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Effect of Dried Distillers' Grains with Solubles (DDGS) in Cattle Diets and Windrow Turning Frequency on Greenhouse Gas Emissions during Feedlot Manure Composting

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ABSTRACT

This study investigated the effect of including dried distiller's grains with solubles (DDGS) in the diet of feedlot cattle and subsequent windrow turning frequency on greenhouse gas (GHG) emissions during manure composting. Manure from two diets were formed into open windrows and turned at two different frequencies. Manure from a typical finishing diet (Check: 82.8% barley grain, 15% barley silage, 2.2% mineral supplement) and the DDGS diet (DDGS: 62.8% barley grain, 30% DDGS, 5% barley silage and 2.2% mineral supplement) were stockpiled for one year prior to being used in an open windrow compost experiment. During 121 days of composting, windrows were turned at a typical (treatment: Check and DG on Days 8, 21, 27, 42, 56, 77, and 100) or reduced frequency (Treatment: CKR and DGR: on Days 22, 43, 77 and 100). The GHG (CO_2, CH_4 and N_2O) surface flux was measured over the 121-day composting period. Preliminary analyses indicate CO_2, CH_4 and N_2O surface fluxes varied considerably over time. The average CO_2, CH_4 and N_2O fluxes were not significantly different when composting manure from different diets, but there were large variations between replicated windrows within each treatment. Turning frequency had little effect on cumulative GHG emission or final compost properties. However fewer windrow turnings could reduce the fuel, labour and machinery costs associated with composting.

1. INTRODUCTION

High oil prices, climate change concerns and government bio-energy initiatives have led to increased ethanol production and use of dried distillers' grains with solubles (DDGS) as a livestock feed in North America (Klopfenstein et al. 2007). With DDGS nitrogen (N) and phosphorus (P) content approximately two to three times that of unprocessed grain (Widyaratne and Zijlstra 2007), adding DDGS to livestock diets changes manure properties, particularly pH, N form and content, and C/N ratio (Hao et al. 2005b; Velthof et al. 2005; Yan et al. 2006; Hao et al. 2009). Changes in livestock manure properties could potentially affect the dynamics of CH_4 and N_2O greenhouse gas (GHG) emissions during manure storage and composting as GHG emissions are affected by manure properties such as pH (Hao et al. 2005a), N status (Szanto et al. 2007), C/N ratio (Yamulki 2006), availability of NH_4^+ and NO_3^- (Hao et al. 2001) and degradability of C and N (Yamulki 2006). A positive relationship between dietary protein level and N_2O emission from solid dairy manure storage has been reported (Külling et al. 2001). High TN and NH_4^+ content in manure could potentially lead to higher gaseous NH_3 and N_2O emissions from stored and composted manure (Hao et al. 2009; 2011a). However, in a previous study, including corn DDGS in a feedlot diet (40% DM) did not affect either manure properties or GHG emissions during composting (Hao et al. 2011b).

Understanding the impact of DDGS in livestock diets on GHG emission from manure is crucial to developing environmentally-sound manure management strategies. The objectives of this study were to compare the rate of GHG emission during composting of manure collected from cattle fed wheat-DDGS with that from a typical barley-based finishing diet and determine whether reducing windrow turning frequency could affect CO_2, CH_4 and N_2O emissions.

2. MATERIALS AND METHODS

2.1. Experimental design and windrow management

One-year-old stockpiled manure originating from cattle fed two different diets was used in the study. Manure from cattle fed each diet was turned at two frequencies, in a 2×2 factorial design with two replications. The two types of manure arose from 1) CK; cattle fed a typical finishing diet (DM basis) containing 82.8% barley grain, 10% barley silage and 2.2% supplement and 2) DG; cattle fed a diet (DM basis) containing 30% wheat DDG, 62.8% barley grain, 5% barley silage and 2.2% supplement. Compost windrows were turned at 1) typical (CK and DG) and 2) reduced (CKR and DGR) frequencies. For the typical turning frequency, compost was turned after 8, 21, 27, 42, 56, 77, and 100 days (7 times) and after 21, 42, 77 and 100 days (4 times) for the reduced frequency. Windrows were turned with a tractor-pulled EarthSaver windrow turner (Fuel Harvesters Equipment Inc., Midland, TX). Compost windrows were built on a clay pad on June 14-15, 2011 and composting was terminated on 13 October, 2011 (Day 121) when windrow temperature dropped to near ambient level.

2.2. Windrow temperature

The ambient and windrow (at 30 and 60 cm below windrow peak) temperatures were recorded every 20 minutes at nine locations using three probes equipped with thermocouples coupled to a data logger (Sciemetric, Nepean, ON). Probes were installed as soon as compost windrows were formed and were removed and reinstalled after each turning.

2.3. Initial manure and final compost properties

A total of 64 samples at the beginning (June 14-15, 2011) and 48 samples at the end of composting (14 Oct. 2011) were collected and analyzed. Additionally, when windrows were turned on Days 21, 42, 77 and 100, two samples were collected from the top, middle and bottom for each windrow and analyzed separately.

Approximately 10 g samples were placed into 200-mL bottle containing 100 mL de-ionized water and shaken on a horizontal reciprocal shaker for 1 h. After measurement of pH (Model 290A pH meter, Orion, Boston, MA), samples were centrifuged at 16,300 *g* for 15 min and filtered. The filtrates were divided into two portions, one for NH_4^+, NO_3^- and SO_4 determination with a Dionex AS50 Ion Chromatograph (Dionex, Sunnyvale, CA) and the other for soluble organic C and N content with Shimadzu TOC-Vcsh and TNMH analyzer coupled with an ASI-V auto-sampler (Shimadzu, Kyoto, Japan). About 1 kg manure/ compost samples were first freeze-dried, then coarsely ground (<2 mm). Subsamples were further finely ground (0.150 mm) for total C (TC), and total organic N (TN) determination using a CN analyzer (NA 1500 Series 2, Carlo Erba Instruments, Milan, Italy). The moisture content was calculated using sample weight prior to and after the freeze-drying process.

2.4. Gas collection and analysis

Greenhouse gas surface fluxes were measured weekly and gas samples (10 mL) were collected at the windrow peak using a vented static chamber technique as described by Hao et al. (2001). Two sets of surface flux samples were collected from each composting windrow (four replications for each treatment) weekly. During sampling, gas samples (10 mL) were collected from each chamber at 0, 5, 10, 20 and 30 min after the chambers were placed on the windrow surface. Each gas sample was extracted with an air-tight syringe and injected into a 5.9-mL, pre-evacuated, septum-stoppered vial (Exetainer; Labco Limited, Buckinghamshire, UK). The samples were analyzed for O_2, CO_2, CH_4 and N_2O concentration using a gas chromatograph (Varian 3800; Varian Instruments, Walnut Creek, CA) equipped with an electron capture detector (ECD), a flame ionization detector (FID), and a thermal conductivity detector (TCD), and a micro-GC (Varian 4900) equipped with ECD and TCD. The concentration versus time relationships for each chamber were fitted with a second-order polynomial equation for each sampling time (SAS Institute, 2005), and the flux at time 0 was calculated by taking derivatives of the second-order polynomials (Hao et al. 2001). Cumulative emissions were estimated by assuming that daily fluxes represented the average for each period. The total GHG emissions over the composting period were expressed per initial unit surface area (kg C m^{-2} and kg N m^{-2} of manure) and initial unit dry weight (kg C Mg^{-1} and kg N Mg^{-1} manure).

2.5. Statistical analysis

All data were analyzed using the MIXED procedure in SAS (SAS Institute 2005). When there was a significant treatment effect, means were separated using the Tukey test ($P < 0.05$).

3. RESULTS AND DISCUSSIONS

3.1. Windrow temperature

Compost windrow temperature increased slowly and did not reach 50 °C until Day 28, where it remained > 50 °C until Day 70 before dropping gradually to only a few degrees higher than the ambient background temperature by Day 100 (Fig. 1). Temperature patterns at 30 cm and 60 cm depths were similar. Temperatures in the regularly turned windrows were higher than in reduced turning windrows during the first half of composting while temperatures were higher in the reduced turning windrows than regularly turned windrows during the second half of composting. Temperature in DG manure generally was lower in earlier composting, but higher later than the CK manure windrows.

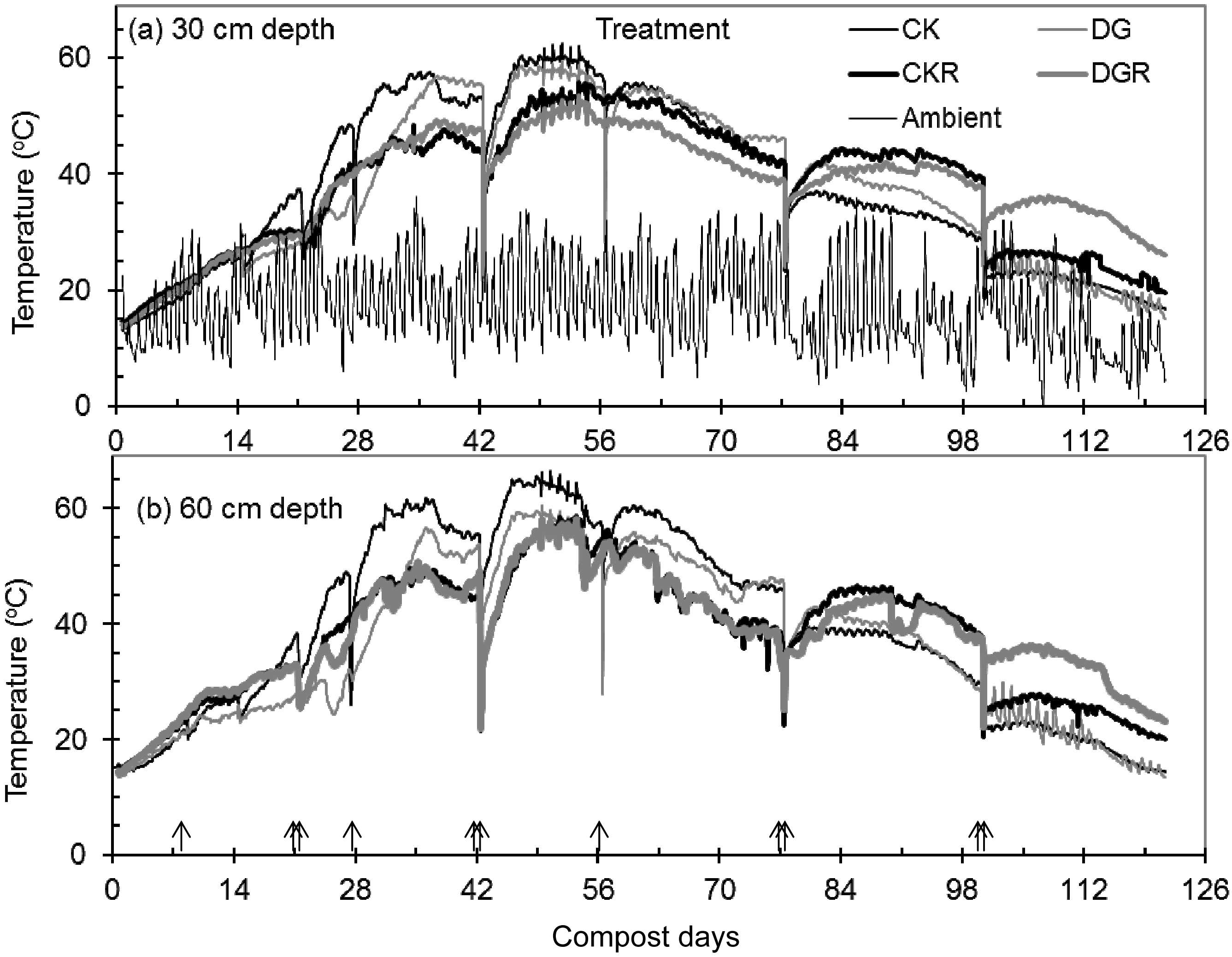

Fig. 1. Compost windrow temperature at (a) 30 cm and (b) 60 cm below the windrow peak (a single arrow indicates windrow turning for the regular turning frequency and a double arrow indicates windrow turning for both regular and reduced turning frequencies).

3.2. Manure and compost properties

Animal treading mixed the manure with soil particles under wet conditions in the feedlot pen and, at the end of feeding trial, manure had low C (198.3 and 206.6 g kg^{-1})

and N (12.89 and 14.46 g kg^{-1}) content when pens were cleaned out for stockpiling storage. During the one-year storage, there were further water, C and N losses resulting in very low moisture (0.482 and 0.503 kg kg^{-1}), C (111.2 and 111.6 g kg^{-1}) and N (11.83 and 12.40 g kg^{-1}) content in the manure used in this study. Storing manure for one year also led to the low NH_4 (118 and 210 mg kg^{-1}) and higher NO_3 (105 and 119 mg kg^{-1}) contents in the manure used in our experiment than reported by others (Hao et al. 2001, 2005a). DG manure had similar pH, TC, TN and NO_3 content, but higher water soluble C, N, SO_4 and NH_4 content than CK manure (Table 1).

Table 1. Initial manure and final compost properties

Date	Treatment	moisture	pH	Water-soluble SO4-S	NH4-N	NO3-N	C	N	TC	TN
		g/g		mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}
Initial	CK	0.503A†	8.0a	172bB	118bA	105aB	2.416bA	1.199bA	111.6aA	11.83aA
	DG	0.482A	8.0a	360aB	210aA	119aB	2.817aA	1.497aA	111.2a	12.40a
Final	CK	0.299B	7.8a	964bA	5aB	375bA	0.081aB	0.045bB	102.8aB	9.37aB
	CKR	0.348B	8.0a	1,030bA	5aB	481bA	0.089aB	0.056bB	109.3aB	10.15aB
	DG	0.311B	7.3b	1,625aA	6aB	713aA	0.099aB	0.084aB	107.8a	11.44a
	DGR	0.388B	7.9a	1,552aA	7aB	351bA	0.093aB	0.046bB	106.1a	12.19a
ANOVA	Manure (M)	0.906	0.427	<0.001	<0.001	0.458	0.005	<0.001	0.723	0.347
	Turning (N)	0.284	0.162	0.718	0.609	0.274	0.413	0.146	0.718	0.628
	Date (D)	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	0.242	<0.001
	M × N	0.632	0.598	0.543	0.048	0.144	0.586	0.687	0.852	0.896
	M × D	0.012	0.009	<0.001	<0.001	0.103	0.006	<0.001	0.021	0.007
	N × D	0.135	0.012	0.673	0.554	0.132	0.407	0.212	0.767	0.637
	M × N × D	0.668	0.048	0.424	0.042	<0.001	0.525	0.382	0.560	0.499

†for each sampling date, data in a column followed by different lower case letters, and for each treatment data in a column followed by different upper case letters differ at 0.05 probability level.

Composting manure for 121 days led to lower moisture, water soluble C and N, and NH_4 contents, but similar NO_3 content, in the final compost. Composting also reduced the TN and TC content in CK manure, but the difference in DG manure was not significant. Turning frequency had no effect on CK manure compost properties, but reduced turning (four times vs. seven times) led to higher pH, lower water soluble NO_3 and N, and similar water soluble SO_4, NH_4, and C, and TC and TN content in DG manure compost. The higher water soluble NH_4, N and C content in DG than CK manure observed at the start of composting was no longer apparent while higher water soluble SO_4 in DG than CK manure persisted until the end of composting.

3.3. Greenhouse gas emissions

The rate of CO_2 surface flux varied between 1.2 and 195.7 g m^{-2} d^{-1} with the maximum emission occurring on Day 28 (Fig. 2a). The CO_2 fluxes generally decreased after Day 28, but increased after each turning event due to increased O_2 supply. There were no significant differences among treatments on most sampling dates. However,

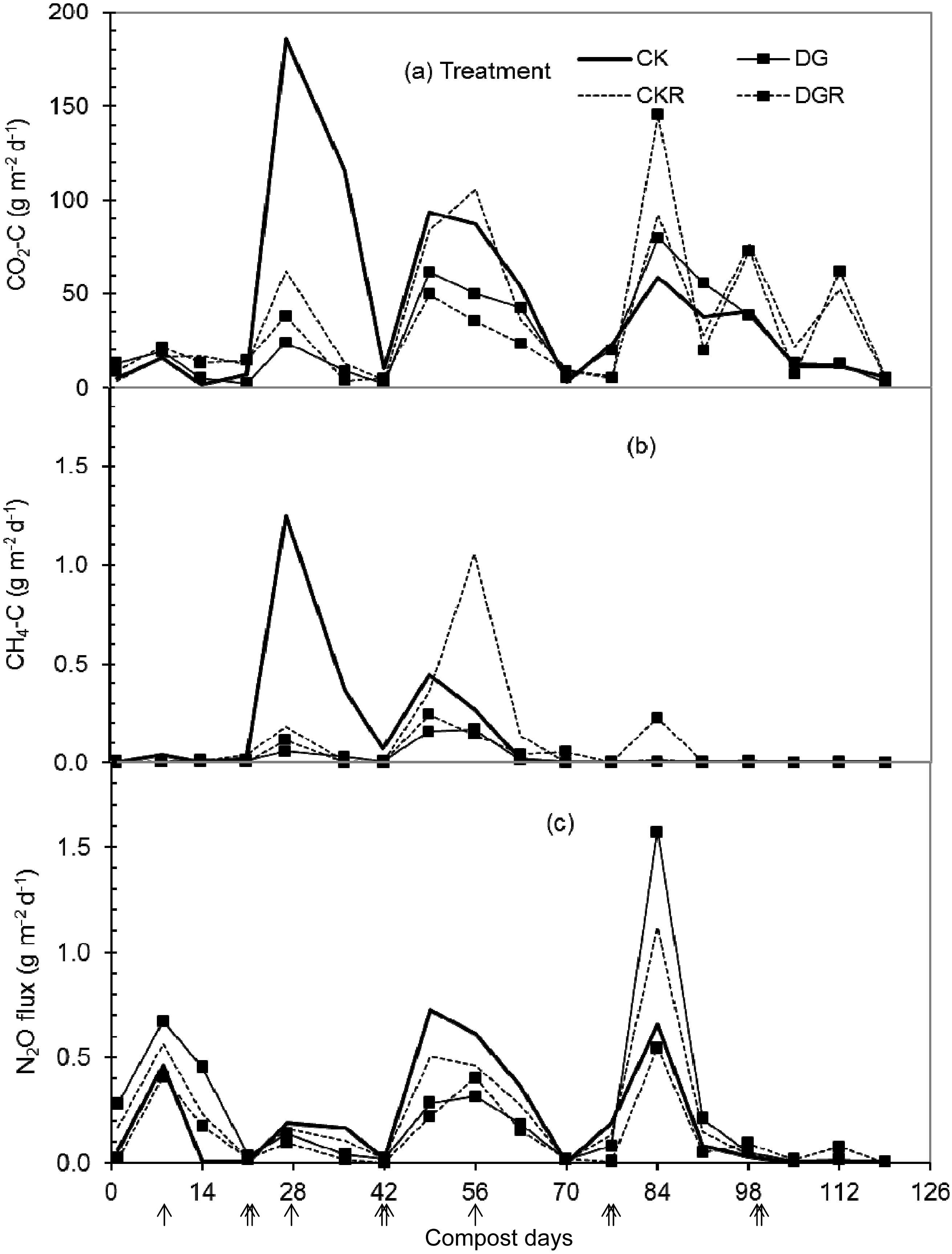

Fig. 2. Greenhouse gas surface flux (a single arrow indicates windrow turning for the regular turning frequency and a double arrow indicates windrow turning for both regular and reduced turning frequencies).

the CO_2 surface fluxes were greater from CK than DG manure on Days 27, 56 and 105. The fluxes were greater in CKR and DGR than CK and DG on Days 14, 21, 98 and 112 with the reverse being true on Day 27. The cumulative CO_2 emissions were similar among all treatments and were not affected by manure source or turning frequency. However, when emission was expressed on a C basis, a lower percentage of C was lost with reduced turning than the regular turning frequency for CK manure, and in DG manure than CK manure (Table 2). Hao et al. (2011a; b) also reported a lower percentage of C lost in addition to a lower rate of CO_2 emission when composting DDGS manure than manure from cattle fed a typical feedlot diet. The differences between the two studies might be due to the lower manure C and N contents used in current study.

The CH_4 surface fluxes were near zero for the first three weeks, increasing sharply on Day 28, then decreasing gradually over the next 30 days to near zero in the second half of composting (Days 60 to 120) (Fig. 2b). There were no significant differences in CH_4 surface flux among treatments on most sampling dates, except on Day 36 when emission from CK manure was greater than from DG manure while regular turning led to higher CH_4 flux than reduced turning on Day 42. Similar to CO_2, cumulative CH_4 emissions were similar among all treatments and were not affected by manure source or windrow turning frequency (Table 2).

The rate of N_2O surface flux varied in the range of 0.5 to 656.2 mg N m^{-2} d^{-1}, with the maximum occurring on Day 84 (Fig. 2c). The N_2O fluxes were not affected by treatment, except on a few occasions over the 121 days of composting. The N_2O fluxes were higher from DG than CK on Days 1, 14, 21 while the reverse was true on Day 56. Additionally, N_2O fluxes were higher with reduced turning on Days 21, 98 and 112 while the opposite occurred on Days 42 and 49. Similar to CO_2 and CH_4, the cumulative N_2O emissions were similar among all treatments and were not affected by manure source or windrow turning frequency (Table 2), reflecting similar N content in the manure used.

Similar compost properties and greenhouse gas emissions observed in our study between regular and DDGS diet manure were attributed to the similar manure C and N content in the one-year old stockpile manure used in our composting study. It is likely the most liable C and N were lost during manure one-year storage.

Table 2. Greenhouse gas emissions

Treatment	CO_2-C	CO_2-C	CO_2-C /TC	CH_4-C	CH_4-C	CH_4-C/TC	N_2O-N	N_2O-N	N_2O-N/TN
	g m^{-2} d^{-1}	kg t^{-1}	%	g m^{-2} d^{-1}	kg t^{-1}	%	g m^{-2} d^{-1}	kg t^{-1}	%
CK	244.6	29.0	26.3 a	0.138	0.069	0.059	0.199	0.092	0.155
CKR	137.1	21.9	19.1 b	0.101	0.045	0.037	0.129	0.057	0.093
DDG	125.3	15.2	13.0 c	0.027	0.012	0.009	0.243	0.102	0.165
DDGR	162.6	15.9	13.4 bc	0.048	0.019	0.016	0.222	0.090	0.140

In summary, including a low level (30% DM) of DDGS in cattle diets had minimal impact on GHG emission over 121 day of composting manure that had previously been stockpiled for one year. Less frequent turning did not significantly affect CH_4, CO_2 and N_2O emission, or affect the final compost properties. However fewer windrow turnings could reduce the overall fuel, labor and machinery costs associated with composting.

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