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MEASURING GREENHOUSE GAS EMISSIONS FROM DAIRY MANURE SLURRY

by
H.A. Jackson[1] N.K. Patni[1], D.I. Massé[1], R.G. Kinsman[1], M.S. Wolynetz[2], D.J. Buckley[1], J.A. Munroe[1], F.D. Sauer[1], R. Desjardins[3], E. Pattey[3]

[1] Centre for Food and Animal Research, Research Branch, Agriculture and Agri-Food Canada, Ottawa, Ontario, Canada, K1A OC6.
[2] Western Region, Research Branch, Agriculture and Agri-Food Canada, Ottawa, Ontario, Canada, K1A OC6.
[3] Centre for Land and Biological Resources Research, Research Branch, Agriculture and Agri-Food Canada, Ottawa, Ontario, Canada, K1A 0C6.

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Summary:

A monitoring system to continuously measure methane and carbon dioxide emissions from dairy cattle manure slurry stored in a 296,000 litre farm manure storage and in 20, 30 and 200 litre laboratory manure storages is described. Results obtained over a 120-day summer period are presented.

Keywords:

carbon dioxide, methane, greenhouse gas, animal manure, rumen, dairy cattle, data acquisition

ASAE, 2950 Niles Rd., St. Joseph, MI 49085-9659 USA
Voice: 616.429.0300FAX:616.429.3852

INTRODUCTION

Greenhouse gases (carbon dioxide, methane and nitrous oxide) accumulate in the atmosphere and contribute to global warming. It is estimated that farm animals are responsible for 30 per cent of total global man-made emissions of methane (USEPA, 1993), 23 and 7 per cent from rumen and manure respectively. Cattle account for about 73 per cent of the emissions attributed to ruminant animals.

There is, however, a great deal of debate concerning the reliability of these estimates. A major problem has been the manner in which these estimates have been made. For rumen emissions, single animals were placed in special sealed chambers and the gas emissions measured. This method, while providing valuable information on gas emissions from cattle, leaves room for significant sampling error in emission estimates. Placing animals in chambers exposes them to additional stress and limits the ability to integrate the variability between animals, both of which can bias results. For manure emissions, estimates are based on emissions from anaerobic digesters which are not representative of typical farm manure storages in Canada.

This paper describes a system developed for continuously measuring greenhouse gas emissions (methane and carbon dioxide) from dairy manure slurry stored in a 296,000 litre on-farm, covered, concrete storage and in 25, 30 and 200 litre laboratory-scale storages. Preliminary results on gas emissions are presented. A review of the literature on methane emissions from animal manure is included. In a related study, a system to continuously measure greenhouse gas emissions from a 118-milking cow barn was described earlier by Jackson et al. (1993).

REVIEW OF THE LITERATURE

Accumulation of methane and carbon dioxide in the atmosphere is contributing to the greenhouse effect and the resultant global warming. Carbon dioxide accounts for 66% of the greenhouse gas effect while methane accounts for 18% (USEPA, 1993). Human activities that have contributed to the increase of greenhouse gases in the atmosphere include flooded rice cultivation, coal mining, oil and gas production and distribution, biomass burning, slash and burn land clearing, landfills, sewage handling, domestic ruminant animals and their waste, and livestock waste management systems (USEPA, 1990).

Several authors have estimated global emissions of methane from all sources including emissions from livestock and livestock wastes (Table 1). The USEPA(1993) acknowledged that the magnitude of these estimates is reasonable but suggested that there are large uncertainties in current estimates.

Farm animals in Canada are contributing a small share of total global emissions. Jaques (1992) estimated methane emissions from ruminant livestock in Canada to be 0.85 Tg/year. Safley et al. (1992) calculated methane emissions from manure in Canada to be 0.33 Tg/year. The total methane emissions from livestock and livestock manure in Canada would then be less than 1% of current estimates of global methane emissions from livestock and livestock manure.

Methane and carbon dioxide are primary end products of anaerobic decomposition of organic material. The quantity of methane and carbon dioxide produced from animal waste depends on species, ration, age of the animal, collection and storage method, temperature, and the amount of foreign material (i.e. bedding)incorporated into the waste (Chen, 1983). The waste management system affects the proportion of waste that is anaerobically degraded and the yield of methane and carbon dioxide. Liquid and slurry systems typically cause anaerobic conditions to develop whereas waste in solid systems and deposited in pastures tends to dry out and aerobic conditions predominate (Safley et al., 1992). Patni and Jui (1985, 1987) found that about 25% of the carbon initially present in dairy cattle manure slurry stored in farm tanks in eastern Ontario was lost during 5 to 9 months of storage presumably in the gas emanating from the slurry. This indicated that stored manure slurry could be a substantial contributor to gas emissions from animal operations.

Optimizing methane production from dairy manure in anaerobic digesters has been reported extensively in the literature (Table 2). Very little information is available relating to methane production and recovery in other manure management systems. It is generally agreed that hydraulic retention time, loading rate, diet, and temperature influence methane production rate in anaerobic digesters. Much of the data in Table 2 were obtained from anaerobic digesters at temperatures in the 35-60ºC range which are not typical of manure storages on the farm and therefore may not be directly applicable.

Average methane production from swine manure at 20ºC in laboratory-scale anaerobic digesters was 7.5 to 15 L/kg VS/day over a 60 day period (Massé et al., 1993). This is considerably less than that indicated in the literature(Table 2) for dairy manure.

MATERIALS AND METHODS

Experimental Setup

One compartment of an on-farm four compartment in-ground covered concrete manure storage at the Centre for Food and Animal Research, Agriculture and Agri-food Canada Greenbelt Research Farm near Ottawa, Ontario, Canada was used for this study (Figure 1). The 7.2 m by 14.7 m by 2.8 m deep compartment with a capacity of 296,000 litres was batch-filled with dairy manure slurry from a 118-cow tie-tall dairy barn.

At the same time, 14 plastic laboratory manure storages (four 200 L barrels, four 30 L bottles and six 25 L bottles) were batch-filled with the same manure slurry to simulate the full-scale storage; an additional four 25 L bottles (initial loading of 4 L) were continuously fed 0.5 L of the same dairy manure slurry once a week during the 4 month monitoring period to simulate continuously fed on-farm storages. The 18 laboratory-scale storages were placed in a controlled environment chamber maintained at the same temperature as the manure at the 1700 mm depth (1100 mm from bottom) of the on-farm manure storage. Figure 2 shows one of the 25 L continuous-feed laboratory-scale storages.

The on-farm and laboratory-scale tests were carried out at the same time to validate the applicability of laboratory simulation to field conditions. Laboratory-scale research permits researchers to evaluate and replicate parameters and treatments at minimal cost compared to field-scale research.

Gas emission monitoring system

The gas emission monitoring system consists of a gas sampling system and a data acquisition system.

In order to monitor gas emissions from the on-farm manure tank, six 500 mm by 1500 mm openings (Figure 2) were cut in the tank concrete cover and protected from weather by an insulated plywood box with hinged lids for easy access. In each opening, a pair of floating covers each consisting of a 500 mm outside diameter by 750 mm long PVC pipe with top end capped were placed to a depth of at least 300 mm in the manure. Under one of the two floating covers, a 450 mm outside diameter PVC pipe was added and it extended from 150 mm above the manure surface to the bottom of the tank (Figure 3). This unit is hereafter referred as the 'long pipe gas collector'. The other floating cover is hereafter referred to as the 'no pipe gas collector'. A 10 mm inside diameter tygon tube connected each floating cover (12 total) to the wet-cup gas flow meters located in a heated and insulated box (separate from the box covering the manure tank opening) maintained at 20ºC by a thermostat control to ensure that water in the wet-cup gas meters did not freeze and its viscosity remained relatively constant. Each tygon tube had a gas sampling port with septa for taking the weekly syringe gas samples, a port for an anti-freeze filled manometer and a port for a D.J. Instruments model LPTV-120-C-2 pressure transducer with a range of 0-300 mm water gauge. The wet-cup gas flow meters required 100 mL of gas to tip and register gas production via a counter on the meter; gas entered the wet-cup gas meters at a pressure 125 mm water gage. Manure temperature was measured with type T thermocouples placed in each of the manure tank openings at the following manure depths from the bottom of the tank: 100 mm, 600 mm, 1100 mm, 1600 mm, 2100 mm and 2600 mm.

The data acquisition consisted of a Sciemetric Instruments model 200 data acquisition and control system connected to an IBM AT compatible computer running two software programs simultaneously (I) Copilot (Howell-Mayhew Engineering, Inc., 15006 - 103 Ave., Edmonton, Alberta, Canada, T5P 0N8), a data acquisition and control program running in the foreground, and (ii) Close-up (Norton-Lambert Corp., PO Box 4085, Santa Barbara, California, 93140, USA), a remote communications program running in the background and configured for dial-back security protection (Figure 4). The data acquisition system recorded the gas pressure inside each cover, the counts from each wet-cup gas meter counter, and the manure temperature. In addition, the gas temperature in each cover, the water temperature in each wet-cup gas meter, and the barometric pressure (Sensotec model A-5 0-170 kPa absolute) were recorded. The data acquisition system was remotely accessed from an IBM compatible computer with a modem.

Carbon dioxide and methane emissions from the on-farm and lab-scale manure storages were continuously measured by the tipping bucket wet-cup gas flow meters. Weekly 10 cc syringe gas samples (from each of the 12 on-farm storage covers and from two of each of the 25 L, 30 L, 200 L batch fed and 25 L continuous-feed lab storages) were taken and analyzed with a Carle model 400AC gas chromatograph for carbon dioxide, methane and hydrogen sulphide concentration. At monthly intervals, one litre manure samples were taken from each of the six openings of the on-farm manure storage and from each lab-scale manure storage and analyzed for carbon and nitrogen, and other manure properties.

For the 18 laboratory-scale manure storages, the manure temperature, controlled environment room temperature, barometric pressure, gas meter counts and gas pressure were measured using the same type of data acquisition system as at the on-farm manure storage.

The on-farm and lab-scale manure storages were loaded at the beginning of June and emptied at the end of September 1994.

RESULTS AND DISCUSSION

The cumulative biogas production for the first 120 days of the June to September 1994 monitoring period is shown in Figure 5. The average cumulative productions as determined from the on-farm 'long pipe gas collectors' and laboratory-scale storages during the summer monitoring period were very similar at about 1.3 litres biogas per litre of manure with a purity of about 25% methane. For the 120-day storage period, this equates to a manure methane emission rate of about 15 L/cow/day (assuming 45 L manure/cow/day x 1.3 L biogas/L manure x 0.25 L methane/L biogas). Jackson et al. (1993) previously reported rumen methane emission from lactating dairy cows to be about 550 L/cow/day, which was near the high end of the range of values reported in the literature. The manure methane emission rate measured in this study is about 10 % of that reported by other researchers. This may be due to a lower temperature of stored manure in this study compared to that in other studies. The average manure temperature for both the on-farm and laboratory storages was about 17ºC for the 120-day summer monitoring period.

The average cumulative biogas production from the on-farm no pipe covers was 41 % of that from the on-farm 'long pipe gas collectors' (0.55 versus 1.34 L biogas/L manure). A possible explanation (Husted, 1993) is that the partial pressure of gas above the manure increases when chambers are inserted into the manure surface. It appears that some of the biogas released from the manure directly below the 'no pipe gas collectors' was being deflected away from the collectors resulting in the lower measured biogas production. Matthias et al. (1978) used mathematical simulation and field trials of nitrous fluxes over soil and water surfaces to conclude that closed (covered) chamber gas fluxes could underestimate open chamber gas fluxes by as much as 55 % and that "open chambers yield better flux estimates than closed chambers because of less disturbance to the natural gas concentration profile". Matthias et al. (1978) defined a closed chamber as one that completely encloses the substance being studied while an open chamber is one that is partly open to continual artificially induced air flow across the surface of the substance.

CONCLUSIONS

Methane emissions from on-farm and laboratory-scale liquid manure storages in this study were 10 % of the magnitude of those reported in the literature from manure storages in more temperate climates. The average daily emission rate of methane over a 120-day summer period was about 15 L/cow/day, about 3 % of the total emissions (rumen plus manure) from lactating cows in a tie-stall barn (Jackson et al., 1993).

Preliminary results suggest that methane emissions from liquid cattle manure stored in eastern Canada are low. Further research to evaluate and/or develop techniques for reducing and/or collecting methane emissions from stored liquid manure under eastern Canadian climatic conditions in order to reduce global warming may not be worthwhile.

Further research is required to determine the reason(s) for the substantial difference in gas production between the 'long pipe gas collector' and 'no pipe gas collector' and to determine the relationship between the 'long pipe gas collector' and the on-farm manure tank with free space under the tank cover.

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Table 1. **Estimates of annual wastes and total global methane emissions from livestock, livestock wastes and total global emissions from all sources**

Source	Livestock	Livestock wastes	Total global emissions
Crutzen, 1991	80		505 ±105
Safley et al., 1992		28.4	
Cicerone and Oremland, 1988	65-100	35	440 - 640
Lerner et al., 1988	75.8		
Crutzen et al., 1986	71		
Seiler, 1984	72-99		225 - 395
Ehhalt, 1974	101		545 -1035

[1] Tg = $1x10^{12}$gm = $1x10^{6}$ tonnes

Table 2. **Reported anaerobic data for methane production from dairy manure in**

Temp (ºC)	Hydraulic retention time (days)	Methane yield (m /kgVS/day)	Methane Production (L CH_4/L manure/day)	Biogas Quality (% CH_4)	Reference
35	3	0.12	0.99	66	Lo et al., 1984
35	4	0.13	0.9	64	Lo et al., 1984
35	6	0.16	0.57	64	Lo et al., 1984
35	8	0.2	0.6	68	Lo et al., 1984
35	10	0.20-0.23	0.58	40	Converse et al., 1977
35	12	0.31	0.52	68	Lo et al., 1984
35	15	0.28-0.31	0.67	53	Converse et al., 1997
35	16	0.29	0.44	68	Lo et al., 1984
35	30	0.22		--	Jewell et al., 1979
37	120	0.04-0.10		--	Chen et al., 1988
40	3	0.17		--	Rorick et al., 1980
40	5	0.24		--	Rorick et al., 1980
40	6	0.17		--	Rorick et al., 1980
40	10	0.16		--	Rorick et al., 1980
60	10	0.16-0.21	1	45	Converse et al., 1977
60	15	0.21-0.22	0.5	48	Converse et al., 1977
27-33*	35	--	0.02	80	Safley and
16-31*	166	--	0.18	80	Westerman, 1990
4-17**	--	--	0-0.05	--	Husted, 1994
17***	120	--	0-0.01	25-35	This study

* Lagoon, continuous feed, very low volatile solids loading rate

** Manure storage tank, continuous feed, very low volatile solids loading rate

*** Manure storage tank, batch feed

Note: Anaerobic digesters, continuous feed, high volatile solids loading rate relative to lagoon

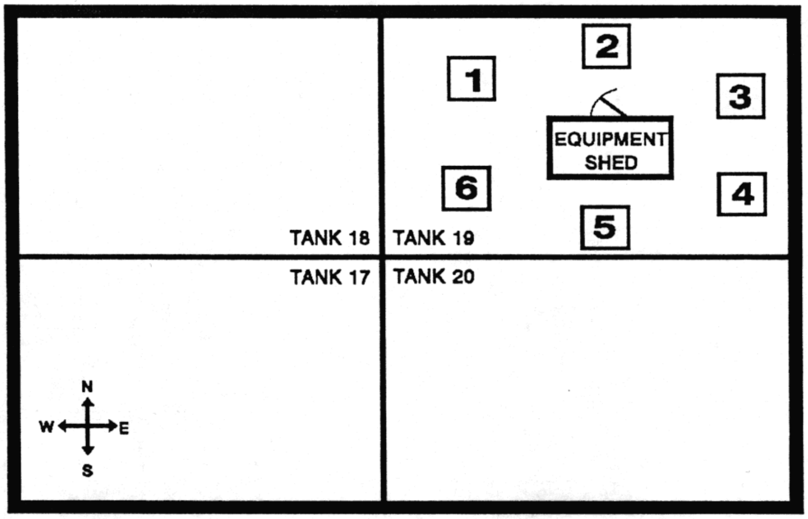

Figure 1. Diagram of the on-farm manure tank compartments and the six access openings in one compartment (7.2 m x 14.7 m x 2.8 m deep) for measuring biogas production from stored dairy manure slurry.

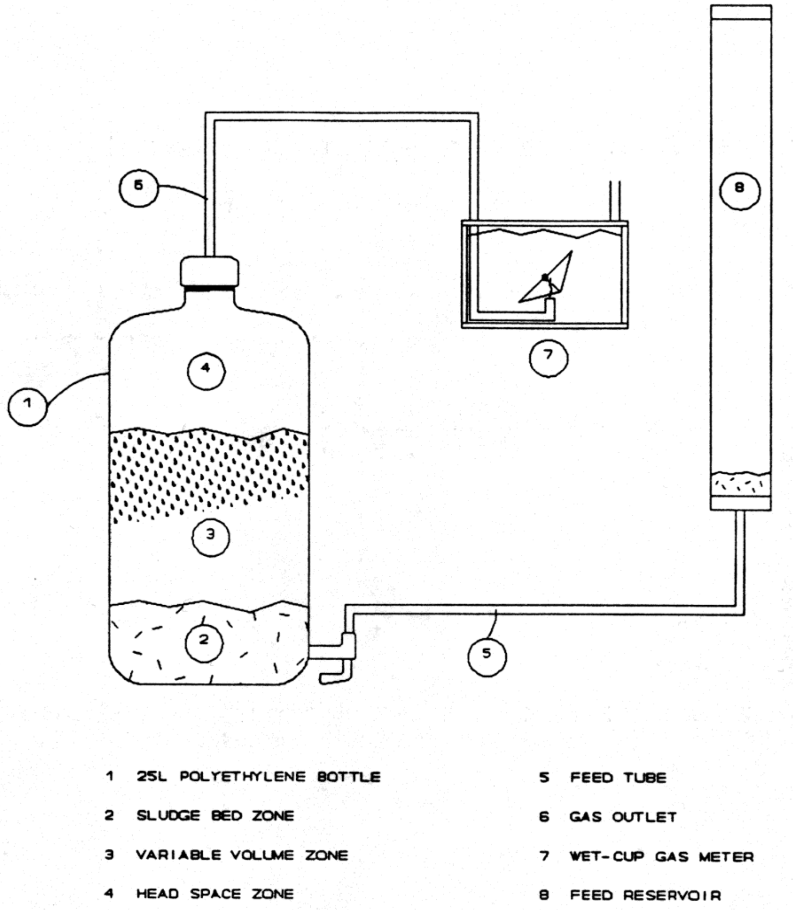

Figure 2 Sketch of 25 litre continuous feed laboratory-scale manure storage.

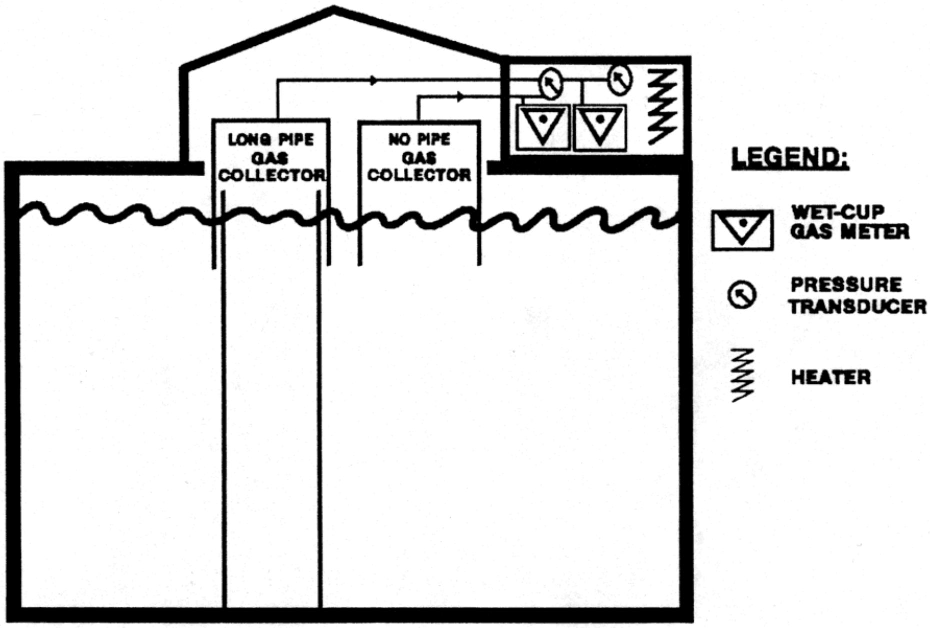

Figure 3. Section through on-farm manure tank opening showing biogas collection system.

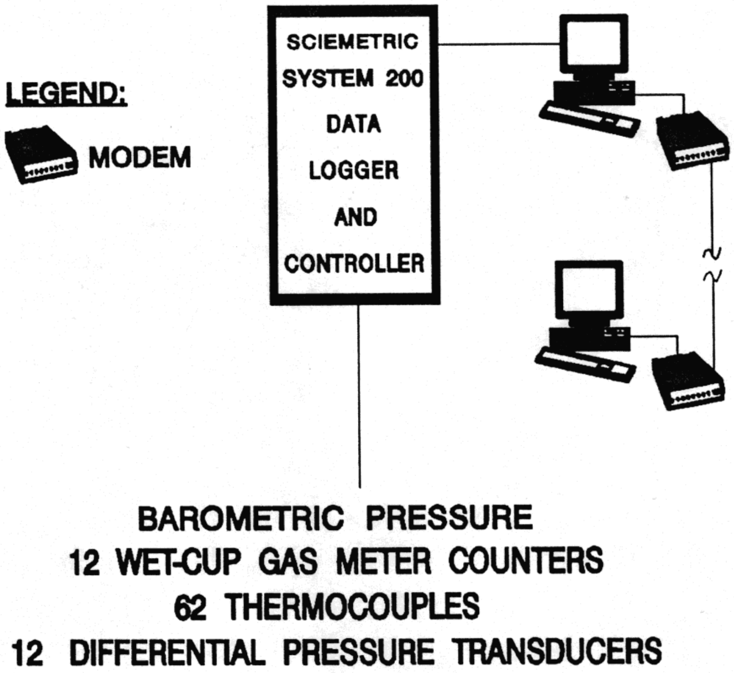

Figure 4 Schematic of the data acquisition system at the on-farm manure tank.

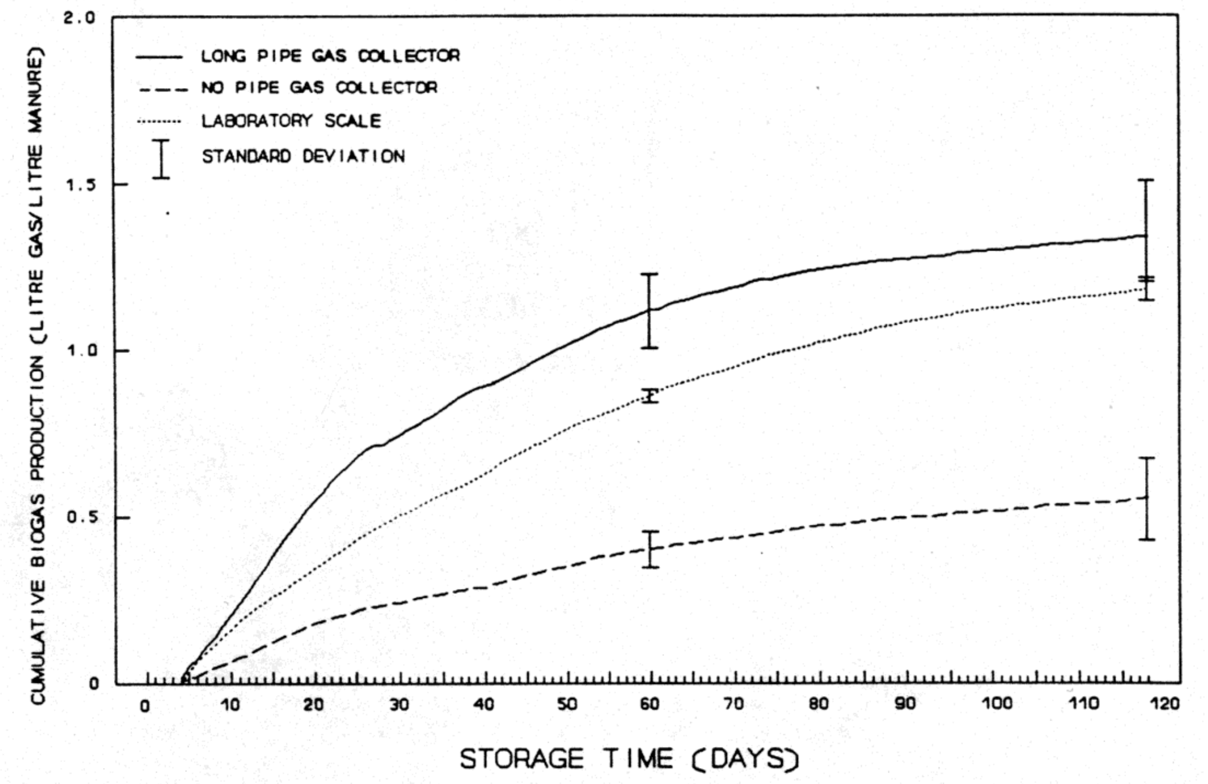

Figure 5 Cumulative biogas production from on-farm and laboratory-scale manure storages.