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Hydrogen sulfide gas (H_2S) in stored spent mushroom compost

Key external stakeholders:

Mushroom industry, mushroom compost producers, spent mushroom compost hauliers and contractors, Health and Safety Authority (HSA).

Practical implications for stakeholders:

Spent Mushroom Compost (SMC) is frequently stockpiled once mushroom crops are finished and then spread on agricultural land in Spring and Autumn. During storage it becomes anaerobic, leading to a build-up of toxic hydrogen sulphide (H_2S) gas within the heap, which is released when the heap is disturbed for land-spreading.

- Stored SMC produces toxic levels of H_2S gas when disturbed and handled, especially when heaps are large and stored outdoors with no protection from rainfall
- Those involved in the haulage and spreading of SMC on land should inform themselves of health and safety risks and take appropriate measures to ensure they are not exposed to toxic H_2S gas.
- In order to safeguard workers we recommend SMC is protected from rainfall and stored in small heaps to minimise the formation and accumulation of toxic H_2S gas.
- Stored SMC has significant levels of NPK from an agricultural fertiliser perspective

Main results:

Recommendations to reduce the potential for H_2S emissions from stored SMC:

1. Where possible SMC should be stored under cover (i.e. open sided barn construction) to prevent rainfall landing on the SMC thereby decreasing the moisture content and reducing the potential for excessive H_2S accumulation
2. SMC should be stored in small heaps where possible to prevent excessive production and buildup of H_2S associated with larger heaps
3. SMC disturbance and removal should only be done when wind speeds are at least > 6 m/s (moderate breeze) to facilitate dissipation and dilution of any H_2S emissions

Recommendations to minimise H_2S exposure risks when working with SMC:

4. Tractor cabs should be maintained in a fit state of repair
5. Drivers of SMC loader tractors should wear a personal H_2S monitor and be trained in its operation
6. Drivers of SMC loader tractors should take a short break every hour away from the SMC storage site
7. Drivers of SMC loader tractors should carry a full face gas mask fitted with an appropriate H_2S filter in the tractor cab when working with SMC, for emergencies, and be trained in its use and maintenance

Opportunity / Benefit:

This work has led to three recommendations to reduce the potential for H_2S emissions from stored SMC and four recommendations to minimise H_2S exposure risks when working with SMC.

Collaborating Institutions:

UCD, Dundalk IT

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1. Project background:

In 2005, a fatality due to hydrogen sulfide (H_2S) gas poisoning occurred during the removal of stored spent mushroom compost (SMC) for application on nearby farmland. SMC that had been stored for several months was identified as the source of the H_2S. The fatality highlighted a previously unidentified health risk for those working with SMC and identified a gap in our knowledge concerning H_2S emissions into the atmosphere from stored SMC. There was no information available at the time on H_2S emissions from stored SMC or what effect different types of storage would have on such emissions. This work was undertaken to address this gap in knowledge.

2. Questions addressed by the project:

- Can H_2S gas be detected and quantified during the disturbance and removal of SMC?
- Do storage conditions and duration of storage affect H_2S buildup and emissions?
- What are the concentrations of H_2S in the human occupied zone that operators, especially tractor drivers, are exposed to?
- What health and safety guidelines and recommendations can be drawn up to reduce emissions and minimise exposure?
- What is the N, P and K content of stored SMC from an agricultural fertiliser perspective?

3. The experimental studies:

Four SMC storage sites around the country were visited between February 2008 and October 2009. Two were uncovered outdoor sites (Sites 1 and 2), and two were indoor sites under cover (Sites 3 and 4). All four sites consisted of concrete platforms with retaining walls 2 to 2.5 m high. SMC at the outdoor sites was left uncovered and exposed to rainfall. The indoor sites were covered with an apex roof structure mounted on steel supports to produce a continuous opening above the retaining walls (main picture page 1). H_2S emissions were monitored during disturbance and removal operations at various locations, both directly above the disturbed zone and peripheral areas occupied by operators, including the inside of the tractor cab. QRAE II, EntryRAE, QRAE+ (www.raesystems.eu), and ITX (www.indsci.com) gas monitors with data loggers were used. The H_2S gas concentration was recorded continuously by the data loggers, which were set to automatically calculate the average concentration at 60 s intervals or 10 s intervals. Gas detection at the face of the SMC heap was done using PVC tubing which was suspended above the SMC heap with the aid of a 7 m fiberglass pole and connected to a gas monitor (see pictures on Page 3). In addition to recording the 10 or 60 s average H_2S concentration, the monitors also calculated and recorded the short-term exposure value (STEV, 15 min average) and the time-weighted average value (TWAV, 8 h average) throughout the operations. All gas monitors were calibrated according to the manufacturers' instructions before the start of each site visit using a cylinder of H_2S gas of known concentration. Analysis of SMC for N, P and K content was done using standard soil analytical methods.

4. Main results:

H_2S gas was consistently detected at high concentrations of up to 2000 ppm directly above SMC heaps undergoing disturbance and at lower concentrations of up to 450 ppm in peripheral locations and human occupied zones.

Outdoor versus indoor SMC storage

Our research has indicated that SMC stored under cover and protected from rain had lower H_2S emissions (Site 3: ≤ 687 ppm; Site 4: ≤ 89 ppm) compared to SMC stored outdoor with no protection from rain (Site 1: ≤ 680 ppm; Site 2: ≤ 2083 ppm). SMC protected from rainfall had average moisture contents of 53-65% compared to SMC with no protection where average moisture contents were higher at 66-72%. High moisture content results in anaerobic conditions, which enhance H_2S production. The lowest H_2S concentrations measured in this study were at a small covered storage site (Site 4) where the average

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moisture content of the SMC was 53-63%. A larger heap stored undercover (Site 3) was not as dry at 62-65% moisture content and this was associated with higher H_2S emissions (≤ 687 ppm) compared with the smaller site (≤ 89 ppm). Thus, where possible SMC should be stored in smaller heaps that are protected from rainfall in order to facilitate drying-out and thereby reducing the potential for high levels of H_2S to be produced.

Monitoring H_2S levels at the SMC face at outdoor Site 1.

The H_2S levels at the large indoor stored heap were much higher than anticipated, given the lower moisture content of the material in comparison to the outdoor sites. The large heap stored under cover also tended to get much hotter (36-51ºC) than the smaller indoor heap (33-41ºC) or outdoor stored heaps (24-36ºC) and it is likely that the higher temperatures increase the activity of thermophilic H_2S-producing bacteria, counteracting the reduced activity due to the lower moisture content, but that hypothesis needs to be tested.

Outside and inside tractor cabs

Hydrogen sulphide gas levels were also monitored in the human occupied zone at the four SMC storage sites during SMC removal for spreading on agricultural land. During removal operations, H_2S gas monitors were mounted on the outside of the tractor, at the SMC periphery and worn by individual tractor drivers. The highest H_2S concentrations at 10 second intervals were detected just outside the tractor cab as it was taking a load of SMC to put into a land-spreading trailer. Concentrations as high as 454 ppm were detected at the outside storage sites and 214 ppm at storage sites under cover. The tractor drivers were within the closed cab of the tractors during these operations, but concentrations inside the cabs reached as high as 100+ ppm at the outdoor storage sites and 51 ppm at the indoor storage sites (100 ppm is the limit of detection of the personal monitors used by tractor drivers). Thus, H_2S is clearly infiltrating the tractor cab during the SMC removal operations and although the concentration inside the cab is reduced to about a quarter of the concentration outside the cab, in many cases there is only one driver who operates the tractors of both the SMC loader and the SMC spreader. Thus tractor drivers are exposed to the higher concentrations outside the tractor cab when they dismount to operate the second tractor.

Highest H_2S concentrations occur when the SMC heap is physically disturbed.

As H_2S is a gas, the concentration in the air fluctuates as it is dispersed and diluted by air currents and tractor movements. However, it is heavier than air so on still days, and when there are no tractor movements, there will be a tendency for it to settle in the vicinity and dissipate slowly. Concentrations as high as 250 ppm were detected at the edges of the SMC storage areas, up to 10 m from the tractor activity – indicating that toxic gas levels can still occur at a distance from the activity itself.

The Short term exposure value (STEV) of 10 ppm (average concentration for 15 minutes) was exceeded at all external locations at outdoor Sites 1 and 2 (i.e. above the SMC heap, outside the tractor cab and at the periphery). The STEV was exceeded above the SMC heap and outside the tractor cab at Indoor Site 3 and it was not exceeded at any location at the small indoor Site 4. The STEV for tractor drivers was exceed only at outdoor Site 2, where the SMC was very wet.

In terms of nutrient characteristics, the total N content of SMC stored undercover was higher (27-28 g/kg dry matter) compared with that of SMC stored outdoors (23-24 g/kg dry mater). Similarly K content of SMC

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stored undercover was sometimes higher (26-37 g/kg dry matter) compared with that of SMC stored outdoors (22-27 g/kg dry matter). P levels were broadly similar (6 - 6.8 g/kg dry matter).

5. Opportunity/Benefit:

The mushroom industry and SMC sector have new information to deal with the risk of H_2S emissions when handling and distributing SMC. This information has been summarised into the seven recommendations outlined on Page 1.

6. Dissemination:

The information generated here has been disseminated to the wider mushroom sector at the 2011 and 2013 All Ireland Mushroom Conference held in Monaghan. Mushroom growers have been informed during various mushroom seminars held between 2009 and 2014. The wider scientific community have been informed via presentations at conferences and meetings in Ireland and France.

Main publications:

Velusami, B., Curran, T. P. and Grogan, H. M. (2013a). Hydrogen sulfide gas emissions during disturbance and removal of stored spent mushroom compost. *Journal of Agricultural Safety and Health* 19(4): 261-275

Velusami, B., Curran, T. P. and Grogan, H. M. (2013b). Hydrogen sulfide gas emissions in the human-occupied zone during disturbance and removal of stored spent mushroom compost. *Journal of Agricultural Safety and Health* 19(4): 277-291(ASABE Superior Paper Award 2014).

Velusami, B., Adjeh, B., Curran, T.P. and Grogan, H.M., 2011, Hydrogen sulphide gas production from spent mushroom compost under field and laboratory conditions, Proceedings of the 7th International Conference on Mushroom Biology and Mushroom Products, (ICMBMP7) 2011, 4-7 October, 2011, Arcachon, France. Vol 1: 437-442.

Velusami, B., Curran, T., Grogan, H., 2011, Hydrogen sulphide gas release from spent mushroom compost, Proceedings of the Irish Meeting 2011 on Agricultural Occupational Health and Safety, 22 -24 August 2011, Dublin, Ireland, p. 31.

Popular publications:

Grogan, H., Velusami, B. Kellegher, T. and Walsh, G. (2009). Health and Safety aspects of working with spent mushroom compost. TResearch, Vol 4, No 1. p 23-25.

Velusami, B., Curran, T. P. and Grogan, H. M. (2014). Danger of H_2S in Mushroom Compost. TResearch, Vol 9, No 3. p 36-37.

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