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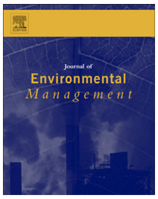

Research article

Bedding additives reduce ammonia emission and improve crop N uptake after soil application of solid cattle manure

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ABSTRACT

This study examined the influences of three potential additives, i.e., lava meal, sandy soil top-layer and zeolite (used in animal bedding) amended solid cattle manures on (i) ammonia (NH_3), dinitrous oxide (N_2O), carbon dioxide (CO_2) and methane (CH_4) emissions and (ii) maize crop or grassland apparent N recovery (ANR). Diffusion samplers were installed at 20 cm height on grassland surface to measure the concentrations of NH_3 from the manures. A photoacoustic gas monitor was used to quantitate the fluxes of N_2O, CH_4 and CO_2 after manures' incorporation into the maize-field. Herbage ANR was calculated from dry matter yield and N uptake of three successive harvests, while maize crop ANR was determined at cusp of juvenile stage, outset of grain filling as well as physiological maturity stages. Use of additives decreased the NH_3 emission rates by about two-third from the manures applied on grassland surface than control untreated-manure. Total herbage ANR was more than doubled in treated manures and was 25% from manure amended with farm soil, 26% and 28% from zeolite and lava meal, respectively compared to 11% from control manure. In maize experiment, mean N_2O and CO_2 emission rates were the highest from the latter treatment but these rates were not differed from zero control in case of manures amended with farm soil or zeolite. However, mean CH_4 emissions was not differed among all treatments during the whole measuring period. The highest maize crop ANR was obtained at the beginning of grain filling stage (11–40%), however ample lower crop recoveries (8–14%) were achieved at the final physiological maturity stage. This phenomenon was occurred due to leaf senescence N losses from maize crop during the period of grains filling. The lowest losses were observed from control manure at this stage. Hence, all additives decreased the N losses from animal manure and enhanced crop N uptake thus improved the agro-environmental worth of animal manure.

1. Introduction

Management of livestock is becoming crucial in many European countries. At current, this sector is mainly accountable for emitting approximately 80% of the European ammonia (NH_3) and 10–17% of nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2), in to the atmosphere (Leip et al., 2015). Around the globe, the sector estimated to contribute 5.6–7.5 $GtCO_2eq\ yr^{-1}$ of greenhouse gases (GHG) emissions during 1995–2005 (Herrero et al., 2016) whereas N_2O alone from manure management and manure after soil application was responsible for 0.21 and 0.49 $GtCO_2eq\ yr^{-1}$, respectively (Herrero et al., 2013). Likewise, in a very recent global meta-analysis study, it is found that soil applied animal manure was accountable for 32.7% increment in N_2O emission compared to the use of chemical fertilizer N alone (Zhou et al., 2017). Global warming potential of N_2O emission was 265–298 times higher compared to CO_2 up to a time scale of 100 years (EPA, 2017) and CH_4 emission from dairy manure was 8–10 times higher than CO_2 (Grant et al., 2015). Both of aforementioned gases play an imperative part in destroying stratospheric ozone layer (Akiyama and

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Tsuruta, 2003). In addition to this, NH_3 emitted to the atmosphere can be deposited in dry or wet form to the soil or waterways and caused acidification or eutrophication of nitrogen (N) in terrestrial or aquatic ecosystems (Amon et al., 2001; Pearson and Stewart, 1993). These nitrogenous losses to the atmosphere or in the water bodies are the principle barriers of animal manure usage as fertilizer in modern climate smart agriculture. Consequently, innovative management strategies are required that may be helpful in the reduction of environmental pollution from animal manure after its application to soil for crop production and therefore help in sustaining its usage as recyclable environmental friendly fertilizer (Shah et al., 2016b; Yitbarek et al., 2017).

The NH_3 emission can be up to 100% of the ammoniacal N applied through solid cattle manure (SCM) (Huijsmans et al., 2001) to grassland. To date, only few attempts have been made for developing the practices that can reduce NH_3 emission after land application of SCM (Shah et al., 2012, 2016a, 2016b; Sommer and Hutchings, 2001; Webb et al., 2014). Immediate SCM incorporation in to the soil by plough as well as combine use of irrigation or lava meal after its surface application are well-known practices to reduce NH_3 emission (Shah et al., 2012; Webb et al., 2004, 2014). Incorporation of SCM cannot be practiced in (i) stony soils, (ii) permanent grassland, (iii) farms without powerful machines and (iv) soils that are vulnerable to erosion because of ploughing. The use of irrigation, lava meal or their combination (Shah et al., 2012) cannot be practiced in water scarce region. Besides, the above measures are only effective after soil application of SCM. So, there is a great need to design, evolve and/or evaluate effective measures that can reduce the gaseous emission or nutrient losses throughout manure management chain at farm scale (Loyon et al., 2016) to enhance overall crop N utilization.

Recently, mixing of zeolite (clinoptilolite), sandy farm soil and lava meal in animal bedding decreased the total N emission losses by 85 and 45% from animal housing and during manure storage, respectively than control manure without additives (Shah, 2013). The lava meal is rich source of Mg and P compounds while zeolite containing negative binding sites, and organic matter (SOM), silt and clay particles present in farm soil may act as absorbent of $NH_4^+{-}N$ or NH_3 and thus could have potential to decrease N losses and especially NH_3 from SCM. Wightman et al. (1982) proposed the mechanisms of reducing NH_3 emission rate from the soil. They explained that clay/silt particles and SOM have negative charges in their surfaces and these complexes exchanged cations thus play an important role in NH_4^+ adsorption or fixation in clay minerals. Also, soils with pH below 6 (acidic soils) are not prone to NH_3 volatilization since at this pH mineral nitrogen is primarily found in $NH_4^+{-}N$ or ionic form therefore N losses through NH_3 volatilization will be very low. Besides, crystalline-hydrated features resultant from three-dimensional zeolite structures make it a very unique and durable adsorbent of many cations (Mumpton and Fishman, 1977; Ndegwa et al., 2008). So, in the animal manure solution, NH_4^+ adsorption lessens the aqueous NH_3 (water) concentrations and thus emission of NH_3 gas (Ndegwa et al., 2008). This phenomenon will also retard the processes of nitrification as well as denitrification in manure (Zaman and Nguyen, 2010). Likewise, lava meal containing Mg and PO_4 will possibly react with NH_4^+ ions and form precipitation of struvite salt thereby reducing its availability for conversion into NH_3 gas (Ali et al., 2013; Zhang and Lau, 2007). Nevertheless, in our best of the information, no single study was found in the literature for elucidating the subsequent influences of bedding additives on reducing NH_3 or N_2O emission and improving crop N uptake after soil application of SCM. Therefore, the aims of this follow-up research were: (i) exploring the mitigative potential of animal bedding additives like lava meal, sandy farm soil and zeolite on NH_3 emission when SCM was surface-spread on grassland and the aforementioned gas as well as N_2O, CH_4 and CO_2 emissions after field incorporation of SCM before sowing of maize crop in an arable field, (ii) to calculate the apparent herbage and maize crop N recovery (ANR) from the manures, and (iii) to understand and explain the N dynamics in maize through crop N uptake or ANR with time from the commencement of grain filling phase to the stage when physiological maturity of maize was reached.

2. Materials and methods

The study was executed at Droevendaal organic Farm (55°99′N latitude and 5°66′E longitude). This is an experimental and training farm of the Wageningen University and Research Centre, located very close to the university's main campus in Wageningen, the Netherlands.

2.1. Production of animal manure and its storage

The animal housing system of the farm was consisted of different sloping-floor barn units. It was a naturally ventilated and normally wheat straw was being used as bedding material. In this housing systems, we used four bedding treatments, i.e. i) control treatment with only straw application ii) straw + zeolite, iii) straw + local farm sand soil, iv) straw + lava meal. A barn unit was consisted of a 42 m^2 bedding area and 21 m^2 of manure alley where young bulls (beef) were kept in a group of eight. The treatments were applied on surface of bedding in barn units three times in a week. These amounts were proportional to 5 kg straw dosage daily per livestock unit (LU), i.e. zeolite 10% (0.5 kg LU^{-1}), 20% of lava meal (1 kg LU^{-1}) and 33% of local farm sand soil (1.7 kg LU^{-1}) that was collected from the top soil layer. Table 1 presents chemical composition of zeolite, lava meal and sand soil used as bedding additives in this study. From manure alley, SCM was collected manually two times, early morning and late afternoon. The manure collection was carried out using a hand scraper during a collection period of 80 days. After weighing, the manure from each treatment was stockpiled inside a roofed building as a separate heap. At the end of collection, the manure was further stored for 80 days at the same place. The complete details with respect to housing and storage phases can be consulted from Shah (2013). Chemical composition of SCM at the time of field application is presented in Table 2.

2.2. Solid cattle manure application

2.2.1. Experimental grassland field (Expt. 1)

At grassland site, circular plots were selected on 16 June 2010 that were previously mown through motorized mower. Each plot diameter was 3 m (Fig. 1a), where 400 kg N ha^{-1} untreated and additive amended SCMs were spread on the surface. The treatments were applied in triplicates in a completely randomized block design. These treatments include i.e., negative control (unfertilized plot), positive control (untreated SCM), lava meal amended SCM, zeolite amended SCM and local farm sandy soil amended SCM.

After treatments application, the grass was harvested three times during 5 months of herbage growth period. The first harvest was done on 5th August, followed by second at 30 September and the last on 18 November 2010. A motorized mower with 0.9 m width of cutting bar was used to cut the herbage sward of each circular plot from an area of 0.9 m × 2 m at 4 cm stubble height from the soil surface during each grass harvest. Border effects were avoided by harvesting all plots from the inner side. Grass was weighed in field and the herbage weight of each field was recorded to calculate fresh herbage yield. After mixing the whole grass, an