Odour mitigation in digestate-based biofertilizers by functional additives: ammonia capture with biochar, zeolite and ammonium sulphate

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Ammonia emissions from organic fertilizers derived from anaerobic digestion residues constitute a significant environmental and social challenge, particularly within sustainable waste management and nutrient recycling frameworks. Digestate-based fertilizers, despite their agronomic value, often suffer from nitrogen losses and odour emissions, limiting their broader acceptance and practical application.
This study evaluates selected functional additives—natural zeolites, digestate-derived biochar, and ammonium sulfate—as tools for mitigating ammonia volatilization from granulated fertilizers produced from the solid fraction of digestate. Laboratory incubation experiments were performed under controlled conditions, and ammonia emissions were quantified over a seven-day period using acid trapping and spectrophotometric analysis.
The results demonstrate that clinoptilolite-rich natural zeolites significantly reduce ammonia emissions, achieving approximately 50% lower NH_3 release at a 10% (w/w) addition rate compared to untreated digestate. Biochar showed a moderate, dose-dependent mitigation effect, while ammonium sulfate increased ammonia emissions due to unfavourable chemical interactions in alkaline digestate matrices.
The findings confirm that zeolite-amended granulated digestate represents an effective and scalable solution for reducing emissions, enhancing nitrogen use efficiency, and improving the environmental performance of waste-derived fertilizers. This approach supports circular economy objectives and aligns with EU strategies for sustainable waste management and ammonia emission reduction.

Ammonia emission was determined from standardized DEMO solid digestate shown in Fig. 1. Milled digestate was placed in an airtight jar for a seven-day period. A laboratory beaker containing the absorption solution (5% H_2SO_4) was placed inside the jar to quantify captured NH_3. After the test, the ammonia concentration in the sulfuric acid absorption solution was determined using the spectrometric indophenol method and recalculated based on the initial digestate sample mass. Duplicate samples were prepared for each variant. The chemical composition of the digestate is presented in Table 1. The following treatment variants were assessed: 5 g ammonium sulphate, 1 g and 5 g biochar, and 1 g, 5 g, and 10 g of Zeolite 1 or Zeolite 2, per 100 g of digestate, plus a control (100 g with no additives). The results are presented in Fig. 2. Sample 1, which contained ammonium sulphate, showed ammonia emissions of 1715.9 mg per kg of digestate (data not shown in Fig. 2).

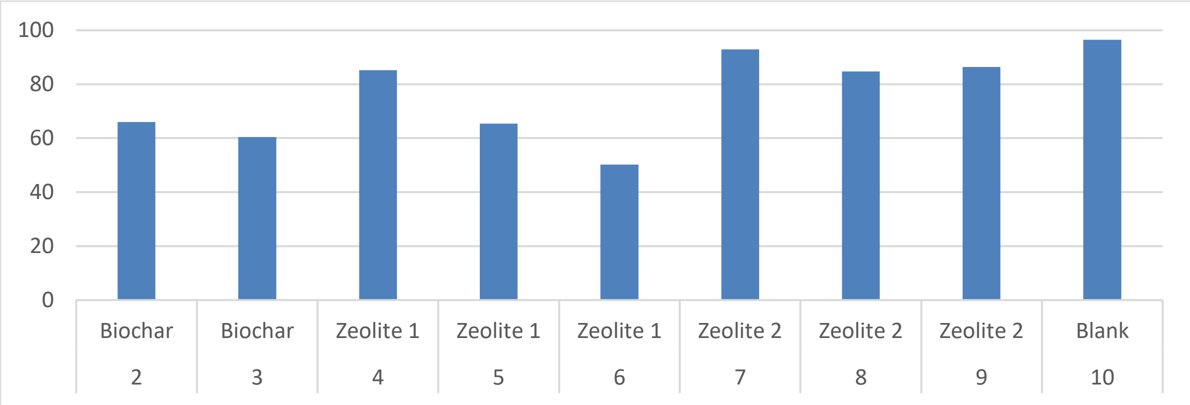
Table 1. Physical-chemical parameters of tested digestate

Parameter	Unit	Value
pH (water extract)		9.99
Dry mass	[%]	80.85
Total organic carbon	[%]	24.18
Total Nitrogen	N [%]	2.39
Phosphorus	P_2O_5 [%]	4.62
Potassium	K_2O [%]	5.70

Fig 1. Pelletized solid fraction of digestate

Unlike to zeolites, ammonium sulphate is decomposed by alkaline digestate by locally increasing the pH within the granule micro-environment and by providing ammonium ions in solution, shifting the NH_3/NH_4^+ equilibrium towards volatile ammonia. Hence, digestate shall not be combined with ammonium fertilizers to avoid ammonia loses.

Fig 2. Ammonia emission from pelletized digestate with additives [mg/kg of digestate].



Key findings are summarized as follows:

- Biochar at 1% w/w: Moderate, but measurable reduction in NH_3 capture compared to the control. The effect is consistent with the known adsorptive capacity of biochar for NH_4^+, though at this loading rate it remains below the threshold described in the literature as sufficient for effective control (~4% w/w).
- Biochar at 5% w/w: Substantially stronger mitigation effect (~38% lower emission compare to control), confirming a dose-dependent response and alignment with published data on biochar-digestate interactions.
- Zeolite 1 at 1 and 5% w/w: Progressive reduction in NH_3 emission (~12-32% lower emission compare to control), demonstrating a clear dose-response relationship consistent with progressive saturation of exchange sites.
- Zeolite 1 at 10% w/w: Strongest mitigation among all treatments tested, representing a reduction of approximately 48% compared to the untreated control. This result confirms that clinoptilolite-type zeolite at ≥10% w/w addition rate can achieve nitrogen retention efficiencies consistent with the upper end of the literature-reported range.
- Zeolite 2 at 1–10% w/w: Less pronounced dose-response (~4-10 % lower emission compare to control), with mitigation efficiency lower than Zeolite 1 across all loading rates tested.
- Control (no additives): Maximum cumulative NH_3 emission, reaching 96,5 mg/kg), confirming the high volatilization potential of alkaline, ammonium-rich digestate.

Odour emissions pose a critical barrier to the large-scale deployment and social acceptance of biofertilizers from anaerobic digestate, particularly near residential and environmentally sensitive areas. In the LIFE DIMITRA project, a pilot-scale granulation line for biofertilizers from the solid digestate fraction was developed; this work focuses on strategies to reduce NH_3 and volatile emissions from final products. Lower NH_3 losses improve farmers' working conditions, minimize community complaints, retain nitrogen in granules (target: 120 kg N/ha), and cut synthetic fertilizer use along with CO_2 emissions from the Haber-Bosch process. This aligns with Directive 2016/2284/EU (NEC), mandating Best Available Techniques (BAT). Zeolite or biochar additives in granules qualify as BAT for BREF documents on livestock and biogas operations.

The experimental results demonstrate that natural zeolites — particularly clinoptilolite-rich zeolites 1 — are the most effective single additive for reducing NH_3 emissions from granulated digestate-based biofertilizers within the dose range tested. At 10% addition, reductions of approximately 47–52% in cumulative NH_3 emission are achievable. For more details about the project please visit: www.life-dimtra.com

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