Agriculture, Ecosystems and Environment 250 (2017) 51–58

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Effects of diet and manure storage method on carbon and nitrogen dynamics during storage and plant nitrogen uptake

Mutian Niu[a], Jayasooriya A.D.R.N. Appuhamy[b], Robert S. Dungan[c], Ermias Kebreab[a], April B. Leytem[c,*]

[a] Department of Animal Science, University of California, Davis, CA 95616, USA
[b] Department of Animal Science, Iowa State University, Ames, IA 50011, USA
[c] USDA-Agricultural Research Service, Northwest Irrigation and Soils Research Laboratory, Kimberly, ID 83341, USA

ARTICLE INFO

Keywords:
Dairy
Manure
Nitrogen
Carbon
Storage

ABSTRACT

Altering dairy cattle diets to reduce both enteric methane (CH_4) production and nitrogen (N) excretion are valuable tools for mitigating the environmental impact of dairy production. We examined the impact of altering diets on changes in physicochemical properties of manure during storage and short term plant N availability. Manure collected from cattle fed diets with differing forage and crude protein (CP) content were stored via two methods (slurry and static pile) for 29 weeks and sampled at week 0, 1, 2, 3, 4, 9, 14, 19, 24, and 29. There was no effect of diet on C and N dynamics during storage for either storage treatment. Mass losses of total carbon (C) were 10% greater for the static pile manure treatment than the slurry ($P < 0.01$). Total N losses ranged from were approximately 46% with no treatment differences. The soil 2-week plant available N was 67% less in the static pile than the slurry treatment, while the short-term plant N use efficiency was similar for both the static pile and slurry treatments (22–24%). Due to the high inorganic N content of slurry following storage, greater care may be needed to ensure that environmental losses do not occur.

1. Introduction

Milk production is the third largest agricultural industry in the United States, with California and Idaho being two of the top three dairy-producing states (USDA, 2016a,b). While dairy cows are able to convert human inedible substrates into valuable food products for human consumption, they can also have a negative impact on environmental quality. Dairy production systems contribute to greenhouse gas (GHG) emissions through enteric methane (CH_4) production as well as production of CH_4 and nitrous oxide (N_2O) from manure storage, grazing, and forage production. According to 2013 estimates, dairy cattle generated approximately 13% of all U.S. agricultural GHG emissions via enteric CH_4 production and manure management alone, equating to 84 Mt Carbon dioxide (CO_2) equivalent (USDA, 2016a,b). Dairy production also contributes to the release of reactive nitrogen (N) into the environment which can have negative impacts on water quality and alter the physical structure of ecosystems which can have cascading effects in the environment (Pardo et al., 2015). Reactive N generated from dairy production consists mainly of ammonia (NH_3) losses from cattle housing, manure storage, and land application of manures, as well as losses of nitrate (NO_3, via leaching) and emissions of N_2O from forage production systems (Rotz and Leytem, 2015).

Mitigation strategies to reduce both CH_4 and reactive N from dairy production include managing cattle diets. For example, modifications in quantity and quality of dietary forage are potential enteric CH_4 mitigation strategies (Kebreab et al., 2006). Research has also shown that reducing protein consumption in excess of the animal's requirement can reduce N excretion to the environment (Colmenero and Broderick, 2006; van der Stelt et al., 2008). By reducing N excretion and enhancing N use efficiency in the animal, less reactive N is available for losses via emissions or leaching post excretion and following land application of manures. These dietary strategies aimed at reducing potential negative environmental impacts of dairy production can also affect carbon (C) and N losses during manure storage and the utilization of nitrogen when used as a fertilizer source for forage/crop production.

There have been several studies that have evaluated the effects of manipulating dairy diets on manure composition and plant utilization of manure nutrients with a focus on Powell et al. (2011) found that changes in dietary crude protein (CP) level affected the losses of NH_3 from dairy slurry applied to soils (48 h) with high CP (16.8% dry matter

* Corresponding author.
E-mail addresses: mniu@ucdavis.edu (M. Niu), appuhamy@iastate.edu (J.A.D.R.N. Appuhamy), robert.dungan@ars.usda.gov (R.S. Dungan), ekebreab@ucdavis.edu (E. Kebreab), april.leytem@ars.usda.gov (A.B. Leytem).

http://dx.doi.org/10.1016/j.agee.2017.08.034
Received 21 February 2017; Received in revised form 29 August 2017; Accepted 30 August 2017
0167-8809/ Published by Elsevier B.V.

[DM]) diets producing 2.1 times more NH_3 than low CP (15.5% DM) diets. The slurry resulting from the high CP diets also had 1.6 times as much soil extractable NH_4 and 1.5 times as much extractable inorganic N than the low CP diets which could affect plant nutrient uptake and N leaching. van der Stelt et al. (2008) reported that NH_3 losses from stored manure slurries were 10 times greater from high CP (19.0% DM) diets vs. low CP (10.8% DM) diets. When compared to fertilizer N as a plant nutrient source, studies have indicated that slurry from dairy cattle with high CP diets have a higher mineral fertilizer equivalent compared to low CP diets (Sørensen et al., 2003; Reijs et al., 2007). N. In contrast, Wu and Powell (2007) found that manure N use efficiency was greatest from low CP (13.4% DM) diets compared to diets with high CP contents (17.1 and 19.4% DM) for an oat-sorghum-sorghum ratoon rotation. In all instances, these data were from manure slurries that, in most cases, did not undergo long term storage prior to use in nutrient uptake studies.

Dairy cattle housing in the western United States (U.S.) is unique, in that 30% of lactating cows are housed in dry lots, which represents most of the dry lot housing in the country (USDA, 2009). Manure handling and storage at dry lot dairies is somewhat unique, as the majority of manure is deposited on the lot surface, scraped and piled, and remains in the lots until it is later removed for composting or land application. Manures can be stored like this for more than a year in some cases. In addition to dry lot dairies, another typical western U.S. housing system consists of freestall dairies that utilize a flush system to handle manure, which is stored in lagoons for up to six months in many cases, and later applied through irrigation systems on surrounding cropland. Therefore, previous studies that have evaluated the effects of dietary manipulation on fresh dairy slurry composition and plant nutrient uptake may not be as relevant to western dairy production systems. Hence our objectives were to: 1. Evaluate the effect of dietary mitigation strategies to reduce both enteric CH_4 production and N excretion on nutrient dynamics of stored manures; and 2. Evaluate the short term nutrient availability and uptake, by barley, in soil amended with these manures following storage.

2. Materials and methods

2.1. Feeding trial and collection of manure

All procedures were approved by Institutional Animal Care and Use Committee at the University of California-Davis. The feeding trial was conducted from July to September of 2014 at the Teaching and Research Facilities of the Department of Animal Science at the University of California-Davis. Feces and urine were collected from 12 Holstein cows fed 4 diets consisting of two dietary forage levels [low forage (LF) and high forage (HF), 37.4 vs. 53.3% of DM] and two dietary CP levels [low protein (LP) and high protein (HP), 15.2 vs. 18.5% of DM]. The rations offered to cows in the feeding trial are shown in Table 1. The diets were mainly comprised of alfalfa hay and steamed flaked corn with the high forage diets having 53% alfalfa while the low forage diets had 37%. The high forage diets had 29% greater NDF, 30% greater ADF and 20% greater lignin than the low forage diets. The CP in the diets varied from 15% for the low protein diets to 18% for the high protein diets. The feeding trial was a 4 × 4 Latin square design with four 18 d periods with each period consisting of a 15-d adaptation followed by 3-d sample collection (Niu et al., 2016). Cows were individually fed a total mixed ration prepared once a week (Table 1). Cows were fed ad libitum twice a day at 105% of previous daily intakes, 60% of which was offered at 0800 h and the balance was offered at 2000 h according to Niu et al. (2014). Refused feed was removed and weighed before feed delivery in the morning.

Feces and urine were individually collected from d 16 to 18 of period 2, 3 and 4 of the feeding trial for use in the manure storage study described below. Feces were scraped out from the rubber mat immediately after defecation using long handle metal scrapers. Scraped feces were stored in a plastic container assigned to each cow. Feces weight was recorded every two hours from 0900 to 2100 h and every 3 h after 2100 h. Urine from individual cows was collected using an indwelling Foley catheter (24 French, 75-cc ballon; C. R. Bard, Covington, GA) connected to 2–3 m of Tygon tubing (Tygon S E-3603 Flexible Tubings; Fisher Scientific, Waltham, MA) running to a 25 L plastic urine collection jar (Nalgene HDPE Jerricans; Fisher Scientific, Waltham, MA), which was placed in a plastic bucket filled with approximately 75% ice. Tubes were switched to an empty jar placed on ice at 0900, 1500, 2100, and 0300 h and urine weights were recorded.

Table 1
Ingredient and chemical composition of the experimental diets.

	HF		LF	
	HP	LP	HP	LP
Ingredient, % of DM				
Alfalfa hay[a]	53.3	53.3	37.6	37.2
Steam flaked corn	19.1	27.0	33.7	41.5
Soybean meal	7.5	0.0	12.0	4.3
Cotton seed	5.5	5.5	5.5	5.4
Rolled barley	4.2	4.2	4.1	4.1
Almond hulls	2.6	2.6	2.6	2.6
Dry distillers grains[b]	6.2	5.6	2.4	2.5
Mineral and Vitamin mix[c]	1.0	1.0	1.0	1.0
$NaHCO_3$	0.4	0.4	0.4	0.4
$CaCO_3$	0.0	0.1	0.3	0.4
NaCl	0.1	0.1	0.1	0.1
P supplement[d]	0.1	0.3	0.1	0.2
Chemical composition[e], % of DM				
CP	18.7	15.3	18.4	15.1
NDF	31.0	30.8	24.5	24.3
ADF	24.8	24.6	19.2	19.0
Lignin	6.0	6.0	4.9	5.0
Starch	18.5	24.2	28.7	34.3
EE	3.6	3.8	3.6	3.8
Ash	7.4	7.2	7.0	6.7
P	0.39	0.40	0.40	0.41
Ca	0.83	0.80	0.79	0.77
Na	0.34	0.37	0.35	0.36
K	1.15	1.01	1.07	0.92
Cl	0.36	0.36	0.31	0.29
TDN	68.9	69.1	72.8	73.1
NE_L, Mcal/kg	1.60	1.60	1.69	1.69
DM, %	89.4	89.2	88.8	88.6

[a] Contained 91.5% DM and 17.6% CP, 44.2% NDF, 2.5% starch, and 16.3% tdNDF on a DM basis.
[b] Dried distillers grains (DDGS) = dried byproducts of whiskey and fuel ethanol production; contained 90.4% DM and 32.2% CP, 28.3% NDF, 6.2% starch on a DM basis.
[c] Mineral and Vitamin mix compositions (DM basis): 0.49% CP; 0.185% fat; 0.72% NDF; 11.8% Ca; 5.33% P; 9.16% Na; 0.08% K; 0.005% Cl; 4.27% Mg; 2.11% S; 4,466.7 mg/kg of Zn; 208.1 mg/kg of Fe; 2,666.7 mg/kg of Mn; 666.7 mg/kg of Cu; 58.7 mg/kg of I; 25.1 mg/kg of Co; 22.7 mg/kg of Se; 0.22% Methionine; 0.01% Lysine; 533,874 IU/kg of Vitamin A (retinyl acetate); 184,800 IU/kg of Vitamin D (Activated 7-dehydrocholesterol); 4180 IU/kg of Vitamin E (dl-α tocopheryl acetate); 58.674 mg/kg of biotin; 933.3 mg/kg of Monensin (Elanco, Greenfield, IN).
[d] Phosphorus supplement; ICL Performance Products LP, St. Louis, MO. contained: 26% of P; 19.3% of Na; 0.03% of S; 30 mg/kg of F; 50 mg/kg of Fe.
[e] n = 3.

2.2. Manure storage study

The manure storage experiment was conducted from August of 2014 to March of 2015 at the Teaching and Research Facilities of the Department of Animal Science at the University of California-Davis. For each period (2–4) of the feeding trial, feces were collected from all cattle on each diet and thoroughly mixed using D-shape drain spade shovel. Manure was then divided into two parts and stored in 2 containers (Rubbermaid Commercial Products LLC, Winchester, VA) which were then transported to the site for the manure storage study on a daily basis. The two different storage treatments were: 1. **slurry**, which would represent flush water from a freestall dairy; and 2. **static pile**,