure level of other types of insulation boards

Type of insulation board/thickness (mm)	Reduction of sound pressure level(dBA)
Mortar /50 mm	10.20
Mortar mixed with 4% Sugarcane leaves /50 mm	20.60
Acrylic sheet/5 mm	17.35
Acrylic sheet/10 mm	17.95
Acrylic sheet/20 mm	18.26
Lightweight Concrete/50 mm	11.90

4. Conclusions

The burning and destruction of agricultural residues is a major environmental problem in Thailand. A significant contributor to this issue is waste disposal from sugarcane harvesting, an important cash crop in the country. Addressing this problem, the researcher conceived the idea of managing such waste materials by incorporating them into mortar mixtures to enhance the noise-blocking potential of sound insulation sheets. The principles of experimental design were applied to the development and production of sample sound insulation panels to test their sound pressure reduction properties. The test results indicated that the sound insulation board with a 4% sugarcane mortar mixture achieved the highest sound pressure level reduction, equal to 20.6 dBA. This optimal proportion was then used in designing, constructing, and installing sound insulation walls for a case study in a real-world factory setting. The study's evaluation of the soundproof wall's effectiveness, determined by measuring the insertion loss, showed a reduction of 23 dBA in sound pressure level after installation. Based on these findings, it can be concluded that soundproofing walls made from mortar mixed with sugarcane leaves have significant potential for development into effective sound insulation sheets. Furthermore, developing such insulation sheets adds value to post-harvest sugarcane leaves, potentially incentivizing farmers to adopt alternative waste disposal methods and contributing to mitigating environmental problems like PM 2.5 dust in a sustainable future. Future research should focus on a comprehensive evaluation of the long-term durability and mechanical stability of the developed sugarcane leaf insulation panels under various environmental and operational conditions. In addition, further studies are required to develop and refine fabrication techniques that allow for the incorporation of higher proportions of sugarcane leaves without compromising structural integrity or acoustic performance. Investigating the scalability of the production process is also essential to determine its feasibility for widespread industrial application. Moreover, expanding the scope of research to include other types of agricultural residues, such as rice husks, coconut fibers, or corn stalks, may contribute to developing a broader range of sustainable and cost-effective insulation materials. This would further enhance the environmental and economic impact of agricultural residues in building applications.

5. Acknowledgements

The Office of the Cane and Sugar Board of Thailand supported this research.

Author Contributions: Conceptualization, P.T., and N.Y.; methodology, P.T. and N.Y.; validation, P.T.; formal analysis, P.T.; data curation, P.T.; writing—original draft preparation, P.T. and N.Y.; writing—review and editing, P.T., N.Y., M.S., M.J., and S.J.; funding acquisition, N.Y. All authors have read and agreed to the published version of the manuscript.

Funding: The Office of the Cane and Sugar Board of Thailand (Contract no. 06/10/2563) financially supported the research.

Conflicts of Interest: The authors declare no conflict of interest.

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