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BIOCOATINGS AS A STRATEGY FOR MITIGATING AMMONIA EMISSIONS FROM MANURE: INFLUENCE OF APPLICATION PRACTICES

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The application of organic coatings (straw, peat, hemp chaff, sawdust) in liquid manure and slurry management is a promising means of reducing NH_3 emissions, related to nutrient conservation and soil quality. A two-chamber experiment was performed at the VMU-AA Thermoenergetic Processes and Emissions Laboratory: 15 L of homogenised cattle manure was stored under identical conditions with and without coatings, systematically increasing the coating thickness. NH_3 concentration was measured with a laser analyser, emissions were calculated using the mass flow method; statistical significance was assessed by ANOVA and Tukey HSD ($p < 0.05$). Emission reduction efficiency increases with cover thickness; hemp chips or sawdust at ~10 cm is a reliable and economical compromise; peat (≥3–5 cm) almost eliminates emissions, but raises sustainability issues; straw is an intermediate, more volatile solution. The decrease in efficiency is explained by processes controlled by porosity and capillary transport.

Keywords: *ammonia, environment, bio-covers, air pollution, dairy cattle.*

INTRODUCTION

Manure and slurry covers, such as straw, peat, and sawdust, have garnered significant attention in agricultural practices due to their impact on soil health, nutrient retention, and greenhouse gas emissions. These organic materials play a critical role in managing manure applications, influencing both the physical characteristics of the soil and the environmental outcomes associated with livestock slurry storage and application.

Straw is widely recognised for its potential as a bedding and cover material for livestock slurry. Its use can help reduce ammonia emissions by absorbing moisture and creating a physical barrier that limits the exposure of slurry to air, which mitigates volatilisation processes leading to nitrogen losses as ammonia gas (Rosvold & Andersen, 2019; Swoboda et al., 2021). However, utilising straw can pose management difficulties due to the risk of straw falling through slatted floors, obstructing drainage systems (Rosvold & Andersen, 2019)(Rosvold & Andersen, 2019). Thus, while straw offers advantages in reducing gaseous emissions, careful management strategies are needed to maximise its benefits while mitigating its risks.

Peat, another frequently used organic material, stands out for its remarkable cation exchange capacity and ability to stabilise nutrients, including heavy metals, in contaminated soils (Lee & Ahn, 2023; Rakotonimaro et al., 2019). When mixed with livestock slurry, peat can enhance the nutrient retention capabilities of the slurry, improving its utility as a fertiliser in agricultural applications. Additionally, peat's unique structural properties can improve soil aeration and water retention, supporting crop productivity (Lee & Ahn, 2023). However, the extraction of peat raises sustainability concerns due to its potential impact on carbon sequestration and biodiversity (Liang et al., 2024). Thus, there is a pressing need to balance the utilisation of peat with environmental considerations.

Sawdust, similar to straw and peat, can also be employed as a cover for slurry. It promotes physical and microbial interactions that can convert slurry constituents into stable organic matter. Furthermore, sawdust can contribute essential nutrients back into the soil, enhancing soil structure and water-holding capacity (Min et al., 2020). Nevertheless, the carbon-to-nitrogen (C/N) ratio of sawdust is typically higher than that of other organic materials, which can influence microbial activity during decomposition processes (Yamika et al., 2019). Therefore, combining sawdust with other nitrogen-rich materials may help maintain an optimal balance in nutrient cycling within the soil.

In terms of managing slurry applications, organic covers can significantly reduce nitrogen losses. Evidence indicates that covering slurries with materials such as straw or peat contributes to lower ammonia volatilisation compared to uncovered slurry applications, which is crucial in conservation agriculture practices, where minimising soil disturbance and maximising nutrient retention are pivotal for sustainability (Silva et al., 2022a, 2022b). Moreover, the selection of appropriate organic covers must consider factors such as climatic conditions, microbial dynamics, and soil characteristics to ensure optimal performance.

In summary, the use of organic materials such as straw, peat, and sawdust as covers for manure and slurry applications offers a multifaceted approach to improve soil health, nutrient retention, and environmental sustainability. While these organic materials present notable benefits, careful consideration of their management and sustainability implications is essential for effective agricultural practices.

RESEARCH METHODS

To quantify the effect of bio-coatings on ammonia (NH3) emissions, an experiment was conducted at the Thermoenergetic Processes and Emissions Laboratory (Vytautas Magnus University Agriculture Academy (VMU-AA)), using the research bench depicted in Figure 1.

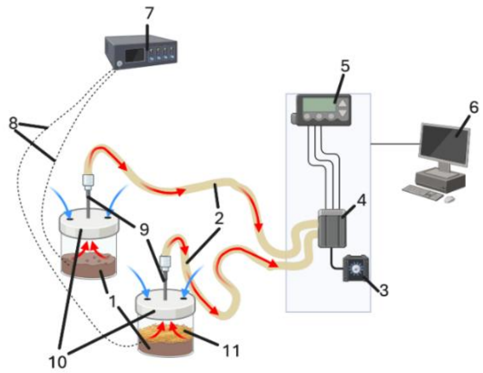


Figure 1. Schematic image of the research bench: 1 – NH_3 gas source (manure); 2 – heated air supply hoses; 3 – membrane air pump; 4–electrically heated three-channel valve; 5 – laser gas analyzer GME700; 6 – data collecting computer (AMR software); 7 – data accumulator-gauge “Almemo 2590-9”; 8 – thermocouples; 9 – air sampling probes; 10 – manure chamber; 11 – bio-cover; → – clean air; → – air contaminated with NH_3.

Fresh liquid cattle manure was collected at the VMU-AA Training farm. Cattle were fed a mixed ration comprising straw, maize silage, grass silage, hay, ground wheat, barley, oats, rapeseed oilcake, soy grits, and water, supplemented with essential minerals, nutritional additives, and trace elements.

The collected slurry was homogenised in a bulk container and portioned into two cylindrical chambers (height 37 cm; diameter 32 cm, volume 30 L) (10). Chamber I served as an untreated control. Chamber II received organic surface covers (11) – straw, peat, hemp chaff, and sawdust. Once NH3 emission reached a steady state, the cover thickness was gradually increased. Each chamber contained 15 L of slurry and was operated under identical environmental conditions (air temperature and near-surface airflow).

Ammonia concentrations were measured with a laser spectroscopic analyser GME700 (SICK MAIHAK GmbH, Germany) (range: 0–2000 ppm; accuracy: 2–4%). The system supports continuous or cyclic automated data acquisition with on-board data storage. Heated sampling lines (2) and a heated three-channel valve (4) prevent condensation and contamination of the measurement cell, enabling accurate readings in < 360 s. At an airflow of 6 L min^{-1} and $NH_3 \leq 30$ ppm, readings stabilise within 60–80 s.

Air temperature and humidity were monitored using sensors connected to an “Almemo 2590-9” (Ahlborn GmbH, Germany) data logger (7). The temperature measuring range was – 30–60 °C and relative air humidity 5–98%, with an instrument accuracy of ±0.1%. Airflow intensity was determined with the same logger interfaced to an anemometer installed in the supply duct near sampling probes (9). Duct airspeed was measured and converted to volumetric flow (range 0–10 m s^{-1}; accuracy ±0.1 m s^{-1}). Manure temperature was measured using Cu–CuNi thermocouples (8) of 0.5 mm diameter (range −25 to 200 °C; resolution 0.1 °C), connected to the “Almemo 2590-9.”

NH_3 concentrations in sample air (ppm) were converted to NH_3 emission intensity per unit manure surface area (mg m^{-2} h^{-1}) and ventilation intensity per unit surface area (m^3 m^{-2} h^{-1}) using the mass-flow approach:

$$E_{NH_3} = (C_o - C_e)G, \quad (1)$$

where C_e – NH_3 concentration in the air entering the manure chamber (Fig. 1), mg m^{-3};
C_0 – NH_3 concentration in the air exiting the chamber, mg m^{-3};
G – manure chamber ventilation intensity, m^3 h^{-1}.

Data were summarised as arithmetic means with corresponding confidence intervals. Statistical significance was evaluated at α = 0.05 using two-way ANOVA followed by Tukey’s HSD test. Results are presented using descriptive statistics.

RESEARCH RESULTS AND DISCUSSION

Ammonia emissions from manure can be significantly reduced when straw cover is used. In 2020, Perta et al. conducted research that found a 12% straw cover efficiency (Perta et al., 2020). Matulaitis et al. (2015) found that straw cover can reduce ammonia emissions by up to 64.4 %(Matulaitis et al., 2015). The study found that straw reduced NH_3 emissions from 43.7% (5 cm) to 74.5% (8 cm) and ~79.4% (12 cm) (Fig. 2a). Without the coating, the change in ammonia release to the environment was insignificant at about 4.3% and 9.0%. In one case, NH_3 emission increased by 4.11%.

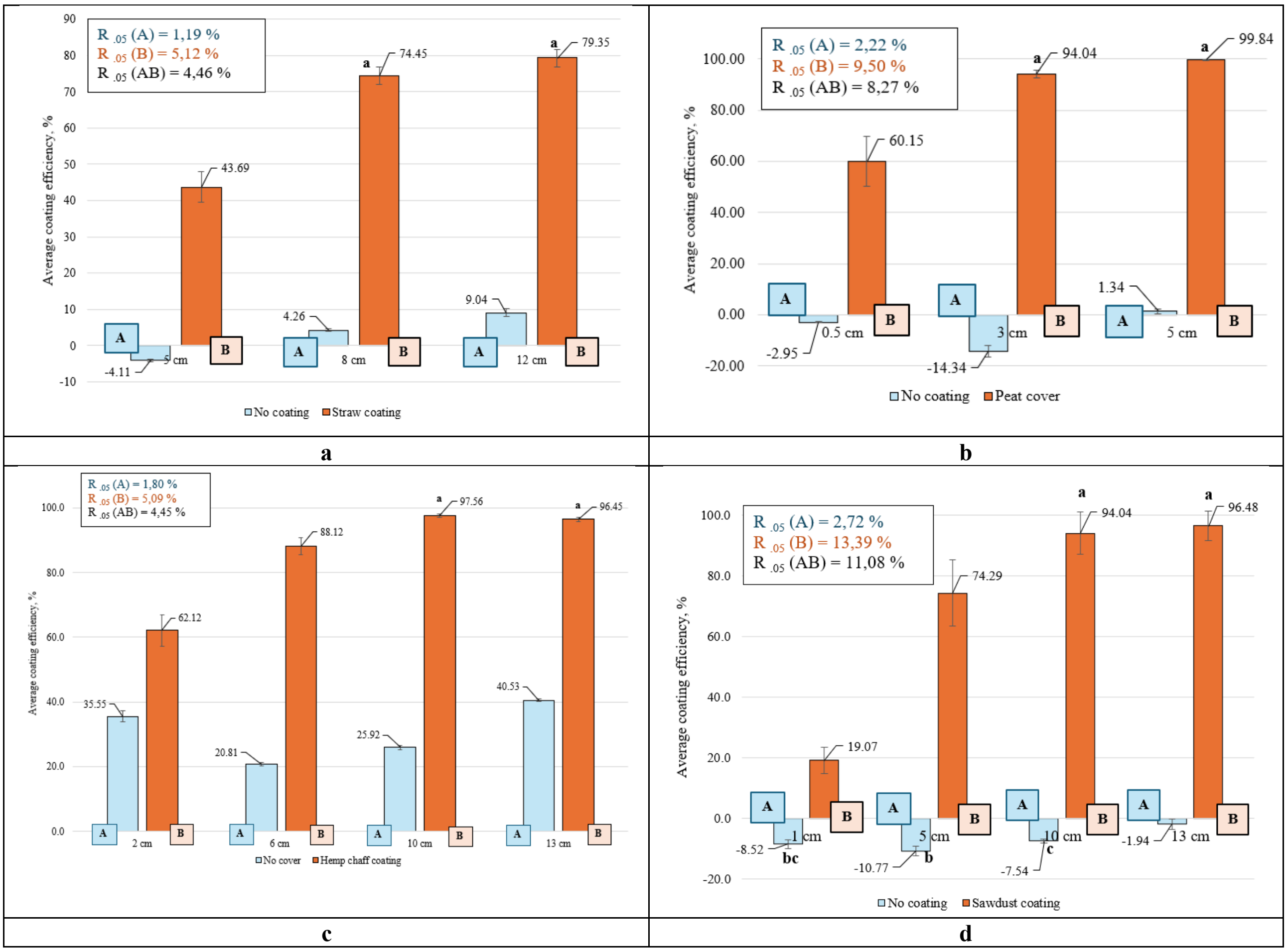


Figure 2. The capability of different bio-coating types and thicknesses in reducing NH3 emissions from dairy cattle manure: (**a**) straw coating; (**b**) peat cover; (**c**) hemp chaff coating; (**d**) sawdust coating.

Scientists also argue that to achieve good efficiency, the depth of the peat layer must be ~20 cm to achieve a significant reduction in NH_3 volatilisation (Barrington & Moreno, 1995). However, the study found that even 0.5 cm of peat provided ~60.2% reduction, 3 cm – ~94.0%, and 5 cm – ~99.8% (Fig. 2b). Without the cover, air pollution with ammonia gas increased by 3.0%–14.3%. Peat is the most effective cover; ≥3 cm practically eliminates emissions. However, it is believed that it is related to the pH parameters of the peat cover. Moreover, the extraction of peat from natural reserves affects carbon sequestration and can impact biodiversity in ecosystems (Hoti et al., 2022).

Studies have shown that hemp bedding, particularly in its chaff form, possesses properties that make it effective for manure covering. Hemp is known for its high absorbency, which limits the growth of bacteria. Also, various research indicates that hemp exhibits a lower environmental impact when composted or digested by livestock (Islam & Hasan, 2024; Masebo et al., 2025). In addition, the effect of covering the manure with hemp chaff has a significant impact: 62.1% (2 cm), 88.1% (6 cm), 97.6% (10 cm) and 96.5% (13 cm). 10 cm onwards, additional thickening does not significantly improve the effect - 10 cm is sufficient to achieve >95% efficiency (Fig. 2c).

The incorporation of sawdust in manure management systems can significantly improve environmental outcomes due to its favourable physical properties. According to Tuffour (2022), sawdust must be applied at a 10-20 cm thickness to ensure maximum benefit (Tuffour, 2022). During the trial, a thin layer of 1 cm reduced NH_3 emissions by ~19.1%, but 5 cm already gave the efficiency of ~74.3% (Fig. 2d). Further thickening to 10–13 cm reached ~94.0–96.5% of effectiveness. However, there is no statistically significant difference between the results of the 10 and 13 cm thick layers. Therefore, using a sawdust layer thicker than 10 cm is uneconomical.

All organic coatings significantly reduced NH_3 emissions, and the efficiency increased with increasing coating thickness. however, the probability of achieving the desired coating efficiency varies greatly (Fig. 3).

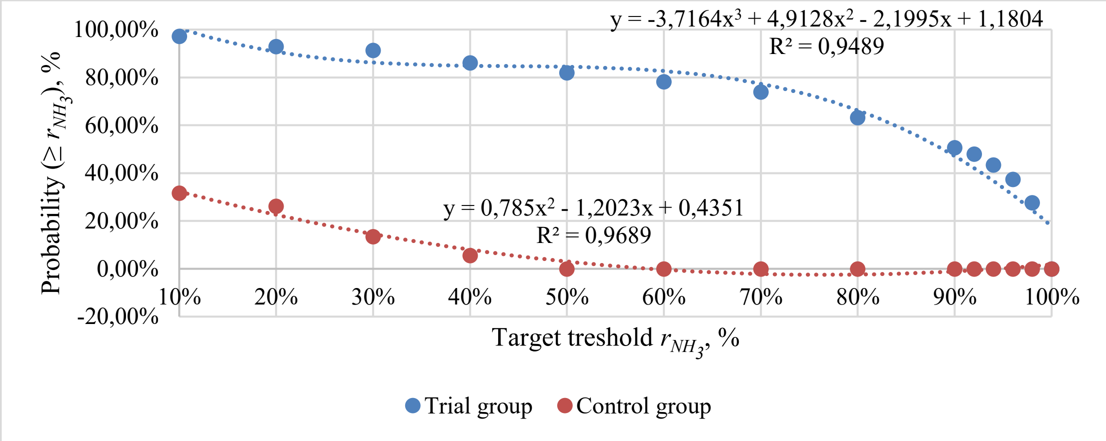
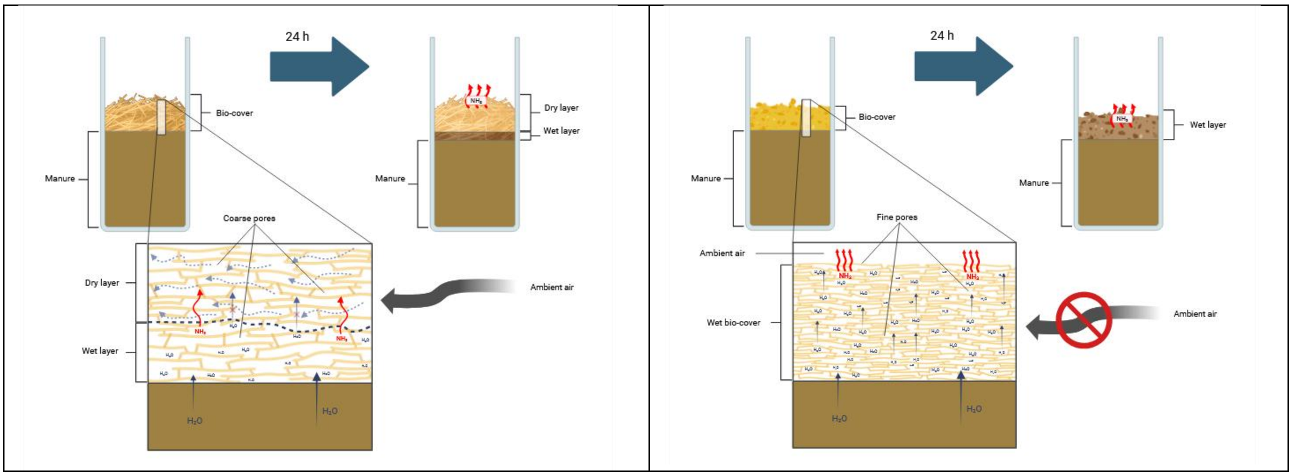


Figure 3. Probability of ammonia emission reduction.

Although studies show that ammonia emissions into the environment can be reduced by almost 100% with some coatings, the probability of such effectiveness is negatively correlated according to a parabolic model ($R^2 \approx 0.95$) with the coating's ability to reduce ammonia emissions into the environment. Based on more than 500 data points, covering manure with any type of coating has a more than 91.39% chance of reducing ammonia emissions into the environment by up to 40%. However, the probability of achieving 90% coating efficiency decreases to 50.62%. The probability of peat coverage efficiency reaching 98% or more, as determined during the study, is only 27.59%.

In comparison, with natural processes occurring and no manure covering used, the probability of ammonia emissions decreasing by at least 10% within the first 24 hours is only 31.71%. The largest recorded reduction without using manure cover was 42.10%, but the probability of such an event is only 5.57%.

It is hypothesised that variable stability of manure covers is due to such bio-cover parameters as porosity, material particle size, and the ability to absorb liquids (Fig. 4).



a **b**

Figure 4. The process of ammonia evaporation from manure covered with high-porosity (**a**) and low-porosity (**b**) materials.

Ammonia enters the environment from manure through convective mass exchange. This process is promoted/inhibited by differences in gas concentrations on the manure surface and in the ambient air. When the manure coating consists of large particles (Fig. 4a), the instantaneous coating efficiency (in the first hour) can reach more than 90%. However, as ambient air penetrates deeper layers of the coating and ammonia-contaminated air rises from the manure surface, the coating's effectiveness decreases to 38–45%. Using manure covers made of fine particles solves the problem that ambient air eventually still reaches ammonia-contaminated air through the large pores of the coating. However, when manure is covered with such materials, nitrogen-contaminated water, or slurry, moves towards the surface of the manure cover due to the capillary process of fluid movement. Within 24 hours of manure cover application, the efficiency of manure coatings consisting of fine particles decreased from >99% to 19–69%.

CONCLUSIONS

1. Mitigation efficacy is thickness-dependent with diminishing returns. Peat exhibits the highest efficacy (≈94% at 3 cm; ≈99.8% at 5 cm), hemp chaff achieves ≥95% at 10 cm, sawdust reaches ≈94–96.5% at 10–13 cm with no statistical gain beyond 10 cm, while straw is variable (43.7–79.4% at 5–12 cm).

2. Probabilistic performance declines at high targets. A quadratic (parabolic) negative relationship ($R^2 \approx 0.95$) links efficacy to its probability: ≤40% reduction is highly probable (>91%), ≥90% drops to ~50.6%, ≥98% only ~27.6%.
3. Transport mechanisms explain decay in efficacy. Coarse, high-porosity covers initially suppress convective NH_3 transfer (>90%) but lose performance as pore-scale aeration develops (to ~38–45%); fine-particle covers limit aeration yet promote capillary wicking of NH_3-laden liquid, dropping >99% to ~19–69% within 24 h.
4. For robust abatement with cost-effectiveness, hemp chaff 10 cm or sawdust 10 cm are recommended; peat (≥3–5 cm) offers near-elimination but entails adverse life-cycle impacts on carbon sequestration and biodiversity. Straw provides moderate, more uncertain control and may suit low-cost contexts.

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