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Gaseous N and C losses during sun-drying of goat manure: *Effects of drying conditions and feed additives*

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Abstract

Animal manure is a key resource in farming systems of arid and semi-arid regions. Its quality is often low due to inappropriate storage. Thus, this study aimed to assess the effects of drying and storage conditions on nutrient losses during typical sun-drying of manure in the Sultanate of Oman, and how these losses can possibly be mitigated by changes in manure properties. Charcoal and tannins are known to stabilize organic matter and increase nitrogen (N) retention in soils and compost. Therefore, they were used as feed additives to stabilize carbon (C) and N in manure.

NH_3-N, N_2O-N, and CO_2-C losses from sun-drying goat manure were measured in three experiments during the cropping season, differing in temperatures and resulting drying rates. Manure was obtained from goats fed a diet of 50% hay, 47% maize and 3% soybean with or without the addition of either 2.6% activated charcoal (AC) or 3.4% Quebracho tannin extract (QT).

The cumulative N and C losses reached up to 1.4% and 2.2% of the initial N and C contents, respectively. During the drying process, control manure lost 138 to 295 mg N kg^{-1}, AC lost 112 to 207 and QT 107 to 208 mg kg^{-1} via NH_3 volatilization and N_2O emissions. Carbon losses during drying ranged from 0.1 to 10.2, 0 to 10.5, and 0.3 to 5.4 g kg^{-1} for Control, AC and QT manure, respectively. Slow drying (up to 84 h) favored CO_2 emissions and reduced NH_3 volatilization due to higher microbial activity and an immobilization of mineral N in manure. In comparison, two times more NH_3-N was lost during quick drying of manure (4 h) than during slow drying, even after manure reached constant weight. In contrast to dietary charcoal, dietary tannins reduced N and C losses by up to 60% during manure drying and storage, potentially increasing its quality as organic fertilizer and improving nutrient recycling.

Key words: Ammonia, nitrous oxide, carbon dioxide, goat manure, activated charcoal, tannin, Oman

Introduction

In many parts of the tropics and subtropics crop production still strongly relies on animal manure as a nutrient source particularly in low input systems (*Rufino* et al., 2007; *Buerkert* et al., 2010). In traditional oasis agriculture of Oman, grazing animals leaving their droppings in stables overnight contribute to accumulating nutrients from huge grazing areas within the crop fields of small villages (*Schlecht* et al., 2011). However, since these droppings are often dried in the sun, collected and stored in plastic bags or left in uncovered heaps until used as manure, considerable amounts of carbon (C) and nitrogen (N) are lost (*Buerkert* et al., 2010). These losses are not only relevant for nutrient cycling within farming systems, but may also lead to environmental hazards such as soil acidification and greenhouse gas emissions. Gaseous emissions from manure depend on the moisture content of stored manure, ambient temperatures and manure properties, such as the C/N ratio (*Liang* et al., 2003; Buerkert et al., 2010).

The adaptation of animal diets offers a way to control emissions from manure as the diet directly affects the amount and composition of manure (*Petersen* et al., 2007). For instance, reducing dietary N intake decreases NH_3 and N_2O emissions from stored dairy cow manure (*Külling* et al., 2001) and from soil incubated with manure (*Lee* et al., 2013) by reducing urinary N excretion and increasing C/N ratio of feces. Therefore, feed additives affecting C and N digestibility of diets such as charcoal or tannins are likely to affect gaseous C and N losses from manure.

Charcoal is used in animal nutrition to improve animal health, reduce greenhouse gas emissions from ruminants and deodorize manure (*Poage* et al., 2000; *Watarai* et al., 2008). As a stable C source, the addition of 3% activated charcoal to goats' diets can increase manure C by 12% and the C/N ratio by 26% (*Ingold* et al., 2015; *Al-Kindi* et al., 2016). Tannins naturally occur in many browse species (*Muir*, 2011) and have a high affinity to bind and precipitate proteins (*Spencer* et al., 1988). This property is responsible for diverse effects in animal nutrition and health, such as reduced methane emission and bloat, increased milk production and growth rates, but also reduced fodder digestibility, toxicity and an altered nitrogen use efficiency and excretion (*Aerts* et al., 1999; *Puchala* et al., 2005; *Makkar*, 2003; *Al-Kindi* et al., 2016). How changes of manure composition due to feed additives such as activated charcoal or tannins affect C and N losses during manure drying requires further research. To fill this research gap three experiments were conducted that tested the effect of activated charcoal (AC) and quebracho tannins (QT) as feed additives on gaseous C and N losses from manure under differing climatic conditions in Northern Oman. We hypothesized that quick drying of manure in the sun reduces C and N losses compared to slow drying, and that AC and QT feed additives stabilize C and N in manure, reducing gaseous C and N losses during drying and storage.

Material and Methods

The experiments were conducted on a private farm near Sohar (24°24 N, 56°79’ E) in the Al-Batinah Plain of the Sultanate of Oman. Experiment 1 was conducted under hot temperatures with high humidity (24.4 to 45.3°C, and 36 to 84% relative humidity). Experiment 2 and 3 were conducted at lower temperatures (18.9 to 39.4°C and 12.0 to 28.9°C, respectively) and differing humidity levels (9 to 72% and 44 to 82% relative humidity, respectively). Manure was collected from male Jebel Akhdar goats fed a basal diet of 50% Rhodes grass hay (*Chloris gayana* Kunth), 46.5% crushed maize (*Zea mays* L.) and 3.5% soybean meal (*Glycine max* (L.) Merr.; *Ingold* et al., 2015). The 60 goats were divided into three groups receiving only the basal diet (control [Co]), or additions of 2.5% of a steam-activated charcoal on coconut shell basis (AquaSorb® CP1, Jacobi Carbons Service (Europe) GmbH, Premnitz, Germany) or 3.6% of a water soluble quebracho tannin extract (*Schinopsis balansae* Engl.; Silva Team S.p.a., San Michele Mondovì CN, Italy), respectively. The collected feces were pooled per treatment and kept in plastic bags for a maximum of two hours before sun drying. Fresh feces were spread in PVC containers of 30 cm diameter in three replicates per treatment at 1.4, 10.8 and 8.8 kg m^{-2} in experiment 1, 2 and 3, respectively. The differing manure quantities resulted in fast drying of manure in experiment 1 (< 4 h) and slow drying (> 80 h) in experiment 2 and 3. Fresh manure contained 56, 52 and 62% moisture, 2.17, 1.88 and 2.26% N, 45.5, 49.3 and 46.2% C and had a pH of 6.0, 6.4 and 6.4 for

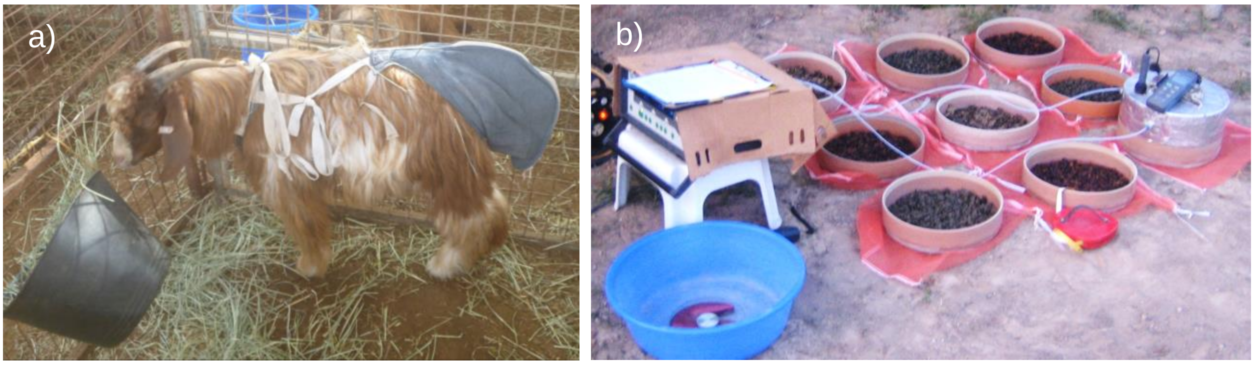

Figure 1: Goat with fecal collection bag in individual crate (a) and in-field gas emission measurement from drying manure using a closed chamber connected to a photo-acoustic multi-gas analyzer in Sohar, Sultanate of Oman (b).

Co, AC and QT, respectively.

NH_3-N volatilization and N_2O-N and CO_2–C emissions during the drying process were measured with a dynamic closed-chamber system using a photo-acoustic infrared multi-gas monitor (INNOVA 1312-5, LumaSense Technologies A/S, Ballerup, Denmark; *Predotova* et al., 2010). The PVC containers were covered with a Teflon® coated PVC cuvette for four minutes, which was attached to the multi-gas monitor by two 1.5 m long Teflon® tubes for in- and out-coming gas. Gas fluxes were calculated using linear regression in the R package “gasfluxes” (*Fuss*, 2017). Linear regressions with $R^2 < 0.6$ were set to zero. Cumulative emission during the drying process (until manure dry matter reached ≥90%) were calculated by linear interpolation of consecutive data points multiplied by the time interval. Gas emission rates were statistically analyzed by generalized linear regressions with individual PVC containers as repeatedly measured subjects and treatment and drying condition (< and ≥90% DM) as fixed factors. In case of non-normal distribution of residuals, a non-parametric Kruskal-Wallis-Test was conducted. Cumulative N and C losses were analysed by ANOVA followed by Tukey-HSD test. All statistical analyses were conducted with IBM SPSS Statistics, Version 24 (IBM Deutschland GmbH, Nürnberg. Germany).

Results and Discussion

NH_3-N volatilization and N_2O-N and CO_2-C emission were highest directly after spreading manure in PVC containers and declined thereafter with decreasing moisture content of manure until constantly low levels (data not shown). The gaseous N and C losses during the drying process in the sun amounted to 0.5 to 1.4% of initial N and 0.01 to 2.2% of initial C content of manure, respectively. They were thus in a similar range as N losses from unroofed manure storage in Niger (*Predotova* et al., 2010). However, cumulative C and N losses from manure conservation and storage are reported to be much higher with up to 50% of initial C and N being lost (*Chadwick*, 2005; *Predotova* et al., 2010; *Tittonell* et al., 2010). In contrast to these studies, manure spread on the ground for sun-drying under the hot and sunny conditions of Oman resulted in very quick drying of manure. When estimating possible C losses during manure storage for 50 days based on emission rates of dried manure, losses amounted to 0.01 to 3.2% of initial manure C. While cumulative N losses over a 50-day storage period in experiments 2 and 3 amounted to 1 to 3.4% of initial manure N; in experiment 1 N losses were estimated to reach 35 to 62%. Depending on the ammonium concentration of manure - the main source of NH_3 volatilization - N losses during longer periods of manure storage can be considerable.

Effect of drying conditions

In experiment 1 average NH_3 volatilization and N_2O emission rates from manure were up to 39-times higher than in experiments 2 and 3, whereas average CO_2 emission rates were up to 48-times lower (Figure 2). The major difference between experiments 1, 2 and 3 was the different quantity of manure per m² resulting in slower drying of manure in experiments 2 and 3 (> 80 h until DM ≥90% compared with 4 h in experiment 1). Correspondingly, manure storage under rainy conditions reduces gaseous N losses and increases gaseous C losses compared to dry conditions (*Chadwick*, 2005, *Predotova* et al., 2010; *Buerkert* et al., 2010). CO_2 evolution is a sign of microbial respiration and indicates the activity of microbial biomass in manure, which is mainly affected by moisture content and temperature (*Liang* et al., 2003; *Buerkert* et al., 2010). Multiple linear regression analysis explained 78% of the variance in CO_2 emissions from drying manure and demonstrated the impact of manure moisture content on CO_2 emissions, whereas temperature was less influential (Table 1). In contrast, the linear model of the physical process of NH_3 volatilization explained 51% of the variance and was driven by manure moisture and air temperature; it negatively correlated with CO_2 emission rates. The negative impact of CO_2 emission rates on NH_3 volatilization, included in the model as an indicator of microbial activity, indicated an immobilization of ammonium N in manure due to synthesis of microbial biomass N.

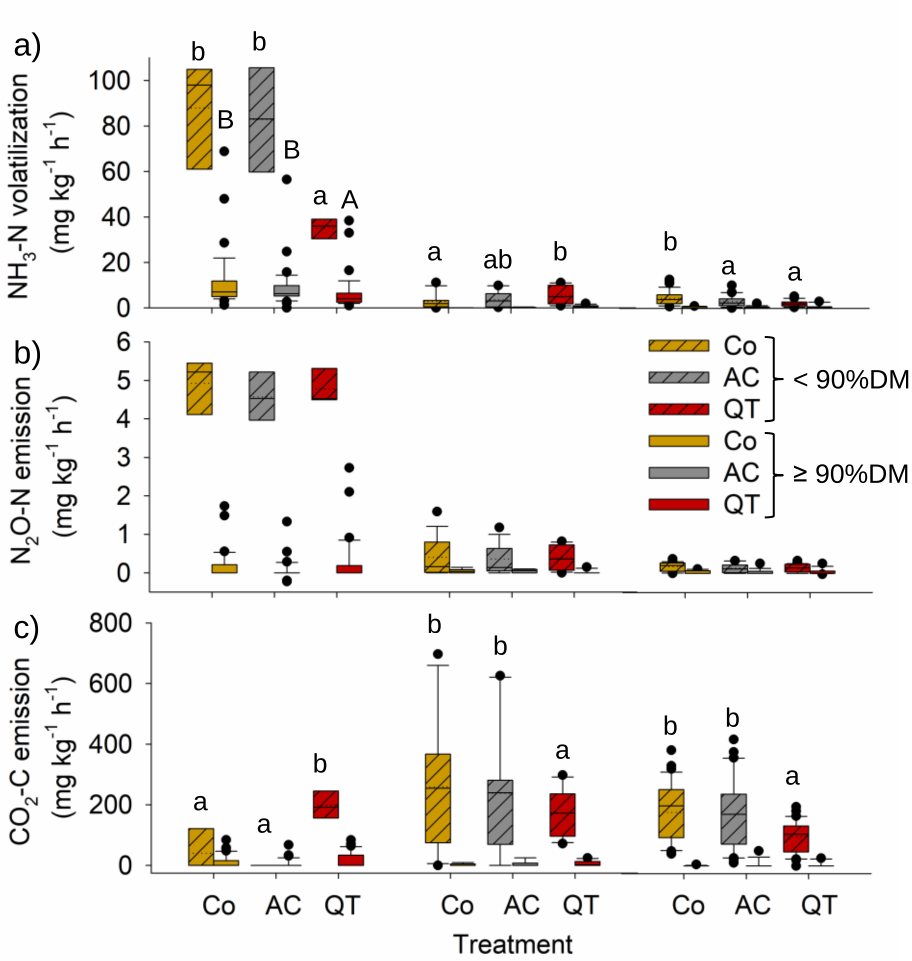

Figure 2: *Boxplots of NH_3-N (a), N_2O-N (b), and CO_2-C (c) emission rates from drying manure (< 90% DM) and after reaching constant weight (≥ 90% DM) measured in three experiments in Sohar, Oman. Small letters indicate significant effects between manure treatments < 90% DM and capital letters significant differences between manure treatments ≥ 90% DM.*

Treatment effects

Charcoal-enriched manure (AC) and tannin-enriched manure (QT) may be considered a by-product of the usage of charcoal or tannin-containing fodder in order to improve animal nutrition and health (*Aerts* et al., 1999; *Poage* et al., 2000; *Makkar*, 2003; *Puchala* et al., 2005; *Watarai* et al., 2008). Feeding charcoal as a C-rich substrate and tannins, known to protect proteins from digestive breakdown, was expected to stabilize C and N compounds in manure by lowering the gaseous C and N losses from manure. The treatments significantly affected the daily CO_2 emission rate and NH_3 volatilization during drying ($P = 0.003$ and 0.041, respectively), whereas N_2O emissions were generally low and unaffected by treatments (Figure 2).

Table 1: *Linear model of predictors (time of drying, manure moisture and temperature) of NH_3-N, N_2O-N and CO_2-C emission rates (mg h^{-1} kg^{-1}) during manure drying of the three experiments conducted in Sohar, Sultanate of Oman, with non-standardised and standardised beta coefficients, standard errors (SE), significance levels (p) and coefficients of determination (R^2).*

		Non-standardised		Standardised		Overall	
		b	SE	β	p	p	R^2
	Constant	-119.8	20.99		<0.001		
CO_2	Moisture	4.8	0.23	0.77	<0.001	<0.001	0.78
	Temperature	3.2	0.64	0.18	<0.001		
	Constant	-1.55	0.19		<0.001		
N_2O	Moisture	0.02	0.00	0.44	<0.001	<0.001	0.34
	Temperature	0.05	0.01	0.41	<0.001		
	Constant	-28.08	3.24		<0.001		
	Time	-0.05	0.02	-0.16	0.003		
NH_3	Moisture	0.57	0.05	0.82	<0.001	<0.001	0.51
	Temperature	1.03	0.08	0.53	<0.001		
	CO_2 emission rate	-0.09	0.01	-0.82	<0.001		

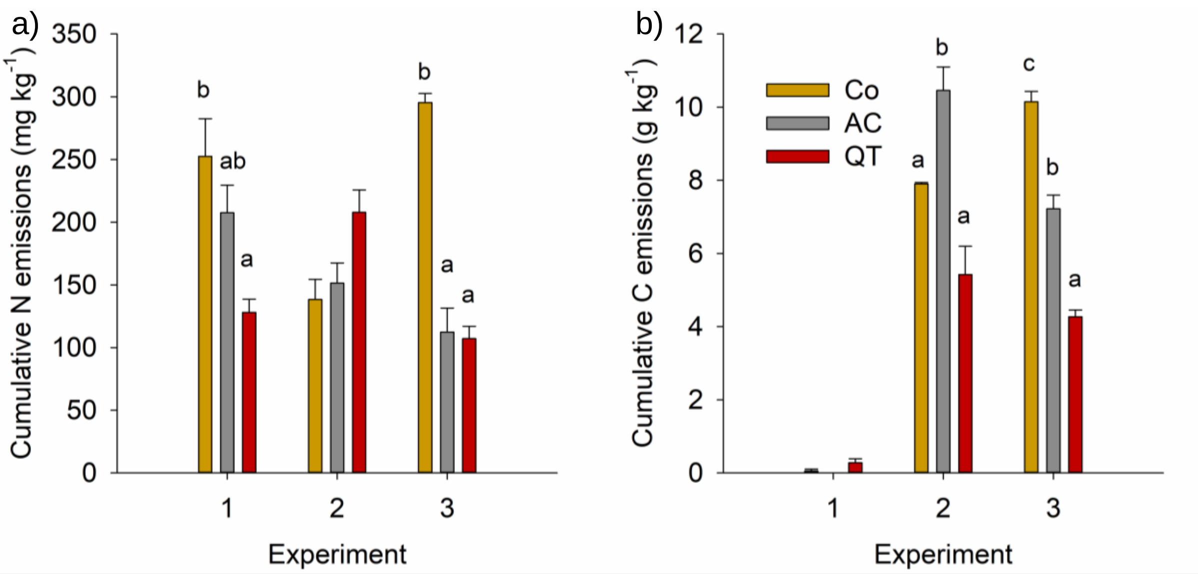

Figure 3 *Cumulative N (a) and C emissions (b) during drying of manure in three experiments conducted in Sohar, Sultanate of Oman. Letters indicate significant treatment effects within the three experiments.*

Charcoal increased fecal C concentration and reduced fecal N concentration resulting in higher fecal C/N ratios compared with unamended control manure (*Ingold* et al., 2015; *Al-Kindi* et al., 2016). Surprisingly, during drying of manure and storage thereafter, no clear effects of dietary AC on the measured gas emission rates were observed. However, cumulative N losses were reduced in two experiments by 18 to 62% (Figure 3), which showed the N conservation potential of AC. Higher C/N ratios and the high sorption capacity of charcoal can lead to an immobilization of N, thus reducing gaseous N losses in form of N_2O and NH_3 (*Cayuela* et al., 2013; *Maurer* et al., 2017). Cumulative C losses were inconsistently affected by AC in the three experiments, which was also reported in a recent review on manure amendment of biochar (*Maurer* et al., 2017).

Quebracho tannins used as feed additives slightly increased C and N concentrations in feces, resulting in similar C/N ratios of about 20:1 (*Ingold* et al., 2015; *Al-Kindi* et al., 2016). During drying and subsequent storage, NH_3 volatilization rates were significantly reduced by 43 to 54% with QT in experiments 1 and 3 compared to Co (Figure 2). CO_2 emissions were differently affected in the three experiments. When manure dried quickly, like in experiment 1, QT emitted on average 4- and 20-fold more CO_2 than AC and Co manure, respectively, although emissions were generally low.

Manure moisture content was found to be the main driver of CO_2 emissions from drying manure, which was with 62% by 11% and 19% higher than in AC and Co, respectively. The higher initial moisture content in manure provided more favorable conditions for microbial activity, measured as CO_2 emission. In experiments 2 and 3, manure dried much slower than in experiment 1, allowing for high microbial activity over several days. Under these conditions, QT reduced CO_2 emissions by 40 to 60% (Figure 3). Tannins are known for their antimicrobial properties (*Scalbert*, 1991) and were found to reduce microbial respiration in soils and compost (*Jordan* et al., 2015), although this inhibitory effect was not always observed (*Hao* et al., 2000). The activity depression can be caused by direct toxic effects on microorganisms or enzyme inhibition due to binding of tannins to bacterial cell walls and enzymes (*Haettenschwiler* and *Vitousek*, 2000). However, after having passed through the animal's gastrointestinal tract, it is likely that tannins are bound to feces components and may therefore not actively inhibit microorganisms (*Degen* et al., 1995) but rather reduce the availability of easily degradable organic substrates by complexation or by a shift of N and C excretion towards more stable forms (*Al-Kindi* et al., 2016).

Conclusions

The results show that N and C losses from sun-drying of feces are with 0.5 to 1.4% N and 0.01 to 2.2% C of initial N and C contents, respectively, relatively low compared with composting and storage in heaps. N and C losses during subsequent storage of properly dried manure were very low, except for NH_3 volatilization losses of quickly dried manure (experiment 1). The considerable NH_3 volatilization rates of quickly drying manure point to the risk of a high loss of ammonium N from manure during storage. Slow drying, which allows microbial biomass to grow for a short time, may preserve mineral N in form of microbial biomass N within manure. While charcoal-enriched manure showed inconsistent effects on gaseous N and C losses, tannins reduced N and C losses by up to 60% compared with control manure and may be a useful tool in conserving N and C during manure drying and storage and thus increasing the efficiency of nutrient cycling within the farming system.

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