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Additives Used with Straw Bedding Can Mitigate Ammonia and Greenhouse Gaseous Emissions from Solid Cattle Manure in Sloping-Floor Housing System

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Abstract: We studied the influence of lava meal, zeolite and top layer of sandy soil as bedding additives on gaseous C and N losses from a sloping-floor barn of naturally ventilated animal housing. We selected four barn units where eight young bulls' group was reared in each barn. Chopped straw of wheat and barley applied daily at the rate of 5 kg per livestock unit (LU) in bedding areas where one LU consisted of 500 kg body mass of live bulls. Zeolite, lava meal and sandy soil (18% clay + silt) applied in barn at the rate of 10, 20 and 30% of straw dose, respectively. Static flux chamber was used to measure gases emissions from the barn unit and mass balance calculation was used to calculate straw manure total N (TN) losses during housing phase. On an average, all bedding additives decreased 85% of the NH_3 emission compared to control; however, they did not influence CH_4 emission. Zeolite decreased CO_2 (35%) and N_2O (37%) emission rates. Subsequently, lava meal, sandy soil and zeolite decreased 23, 37, and 50% of TN losses from barn manure, respectively. Overall, measured N emissions through NH_3-N and N_2O-N from the barns was 11% of calculated TN losses while remainder 89% was most probably attributed to di-nitrogen (N_2), a harmless gas. Hence, in straw-based cattle housings, zeolite could be a promising additive for reduction of CO_2, N_2O and NH_3 emissions and sandy soil can be considered as cheap and readily available resource for reducing NH_3 emission.

Keywords

Cattle straw manure; Bedding additives; Ammonia; Greenhouse gases; Zeolite

1. Introduction

Livestock is among the main agricultural sectors contributing substantially to greenhouse gases (GHG) emissions and global climate change (Henderson et al., 2018; Steinfeld et al., 2015). Gerber et al. (2013) estimated that this sector was responsible for 14.5% emission of GHG around the globe. According to Herrero et al. (2016), this sector contributed 5.6–7.5 $GtCO_2eq\ yr^{-1}$ to GHG emissions between 1995-2005 globally. In European countries, 80% NH_3 and 10-17% of GHGs such as CO_2, CH_4 and N_2O were emitted to the atmosphere through livestock sector (Adrian et al., 2015). Such contribution is coming mainly from supply chains of livestock that include CH_4 through enteric fermentation, GHG emitted from manure management chain, started from manure production in the barn to its soil application, as well as indirect contribution to emissions during production of animal feed and products (Gerber et al., 2013; Henderson et al., 2018). Therefore, the aforementioned sector has a great GHG mitigation potential in agriculture through adopting management measures, which can intensify sustainable livestock production and decease GHG emissions from manure management chains, promoting rangelands carbon sequestration and reducing the need of livestock products (Herrero et al., 2016).

Recently, European farmers are considering straw-based housing as an alternative to cattle cubicle barns in order to overcome the concerns on animal health, welfare and GHG emissions. Therefore, the sloping floor, deep as well as other litter barns have gained significance attention among the Dutch farmers. Nevertheless, these housing systems are prone to substantial losses of nitrogen (N) to the environment. These may occurred in the form of ammonia (NH_3) volatilization, urea hydrolysis, dissociation and denitrification processes which resulted in the emission of nitric oxide (NO), nitrous oxide (NO_2), and di-nitrogen (N_2) gases (Bai et al., 2017; Hou et al., 2016; Mosquera and Hol, 2005; Oenema et al., 2008). Along with N losses, these aerobic and anaerobic manure decomposition pathways led to C emissions through carbon dioxide (CO_2) and methane (CH_4) (Hao et al., 58 2004; Hempel et al., 2016). The deposition of atmospheric NH_3 is among the main sources of eutrophication in oligotrophic ecosystems (Sutton and Fowler, 2002) and afterward, nitrification of this gas also causes acidification in soils and waterways (ApSimon and Wilson, 1987). This process in various ecosystems is also thought to indirectly cause N_2O emission (Novak and Fiorelli, 2010). These N_2O and CH_4 emitted to the atmosphere can contribute to destroy the layer of ozone present in stratosphere (Morgenstern et al., 2018), whereas N losses reduce the fertilizer value of animal manure (Shah et al., 2016; 2018).

According to Mosquera et al. (2006) deep litter barn are much prone to NH_3 emission. They found in the Netherlands that deep litter housing systems emit ~1.5 time higher NH_3 emission than cubicle barns where slurry is produced. On the other hand, few other techniques are also available in the literature to reduce N losses from the straw-based housing systems. These include high amount of straw usage in animal bedding, removing solid manure from the barns frequently and installation of scrubbers or filter in air exhaust system to capture NH_3 from mechanically ventilated barns (Gilhespy et al., 2009; Loyon et al., 2016; Ndegwa et al., 2008; UNECE, 2014). In addition to these, various chemical and biochemical additives were also used in the animal feed or bedding to effectively decrease the gaseous emission from the straw-based housing systems (Al-Kanani et al., 1992; Amon et al., 1997; Husted et al., 1991; Loyon et al., 2016). The additives mode of action of these additives to combat gaseous emission were used to categorize them into acidifying, digestive, enzyme inhibitor and adsorbents (McCrory and Hobbs, 2001). Acidifying additives decrease the NH_3 emission by relocating the equilibrium between NH_4^+ and NH_3 towards NH_4^+ in the animal manure solution (Husted et al., 1991). On the other hand, digestive additives promoted microbes in the animal manure that led to immobilize ammonium (NH_4^+) and thus decrease NH_3 volatilization (Hendriks and Vrielink, 1997). Moreover, adsorbent materials such as clay, peat, zeolite, and silt adsorbed the NH_4^+ on their surface to reduce NH_3 emission from the manure (Lefcourt and Meisinger, 2001). Among all, only those additives are much effective for NH_3 emission by influencing more than one biochemical processes. For instant, yucca plants extract possessed the ability to conserve NH_4^+ through urease activity inhibition (Asplund and Goodall, 1991) as well as bound NH_4^+ to reduce its availability for microbes and thereby preventing the processes of nitrification and denitrification (Panetta et al., 2005). Magnesium (Mg) and phosphorus (P) are water soluble salts that greatly decreased NH_3 emission from the food waste composting process (Jeong and Kim, 2001). Basically these salts precipitated NH_4^+, produced during decomposition of organic substances, into struvite (ammonium magnesium phosphate; $NH_4MgPO_4.6H_2O$) compound which is the product of chemical reaction occurred among NH_4^+, PO_4^{-3}, and Mg^{+2} when they mixed at a molar ratio of 1:1:1 (Ali et al., 2013). This chemical reaction occurred at an optimum pH range of 7 to 9 (Nelson et al., 2003), and the product formed is also termed as slow N release inorganic fertilizer (Ali et al., 2013; Shah et al., 2012). Besides, clayey soil and zeolite reduced the NH_3 emission during sewage sludge composting through adsorbing released NH_4^+ or volatilized NH_3 (Witter and Lopez-Real, 1988). Consequently, use of additives such as lava meal (solidified magma) having Mg and P compounds and zeolite and farm silty clay soil can be used to reduce manure NH_3 emissions from straw-based animal beddings. Organic matter and clay/silt particles with negative 108 charged surfaces adsorbed NH_4^+ to form cation exchange complexes and clay minerals fixed this cation thereby reduced NH_3 volatilization (Wightman et al., 1982). Moreover, zeolite are three-dimensional crystalline-hydrated aluminium silicates consisted of framework cavities, which can occupy ions and water molecules, such characteristics will make zeolite a strong cations adsorbent of NH_4^+ (Abdullahi et al., 2017; Mumpton and Fishman, 1977). Therefore, most of the studies are carried out to mitigate NH_3 emission, to our knowledge no attempt has been made until now for deceasing N_2O and CH_4 emissions from litter barns by using the aforementioned additives as an abatement technology. So, this study aimed, (i) to investigate the influence of lava meal, zeolite and sandy farm topsoil when mixed with straw as bedding material on NH_3, N_2O, CO_2, and CH_4 emissions from the sloping-floor barn accommodated beef bulls. (ii) To quantify the impact of these additives on N losses from the solid cattle straw manure during housing and storage phases.

2. Materials and Methods

The study was performed at Experimental and Training Organic Farm Droevendaal (latitude 55°99'N and longitude 5°66'E), of Wageningen University and Research Centre, which is situated in the north 1 km away from Wageningen city, the Netherlands. The young bulls were housed in sloping-floor barn for period of 80 days while the collected manure from the barn unit was stored for another 80 days inside the roofed building.

2.1. Housing experiment

The bulls were housed in a natural ventilated straw-bedded housing system with sloping-floor barn. In this experiment, we used four barn units to assign four different treatments: i) control (only straw application) and mixing of ii) lava meal, iii) zeolite and (iv) sandy soil at particular ratios in straw applied barn units. Barn units' layout is presented in a schematic drawing (Fig. 1). Zeolite (clinoptilolite) and powdered lava meal (Eifelgold®) was provided by "Zeolite products®" Arnhem, the Netherlands and

"Lava-Union®" Germany, respectively. These companies also provided their chemical composition (Table 1). The sandy [silt (14%), clay (4%), sand (82%)] textured soil was sampled form the top 25 cm depth of the same farm where spring wheat was cultivated previously, and then air dried. Soil chemical characteristics were presented in Table 1.Bedding area of each barn unit consisted of 42 m_2 with 21 m^2 manure alley. Control and lava meal treatments were applied in the barn unit with slopes 6 to 8°, and in case of zeolite and sandy soil treated barn these were 4 to 6° (see Fig. 1). Eight beef bulls (young) were grouped to house in each barn unit. To avoid fight among them, grouping was made according to their age. At the beginning of experiment, the age of the bulls was ranged between 12 and 17 months where body weight of each bull varies between 291 to 526 kg (Table 2). The bulls' weight with empty stomach was recorded for three days consecutively in the morning at each weighing session taken place at the first day, mid, and end of experiment. The straw manure and other organic debris present in beddings of the selected barn units were removed before the execution of experiment. Wheat and barley chopped straw with length of $\leq$ 10 cm were broadcasted on bedding units at 5 kg livestock unit^{-1} (LU) on daily basis where 1 LU represents the live bulls with 500 kg body weight (Costa and Guarino, 2009) prior to the commencement of experiment. Bedding additives such as sandy soil, zeolite and lava meal were applied at the daily straw dosages of 33, 20, and 10% of applied straw on weight basis, respectively. We selected these rates of bedding additives based on the preliminary laboratory experiment where different amounts of each additive were applied in the bedding of sloping-floor barn to measure the reduction of NH_3 emission from the solid straw manure (data not shown). For this experiment, we only selected those rates which reduced ~ 80% of the NH3 emission from the control (untreated).

2.2. Characteristics of bulls feed

The bulls were fed with silages of 1:1 (w/w) ratio mixture of oats-faba bean and grass-clover during initial eight weeks. In last three weeks of housing phase, they were fed with triticale-grass-clover and grass-clover mixture with same aforementioned ratio due to unavailability of initial feedstock. Additionally, each bulls' group was also fed with 20 kg of crushed cereal grains (wheat and barley) daily during the whole housing experiment. On each day, before giving fresh food to the bulls, collected feed refusal was weighed. Mean feed intakes of one LU in the form of dry matter (DM) and N is represented in Table 3 and calculated as:

$$\mathrm{DMin} = \mathrm{DM}_{\mathrm{off}} - \mathrm{DM}_{\mathrm{ref}} \tag{1}$$

$$\mathrm{FNi} = \mathrm{TN}_{\mathrm{off}} - \mathrm{TN}_{\mathrm{ref}} \tag{2}$$

Where $\mathrm{DM}_{\mathrm{in}}$ shows the feed intake of DM (kg DM LU^{-1} day^{-1}) per day, $\mathrm{DM}_{\mathrm{off}}$ indicates feed offered to bulls per day (kg DM LU^{-1} day^{-1}). $\mathrm{DM}_{\mathrm{ref}}$ represents feed refusal by bulls per day kg DM LU^{-1} day^{-1}), FNi indicates N intake from feed by bulls per day (kg DM LU^{-1} day^{-1}), $\mathrm{TN}_{\mathrm{off}}$ shows TN present in feed offered to the bulls per day (kg DM LU^{-1} day^{-1}), as well as $\mathrm{TN}_{\mathrm{ref}}$ represents TN found in feed refused by bulls (kg DM LU^{-1} day^{-1}).

2.3. Bull dirtiness score

Bedding materials played an imperative role in providing hygiene conditions and cleanliness to the animal since Small et al. (2005) observed a direct association between cattle carcass surface and microbial loads presence on their hide. Therefore, we used a scoring system to study the influences of bedding additives on bull dirtiness. The dirtiness scoring was carried out on day 38 and 78 of housing phase during the weighing sessions by using scoring sheet (Scott and Kelly, 1989). The sheet divided right and left sides of entire bull body (lower legs, hooves and hind underbelly) into 35 areas. Dung presence on each body area was scored and a zero score was allotted if no dung was found in the area while up to three integer values were assigned to dung dirty areas. The final score of each bull body was 70, a total sum of dirtiness scores.

2.4. Bulk density and thickness of bedding with straw manure

The influence of difference in live weight of bull on the animal manure bedding and physical characteristics of each barn unit was monitored by measuring the bulk density and thickness. Graduated metallic rod was used to measure the straw manure beddings thickness by inserting it down until concrete floor where gaseous measurement took place. In one measurement session, bedding thickness was measured at nine different locations from each barn unit. Leftover straw manure was scraped and weighed from the bedding of each barn at the end of housing experiment. Subsequently, straw manure bedding bulk density was calculated using following equation:

$$\mathrm{BD} = \frac{\mathrm{W}_{\mathrm{e}}}{\mathrm{A}_{\mathrm{bu}} \times \mathrm{L}_{\mathrm{t}}} \tag{3}$$

Where BD indicates the straw manure bedding bulk density (Mg m^{-3}), W_{e} represents the straw manure total weight scraped from the bedding area (Mg), A_{bu} shows barn unit area covered with straw manure (m^2), and L_t indicates mean manure bedding thickness at the end of experiment (m).

2.5. Gaseous concentrations measurement

There was no air separation among barn units, therefore it was not possible to measure ventilation fluxes from each barn unit. Consequently, a static flux chamber consisted of internal gas circulation system connected by two Teflon tubes (inner diameter, 3 mm) with an INNOVA (1412A, Denmark), photoacoustic gaseous monitoring device (Predotova et al., 2010; Teye and Hautala, 2010) was used to calculate the fluxes of N_2O, CO_2, CH_4 and NH_3 from the animal beddings with straw manure. This instrument can detect up to CO_2 = 5100 ppb, NH_3= 200 ppb, CH_4 =100 ppb, and N_2O =30 ppb. Bottom edge of the flux chamber was sharp with 0.3 m internal diameter whereas its weight was about 10 kg. The chamber was made of poly vinyl chloride (PVC), which has very low capacity to adsorb NH_3 (Shah et al., 2006). At all measurement occasions, flux chamber inserted carefully into the straw manure-bedding surface until 4-5 cm depth with minimum disturbance. Subsequently, INNOVA recorded the concentrations of CO_2, NH_3, N_2O, and CH_4 for a period of 10 to 15 minutes. The heavy weight (about 10 kg) of flux chamber used to seal the surface of bedding, so the gases could not escape from chamber around its base. Three random places from the bedding surface of each barn unit were selected to measure the gaseous emission twice in a week (Friday and Monday) just before additives' and fresh straw application. However, we did not measure gaseous emission during week 5 of housing phase owing to technical problems. The gaseous measurement system in INNOVA computes gases vertical fluxes coming from the manure present on bedding surface. The built-in system in the instrument sucked influx air just directly above from the emitting surface and laterally pumped back to the closed chamber. Similar measurement system had already been utilized for reliable estimation of NH_3 volatilization from broiler houses with litter surfaces (Brewer and Costello, 1999). Nevertheless, in another study, Predotova et al. (2010) found that the measuring set-up had some errors in the estimation of CO_2 (5%), N_2O (12%), NH_3 (-13%), and CH_4 (-2%) during validation sessions, which could slightly underestimate possible gaseous N losses. In our study before the measuring session, ENMO services (Belgium) twice calibrated our multi-gas monitor. They certified on both occasions that instrument was in well-performing conditions. Moreover, there was a built-in compensation in the instrument for CO_2 and water vapours if these can cross interfere with CH_4, NH_3 and N_2O gases (Predotova et al., 2010).

2.6. Gaseous fluxes calculation

NH_3 gas accumulated in the flux chamber through mass transport by diffusion process (Szánto, 2009). Since rate of NH_3 emission is dependent on time in the flux chamber, therefore it gradually deceases with increasing concentration of NH_3 (Teye and Hautala, 2010). Consequently, when NH_3 gas concentration in the flux chamber attained an equilibrium state with aqueous NH_3 present in the top manure-bedding layer, gaseous measurements were stopped based on the assumption that there was no NH_3 emission once gas-liquid phase reached at steady-state (1:1 ratio). The actual NH_3 emission rates from the bedding of each treatment was calculated by fitting a non-rectangular hyperbola (Eq. 4) from each data set of NH_3 measurement from the curve's initial slope obtained from concentration (mg m^{-3}) of NH_3 (gas) and time in minutes (Fig. 2) which signifies the instantaneous rate of NH_3 emission.

$$[NH_3C] = D_0 + \frac{1}{2A_s}\left\{B_1 \times t + C_e - \sqrt{(B_1 \times t + C_e)^2 - 4A \times B_1 \times C_e}\right\} \qquad (4)$$

Where $[NH_3C]$ represents the concentration of NH_3 gas measured from the flux chamber (mg m^{-3}). A_s signifies the sharpness parameter of the curve and its value lies between 0 (Michaelis-Menten relation) and 1 (Blackmann curve), B_1 shows initial slope of the curve in unit of mg m_{-3} min_{-1}272 . C_e indicates concentration (mg m^{-3}) of NH_3 gas at state of equilibrium, t indicates time (min), and D_0 represents concentration of NH_3 gas at zero time (mg m^{-3}). Biochemical processes drive production of CH_4, N_2O, and CO_2 from bedding of straw manure (Laguë, 2003) which resulted in continuous increase in the concentrations of aforementioned gases inside the flux chamber. Thus, the linear slope obtained from the data of gaseous concentration in unit of mg m^{-3} and time in minutes denoted rate of emission at any instant (B_2) (Shah et al., 2016). The following relation was used to convert total barn unit gaseous emission rates (R) in g LU^{-1} day^{-1}:

$$R = 1.44 \times B_{i=1,2} \frac{V_T \times A_{BU}}{A_C \times LU} \qquad (5)$$

Where 1.44 indicates the factor of conversion used to up-scale mg min^{-1} to g day^{-1}. B_1 shows rate of NH_3 emission at any instant (mg m_{-3} min^{-1}), B_2 represents slope obtained from concentration of CH_4, N_2O or CO_2, and time (mg m_{-3} min^{-1}). V_T shows air total volume (1.82×10^{-2} m^3) inside the monitoring system during gaseous measurement. A_c

indicates straw manure bedding surface area ($7.07*10^{-2}$ m^2) inside the flux chamber. A_{BU} indicates the barn unit area covered by straw manure (42 m2291), and LU shows livestock units present in each barn. V_T is the subtraction of flux chamber reduced volume of $3.18*10^{-3}$ m^3 that is inserted into the animal bedding from the internal total volume of chamber ($2.12*10^{-2}$ m^3) and then added internal PVC tubes volume ($1.41*10^{-5}$ m^3) and air volume extant in the gas monitor ($1.4*10^{-4}$ m^3). Afterward, rates (R_2) of NH_3 or N_2O emitted from each barn unit (g kg^{-1} N excreted day^{-1}) were calculated by:

$$R_2 = \frac{R_1}{T_{NE}} \qquad (6)$$

Where R_1 indicates the rate of NH_3 or N_2O emitted (g $group^{-1}$ day^{-1}), T_{NE} shows the excreted total N, which is calculated by subtraction of $TN_{retention}$ (kg N bulls $group^{-1}$) from daily feed N intake (kg N bulls $group^{-1}$) and. $TN_{retention}$ is the multiplication of gain in daily bulls body weight (kg $group_{-1}$) and $28*10^{-3}$ kg N kg^{-1}, a factor of N content used for a common growing bull live weight (Haas et al., 2002).

2.7. Barn unit TN losses calculation

Mass balance and total N (TN) to ash ratio methods (Paz and Weiss, 2012) was used to quantify TN losses from each barn. The total N losses from barn unit ($BuNL_{mass}$) using mass balance technique were quantified as:

$$BuNL_{mass} = TN_{inp} - TN_{outp} \qquad (7)$$

$$TN_{inputs} = TN_{fe} + TN_{str} + TN_{addi} \qquad (8)$$

$$TN_{outp} = TN_m + TN_{retention} \qquad (9)$$

Where TN_{fe} shows the difference in TN found in offered and refused feed (kg N $group^{-1}$). TN_{str} indicates multiplication of straw total mass applied to bulls (kg $group^{-1}$) and its N content. TN_{addi} represents the multiplication of total additive mass applied in barn (kg $group^{-1}$) and N content present it. TN_m indicates the amount of TN present in manure trampled down by bulls from the barn unit in housing as well as manure accumulated in bedding area in barn unit at the termination of housing phase (kg N $group^{-1}$), and $TN_{retention}$ described in equation 6. Total N losses from the barn unit by adopting the method of TN: ash ratio ($BuNL_{TN:ash}$) were calculated as:

$$BuNL_{TN:ash}\ (\%\ \text{of inputs}) = \frac{(TN{:}\,ash)_{inp} - (TN{:}\,ash)_{outp}}{(TN{:}\,ash)_{inp}} \times 100 \qquad (10)$$

Finally, the unaccounted N losses (UnNL) that are part of the established total N losses from gases was quantified using following relation:

$$\text{UnNL} = \frac{\text{BuNL}_{\text{mass}} - \text{Total NH}_3\text{-N} - \text{Total N}_2\text{O-N}}{\text{BuNL}_{\text{mass}}} \times 100 \qquad (11)$$

Periodic total emission of NH_3-N and N_2O-N was estimated by taking the mean of emission rates occurred between two successive sampling intervals and multiplied this with day numbers amid these intervals (Chadwick, 2005). Afterward, TN emission during whole housing phase was calculated by summing instantaneous emission rate estimated between two sampling intervals.

2.8. Storage phase

2.8.1.Manure collection and storage

From Monday to Friday, manual collection of straw manure (trampled-down by the bulls from sloping floor to the manure alley of each barn unit) was carried out early in the morning and late in afternoon through hand scraper daily. The collected manure weighed and subsequently stockpiled inside the roofed building. For manure storage, 1.5 m high concrete blocks were used to construct compartments on the concrete floor. Each compartment consisted of 4 m x 3 m x 1.5 m area and lined leaching was avoided by lining an impermeable plastic sheet. Here, the manure was stored for further 80 days after collection. However, due to unavailability of labour during weekend, the trampled down straw manure present in the manure alleys was mechanically scraped together from all barn units five times a day with an auto-scraper. This manure was stored in a separate common storage place. Consequently, the data was interpolated to the adjacent weekdays for the calculation of the amounts of the trampled-down manure from each treatment during Saturday and Sunday.

2.8.2. Sampling of straw manure from bedding and storage phase

We sampled the straw manure two times in a week (Monday to Friday) from each treatment during housing phase. Straw manure was manually sampled at the top to bottom in the bedding layer from nine random locations (~100 g from each) and then these samples were thoroughly mixed to make a composite sample. After weighing the total heap, the manure was manually sampled from 25 different positions at termination of storage phase and then mixed to form a composite sample (Shah et al., 2016). These samples were refrigerated at -18°C till further use to avoid N transformations.

2.8.3. Straw manure and feed analysis

After taking out the samples from deep freezer, their thawing were carried out at ~20°Cand after ~20 minutes, samples were sliced into small pieces (straw length ≤2 cm) with a cutting machine (Sommer and Dahl, 1999). The representative samples were subjected to DM, pH-$CaCl_2$, TN, nitrate-N, (NO_3^--N), NH_4^+-N, and raw ash content analyses. DM and ash content determined gravimetrically after samples were oven dried at 105°C for 24 h and loss on ignition was determined at 525ºC for 6 h, respectively. Percentage of OM was determined by subtracting ash content from 100. Subsequently, it was assumed that 50% content of the OM consisted of total C (Pettygrove et al., 2009). Segmented-flow analysis was used to determine the NO_3^--N and NH_4^+-N content from 10: 1 of $CaCl_2$ (0.01 M) /fresh manure extract (Houba et al., 1989). Manure pH was determined from the same extract using a pH meter. Like manure, feed samples were also subjected to DM content analysis by oven-drying at 70°C for 48 hours. Subsequently, they samples were ground and analysed for total N through Kjeldahl digestion (Bremner, 1960; MAFF,1986).

2.8.4. TN losses

Total manure N losses from the manure before field application was calculated by summing the losses occurred during housing and storage phases. The total housing N losses consisted of the losses estimated from straw manure bedding and manure alley, which were difference of gross N inputs (after animal retention correction) and outputs. Likewise, N losses occurred during manure storage were the difference of total amount of N found in trampled-down straw manure (housing period, after correcting for weekend days) and corresponding manure heap total N at the end of storage phase.

2.9. Statistical analysis

The mean values (n= 3 for gaseous emissions and n= 9 for bedding thickness) were subjected to univariate analysis by using PASW Statistics software (19.0; SPSS Inc, Chicago, IL, USA) at 5% probability level. For this statistical analysis, the treatments (n=4) and measurement days (n=18) were defined as fixed and random factors, respectively. Multiple comparison among treatments were carried out by uncan’s multiple range test. Using ANOVA, the difference among treatments for N excreted, straw-to-N excreted ratio DM intake, and feed N intake were statistically analyzed. Equation 4 was used to estimate the average instantaneous NH_3 emission rate (B_1) for each data set through non-linear regression model. Moreover, the relation between CH_4 and N_2O as well as their relations with straw manure bedding thickness were estimated by linear regression (Jeppsson, 1999). The data set for bulls' dirtiness was obtained by summing 70 scores for every bull during each of the two measuring days. The summed value was treated as one replicate (Jeppsson, 1999).

3. RESULTS

3.1. Dirtiness scores of bulls

Table 4 presents bulls' dirtiness scores means for each group during housing phase on 38 and 78 days. This score in lava meal bulls' group was greater than bulls groups kept in zeolite and sandy soil beddings at day 37 and 78 ($P < 0.05$). There was, however, control and lava meal groups bulls were no differed ($P > 0.05$) in dirtiness scores at day 37.

3.2. Chemical characteristics of straw manure

The straw manure DM and C content were the highest for sandy soil bedding and control treatments respectively (Table 5). Contrarily, straw manures C:N ratio were on average lower in additives amendments compared to control (23.5 vs. 25.5).

3.3. Gaseous emissions

Overall, during initial six weeks, rates of NH_3 emission per LU fluctuated and then these rates were stabilised (Fig. 3a). On the other hand, CH_4, N_2O, and CO_2 emission rates were low at initial stage and then increased to the end the housing experiment (Figs. 3b-3d). The highest mean emission rates (g LU^{-1} day^{-1} and g kg^{-1} N) of CO_2, NH_3, and N_2O were observed in control and the lowest for zeolite treatment. Interestingly, rates of CH_4 emission did not differ significantly among treatments ($P > 0.05$; Table 6). CO_2 and N_2O emission rates followed the same patterns (Figs. 3b and 3c), and there was a significant linear correlation ($P < 0.001$) between the emissions rate of N_2O and CO_2 (Fig. 4).

3.4. CH_4 and N_2O emissions relation with manure beddings thickness

In general both CH4 and N2O show positive relationship with bedding thickness (Fig 5a, 5b). In case of CH_4, the emission rate was greatly enhanced at bedding thickness exceeded from 10 cm height (Fig. 5a). However, this increment was only higher ($P < 0.05$) for sandy soil than control. Gradual increase in N_2O emission was observed with increasing thickness of bedding layer, which was established from trend lines (Fig. 5b).

3.5. Total N losses from barn unit

Both mass balance ($BuNL_{mass}$) and total N (TN) to ash ratio ($BuNL_{TN/ash}$) methods showed a marginal difference in TN losses from additive amended beddings treatments however, we did not observe any difference in this parameter among bedding additive treatments and control (Tables 7a and 7b). The TN losses from the control barn unit was 11% of N inputs. These losses were reduced 48, 62 and 75%, with application of lava meal, sandy soil and zeolite additives, respectively in the bedding of different barn units. Therefore, $BuNL_{mass}$ levels were lower than control despite of high total N inputs in additive amended treatments (Table 7a). Bedding additives also reduced total emission of NH_3-N by on average 75% than control (0.37 vs 1.47 kg NH_3-N- bulls' group^{-1}). Nevertheless, theclosses occurred from bedding additives amended treated barn units ranged between 4.5-13.8% of TN losses (Table 8). From the aforementioned treatments, N_2O-N emission was only 1.86%, of TN losses and 0.7% from control. However, average unaccounted N losses was 89% of T N losses.

3.6. Total N losses from housing and storage phases

Additive amendments in animal bedding resulted in on average lower TN losses in housing than storage phase (27% vs. 73% of TN losses; Table 9). Conversely, similar share in TN losses was observed from control treatment in both phases. Additive used in animal bedding reduced 37% of TN losses (after correcting animal retention) when these losses were presented as part of the gross inputs during both housing and storage phases than control. This reduction was mainly linked to TN losses occurred during housing (61%) phase than storage period (15%).

4. DISCUSSION

The selected barn units for this experiment were consisted of different degrees of slopes in bedding areas. Therefore, by varying slope height and straw amount that was applied in bedding areas that helped us to compensate the live weight of each bulls' group. Since, trampling activities of lower live weights bulls can enhance outflow of the manure when housed on steeper slope beddings. This resulted in low amount of straw manure left on bedding area that did not vary much from other treatments with relatively high bulls weight (Table 4). Moreover, average manure beddings thicknesses in lower weight bulls' treatment remained similar and bulk density differed marginally to other treatments throughout the experiment ($P > 0.05$; Table 3, 4). Most of the all, the applied amounts of straw in bedding was proportional to the bulls' number in each group, this resulted in approximately same excreted straw-to-N ratio in the manure ($P > 0.05$; Table 3). Therefore, different inputs of straw applied to barn units housing various bulls' groups did not influence on NH_3 emission rates. Consequently, the observed reduction in gaseous emission from the straw manure could be attributed to the application of bedding additives in animal housing.

In preliminary housing experiment, we adjusted additive applied amount to attain 80% NH_3 emission reduction from the bedding area. For instance, 0.5 kg per LU per day zeolite application decrease 87% of NH_3 emission (Tables 1 and 6). On the other hand, high amount of sandy soil and lava meal was required to achieve this reduction in gaseous emission. In case of lava meal, 1.0 kg per LU per day was required to obtain 85% emission reduction regardless of its tendency to form struvite after capturing NH_4^+ through P and Mg compounds. Physio-chemical characteristics of sandy soil makes it effective to lessen losses of N from cattle manure management. These are textural properties like silt and clay as well as chemical characteristics including organic matter, cation exchange capacity (CEC), and soil pH. Clay adsorbs more NH_4^+ cations compared to silt however, it perhaps desorbs these ions quickly than clay contents. We used sandy soil (CEC: 2 cmol kg^{-1} ; Table 1) that has very less capacity to decrease NH_3 and N_2O emissions, however its acidic nature (pH_{CaCl_2} 4.9) could have increased its binding capacity of NH_4^+ ions (non-volatile) that would have played a role in reducing NH_3 emissions from the straw beddings. Hence, this additive required higher daily application rate (1.65 kg per LU) than other additives used in this study to attain 84%reduction in NH_3 emission.

According to an old saying "too much of a good thing is bad", therefore, high clayey soils application rates could lead to fix NH_4^+-N in the interlayer spaces of clay minerals (Nieder et al., 2011; Witter and Lopez-Real, 1988). Secondly, organic N complexes present in animal manure can entrap in soil aggregates and hence could not be accessed by microbes. Moreover, higher clay contents had a potential to protect microbial biomass physically in the structure of soil (Van Veen and Kuikman, 1990). An inverse relation of soil clay content with manure net N mineralization rate reported in many studies (Castellanos and Pratt, 1981; Chescheir et al., 1986; Shah et al., 2013a; Sørensen and Jensen, 1995). Consequently, all these processes might decrease the N availability from animal manure for crop uptake after its soil application. Yet, more research is required to figure out the different soil types with varying pH levels as well as silt and clay contents and their appropriate application rates for establishing the rigorous working principles of mitigating NH_3 and N_2O emissions from animal manure housing systems.

The economic feasibility analysis of bedding additives used in this study was carried out to know their suitability on farm use (Shah et al., 2018). The cost of the soil, when used as bedding additives, was associated with collection equipment, transportation, time and drying. On the other hand, lava meal and zeolite costs were calculated by the multiplication of purchasing cost (0.25 € per kg for bulk) and amounts required (523 and 315 kg, respectively) for reducing 1 kg of NH_3-N emission from the manure. This analysis showed that costs for reducing 1 kg of NH_3-N losses from animal housing for sandy soil, zeolite and lava meal bedding additives were 10, 79 and 131 €,respectively. Hence, based on the economic analysis and easiness of availability on farm, it can be concluded that sandy soil as bedding additive is a sustainable resource for mitigating NH_3 emissions in such housing systems.

On the other hand, CO_2 and N_2O from barn units were only decreased by zeolite than control ($P < 0.05$). Such reduction in these GHG gases can be attributed to its distinctive gaseous adsorption characteristics (Abdullahi et al., 2017; Wheeler et al., 2011; Witter and Lopez-Real, 1988). Since NH_4^+ adsorption hinders the processes of nitrification and denitrification during animal manure decomposition (Zaman and Nguyen, 2010), therefore we observed only a tendency in reduction of N_2O losses by the application of sandy soil and lava meal. However in our study, all bedding additives did not reduce CH_4 emission from the whole housing phase since this gas could not be adsorbed by the additives due to its non-polar molecular structure (Wheeler et al., 2011). Contrarily, rate of CH_4 emission was even higher in sandy soil amended beddings than control ($P < 0.05$), when the height of bedding layer thickness was increased above 10 cm. This can be explained by the soil capacity to hold water that decreases the oxic zones presence and hence encourages the process of methanogenesis (Whalen and Reeburgh, 1996).

We observed a significant direct linear 545 correlation ($P < 0.001$) between all the data points of the rates of N_2O and CO_2 emission from animal manure exerted on straw beddings (Fig. 4). This relationship was much similar to the relation between the aforementioned gases emitted after decomposition of plant residues in soil as observed by Huang et al. (2004). In both studies, labile organic compounds from organic matter (plant residues or manure) subjected to microbial decomposition and nutrient mineralization which resulted to enhance the substrate (e.g. NH_4^+) for the processes of nitrification and denitrification (Millar et al., 2004) to emit CO_2 and N_2O simultaneously.

Denitrification process converts nitrate into NO_2, NO, N_2O, and N_2 (Nikolić and Hultman, 2005; Van Cleemput, 1998). However, we did not measure NO_2, NO, and N_2 emissions. Our calculation showed that sum of N losses through aforementioned gases were between 85 to 94% of the total N lost during housing phase (80 days) (Table 8). In accordance with our findings, Gilhespy et al. (2009) observed 76 to 92% of unaccounted N losses from beef cattle system during a housing duration of 144 days. Small part of the aforementioned high unaccounted losses of N could be attributed to the N emission during bulls' trampling activities that were not used in the calculation since number of discrete measurements were used to derive the cumulative figures instead of using continuous measurements (Moral et al., 2012). Taking a representative sample of the straw manure from animal bedding could be other source of error that led to increase in unaccounted N losses. Since, precise straw manure sampling is very difficult from the bedding area because animal urine could be prone to percolation from the bedding layer and hence it remained stagnant on the barn floor and could not become part of the sampling. Therefore, it led to underestimate the N content present in straw manure (Misselbrook and Powell, 2005). Nevertheless, certainly the most portion of unaccounted N losses occurred as N_2, which is a harmless gas and denitrification process end-product (Harper et al., 2000). In our study, N_2O-N emission was only ~2% of total N losses, therefore biological nitrification and denitrification processes through bacteria were expected to play a trivial role. Therefore, chemical denitrification (Van Cleemput, 1998), and methanotrophic or heterotrophics nitrification denitrification processes that carried out in the absence of oxygen (Harper et al., 2000) were most probably dominated. An alkaline pH of the substrate play an important role to spontaneously convert NH_4^+ into N_2 during chemical denitrification process (Nikolić and Hultman, 2005). This phenomena could occur in our study as pH-$CaCl_2$ of the manure in all bedding treatments was >eight (Table 5).

Generally, it is recommended to keep all animal hygiene, health, and environment aspects in mind while working with bedding additives. Cleanliness of bulls is considered as an important factor to ensure hygienic production of meat and animal's well-being. We measured this parameter from all the treatments and found that the bulls kept on the straw beddings mixed with zeolite and sandy soil were much cleaner than those of lava meal mixed bedding were. This could be linked to the relatively higher water absorbing capacity of sandy soil than lava meal and zeolite (Arshad and Coen, 1992; Nguyen and Tanner, 1998; Witter and Lopez-Real, 1988). Moreover, it was visually observed that immediately after additives application in animal beddings, dust in air was greater in zeolite and lava meal amended barn units than sandy soil. Since, dust inhalation can influence the respiratory health of cattle and people working in the animal housing. Therefore, sandy soil as bedding additive can provide both better air quality and cattle cleanliness in the barn units.

5. CONCLUSIONS

The results clearly indicated that using sandy soil, zeolite and lava meal as additives in animal bedding has a great potential to reduce NH_3 and total N losses from straw-based animal housings. Zeolite reduced mean emission rates of CO_2 and N_2O but any of the bedding additives did not influence CH_4 emission. Economic analysis indicated that sandy soil having significant proportion of silt clay is the cheaper and most attractive bedding additive than commercially accessible zeolite or lava meal for mitigating both total N losses and NH_3 emission until field application of animal manure. In addition, this additive produces very small dust in the barn during it application and thus provides better air quality inside the cattle housing, moreover it also keeps the bulls clean and improves their hygiene and well-being. This study provide a significant contribution to integrated analysis of the effectiveness of mitigation practices as well as C and N losses pathways from solid cattle manure management chain at farm level, c.f. Shah et al. (2013b).

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Tables

Table 1. Mineral nitrogen (N_{min}), total nitrogen (TN), pH ($CaCl_2$) organic matter, available phosphorous (P_2O_5), magnesium oxide (MgO), cation exchange capacity (CEC) along with application rates of the zeolite (Z), lava meal (LM) and sandy soil (SS) as bedding additives used in the study.

Additives	rate applied	TN	N_{min}	Organic Matter	P_2O_5	MgO	CEC	pH
	(kg LU^{-1} day^{-1})	(g kg^{-1} DM)					(cmol kg^{-1})	
Z	0.5	0.001	0	0	0.2	0.9	90	7.8
LM	1.0	0.002	0	0	10.0	85.0	12	7.9
SS	1.7	1.2	0.13	29	0.4	-‡	2	4.9

‡not analysed

Table 2. Means of bulls' physiognomies (n=8 ± S.E) in control (C), zeolite (Z), lava meal (LM) and sandy soil (SS) at 0, 40 and 80 days of the housing phase.

Groups	Day number	Age (months)	Body weight (kg bull^{-1})	Body Weight Gain (kg bull^{-1} day^{-1})	LU†
C	0	12.0 ± 1.0†	291 ± 24		4.7
	40	13.3 ± 1.0	342 ± 25	1.3 ± 0.1	5.4
	80	14.6 ± 1.0	378 ± 26	0.9 ± 0.1	6.1
Z	0	16.0 ± 0.5	514 ± 22		8.2
	40	17.3 ± 0.5	579 ± 24	1.6 ± 0.1	9.3
	80	18.6 ± 0.5	624 ± 26	1.1 ± 0.1	10.0
SS	0	17.0 ± 0.6	526 ± 8		8.4
	40	18.3 ± 0.6	590 ± 9	1.6 ± 0.1	9.4
	80	19.6 ± 0.6	634 ± 12	1.1 ± 0.1	10.1
LM	0	13.0 ± 0.7	427 ± 15		6.8
	40	14.3 ± 0.7	484 ± 15	1.4 ± 0.1	7.7
	80	15.6 ± 0.7	526 ± 15	1.0 ± 0.1	8.4

† 1 LU (livestock unit) = 500 kg bulls' live body weight

Table 3. Mean (n=18 ± S.E) thickness (T) of animal manure beddings, intake of dry matter and feed N content, excreted N, and excreted straw:N during housing phase. Treatments abbreviation can be found in title of the table 2.

Treatments	T	Dry Matter Intake	N Intake from Feed	Excreted N	Excreted straw:N ratio
	(cm)	kg LU^{-1} day^{-1}			
C	12.22^{a} ± 0.91†	10.88^{b} ± 0.35	0.18^{b} ± 0.008	0.140^{a} ± 0.014	37^{a} ± 1.95
Z	11.54^{a} ± 0.94	8.78^{a} ± 0.34	0.15^{a} ± 0.007	0.122^{a} ± 0.013	43^{a} ± 1.94
SS	10.63^{a} ± 0.73	9.05^{a} ± 0.30	0.15^{a} ± 0.006	0.123^{a} ± 0.011	42^{a} ± 2.22
LM	11.20^{a} ± 0.84	9.67^{a} ± 0.31	0.16^{ab} ± 0.08	0.129^{a} ± 0.014	40^{a} ± 2.05

† Different small letters within a column as superscript of mean values indicate significant difference among treatments ($P \leq 0.05$)

Table 4. Bulls' dirtiness score mean (n= 8 ± S.E.), as well as straw manure weight (Wt) scraped down from bedding area, mean manure bulk density (BD) and thickness (T) of animal beddings at termination of housing phase. Treatments abbreviation can be found in title of the table 2.

Treatments	Wt	T	BD	Dirtiness scores (days)	
	(Mg)	(m)	(Mg m^{-3})	38	78
C	6.41	0.181	0.91	20.4^{bc} ± 2.1†	5.6^{a} ± 0.9
Z	6.13	0.152	1.01	16.0^{ab} ± 1.4	6.4^{a} ± 0.7
SS	5.14	0.111	1.12	15.4^{a} ± 1.7	5.1^{a} ± 0.5
LM	5.62	0.143	1.04	23.1^{c} ± 0.9	9.0^{b} ± 1.0

†Different small letters within a column as superscript of mean values indicate significant difference among treatments ($P \leq 0.05$)

Table 5. Mean (n=18, ± S.E) pH ($CaCl_2$), dry matter (DM), ash content (AC), total carbon and N (TC, TN), NH_4^+-N and C:N ratio of animal beddings in housing phase. Treatments abbreviation can be found in title of the table 2.

Treatments	DM	AC	TC	TN	NH_4^+-N	C:N	pH‡
	(%)		(g/kg DM)				
C	26.7 ± 0.61	12.1 ± 0.41	451 ± 1.5	17.7 ± 0.43	0.83 ± 0.09	25.5 ± 0.62	8.2
Z	27.1 ± 0.44	17.4 ± 0.32	426 ± 1.3	17.8 ± 0.45	1.15 ± 0.10	23.9 ± 0.64	8.3
SS	28.6 ± 0.82	27.3 ± 0.43	385 ± 2.2	17.1 ± 0.68	1.11 ± 0.15	22.5 ± 0.71	8.2
LM	27.2 ± 0.63	20.2 ± 0.33	407 ± 1.3	16.9 ± 0.69	0.80 ± 0.08	24.1 ± 0.80	8.3

‡ Standard errors of the pH in all treatments were < 0.1

Table 6. Mean (n=18 ± S.E) fluxes of greenhouse gases (CO_2, N_2O and CH_4) as well as NH_3 from animal bedding in housing phase. Treatments abbreviation can be found in title of the table 2.

Treatment	Rate of gases emission‡					
	NH_3	N_2O	CO_2	CH_4	NH_3	N_2O
	(g LU^{-1} day^{-1})				(g kg^{-1} of N excreted day^{-1})	
C	5.191^{a} ± 0.98 (100)†	0.652^{a} ± 0.08 (100)	653^{a} ± 86 (100)	4.54^{a} ± 1.50 (100)	35.20^{a} ± 5.4 (100)	5.13^{a} ± 0.8 (100)
Z	0.672^{b} ± 0.12 (13)	0.411^{b} ± 0.04 (63)	428^{b} ± 49 (65)	4.54^{a} ± 1.11 (100)	5.33^{b} ± 0.8 (15)	3.43^{b} ± 0.3 (67)
SS	0.840^{b} ± 0.12 (16)	0.522^{ab} ± 0.07 (80)	561^{ab} ± 78 (86)	6.25^{a} ± 1.62 (138)	7.07^{b} ± 1.0 (20)	4.64^{a} ± 0.7 (90)
LM	0.871^{b} ± 0.18 (17)	0.594^{ab} ± 0.05 (91)	610^{ab} ± 66 (93)	5.25^{a} ± 1.74 (116)	6.91^{b} ± 1.4 (20)	5.03^{a} ± 0.6 (98)

‡ Relative gaseous losses than control treatment are presented in parentheses within same column.

† Different small letters within a column as superscript of mean values indicate significant difference among treatments ($P \leq 0.05$).

Table 7a. Summary of barn unit N balance estimated through mass balance calculation (BuNL$_{mass}$). Where BA, BR, S and SM are bedding additives, bulls' retention, straw and straw manure, respectively. Treatments abbreviation can be found in title of the table 2.

Treatments	Inputs				Outputs				BuNL$_{mass}$	
	Animal feed	S	BA	Total	BR	SM		Total	kg Ngroup^{-1}	% of inputs
						Collected†	Scraped††			
				(kg N/group)						
C	88.5	8.3		96.8	19.1	33.7	33.4	86.2	10.6	11.0 (100)‡
Z	122.6	13.8	0.0	136.4	24.0	74.2	34.5	132.7	3.7	2.7 (25)
SS	126.2	14.2	1.2	141.6	23.4	85.2	28.4	137.0	4.6	3.3 (30)
LM	112.8	10.9	0.0	123.7	21.7	69.7	24.5	115.8	7.9	6.4 (58)

† Total N content of the manure trampled down by bulls to each barn-unit manure alley from bedding area.
††Total N content present in manure scraped from animal bedding at termination of housing phase.
‡ Relative gaseous losses than control treatment are presented in parentheses within same column.

Table 7b. Summary of barn unit N balance estimated by ratio of total N (TN) to total ash (TA) ($BuNL_{TN/ash}$) in housing phase. Where BA, BR, S and SM are bedding additives, bulls' ash retention, straw and straw manure, respectively. Treatments abbreviation can be found in title of the table 2.

Treatment	Inputs					Outputs					$BuNL_{TN/ash}$
	animal feed	S	BA	Total	TN/TA ratio	BAR≠	SM		Total	TN/TA ratio	% of inputs
							Collected†	Scraped††			
	(kg ash/group)					(kg ash/group)					
C	365.1	108.4		473.5	0.20	2.9	258.1	210.4	471.4	0.18	11.0 (100)‡
Z	530.7	184.8	365.0	1080.5	0.13	3.6	791.4	283.4	1078.4	0.12	2.7 (25)
SS	553.0	187.1	1182.1	1922.2	0.07	3.5	1544.2	389.9	1937.6	0.07	5.0 (46)
LM	485.6	153.7	610.0	1249.3	0.10	3.3	967.7	271.0	1242.0	0.09	5.1 (47)

≠ BAR [Bulls ash retention (kg ash/group)] was calculated as total body weight gain by the bulls (kg/group) during the housing period multiplied by a common live weight ash content of 4.2×10^{-3} kg ash/kg for growing bulls (Haas et al. 2002)

† Total ash of trampled-down straw manure collected from the manure alley of each barn-unit during the housing period

†† Total ash of straw manure scraped from the bedding area at the end of the housing period

‡ Values in parentheses in the same column represent relative losses compare to the control

Table 8. Total N (TN) measured and unaccounted gases losses from straw manure beddings of housing phase. Treatments abbreviation can be found in title of the table 2.

Treatments	NH_3-N		N_2O-N		Unaccounted N losses
	kg group^{-1}	% of TN losses	kg group^{-1}	% of TN losses	% of TN losses
C	1.47	13.8	0.08	0.7	85
Z	0.33	8.9	0.08	2.2	89
SS	0.42	9.0	0.10	2.2	89
LM	0.35	4.5	0.10	1.2	94

Table 9. Total N losses from cattle straw manure up to field application (housing (HP) and storage phases (SP)) during the entire experimental period. Treatments abbreviation can be found in title of the table 2.

Treatments	HP			SP			Total housing and storage N	
	GNI†	GNO††	N Losses	Initial N£	Final N‖	N Losses	kg N group^{-1}	% of GNI
					(kg N/group)			
C	78	67	11	34	22	12	23	30 (100)≠
Z	113	109	4	74	61	13	17	15 (50)
SS	119	114	5	85	68	17	22	19 (63)
LM	102	94	8	70	55	15	23	23 (77)

† Gross N inputs (GNI) = (N in Feed + N in Straw + N in additive) – Retention of N by bulls

†† Gross N outputs (GNO) = Total N content of the manure trampled down by bulls to each barn-unit manure alley from bedding area + Total N content present in manure scraped from animal bedding at termination of housing phase.

£Total N content of the manure trampled down by bulls to each barn-unit manure alley

‖Total N content present in manure scraped from animal bedding at termination of housing phase

≠ Relative gaseous losses than control treatment values are presented in parentheses within same column

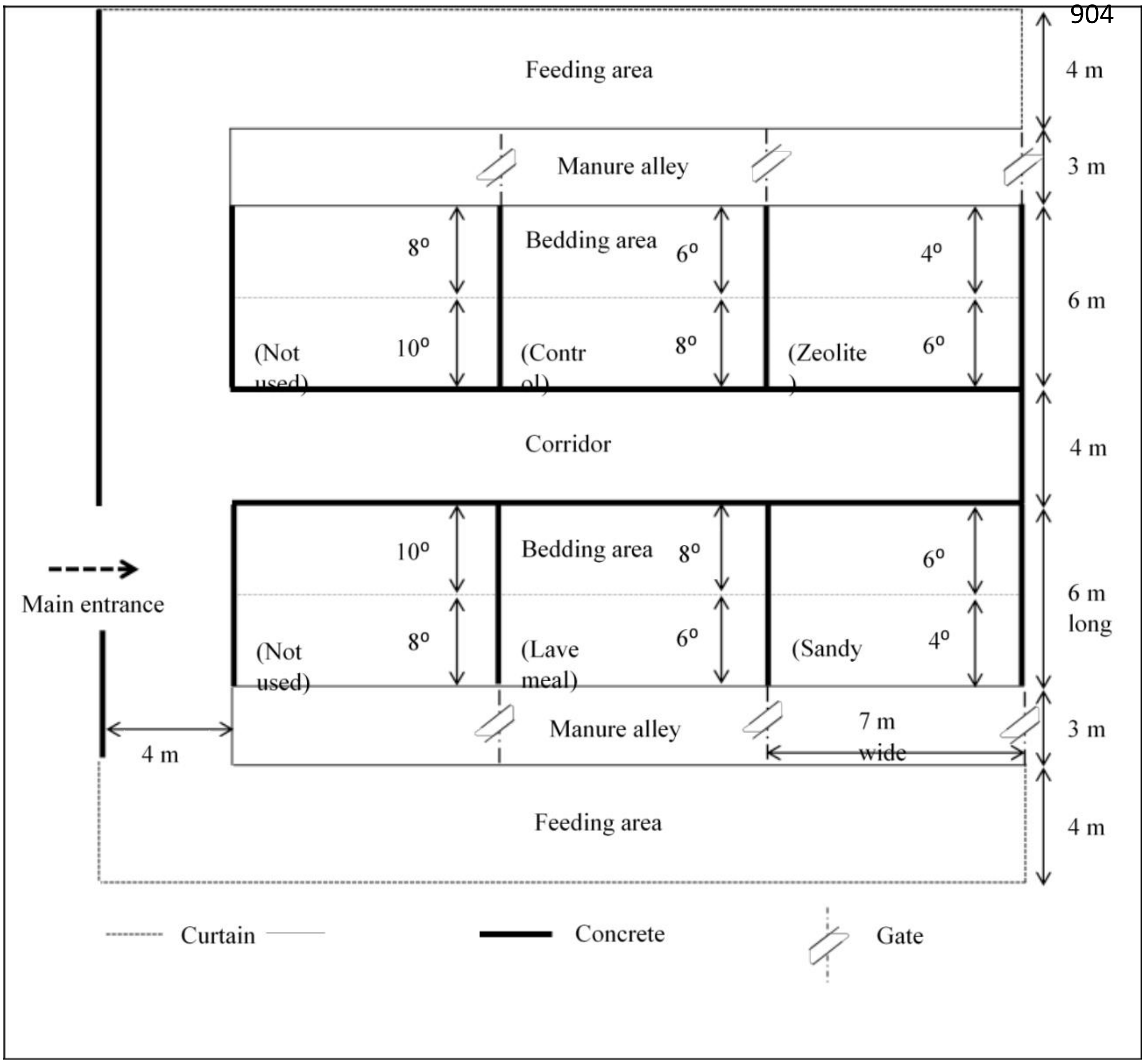


Fig. 1. Schematic layout of the barn unit used in this study.

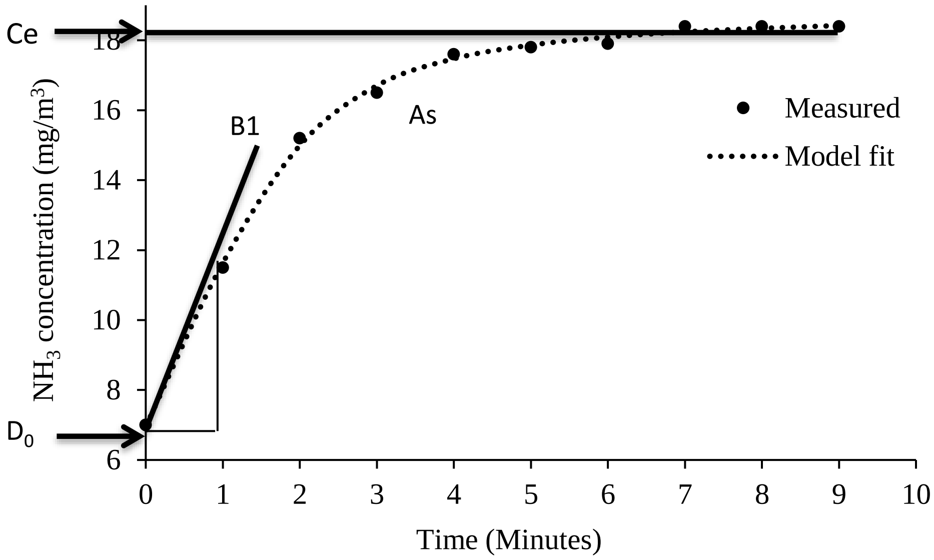
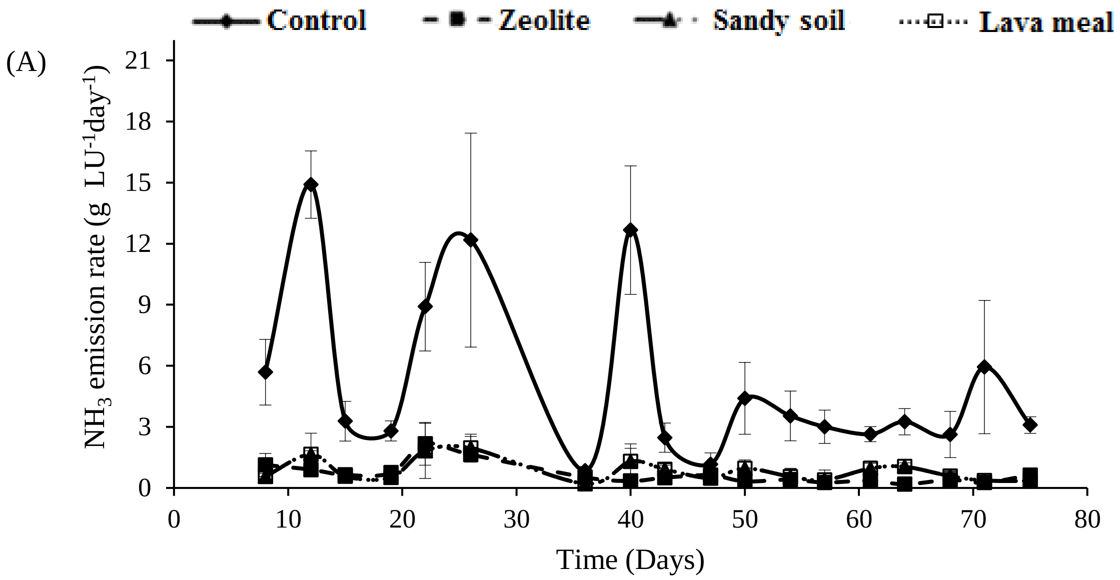
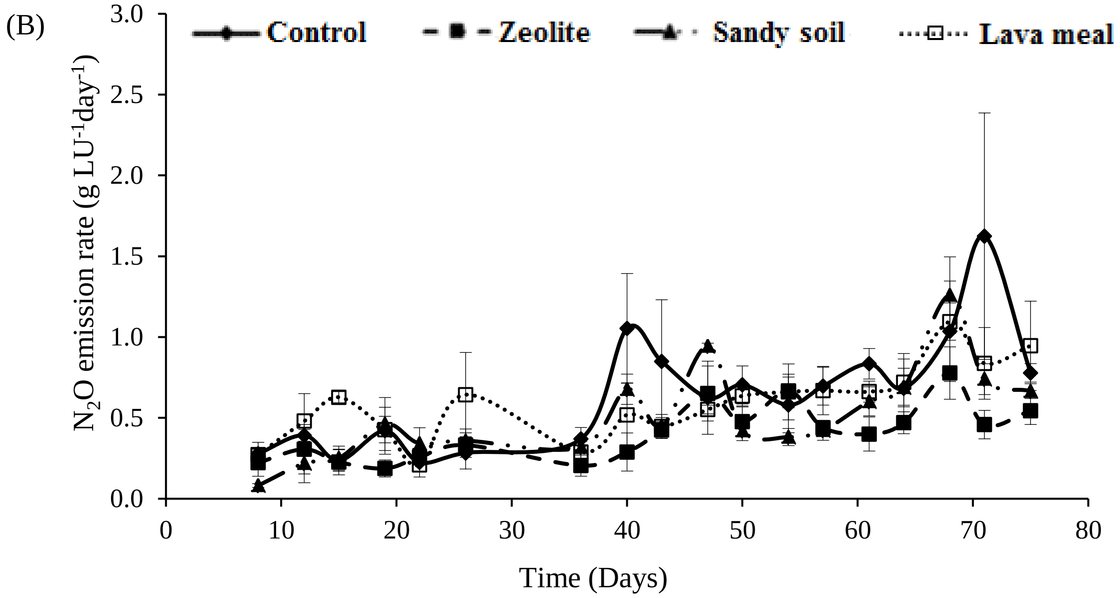


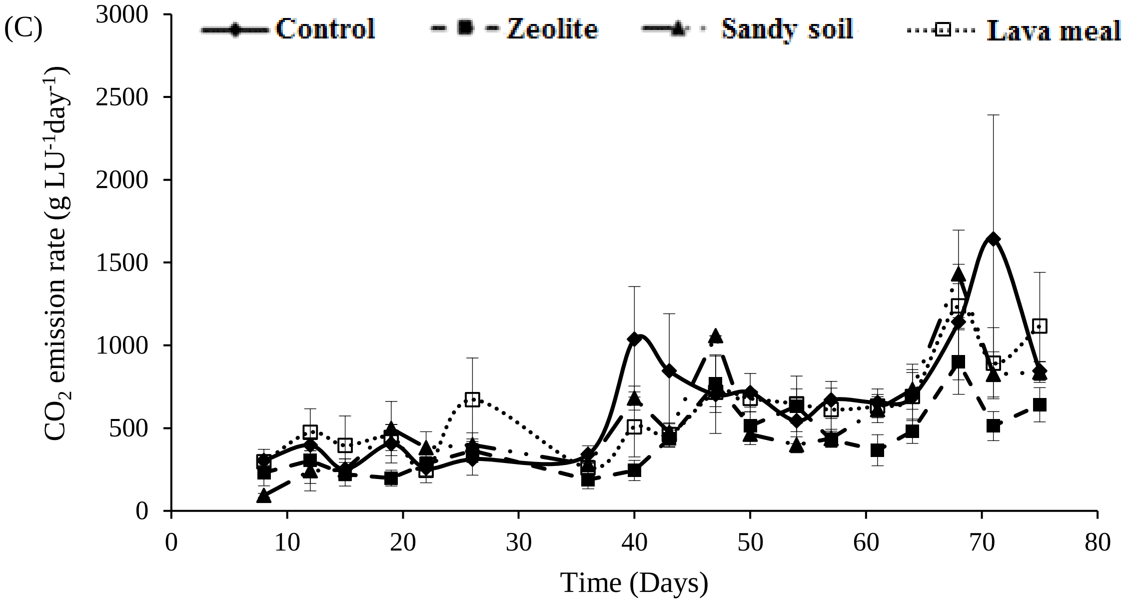
Fig. 2. A model fitting on the concentration of NH_3 (gas) per unit time in minutes. As signifies the sharpness parameter, B1 shows initial slope of the curve in unit of mg $m^{-3}min^{-1}$, Ce indicates concentration (mg m^{-3}) of NH_3 gas at state of equilibrium, and D_0 represents concentration of NH_3 gas at zero time (mg m^{-3}).


(A)
Control
Zeolite
Sandy soil
Lava meal
NH_3 emission rate (g LU^{-1}day^{-1})
21
18
15
12
9
6
3
0
0
10
20
30
40
50
60
70
80
Time (Days)

935


(B)
Control
Zeolite
Sandy soil
Lava meal
N_2O emission rate (g LU^{-1}day^{-1})
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
50
60
70
80
Time (Days)

936



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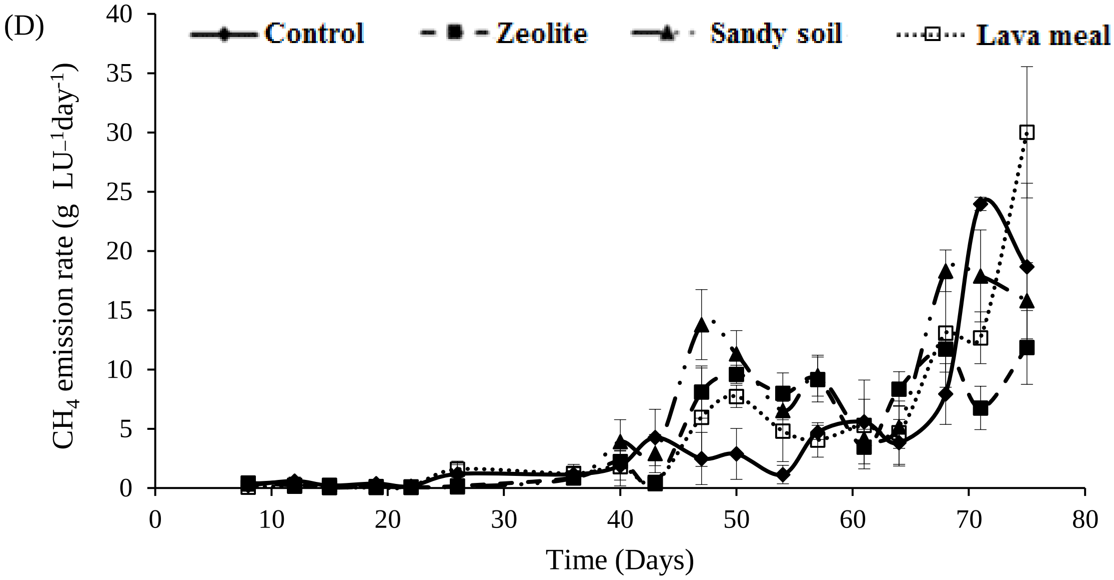

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939 **Fig.3**. Rates of (A) NH_3, (B) N_2O, (C) CO_2 and (D) CH_4 (g LU^{-1}day^{-1}) emissions with
940 time from animal bedding. Mean standard errors is represented by error bars.

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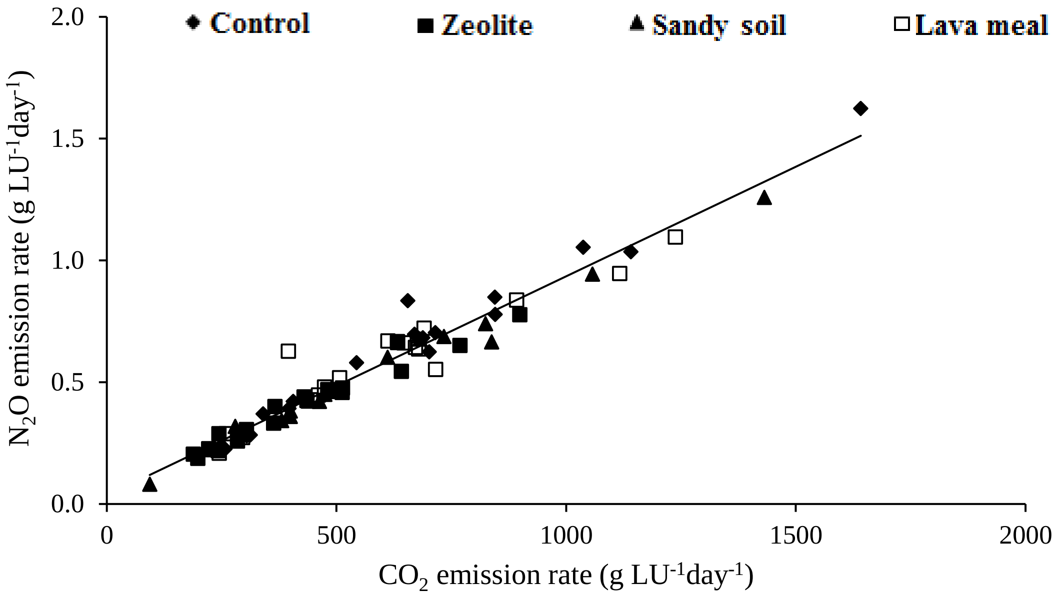
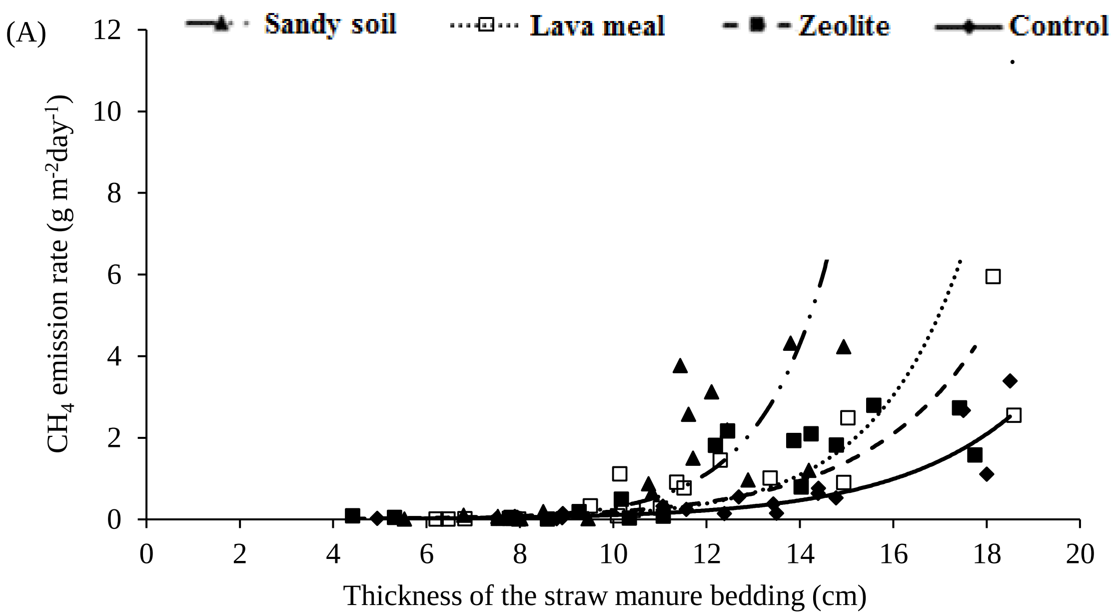


Fig. 4. Regression analysis showing linear relation between emission rates of N_2O and CO_2 from all treatments applied in animal beddings ($P<0.001$; $y = 0.0009x$; $R^2 = 0.96$).



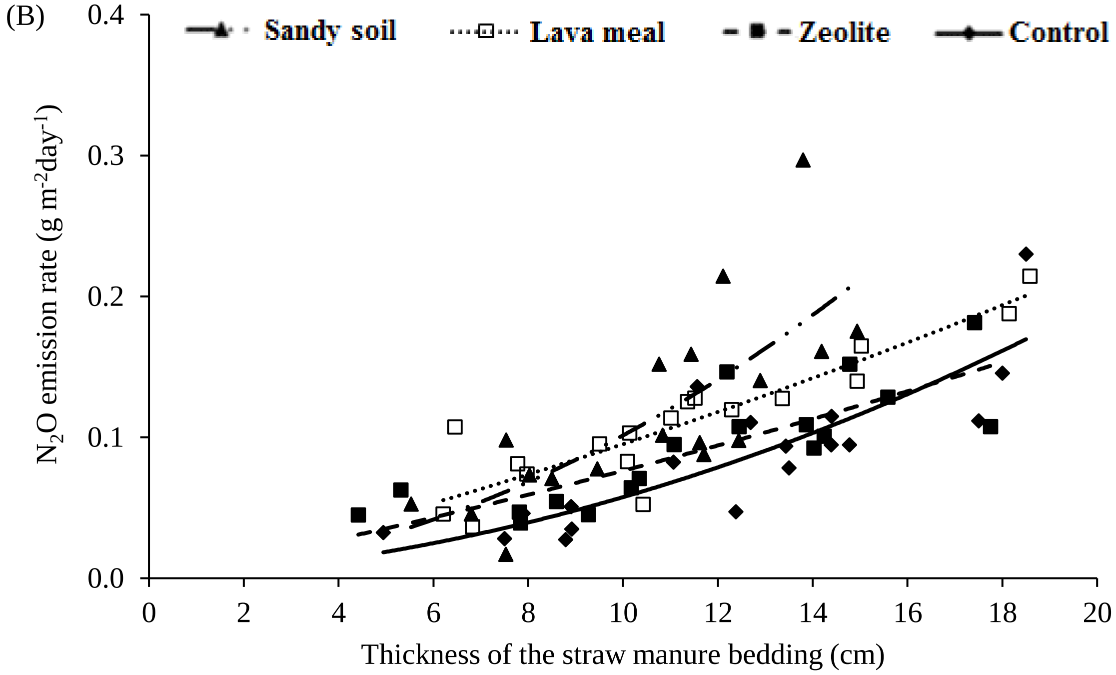


Fig. 5. Rates of CH_4 (A) and N_2O (B) emissions and trend lines fitted on the data points of the aforementioned gases emitted from all treatments applied in animal beddings.