Agronomic and Greenhouse Gas Assessment of Land Applied Anaerobically-Digested Swine Manure

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Abstract

Management of animal wastes from intensive livestock operations (ILO) must be economically feasible, environmentally friendly and socially acceptable. Anaerobic digestion is a promising technology that could provide an option for managing animal waste that may reduce greenhouse gas emissions by utilizing the biogas produced during digestion to displace fossil-fuels and by reducing emissions during lagoon storage. A three-year study was conducted at two locations, Swift Current and Melfort, to compare the agronomic performance and gaseous N loss of land-applied anaerobically digested swine manure (ADSM) to conventionally treated swine manure (CTSM). Treatments included spring and fall applications of CTSM and ADSM at a 1x rate (10,000 and 7,150 L ha^{-1} respectively) applied each year, and a 3x rate (30,000 and 21,450 L ha^{-1} respectively) applied once at the beginning of the study. A treatment receiving commercial fertilizer (UAN) and a check (no N) were also included. Nitrogen use efficiency for single applications of ADSM or CTSM at the 3x rate were lower than three annual applications at the 1x rate, while UAN was intermediate. Nitrogen use efficiency of ADSM and CTSM applied in the fall was equal to spring when applied at 1x rate and, in general, agronomic performance of ADSM was similar or better than CTSM. Ammonia loss from ADSM was similar to CTSM, except for CTSM at the 3x rate applied in the fall at Melfort and in the spring at Swift Current, which had significantly higher losses than all other treatments. The percentage of applied N lost as N_2O measured at the Melfort site was generally higher for treatments receiving CTSM compared to ADSM or UAN, and losses from ADSM and UAN were similar. The results from this study suggest that ADSM is equal or better than CTSM in terms of agronomic performance, but has lower environmental impact with respect to gaseous N loss.

Introduction

Management of animal wastes from intensive livestock operations (ILO) must be economically feasible, environmentally friendly and socially acceptable. Currently, animal waste from hog barns is washed into a lagoon where it is stored until it can be land-applied. Considerable amounts of methane (CH_4) and nitrous oxide (N_2O), both powerful greenhouse gases, are emitted to the atmosphere during handling and storage of the material. Further losses of N_2O occur when this material is land-applied. Anaerobic digestion is a promising technology that could provide an option for managing animal waste that may reduce greenhouse gas emissions by utilizing the biogas produced during digestion to displace fossil-fuels and by reducing emissions during lagoon storage. However, little information is available regarding the agronomic performance and greenhouse gas implications of land-application of the digested material. The objective of this study was to compare agronomic performance and gaseous N loss of land-applied anaerobically digested swine manure (ADSM) to conventionally treated swine manure (CTSM).

Materials and Methods

A 3-year study (2006-2008) was conducted at two field sites, Swift Current (Brown Chernozem soil) and Melfort (Dark Gray Luvisol soil), having contrasting soil and climatic conditions. Eleven treatments (**Table 1**) were arranged in a randomized complete block design with four replicates. Liquid manures were applied by the Prairie Agricultural Machinery Institute (PAMI) using a customized applicator, and all plots were seeded to barley (*Hordeum vulgare* L.) in each of the three years (AC Rosser in 2006 and 2007; Newdale in 2008). Seeding dates and rates, weed control and harvesting operations followed standard agronomic practice.

Table 1. List of treatments and the corresponding total amount of N applied during a three-year field study at Swift Current and Melfort, Saskatchewan

Time of application	Product applied	Application rate	Total N applied (3-year cumulative)
Fall			
	[Z] ADSM-3x	21 450 L ha^{-1}	214
	ADSM-1x	7 150 L ha^{-1}	205
	CTSM-3x	30 000 L ha^{-1}	403
	CTSM-1x	10 000 L ha^{-1}	360
	Control	-	-
Spring			
	ADSM-3x	21 450 L ha^{-1}	257
	ADSM-1x	7 150 L ha^{-1}	255
	CTSM-3x	30 000 L ha^{-1}	343
	CTSM-1x	10 000 L ha^{-1}	326
	UAN	60 kg N ha^{-1}	180
	Control	-	-

[Z] ADSM = Anaerobically digested swine manure, CTSM = Conventionally treated swine manure, UAN = Urea ammonium nitrate (liquid).

Conventionally treated swine manure (CTSM) was obtained from a 1200 sow farrow-to-finish barn operated by Cudworth Pork Investors Group Ltd (CPIG), located near Cudworth, SK. Initial batches of the ADSM was obtained from a full-scale mesophyllic pilot digester also located by the CPIG barn. Later batches (fall 2007 and spring 2008) were obtained from a small-scale pilot digester operated by PAMI. Operating conditions for the small-scale digester were comparable to the full scale version.

Previous research has indicated that application rates of CTSM providing between 75 and 150 kg N ha^{-1} are most effective for agronomic performance (Schoenau et al. 2001). Based on analysis of the CTSM to be applied in the first fall (2005) of the study, an application rate of 10,000 L ha^{-1} (3,000 gal ac^{-1}), a typical rate used by producers in Saskatchewan, would provide about 100 kg N ha^{-1}. Similarly, based on analysis of the ADSM supplied for application in the fall of 2005, an application rate of 7,150 L ha^{-1} (2,125 gal ac^{-1}) provided a comparable amount of N. Treatments receiving CTSM and ADSM at 3x this rate were also applied. The “1x” rate was applied in each of the three years while the “3x” rate was applied only once at the beginning of the study. Rates were held constant on a volume basis throughout the study. However, the N concentration contained in both the CTSM and ADSM varied considerably from application period to application period. The cumulative N applied over the life of the study is presented in **Table 1**. To account for the differences in the actual N applied, grain yields and ammonia and nitrous oxide losses were normalized by expressing them as a ratio of N applied prior to statistical analysis.

Ammonia (NH_3) volatilization was measured using the “double-sponge open-chamber” technique (Grant et al. 1996), with measurements made on a set schedule for 2-3 weeks following application of the treatments. Cumulative losses for each sampling period were calculated by interpolating between data points and integrating over time assuming a constant flux. Cumulative losses were normalized by subtracting the NH_3-N lost from the check (no N applied) treatment and dividing that difference by the total NH_4-N applied.

Nitrous oxide sampling was only conducted at the Melfort location. Non-steady state vented soil chambers were employed, and gas samples were collected at least weekly from snow melt until the end of July. Sampling frequency was increased when expected emission activity was high (after snow melt and application of manure or fertilizer) and was reduced during the latter part of the season when soil-water contents were low. Seasonal estimates of N_2O emissions were calculated by interpolating between data points and integrating over time assuming a constant flux (Lemke et al. 1999). The percentage of applied N lost as N_2O-N was calculated by subtracting the N_2O-N lost from the check (no N applied) treatment and dividing that difference by the total N applied.

Results and Discussion:

Good growth was observed at Swift Current early in the growing season of 2006, but with rainfall only at about 56% of the long-term mean during July-August (**Table 2**), the crop was drought stressed during grain filling and final grain yields were depressed on any treatment that received an application of N (data not shown). Drought conditions prevailed throughout the 2007 season and yields were very low and tended to be depressed on any treatment that received N (data not shown). In 2008, the site was hit with hail on July 9th and the validity of the yield results is uncertain (data not shown). We don’t consider the grain yield data from Swift Current to be representative of treatment response, therefore no further discussion will be presented in this paper.

Table 2. Monthly cumulative precipitation during 2006, 2007, and 2008, at Swift Current and Melfort, Saskatchewan

Year	**May**	**June**	**July**	**August**	**September**
Swift Current			Precipitation (mm)		
2006	35	96	31	21	50
2007	26	48	10	19	21
2008	27	152	64	69	19
30-year mean	50	66	52	40	30
Melfort					
2006	63	73	39	46	120
2007	71	119	47	40	20
2008	6	32	117	22	11
30-year mean	46	66	76	57	40

Rainfall at the Melfort site was somewhat lower than the long-term mean during the July-August period in 2006 and 2007 (**Table 2**), but above average precipitation during the early part of the season (May-June) carried the crop through with good yields in 2006 (**Table 3**), and modest yields in 2007. Extremely low rainfall was received in May and June, above average rainfall in July, followed by very dry conditions through August of 2008. This somewhat erratic rainfall pattern resulted in modest grain yields.

Nitrogen use efficiency (NUE) of barley for the various treatments at the Melfort location are presented in **Table 4**. NUE was calculated as:

$$[(\text{3-year total grain yield ha}^{-1}\text{ for treatment}) - (\text{3-year total grain yield ha}^{-1}\text{ for check})] \div [\text{3-year total N applied to treatment}]$$

In general, the 1x application rates of ADSM or CTSM had the highest NUE, the 3x application rates the lowest, and UAN was intermediate. Further, ADSM tended to have similar or better NUE compared to CTSM.

Table 3. Barley grain yields from various treatments for three years at Melfort, Saskatchewan

Time	N source/ rate	2006	2007	2008
			kg ha^{-1}	
Fall	[Z] ADSM-3x	6268	2213	3325
	ADSM-1x	5609	2792	3497
	CTSM-3x	5837	3256	3924
	CTSM-1x	6375	4257	4699
Spring	ADSM-3x	6250	2502	3258
	ADSM-1x	6202	3050	4504
	CTSM-3x	5946	2913	3653
	CTSM-1x	6437	3228	4725
	UAN	5138	1985	3565
	Control	3487	1241	2629

[Z] ADSM = Anaerobically digested swine manure, CTSM = Conventionally treated swine manure, UAN = Urea ammonium nitrate (liquid).

Table 4. Nitrogen use efficiency (NUE) of barley grain yield for varying rates and sources of applied N at Melfort, Saskatchewan

Time	N source/ rate	[Y] NUE
		kg grain kg^{-1} applied N ha^{-1}
Spring	[Z] ADSM-1x	25 a
Fall	ADSM-1x	22 b
Fall	CTSM-1x	22 b
Spring	CTSM-1x	22 b
Fall	ADSM-3x	21 bc
Spring	UAN	19 cd
Spring	ADSM-3x	18 d
Spring	CTSM-3x	15 e
Fall	CTSM-3x	14 e

[Z] ADSM = Anaerobically digested swine manure, CTSM = Conventionally treated swine manure, UAN = Urea ammonium nitrate (liquid).

[Y] [(3-yr total grain yield ha^{-1} for treatment) – (3-year total grain yield ha^{-1} for control)] ÷ (3-year total N applied ha^{-1} to treatment).

Ammonia volatilization losses were generally quite low at the Melfort location. Cumulative losses over all sampling periods ranged from less than a kilogram to about 3 kg of N ha^{-1} (**Table**

5). The exception was the fall applied CTSM-3x treatment which lost over 8 kg N ha^{-1}. When these losses were compared on a relative basis, (g NH_3-N kg^{-1} applied NH_4-N), the fall applied CTSM-3x treatment was significantly higher than all other treatments. There were no other significant differences.

Table 5. Estimated ammonia-N (NH_3-N) loss over three sampling periods from various treatments at Melfort, Saskatchewan

Time	**N source/ rate**	**Net ammonia-N loss**	[Y]**Ammonia-N loss response**
		g N ha^{-1}	g NH_3-N kg^{-1} applied N ha^{-1}
Fall	[Z] ADSM-3x	2 600 b	13 ab
	ADSM-1x	1 200 b	6 b
	CTSM-3x	8 100 a	24 a
	CTSM-1x	3 000 b	10 b
Spring	ADSM-3x	1 100 b	5 b
	ADSM-1x	1 700 b	8 b
	CTSM-3x	1 700 b	6 b
	CTSM-1x	2 500 b	10 ab
	UAN	800 b	6 b

[Z] ADSM = Anaerobically digested swine manure, CTSM = Conventionally treated swine manure, UAN = Urea ammonium nitrate (liquid).

[Y] [(Cumulative NH_3-N lost from treatment) – (Cumulative NH_3-N lost from control)] ÷ [Cumulative NH_4-N applied].

Ammonia volatilization losses were highly variable at the Swift Current location. Very high (over 30 kg N ha^{-1}) losses were measured on the spring applied CTSM at the 3x rate, with lower but still substantial losses (> 10 kg N ha^{-1}) measured on the other 3x treatments (**Table 6**). Losses from the ADSM and CTSM at the 1x application rate were very low and not significantly different from the UAN treatment. The same pattern emerged when the losses were compared on a relative basis (**Table 6**).

Nitrous oxide emissions responded to the treatments in a relatively consistent fashion. Emissions were highest from the CTSM treatments, with particularly high losses in the first year of the study on the treatment receiving CTSM at the 3x rate (**Table 7**). When emissions were expressed as a percentage of applied N lost as N_2O, losses were significantly higher from the treatments receiving CTSM at the 1x and 3x rate compared to treatments receiving ADSM at the 1x rate and the UAN treatment (**Table 8**). The treatment receiving ADSM at the 3x rate was intermediate and significantly different from CTSM at the 3x rate applied in the fall.

Table 6. Estimated ammonia-N (NH_3-N) loss over three sampling periods from various treatments at Swift Current, Saskatchewan

Time	N source/ rate	Net ammonia-N loss	[Y] Ammonia-N loss response
		g N ha^{-1}	g NH_3-N kg^{-1} applied N ha^{-1}
Fall	[Z] ADSM-3x	5 500 bc	26 cd
	ADSM-1x	800 c	4 d
	CTSM-3x	10 300 b	31 bc
	CTSM-1x	2 100 c	7 cd
Spring	ADSM-3x	12 100 b	51 b
	ADSM-1x	800 c	4 d
	CTSM-3x	31 400 a	107 a
	CTSM-1x	1 500 c	6 d
	UAN	600 c	7 cd

[Z] ADSM = Anaerobically digested swine manure, CTSM = Conventionally treated swine manure, UAN = Urea ammonium nitrate (liquid).

[Y] [(Cumulative NH_3-N lost from treatment) – (Cumulative NH_3-N lost from control)] ÷ [Cumulative NH_4-N applied].

Table 7. Estimated annual and three-year cumulative N_2O-N loss from various treatments at Melfort, Saskatchewan

Time	N source/ rate	2006	2007	2008	3-year total
			kg N ha^{-1}		
Fall	[Z] ADSM-3x	2.9	1.1	3.4	7.4
	ADSM-1x	1.3	2.2	2.0	5.5
	CTSM-3x	16.3	1.8	3.4	21.5
	CTSM-1x	3.6	5.9	7.3	16.8
Spring	ADSM-1x	1.7	2.1	2.2	6.0
	CTSM-1x	3.2	5.4	6.7	15.3
	UAN	1.1	1.1	2.3	4.5
	Control	0.8	0.8	1.6	3.2

[Z] ADSM = Anaerobically digested swine manure, CTSM = Conventionally treated swine manure, UAN = Urea ammonium nitrate (liquid).

Table 8. Percentage of applied N lost as N_2O-N over three years at Melfort, Saskatchewan

Time	**N source/ rate**	**Percent N loss**
		– % –
Fall	[Z] CTSM-3x	4.5 a
Fall	CTSM-1x	3.8 ab
Spring	CTSM-1x	3.7 ab
Fall	ADSM-3x	2.0 bc
Fall	ADSM-1x	1.1 c
Spring	ADSM-1x	1.1 c
Spring	UAN	0.7 c

[Z] ADSM = Anaerobically digested swine manure, CTSM = Conventionally treated swine manure, UAN = Urea ammonium nitrate (liquid).

Conclusions

Nitrogen use efficiency of barley for single applications of ADSM or CTSM at the 3x rate was lower than three annual applications at the 1x rate, while UAN was intermediate. Nitrogen use efficiency of ADSM and CTSM applied in fall was equal to spring when applied at 1x rate and, in general, agronomic performance of ADSM was similar or better than CTSM. Ammonia N losses for all treatments at Melfort and for the 1x application rate at Swift Current were low (< 1 kg N yr^{-1}); but more substantial (2-10 kg N yr^{-1}) on the 3x application rates at Swift Current. In general, NH_3 loss from ADSM was similar to CTSM except for CTSM at the 3x rate applied in the fall at Melfort and in the spring at Swift Current. The percentage of applied N lost as N_2O measured at the Melfort site was generally higher for treatments receiving CTSM compared to ADSM or UAN, while losses from ADSM and UAN were similar. The results from this study suggest that ADSM is equal or better than CTSM in terms of agronomic performance, and has a lower environmental impact with regard to gaseous N loss.

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