IEA Bioenergy Task 37

# Assessment of Environmental Impacts from On-farm Manure Digesters

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Natural Resources Canada    Ressources naturelles Canada

# Benefits of Anaerobic Digestion

1. Production of renewable energy – electricity and heat.
2. Permits the addition of high strength wastes to manure to increase biogas yields (these wastes are otherwise more difficult to treat alone.
3. Odour reduction.
4. Reduction of pathogens.
5. Reduction of greenhouse gas (GHG) emissions.
6. Improves the immediate fertilizer value of the manure.

# Studies Assessing Environmental Impacts from Anaerobic Digesters

Several studies are being conducted to investigate environmental impacts associated with on-farm manure digesters:

- University of Guelph :

  Characterizing digestate quality and impacts to air, soil and groundwater quality after land application.

- Agriculture and Agri-food Canada (AAFC):

  Measurement of fugitive $CH_4$ and $NH_3$ emissions at the farm.

- Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA):

  Collection of data to develop of a GHG Offset Protocol.

# University of Guelph

## Air, Soil and Groundwater Quality Monitoring of Raw and Digested Manure Land Application Trials

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Claudia Wagner-Riddle, Ph.D.

UNIVERSITÉ de GUELPH
CAMPUS d'ALFRED

# Project Overview

- Anaerobic Digesters:
  - Monitoring of 2 on-farm anaerobic digesters
  - Evaluate use of co-substrates for enhanced biogas production (pilot & full scales)
- Land Application Trials:
  - Land application trials for GHG measurements (AAFC)
  - Land application trials for fate of nutrients and pathogens in soil and water

# Anaerobic Digesters

1. Fepro Farms (dairy operation) – Cobden, Ontario
2. Terryland Farm (dairy operation) – St. Eugene, Ontario

## Monitoring Parameters

| Digester System Performance | Environmental Impacts |
|---|---|
| Biogas production & $CH_4$ concentration | Volatile fatty acids (VFAs) |
| Electricity & heat production | *E.coli* |
| Organic Matter: COD, Volatile Solids | *Salmonella* |
| Nutrients: $NH_4^+$, Organic-N, o-$PO_4^{3-}$, TP | *C.perfringens* |
| pH, IA/TA ratio (FOS/TAC) | Enterococci |

# On-farm Anaerobic Digesters

**Fepro Farm Digester (Cobden, Ontario)**

- Owned by Paul and Fritz Klaesi
- Mesophilic system (40ºC)
- 500 kW generator
- Co-digestion of dairy manure & grease
- Electricity production sold to grid
- Heat production used to heat digester, 2 homes, milking parlour


**Terryland Farm Digester (St. Eugene, Ontario)**

- Owned by George and Linda Heinzle
- Mesophilic system (40ºC)
- 180 kW generator (soon to be 360 kW)
- Co-digestion of dairy manure & grease
- Electricity production sold to grid
- Heat production used to heat digester, home, milking parlour and to dry silage

# Electricity Production

**Example: Terryland Farm Digester, St. Eugene, ON**

| | **Average Biogas*** **($m^3$/day)** | **Average Electricity with 180 kW Generator (kWh/day)** | **Average Biogas Yield ($m^3$/kg $VS_{in}$)** |
|---|---|---|---|
| **Terryland Digester** | 1692 | 3917 | 0.67 |
| **STDEV** | 187 | 362 | 0.19 |

* Average methane content of biogas 62%

- Biogas production when 18% (by volume) of grease residue is added to digester
- Biogas production is over 4 times higher from when only manure was used as feedstock (415 $m^3$/day)
- Waste heat is used on the farm (potential of 730,000 Btu/h)

# Odours

- Odours: ammonia ($NH_3$), volatile fatty acids (VFA), phenolic compounds
- 96 % reduction of VFAs

**Example: Fepro Farm Digester, Cobden, ON**

| | Total VFA Concentrations (mg/L) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Raw Manure | | | | Digested Manure | | | |
| | Acetic Acid | Propionic Acid | Butyric Acid | **TVFA** | Acetic Acid | Propionic Acid | Butyric Acid | **TVFA** |
| **Average** | 4625 | 1521 | 884 | **7030** | 171 | 78 | 1 | **250** |
| **STDEV** | 1184 | 589 | 434 | **2207** | 94 | 22 | 1 | **117** |
| **% Red.** | | | | | 96 | 95 | 99.9 | **96** |

# Pathogens

- 70-95% reduction in pathogens (~ 1-2 logs)

| Pathogens | Geometric Mean Bacteria Concentrations (CFU/100mL) | | | | | |
|---|---|---|---|---|---|---|
| | Klaesi Digester | | | Terryland Digester | | |
| | Raw Manure | Digested Manure | Log Reduction | Raw Manure | Digested Manure | Log Reduction |
| *E.coli* | 6.00 E+07 | 2.90 E+05 | **2.32** | 1.21 E+07 | 3.03 E+05 | **1.60** |
| Log STDEV | 1.08 | 0.73 | | 0.58 | 0.66 | |
| *Salmonella* | 6.51 E+04 | 8.84 E+03 | **0.87** | 1.27 E+05 | 3.48 E+04 | **0.56** |
| Log STDEV | 1.02 | 0.94 | | 0.79 | 0.52 | |
| *C.perfringens* | 3.81 E+06 | 2.99 E+05 | **1.11** | 2.20 E+06 | 2.55 E+05 | **0.94** |
| Log STDEV | 0.48 | 0. 55 | | 0.49 | 0.25 | |
| **Enterococci** | 9.11 E+06 | 7.29 E+05 | **1.10** | 4.86 E+06 | 3.19 E+05 | **1.18** |
| Log STDEV | 0.51 | 0.60 | | 0.61 | 0.78 | |

*E.coli* in raw manure sample

*E.coli* in digested manure sample

# Land Application Trials

- University of Guelph at Alfred – Monitoring of soil and water after land application of raw manure, digested manure and inorganic fertilizer.

- **Monitoring Parameters**

| **Groundwater and Soil Samples** | **Air Measurements** |
|---|---|
| Nutrients : $NH_4^+$, $NO_3^-$, o-$PO_4^{3-}$, TP, Organic-N | $NH_3$ & $N_2O$ |
| *E.coli* | **Plant Samples** |
| *Salmonella* | Nutrients: Yield, Total-N, Total-P |
| *C.perfringens* | |
| Enterococci | |

# Characteristics of Digested Manure

- 70% reduction in volatile solids (VS)
- 61% reduction in chemical oxygen demand (COD)
- 29% increase in ammonium-nitrogen ($NH_4^+$ -N)

**Example: Terryland Farm Digester, St. Eugene, ON**

| Parameters | Raw Manure | Grease | Digested Manure |
|---|---|---|---|
| % Dry Matter | 11.3 | 23.3 | 5.7 |
| Total Solids (g/L) | 113 | 233 | 57 |
| Volatile Solids (g/L) | 94 | 219 | 37 |
| Chemical Oxygen Demand (g/L) | 65 | 135 | 31 |
| Total Nitrogen (g/L) | 3.45 | 0.19 | 3.58* |
| Total Ammonium (g/L) | 1.73 | 0.17 | 2.23* |
| Total Phosphorus (g/L) | 0.71 | 0.10 | 0.61* |

* Corrected for the dilution effects from addition of grease

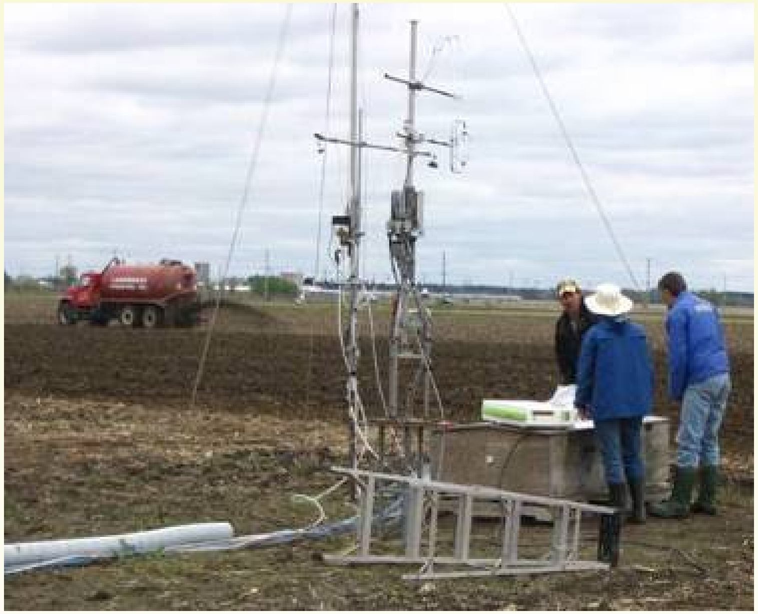
# Corn Yields

| Application Rate (kg N/ha) | Corn Yield (bu/ac) * | | |
|---|---|---|---|
| | Raw Manure | Digested Manure | Increase in Yield |
| 2007 – 120 kg N/ha | 128 | 196 | 53% |
| 2009 – 140 kg N/ha | 84 | 105 | 25% |

* Corn yields are standardized to 15.5% moisture and 56 lbs per bushel

# Land Application Trials Raw & Digested Manure

- Study conducted by Dr. Pattey (AAFC)
- Spray broadcast and incorporated within 24 hours (~ 70 kg N/ha)
- Higher ammonia emissions from digested manure (up to 2 times higher)
- Ammonia peaks within first day after application and reaches background just after incorporation
- $N_2O$ slightly higher in digested manure for fall application



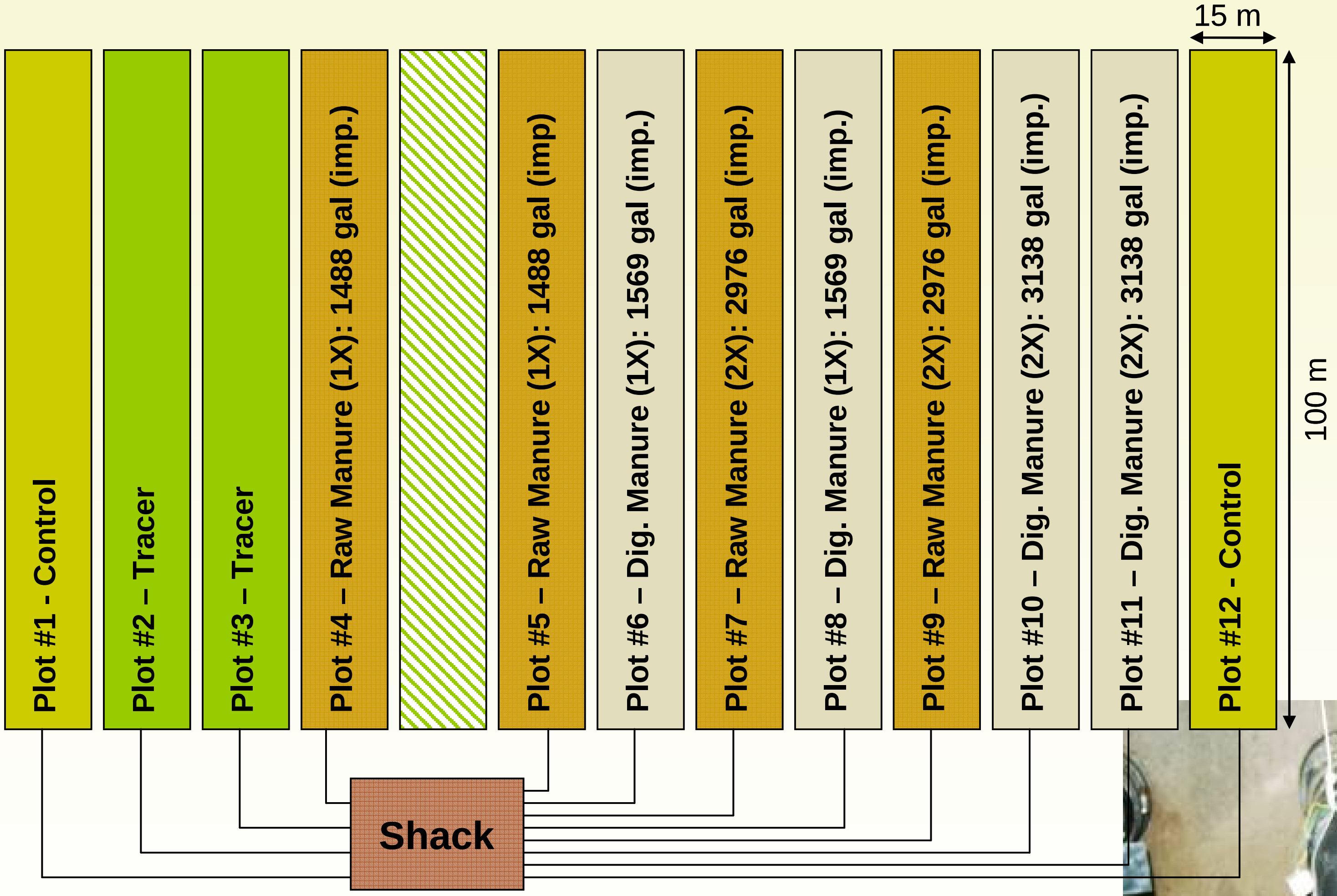
| | **Raw Manure Application (Fall)** | **Digested Manure Application (Fall)** | **Raw Manure Application (Spring)** | **Digested Manure Application (Spring)** |
|---|---|---|---|---|
| Cumulative $N_2O$ Emissions (kg $N_2O$-N/ha) | 1.5 | 2.4 | 1.50 | 1.55 |
| **$N_2O$ Emission Factor (kg $N_2O$ per kg Inorganic-N applied)** | **0.027** | **0.031** | **0.025** | **0.021** |

**Source:** Dr. Elizabeth Pattey (AAFC – Ottawa)

# Plot Trials at Alfred Campus

- Clay soil plots with surface and subsurface drains
- Twelve 0.15 ha plots (15 m x 100 m)
- Plots hydraulically isolated with liner between plots to a depth of 2 m
- Surface drains at 15 cm depth and subsurface drains at 1 m depth
- 3 m wells around plot perimeter
- Application of raw and digested manure in both spring and fall (spray broadcast and incorporated within 24 hrs)
- Low N loading: 120 kg N/ha
- High N loading: 240 kg N/ha
- Crop rotation barley/corn/corn

# Alfred Plots – Layout of Clay Soil Plots




Both surface and subsurface water drainage are collected

# Alfred Field Station

- All 24 drains run into basement of cabin
- Flow measured using tipping buckets (datalogged)
- Flow proportional composite samples are taken (tipping buckets control sampling pumps)

# Nitrates in Subsurface Drains

| Land Application Trials | Flow-weighted Mean $NO_3$-N Concentrations (mg/L) 60-day Period After Land Application | |
|---|---|---|
| | Subsurface Drains | Subsurface Drains |
| **Spring 2008** | **1x Agronomic Rate (75 kg N/ha)** | |
| **Raw Manure** | 7.3 | |
| **Digested Manure** | 9.5 | |
| **Fall 2008** | **1x Agronomic Rate (75 kg N/ha)** | |
| **Raw Manure** | 4.2 | |
| **Digested Manure** | 3.9 | |
| **Spring 2009** | **1x Agronomic Rate (140 kg N/ha)** | **2x Agronomic Rate (280 kg N/ha)** |
| **Raw Manure** | 9.3 | 14.8 |
| **Digested Manure** | 13.1 | 16.9 |

- Nitrate concentrations in control plots range from 1.9 to 3.7 mg/L
- Peak nitrate concentrations in subsurface drains observed 30 days after manure application:

  * 9.6 mg/L (140 kg N/ha) & 15.5 mg/L (280 kg N/ha) in plots with raw manure

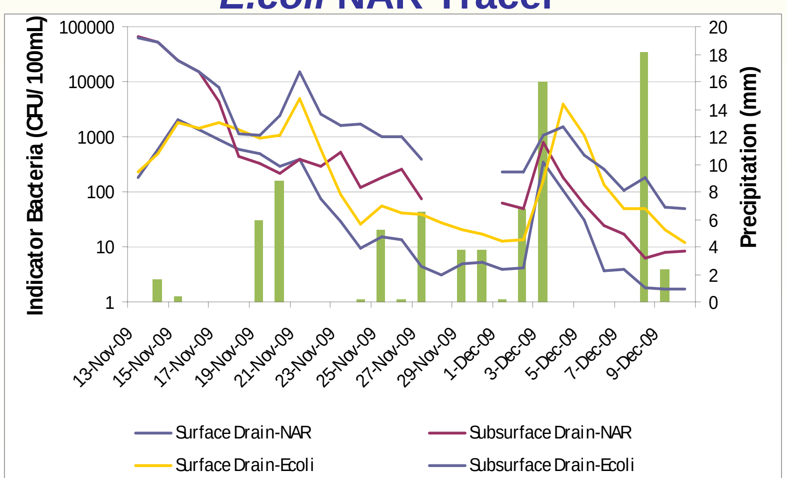
  * 17.5 mg/L (140 kg N/ha) & 28.4 mg/L (280 mg/L) in plots with digested manure

# Bacteria in Subsurface Drains

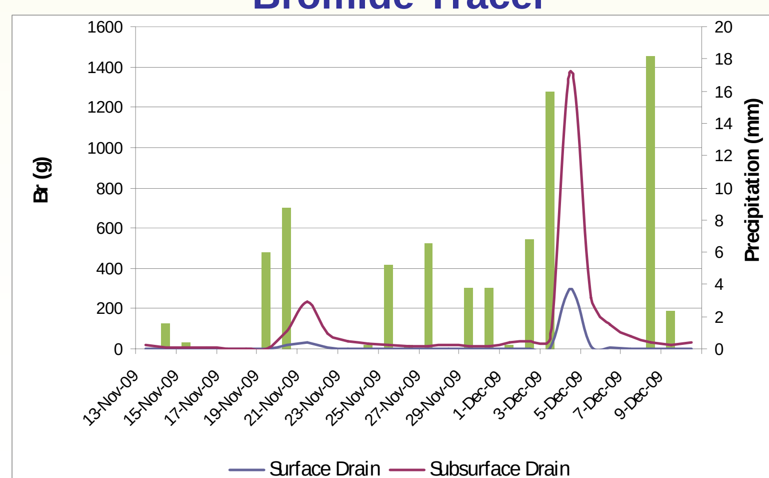
## Geometric Log Mean of Pathogen Indicator Numbers in Subsurface Drains (log CFU/100 mL)

| | *E.coli* | *Salmonella* | *E.coli* | *Salmonella* |
|---|---|---|---|---|
| **2008** | **1x Agronomic Rate (75 kg N/ha)** | | | |
| **Raw Manure** | 1.8 ± 0.9 | 0.8 ± 0.8 | | |
| **Digested Manure** | 1.7 ± 0.7 | 0.9± 0.7 | | |
| **Control (no treatment)** | 1.8 ± 0.5 | 0.7 ± 0.4 | | |
| **2009** | **1x Agronomic Rate (140 kg N/ha)** | | **2x Agronomic Rate (280 kg N/ha)** | |
| **Raw Manure** | 2.8 ± 0.9 | 2.1 ± 0.9 | 3.1 ± 0.5 | 2.3 ± 0.8 |
| **Digested Manure** | 2.6 ± 0.* | 2.0 ± 0.8 | 3.0 ± 0.3 | 2.0 ± 0.8 |
| **Control (no treatment)** | 1.6 ± 0.7 | 1.2 ± 0.6 | --- | --- |

### *E.coli* NAR Tracer




### Bromide Tracer



# Research Study Outcomes

- Life Cycle Analysis (LCA) for the on-farm manure anaerobic digester technology (as part of a larger study lead by Dr. Wagner-Riddle).
- Recommendations for land application of digested manure that minimize nutrients & pathogens to surface and subsurface waters under varying agronomic conditions.
- Recommendations for mitigating GHG emissions from the land application of digested manure.

# Agriculture and Agri-food Canada (AAFC)

Measurement of Fugitive $CH_4$ Emissions from Digestion System and $NH_3$ Emissions following Land Application of Digested Manure

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**Researcher:** Ray Desjardins, Ph.D.

Agriculture and Agri-Food Canada
Agriculture et Agroalimentaire Canada

# Project Overview

- Anaerobic Digesters:
  - Quantify $CH_4$ fugitive emissions from the whole biodigestion system
- Land Application Trials:
  - Measurements of $NH_3$ emissions following land application of digested manure

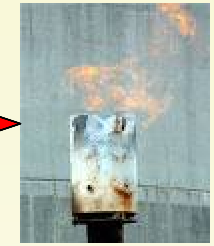
# On-farm Anaerobic Digester

- Integrated Manure Utilization System (IMUS) Biogas Plant
- Thermophilic system (55$^{o}$C)
- 1 MW generating capacity
- Feedlot of 36,000 head of cattle
- 100 tonnes of manure consumed daily (20% of feedlot manure)
- Electricity sold to grid and heat used on-site
- Solid/liquid separation of digestate:  liquid to storage lagoon and solid used as fertilizer

# The Integrated Manure Utilization System

Manure Mixing Hopper

Anaerobic Digesters



Flare (only when needed)

Liquid for recycling

Solid/liquid Separation

Biogas collection

Heat and Electricity Generation

Bio-fertilizer for market

There are multiple opportunities for fugitive (unintended) methane emissions throughout the biogas production and consumption process.

# Quantifying Fugitive $CH_4$ Emissions from Digesters

- Anaerobic digesters reduce GHG emissions & generate clean energy.
- GHG reductions depend on many factors (design, feedstock, etc.), including quantity of fugitive $CH_4$ emissions.
- Minimizing fugitive emissions can maximize energy production, while minimizing environmental impacts.

- Quantifying fugitive $CH_4$ emissions is difficult – commonly assumed:
  - 15% of total $CH_4$ production (California Climate Action Registry)
  - 15% of production (Clean Development Mechanism (CDM), 2005)
  - 10% of production (Intergovernmental Panel on Climate Change (IPCC), 2006)
  - 5% of production (US Environmental Protection Agency (USEPA) – for covered anaerobic lagoons)

# Observations

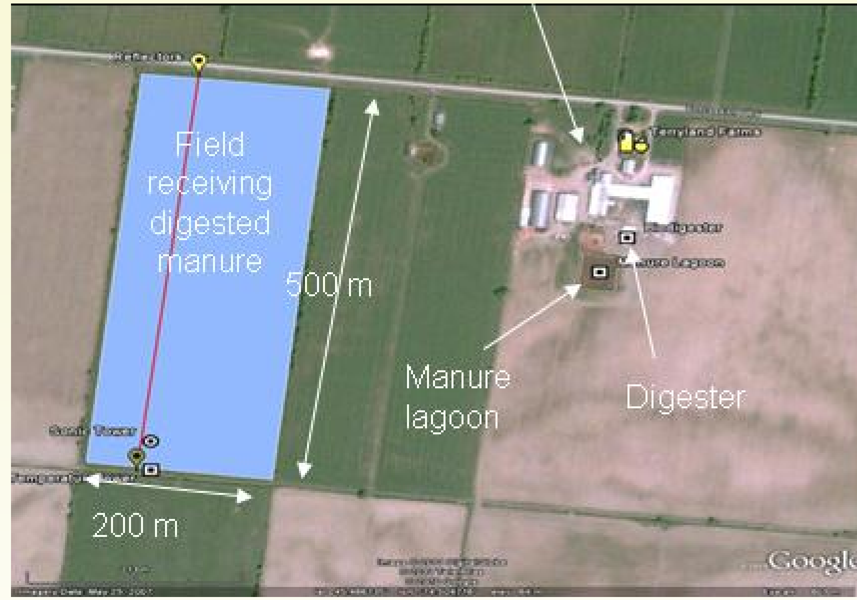
**Flare not efficient at burning-off methane in biogas:**

- Flare used when gas cannot be used for electricity generation.
- Enhanced $CH_4$ emissions during flaring is evidence of inefficiency.
- Estimates of flare burning efficiencies are as low as 50%.

**Manure hopper significant source of fugitive methane:**

- Manure enters biogas plant at hopper, where warm water is mixed with the manure & is open to atmosphere.
- Suggests reduction in emissions when hopper is redesigned with better seal (negative pressure).

# Quantifying $NH_3$ Emissions from Land Application of Digested Dairy Manure

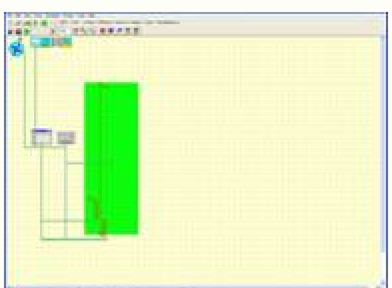

- Increased concentration of $NH_4^+$-N in digested manure can lead to increased $NH_3$ emissions during land application
- Land application trials using digested dairy manure are conducted at Terryland Farms
- Digested manure is spray broadcast in 8m wide bands and incorporated within 24 hours
- Digested manure is applied at 1x agronomic rate for nitrogen

# Methodology for $NH_3$ Emission Measurements from Land Application Trials

Digested dairy manure is applied to an alfalfa field using a 12,000 L tanker

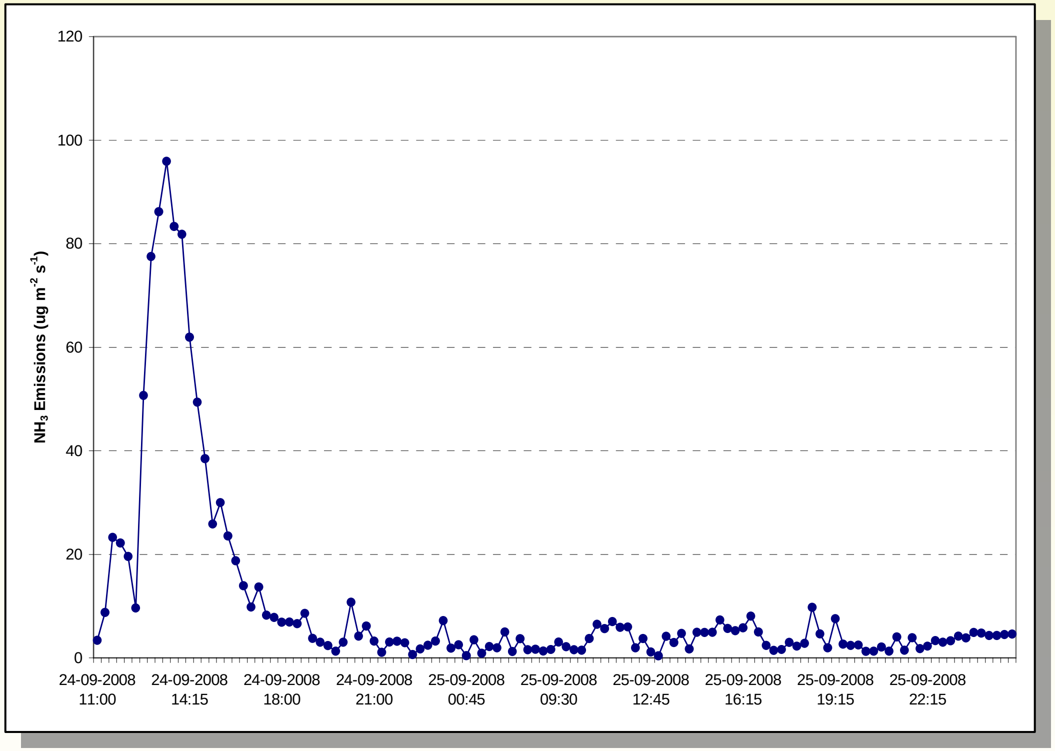
Ammonia concentration in air downwind of applied digested manure is measured continuously using open path lasers

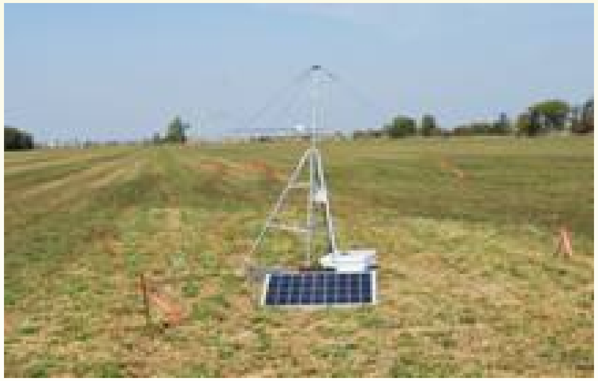
Wind direction and atmospheric stability is simultaneously monitored



Measured ammonia concentrations and wind statistics are incorporated into a backwards lagrangian stochastic modeling technique to estimate the rate of ammonia emissions

# Preliminary Results



- Ammonia emissions begin immediately after application and peak about 3 hours after land application was started
- $NH_3$ emissions continue for 36 hours later at very low rates

# Research Study Outcomes

- Quantify $CH_4$ and $NH_3$ emissions from farms with biodigesters.
- Recommendations to improve on-farm management of raw and digested manure that minimize methane emissions.
- Improve efficiency of $CH_4$ flaring.
- Recommendations for land application of digested manure that minimize ammonia emissions.