Odour reducing microbial-mineral additive for poultry manure treatment

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Abstract: Poultry production systems are associated with emissions of odorous volatile organic compounds (VOCs), ammonia (NH_3), hydrogen sulfide (H_2S), greenhouse gases, and particulate matter. Development of mitigation technologies for these emissions is important. Previous lab-scale research on microbial-mineral treatment has shown to be effective for mitigation of NH_3, H_2S and amines emissions from poultry manure. The aim of this research was to assess the effectiveness of surface application of a microbial-mineral treatment for other important odorants, i.e., phenolics and sulfur-containing VOCs. Microbial-mineral litter additive consisting of 20% ($w \cdot w^{-1}$) of bacteria powder (six strains of heterotrophic bacteria) and 80% of mineral carrier (perlite-bentonite) was used at a dose of 500 $g \cdot m^{-2}$ (per ~31 kg of manure). Samples of air were collected in two series, 4 and 7 days after application of additives. An odor profile of the poultry manure was determined using simultaneous chemical and sensory analysis. Reduction levels of VOCs determined on Day 4 was between 31 and 83% for mineral adsorbent treatment and in the range of 9 and 96% for microbial-mineral additive, depending on the analyzed compound. Reduction levels on Day 7 were considerably lower than on Day 4, suggesting that the odorous VOCs treatment efficacy is relatively short. There was no significant difference between treatments consisting of microbial-mineral additive and mineral carrier alone.

Keywords: Odour Mitigation, Poultry Manure Additive, GC-MS-Olfactometry, Volatile Organic Compounds.

1 Introduction

Global growth in poultry production, especially in Europe where Poland is the largest producer of poultry meat within EU (2014) [1], is strongly linked with livestock odour that has become a nuisance for people living in surroundings of poultry houses [2] as well as a problem for animal health [3]. There have been many studies on methods for mitigating emissions of livestock odour, however, most of the papers focus on the swine production [4, 5]. Methods of emission mitigation from poultry manure are less studied. The reported methods on mitigation of emissions from swine manure rely on addition of different adsorbents to the manure, amendment with yeast strains, or use of filtration and biofiltration beds [6, 7, 8, 9, 10]; however, there have been some evaluations of bacterial additives [11, 12], mineral additives or air filtration [13, 14, 15, 16, 17] in mitigation of emission from poultry manure. Research by Matusiak et al. [18] has shown that the microbial-mineral litter additive (MMLA) consisting of mineral carrier and bacteria powder can be effective at reducing NH_3, amines and H_2S emissions from poultry manure. Nonetheless, more comprehensive assessment of the MMLA is needed for treatment of odour-generating compounds such as phenolics and sulfur-containing compounds.

Thus, the aim of the study was to evaluate the effectiveness of an innovative MMLA in mitigating emissions of odorous volatile organic compounds (VOCs) from poultry manure under conditions simulating a typical poultry house environment (air temperature, ventilation rate, stocking density, and amount of manure generated). Our working hypothesis was that the MMLA treatment performs as well as other additives previously reported for other key odorants of concern [18] and that the microbial treatment significantly improves the performance of MMLA treatment mix.

2 Materials and methods

The research was carried out at the Air Quality Laboratory in the Department of Agricultural and Biosystems Engineering at Iowa State University. Microbial-mineral litter additive (six strains of heterotrophic bacteria on a perlite-bentonite carrier) [18] was tested under laboratory conditions. The MMLA, consisting of a mineral carrier and bacteria powder, was added topically to nearly fresh manure from laying hens in order to reduce the emissions of odorous VOCs. The manure (with cake-like consistency) was accumulated in a layers house for 3 days and used for the trials directly after collection.

2.1 Experimental conditions

The treatment containers (six 1 L glass jars, 64.5 cm^2 of surface area) were filled, on the Day 1 of each trial with, 200 g of nearly fresh manure from laying hens mixed with water (representing two weeks of manure accumulation). Additional water was added to the manure (25 mL of water per 100 g of manure) to prevent the manure from drying out and to facilitate manure homogenization. All treatment containers were simulating a scaled-down surface of poultry manure (~4 cm of manure depth) with controlled airflow over the surface matching regular ventilation conditions.

<Figure 1>

Airflow through the containers was 12 exchanges per h, which was lower than the airflow expected in a typical poultry house (approximately 27 exchanges per h [19]) due to apparatus limitations. This lower airflow provided higher concentrations of VOCs and improved the sensitivity of gas measurements while simulating a more environmentally adverse situation (e.g., lower air exchanges during cool season). The inlet air (~200 $mL \cdot min^{-1}$) was filtered through an activated carbon scrubber and humidifier. The temperature and relative humidity of the air were measured after the air passed through the humidifier, and were respectively 22 °C and 99%. In a single trial 3.2 g of the MMLA (which corresponds to the dose of 500 g of MMLA per 1 m^2), consisting of an 80% ($w \cdot w^{-1}$) mineral perlite-bentonite carrier and 20% of bacteria powder, was added topically to the manure in two treatment containers. Concentration of bacteria powder was adopted on the basis of previous work [20]. Two treatment containers were treated with perlite-bentonite carrier only (2.56 g) to evaluate the influence of the mineral absorbent (MA) alone. Two treatment containers were control (200 g of poultry manure only). The trials lasted for 7 days and were carried out 3 times.

2.2 Sampling and chemical analysis

Manual solid phase microextraction (SPME) with StableFlex 50/30 μm divinylbenzene/Carboxen/polydimenthylsiloxane (DVB/CAR/PDMS) fiber (Supelco, Bellefonte, PA) was used for extraction of odorous compounds from the headspace inside the treatment containers on Day 4 and Day 7 of each trial. An optimal sampling time of 30 min was determined during preliminary experiments, according to the procedure described by Cai et al. [17]. The sampling procedure was as follows: airflow was stopped for a single container by closing inlet and outlet of the treatment container, conditions inside the treatment container were allowed to stabilize for 10 min and gas sampling was conducted for 30 min. Collected gas samples were analyzed using a gas chromatograph – mass spectrometry – olfactometry (GC-MS-O) (Microanalytics, Round Rock, TX, USA). The GC-MS-O system components, acquisition software and basic GC oven programs are described in detail by Cai et al. [21].

Odorous VOCs were tentatively identified on the basis of comparative analysis of the determined mass spectrum and the National Institute of Standards and Technology (NIST05) MS library. During the GC separation, aroma and odour intensity of individual compounds were measured simultaneously, with the use of a sniff port and AromaTrax 10.1 software. Evaluation of air purification effectiveness was made on the basis of the relative reduction value (RRV, %) determined for each tentatively identified odorous VOC. The RRV was calculated similarly to the formula given by Cai et al. [17] as the ratio of the difference between the control and treatments mean (of 6 replicates) peak height counts of the tentatively identified odorous VOCs. Peak heights were used for comparison instead of peak areas, to improve integration of asymmetric or low chromatographic peaks.

2.3 Statistical analysis

Due to the high statistical dispersion, 180 outliers were removed from a total of 720 values using Q-Dixon test. Practically, the lowest and the highest measured peak height for each compound, for each trial was an outlier. Data were tested for normality with Shapiro-Wilk test and no set of values showed normal distribution. Statistical comparisons between the treatments were done via Kruskal-Wallis test using GraphPad Prism 5.04 (Prism for Windows, GraphPad Software Inc., La Jolla, CA). Differences among treatment means were tested for significance using the Dunn's test. Differences were considered significant at $P < 0.05$.

3 Results and discussion

A total of 15 VOCs were tentatively identified in the analyzed gas samples emitted from the treated/untreated poultry manure. The compounds along with their matching percentage of identity assignment in the MS spectral database, GC column retention times and mean peak height are shown in the Table 1. Significant differences between treatments were noted only for dimethyl disulfide on Day 7, where mineral adsorbent (MA) alone was showing better deodorizing effect. Statistically significant differences between control group and microbial-mineral litter additive (MMLA) treatment were determined for methanethiol, dimethyl sulfide, 2-butanone, 2-pentanone, s-methyl thioacetate and methyl ethyl disulfide on Day 4 of treatment. Statistically significant differences between control group and MA treatment were noted for s-methyl thioacetate on Day 4 of treatment. Relative reduction of target VOCs in comparison to the control group on Days 4 and 7 are shown on Figures 2 and 3, respectively.

<Table 1>

<Figure 2>

<Figure 3>

In this study, obtained reduction levels of tentatively identified VOCs content determined on Day 4 ranged between 31 and 83 % for the MA treatment and between 9 and 96 % for MMLA treatment, depending on the analyzed compound. Reductions on Day 7 ranged from -243 to +65% (MA) and -219 to +59% (MMLA) depending on the analyzed compound. Negative values indicate increase in content of particular VOC. The increase of VOCs content can be explained by decrease in adsorption ability over time (sorbent saturation effect) and also by re-emission of VOCs adsorbed within first days after application of MMLA.

Results can be compared with prior research testing various methods of odor reduction from livestock buildings, including deodorization of manure. Deodorization of poultry manure with bacterial additives has been carried out by Matusiak et al. [18] and reduction between 58% and 73% has been reported after day 4 of treatment. The 58% to 73% reduction corresponds to the ~40% adjusted reduction, considering the drop of VOCs content in the control group itself (as an effect of treatment time). Biofiltration conducted at the reproductive hen farm reduced VOCs containing sulfur by 51% (max. 70%), while for aldehydes and ketones the reduction ranged between 62 and 99% [22,23]. Cai et al. [17] reported, that average reduction of the odor was between 51 and 67% after topical application of zeolite on the poultry manure. Opaliński et al. [24] filtered the air polluted by poultry manure through aluminosillicates adsorbents and the reduction of NH_3 and VOCs emissions ranged between 58 and 84%. Considering the above, it can be assumed that a mineral adsorbents could have sufficient deodorizing potential.

It is also worth noting that concentration of bacteria powder in the MMLA used in this research was 20%, which is economically unjustified at this point of development of the litter additive. There were no significant differences between MA and MMLA treatments at the investigated concentration of bacteria. Thus, mineral adsorbent alone appears to be responsible for major deodorizing effect in the investigated additive, at least during the first week after its surficial application to manure.

3.2 Aroma profile of the manure

A total of 14 aromas have been detected and recorded in the analyzed gas samples. The aromas represent a panelist’s response to separated odorants eluting from GC column and a sniff port. Aromas along with the compounds corresponding to them are shown in the Table 2. An example aromagram is shown in Figure 4.

<Table 2>

<Figure 4>

By comparison of GC column retention times of tentatively identified VOCs with retention times of aroma events it can be assumed that: *animal/fecal*, *hay/straw*, *characteristic, fecal, mushroom, sauerkraut* aromas can be associated with *methanethiol, dimethyl sulfide, s-methyl thioacetate, dimethyl disulfide, 3-octanone, dimethyl trisulfide,* respectively. All aromas of the sulfur-containing compounds present during the analysis are reported to be rotten- or fermented-like [25] and occur in manure matrixes [21, 26].

Parcsi and Stuetz [27] analyzed gas samples from different poultry houses and identified 6 odorants with the use of olfactory detection port, which two of them (dimethyl disulfide and dimethyl trisulfide) were consistent with the odorants reported in this study. The effectiveness in aroma reduction in comparison to the control group on Day 4 and Day 7 ranged between -250% and +100% and is shown in Figures 5 and 6, respectively.

<Figure5>

<Figure 6>

Influence of the investigated additives on the reduction of aroma intensities was not statistically significant because the evaluation was limited to one panelist; however, a general observation was made, that the MA treatment had better effect in reducing the aroma intensity compared to MMLA which also was confirmed after smelling the headspace of treated manure directly, at the end of a trial.

Economic analyses are ultimately needed for scale-up to farm applications. Material and labor costs, feasibility of practical farm-scale application, biosecurity, toxicology, manure quality and land application concerns have to be considered. To date, most published literature involving economics of gaseous emissions from livestock operations are focused on swine production [5,28]. It is recommended that economic analyses are performed to estimate full scale application costs.

4 Conclusion

The microbial-mineral litter additive and mineral adsorbent (MMLA and MA, respectively) were tested in lab-scale experiments for its potential to treat odorous VOCs emissions from poultry manure within 7 days of its surficial application. Conditions under which the study was carried were simulating scaled-down conditions occurring in a typical poultry house in terms of ventilation rate and amount of manure per area. Reduction level of tentatively identified VOCs content determined on Day 4 was between 31 and 83% for the MA treatment and in the range of 9 and 96% for MMLA treatment, depending on the analyzed compound. MMLA and MA treatments efficacies were considerably lower on Day 7 than on Day 4, and the increase in content of some VOCs was observed likely due to saturation of the adsorbent and re-emission of VOCs. There were no significant differences between treatments consisting of MMLA and MA. Thus, based on these initial and short term (1 week) screening tests, there appears to be no justification in enrichment of mineral adsorbents with investigated bacteria strains. Additional research with either (a) longer treatment time, (b) optimization of bacteria concentration, and/or (c) farm-scale research with poultry present during the experiment is recommended. Economic analyses will also be needed to estimate full scale application costs.

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Figure Captions

Figure 1. Laboratory-scale system for controlled studies of surficial treatments of poultry manure and mitigation of odour and gaseous emissions at Iowa State University.

Figure 2. Comparison of % reduction in target gas emissions, Day 4.

Figure 3. Comparison of % reduction in target gas emissions, Day 7.

Figure 4. Gas sample comparison of aromagram (bold line) and chromatogram (thin line) resulting from a simultaneous chemical and sensory analyses. An image generated from AromaTrax software by a panelist assessing separated compounds eluting from the sniff port.

Figure 5. Odour intensity reduction associated with target compounds determined by panelist at the sniff port of GC-MS-O, Day 4.

Figure 6. Odour intensity reduction associated with target compounds determined by panelist at the sniff port of GC-MS-O, Day 7.

Tables

Table 1. Effect of investigated treatments on selected tentatively identified VOCs (mean, n=6).

compound	R_T / min	spectral match with MS database	day 4								day 7							
			C		MA		MMLA		SEM	P-Value	C		MA		MMLA		SEM	P-Value
			H	SD	H	SD	H	SD			H	SD	H	SD	H	SD		
1. methanethiol	2.80	86 %	12723	9125	7244	4430	3516	1104	1698	0.0294	4126	1225	5339	1916	6444	3176	468	0.2269
2. dimethyl sulfide	3.17	93 %	100273	71083	18316	17684	3555	971	16984	0.0463	15884	16852	11845	11439	16268	11947	2917	0.6387
3. 2-butanone	4.15	74 %	72537	53920	12340	11897	2879	311	12589	0.0151	16463	17514	14830	16224	13967	9853	3074	0.8671
4. 2-butanol	5.22	79 %	16139	6138	3502	2444	14640	19361	3503	0.0961	13108	15861	10728	9628	7567	4230	2294	0.9828
5. 2-pentanone	5.60	59 %	15271	9187	4170	3129	2298	1098	2154	0.022	2655	1695	4304	3228	6456	3864	706	0.1572
6. s-methyl thioacetate	6.37	93 %	8170	3478	1690	774	1413	442	1002	0.0066	3516	3716	2636	1980	1436	946	551	0.4263
7. dimethyl disulfide	7.25	94 %	800227	790731	513895	513207	129163	126608	148947	0.2443	19666	20920	6995	1875	62689	46311	8056	0.0225
8. methyl ethyl disulfide	9.55	88 %	15019	16269	9489	10108	1304	227	3160	0.0423	1001	249	3438	4942	1634	396	736	0.1389
9. 2-hepatanone	10.87	81 %	9830	7951	6797	6849	1991	948	1670	0.2963	2404	1820	1822	1028	3246	1817	337	0.2758
10. 3-octanone	13.32	93 %	18672	17429	8445	8031	1834	729	3327	0.0716	3036	1409	4208	3260	3150	1796	488	0.8176
11. dimethyl trisulfide	14.07	95 %	441651	484344	112144	100126	50238	19648	80870	0.1129	15804	14597	5569	4293	38127	29594	4846	0.0718
12. 2-acetylfuran	14.48	54 %	12110	10497	5762	5490	2650	1919	1933	0.1661	1676	853	3040	3049	1966	890	436	0.8043
13. phenol	21.87	94 %	287710	173152	136910	82087	209976	132015	34648	0.3295	143685	132660	109257	144833	156696	149677	28073	0.5458
14. 4-methylphenol	23.15	94 %	28404	22409	10343	5932	11713	7108	3753	0.3505	12585	11991	13431	13327	6345	2967	2312	0.7562
15. 4-ethylphenol	24.58	94 %	65738	63272	25621	19660	24479	17635	10164	0.5195	41488	35413	34562	26047	28151	18146	5646	0.8190

R_T, retention time; C, control group; MA, mineral adsorbent; MMLA, microbial-mineral litter additive; H, mean peak height; SD, standard deviation; SEM, standard error of the mean;

Table 2. Summary of sensory analyses on aromas and odors emitted from poultry manure.

A_T / min	odor	corresponding compound
2.89	animal/fecal	methanethiol
3.20	hay/straw	dimethyl sulfide
6.24	characteristic	s-methyl thioacetate
6.80	sweet	-
7.37	fecal	dimethyl disulfide
8.97	characteristic	-
9.24	sweet/berry	-
13.36	mushroom	3-octanone
14.12	sauerkraut	dimethyl trisulfide
16.07	burnt bacon	-
16.23	soil/dusty	-
18.97	sour/dusty	-
19.37	burnt bacon	-
19.92	rotten eggs	-

A_T, detection time (‘time stamp’) when panelist detected an odor while performing simultaneous chemical and sensory analyses using GC-MS-Olfactometry;