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Review papers

Improving sustainability of peat moss through its application in reducing livestock emissions

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ABSTRACT

Peat, also known as peat moss, is comprised of decomposed plants. Peatland ecosystems act as natural carbon sinks and carbon storage systems and support biodiversity. Owing to its beneficial properties, peat moss has been widely used in the horticultural and agricultural industries as a substrate and in the waste management industry as an absorbent. However, its harvest from peatland releases anthropogenic greenhouse gas (GHG) emissions. Thus, using peat moss to reduce GHG emissions from other sectors could compensate for the emissions from peat moss harvesting. Livestock practices emit GHGs, including methane (CH_4) and nitrous oxide (N_2O), and release non GHG emissions such as ammonia (NH_3). Though peat moss has been used as bedding material in animal pens, its effect on reducing emissions from livestock practices remains unknown. This paper reviews the potential of peat moss in livestock manure management to reduce CH_4, N_2O, and NH_3 emissions, presenting alternatives for sustainable use of peat moss. Manure treatments using materials with similar attributes to peatmoss, e.g., acidification treatment, showed that CH_4, N_2O, and NH_3 emissions were effectively reduced. Further, the use of peatmoss as bulking materials in manure enhanced the sorption of NH_3. Hence, peatmoss application in manure may potentially reduce CH_4, N_2O, and NH_3 emissions. Moreover, the benefit of peatmoss application is not only limited to reduction of emissions, but it may also improve soil health when peatmoss-treated manure is applied to soil due to its high carbon content. Therefore, peatmoss application in the livestock industry should be further explored.

Key words: Peat Moss, Livestock, Ammonia Emissions, Greenhouse Gas

1. Introduction

Peat moss is the decomposed residue of plants, mostly mosses in wetland habitats such as peatlands, bogs, and fens (Klavins and Purmalis, 2014). Approximately 423 million hectares of peatlands cover nearly 1–2% of the Earth's surface area, (Cojocaru et al., 2011) serving as an important carbon sink and biodiversity habitat and regulating hydrological cycles.

The adaptability of peat moss to a wide range of management practices and its low cost have increased its demand for various applications (Mohan and Pittman, 2006; Surendran, 2018). The global production of peat for horticultural use decreased by 6.1% in 2018 compared to the level in 2014 but peat production for total use (fuels, horticultural applications, and others) increased by 0.7% (Brioche, 2018). Nevertheless, the unique characteristics of peat moss may also be disadvantageous for some practices, for example, being too acidic for some crops (Thakulla et al., 2021) or causing loss of sorbent buoyancy

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for water surface cleaning (Rotar et al., 2016). More importantly, the large-scale harvesting of naturally derived peat moss from peatlands has become a major and increasing source of anthropogenic greenhouse gas (GHG) emissions (Pakalnis et al., 2009), mainly methane (CH_4) and carbon dioxide (CO_2). Thus, a practical option for reducing emissions from peatland drainage is to use peat moss acquired from drained land to compensate for emissions from other sectors.

Livestock contributes 4.6% of total GHG emissions and is responsible for 50.18% of agricultural GHG emissions in Annex I countries (industrialized countries and economies in transition) (UNFCCC, 2021). Livestock operations produce GHG and ammonia (NH_3) emissions. This paper discusses the advantages and disadvantages of peat moss application and its potential to reduce emissions from the livestock industry based on previous studies.

2. Characteristics of peat moss

2.1. Low pH and antimicrobial properties

The antimicrobial properties of living Sphagnum plants and Sphagnum peat have been well-established for centuries. Sphagnum moss is acidic owing to the presence of uronic acids and the low buffering capacity of the environment (Taskila et al., 2016). Sphagnans inhibit microbial growth by decreasing the pH of the environment (ballance et al., 2008; Stalheim et al., 2009), making them effective antimicrobial agents.

2.2. Large surface area and porous structure

Peat moss has a large surface area (>200 m^2/g) and highly porous structure that binds heavy metals (Balan et al., 2010; Kitir et al., 2018). The bulk density of peat varies greatly from 0.05 to 0.20 g/cm^3 and may increase to 0.50 g/cm^3 depending on the types of plant residues and their decomposition rates (Kitir et al., 2018). The highly porous structure of peat moss provides a large surface area for pollutant adsorption (Pandey and Alam, 2019). The combination of a well-defined structure and pore space provides the required physical and chemical properties for the use of peat moss as a potting or growth medium in the horticultural industry (Balan et al., 2010; Surendran, 2018).

2.3. High sorption

Sphagnum hyaline cells absorb water 16–25 times their dry weight (Willför et al., 2009). The absorption ability of Sphagnum is three to four times greater than that of cotton equivalents (Painter, 2003). Furthermore, the high adsorption ability of peat moss may reduce its alkalinity by acidifying the surrounding environment (Mandal et al., 2018). Owing to the presence of carboxylic, phenolic, and hydroxylic functional groups in the peat structure, peat moss has a high potential for metal adsorption (Brown et al., 2000; Pandey and Alam, 2019).

3. Trade-offs of peat moss application

In recent years, peat moss use has faced drawbacks, mainly because of its contribution to GHG emissions. Peatlands sequester more than 30% of the soil carbon (Joosten et al., 2016) and their harvest is associated with a large ecological footprint. The emissions from drained peatlands due to peat and peat moss extraction are estimated at 1.9 Gt CO_2 equivalent per year (IUCN, 2021). In addition, although peat moss has characteristics that are a major appeal, they also have detrimental characteristics. Rotar et al. (2016) found that the high moisture absorptivity of peat moss is disadvantageous for cleaning water surfaces. In addition, peat moss is also considered a substrate conducive to soil-borne diseases and its acidity can harm crops (Thakulla et al., 2021).

Despite its disadvantages, peat moss has applications in many industries (Table 1). Peat moss is the most commonly used organic amendment in intensive agriculture owing to its beneficial characteristics, low cost, and high availability (Caron and Rochefort, 2013; Singh et al., 2022). Organic amendments to soil can improve the physical and chemical properties of soil, for example, by increasing the C/N ratio (Wiseman et al., 2012), thereby assisting in sequestering carbon in agricultural lands and reducing the release of GHG gases (Farooqi et al., 2018). Duddigan et al. (2022) observed that soils with peat moss showed higher carbon concentrations than unamended soil and that peat moss had a higher carbon concentration than other organic amendments, e.g., compost, sawdust, etc.

Recently, biochar has attracted interest as an adsorption material because of its high sorption capacity. Kim et al. (2019) found that peat moss is a cost-effective feedstock for biochar and that peat moss biochar effectively removes volatile organic compounds. Biochar derived from peat moss can be used as an effective adsorbent to clean heavy-metal-contaminated water (Park et al., 2016). Previous investigations have reported that peat-derived biochar is recommended as a peat substitute because of its higher porosity and cation-exchange capacity (Lee et al., 2015; Margenot et al., 2018). Peat-derived biochar also has better sorption of heavy metals from contaminated water owing to the removal of volatiles via pyrolysis, which creates a carbon-dense and more porous structure (Lee et al., 2015; Park et al., 2016). The conversion of Sphagnum moss into a carbonaceous material was highly effective for the removal of organic pollutants from aquatic ecosystem, achieving a removal rate of 78% in 12 hours (Dong et al., 2024). Another study reveals that activated peat moss biochar has a high potential for

Table 1. Advantages and disadvantages of peat moss application in industries

Issue	Application	Advantage	Disadvantage
Animal health	Bedding for dairy cattle	Prevents the growth and spread of harmful bacteria	
	Bedding for horse	Bactericidal because of its acidic composition	
	Bedding for horse	Causes less neutrophil percentage in the lower airway of healthy horses	
	Bedding for poultry	Chemical-free litter amendment	
GHG emissions	Soil amendment	Assists carbon sequestration in agricultural lands	Emits greenhouse gases (CH_4 and CO_2) during harvest Unsustainable
Odor	Bedding for horses	Neutralizes the odor of NH_3 from animal urine	
Nutrient	Bedding for broiler chicken	Supplements inorganic fertilizers	
	Mixed with dairy cattle manure	Achieves high removal efficiencies for organic matter and total nitrogen	
Metal contamination	Biochar	Removes volatile organic compounds	Reduces sorbent buoyancy
	Biosorption column	Removes metals	
	Sorption agent	Removes Cr (VI) from solution	
Soil health	Soil amendment	Improves soil quality and organic carbon storage	Agent for soil-borne disease
	Soil amendment	Loosens and aerate soil that is high in clay	
	Soil amendment	Neutralizes alkaline soil	
	Soil amendment	Reduces leaching and runoff	
	Soil amendment	Remediates toxic metal concentration in contaminated soils	
Plant growth	Soil amendment	Promotes initial growth and establishment of plant species	Too acidic for some crops

Sources: Angelova et al. (2010); Aschenbach et al. (2012); Balan et al. (2010); Champagne and Li (2009); Downer and Faber (2021); Kim et al. (2019); Rodríguez Niño et al. (2015); Rotar et al. (2016); Sankar Ganesh et al. (2017); Singh et al. (2018); Thakulla et al. (2021); Wen et al. (2020):

handling wastewater containing metal pollutant such as Chromium ions (Aljumaili and Abdul-Aziz, 2023).

Peat has a high heavy metal adsorption capacity (Chwastowski et al., 2017; Koivula et al., 2009). A 1-m peat layer can absorb high metal concentrations for 200 years in an industrial waste landfill under the climatic conditions prevailing in Finland (Koivula et al., 2009). Furthermore, peat has a high cation-exchange capacity and its removal effectiveness for acidic and basic dyes has been reported to be better than that of activated carbon (Mo et al., 2018).

4. Issues in livestock industry

4.1. NH_3 emissions and $PM_{2.5}$

NH_3 is an odorous gas produced during livestock operations that creates a nuisance for neighboring households (Kim et al., 2013). A mixture of litter and manure is a significant source of NH_3 (Liu et al., 2007), with the amount of NH_3 dependent on the treatment and management of animal wastes, including how long the manure is stored before application as a fertilizer, the pH, and temperature. Moreover, NH_3 emissions from broiler houses are sensitive to the litter moisture content (Liu et al., 2007).

The formation of particulate matter (PM) is strongly correlated with NH_3 emissions, indicating that reducing NH_3 emissions significantly affected PM reduction. PM, especially $PM_{2.5}$ (PM with an aerodynamic diameter smaller than 2.5 μm), can penetrate the respiratory system and cause tissue damage if inhaled (Dijkstra et al., 2013).

4.2. CH_4 and N_2O emissions

Livestock manure is rich in organic matter and thus serves as a source of energy for microbial growth. Methanogens produce CH_4 as a byproduct of this process in the absence of oxygen. The generation of CH_4 emissions is affected by several factors that influence methanogens, such as temperature, rainfall, organic matter content, moisture, and pH, as methanogens are poorly adapted to pH variations; thus, an optimal pH range of 6.5–7.5 should be maintained (Li et al., 2019; Westermann, 1993).

Although the contribution of nitrous oxide (N_2O) emissions is not as significant as CO_2 and CH_4 to global climate change, it is a crucial GHG with a high global warming potential of 298 (IPCC, 2014). N_2O is an inevitable byproduct of the nitrogen cycle and is generated during the nitrification and denitrification processes, which are in turn affected by environmental conditions, such as temperature, salinity, dissolved oxygen, and pH (Pijuan and Zhao, 2022).

5. Potential reduction of emissions from livestock practices by peat moss application

Studies to observe the benefit of peat moss utilization in livestock industry has been conducted. Accordingly, peat used as a feed supplement for piglets prevents diarrhoeal diseases due to its low pH (Trckova et al., 2005). Moreover, incorporating peat in the feed has been observed on providing stimulation of growth and production performance in broiler chicken layer chicken. Even more, the beneficial effect on the general health status was observed in piglet supplemented with peat (Trckova et al., 2005). Recent study by Lee and Ahn (2023) showed that CO_2 and CH_4 emissions from slurry of peat-supplemented-pig were 23 and 44% lower than that from slurry of pig without peat supplement, respectively. Nonetheless, the most common application of peat moss in livestock is as a bedding material (Table 1). Bedding materials are usually selected based on several factors such as water absorbance ability, availability and cost, density, animal comfort, absence of toxicity, and suitability as fertilizer or livestock feed after removal (Spiehs et al., 2012; Tasistro et al., 2007). Good quality litter should readily give up moisture and offer a reasonably quick drying time (Bilgili et al., 2009; Grimes et al., 2002) and should have dedicated applications, such as fertilization and soil amendment, following removal from the broiler house (Tabler et al., 2020). Furthermore, the type of bedding material affects growth performance (Oketch et

Table 2. Characteristic attribution and potential benefits of peat moss application in the livestock sector based on previous studies

Reduction target	Research material	Target	Results	Peat moss characteristics	Reference
NH_3	Acid	Slurry	41% of NH_3 reduction at pH 6.5, 53% reduction at pH lower than 5	Low pH	Sokolov et al. (2019)
	Maize silage	Bedding	Reduced NH_3 and lower PM by 14%	Low pH	He et al. (2020)
	-	-	Reduced moisture content, increased oxygen availability	Large, porous surface; high absorption	Liang et al. (2005)
CH_4	Acid	Dairy manure	81% to 88% of CH_4 reduction	Low pH	Sokolov et al. (2019, 2021)
	-	-	Methanogens were disrupted by low pH	Low pH	Sokolov et al. (2019, 2021)
N_2O	-	-	Acidification lowered N_2O emissions	Low pH	Saue and Tamm (2018)

al., 2023).

Switching from conventional bedding material (rice straw, husks, etc.) to alternative materials (i.e., paper products, wood products, organic products) may provide an economic and environmental alternative to the operation (Niraula et al., 2023). The switch to peat moss may impose high up-front cost, but the maintenance is generally cheaper than for straw or shavings (Westendorf and Krogmann, 2013). Peat moss also has excellent compostability, and for its better performance (i.e., dust controlled, odor controlled, cleaning ease, etc.) than other materials, peat moss is relatively economically and environmentally beneficial (Westendorf and Krogmann, 2013).

5.1. Reduction of NH_3 emissions

NH_3 is in pH-dependent equilibrium with ammonium ions such that the rate of ammonium conversion to dissolved NH_3 increases as the pH increases, thereby increasing the quantity of dissolved NH_3 available for volatilization (Jones et al., 2013; Merl and Koren, 2020). Suppression of the substrate pH prevents the conversion of ammonium ions into dissolved NH_3; thus, emissions are not produced. Sokolov et al. (2019) showed that slurry with a pH of 6.5 reduced NH_3 emissions by 41%, and further reduction by 75–83% was found in further reduction of pH to 5.5 (Fuchs et al., 2021). Using silage maize as a bedding material not only reduces NH_3 concentration but also lowers $PM_{2.5}$ concentrations by 19% (van Harn et al., 2012).

Previous studies have demonstrated that the use of Sphagnum peat as a bulking material enhances the sorption of ammonium and urine during manure composting (Vuorinen and Saharinen, 1997, 1999). The abatement of NH_3 emissions in livestock manure reported in Ndegwa et al. (2008) indicated that Sphagnum moss (*Sphagnum fuscum* peat) is more effective on animal slurries than on solid poultry manure, similar to zeolite.

Furthermore, peat moss has been shown to reduce NH_3 emissions during food waste composting and increase nitrogen content in the final compost product (He et al., 2020).

5.2. Reduction of CH_4 and N_2O emissions

Peat moss has the potential to reduce CH_4 and N_2O emissions from the livestock sector. This potential can be potentially explored due to peat moss characteristic that mimics current manure treatment (Table 2). Acidification of dairy manure reduces CH_4 production by 81–88% (Sokolov et al., 2019, 2021). Methanogens are sensitive to pH (Monteny et al., 2001) and the low pH of peat moss may inhibit CH_4 generation from livestock manure by disrupting methanogenesis (Ma et al., 2022). Moreover, the moisture content and oxygen availability also determine the amount of CH_4 emissions (Liang et al., 2005). N_2O emissions in dairy barn vary depending on the range of carbon dioxide and moisture levels (Akdeniz et al., 2009). Several studies have reported mixed results regarding the relationship between low pH and decreased N_2O emissions, however, most have indicated that acidification reduces N_2O emissions (Saue and Tamm, 2018).

6. Conclusion

Peat moss has unique physical properties that make it ideal for use as a growth agent or material in other industries; however, the high GHG emissions released during its extraction remain an issue. Nonetheless, owing to its beneficial characteristics, the emissions generated during peat moss extraction can be compensated for through its application in many industries. Further, its characteristics imitate some mechanism of manure treatment process in reducing emissions, thus, peat moss could potentially contribute to reducing emissions (CH_4, N_2O, and NH_3) from livestock houses. It is clear that the application of peat in the livestock industry can compensate for the emissions released from its extraction from peatlands, making it a more sustainable option and more studies to evaluate the benefit of peat moss application in livestock industry are required.

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