California Air Resources Board
Chair's Air Pollution Seminar Series
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# Non-Enteric ROG Emissions from Dairies in the San Joaquin Valley


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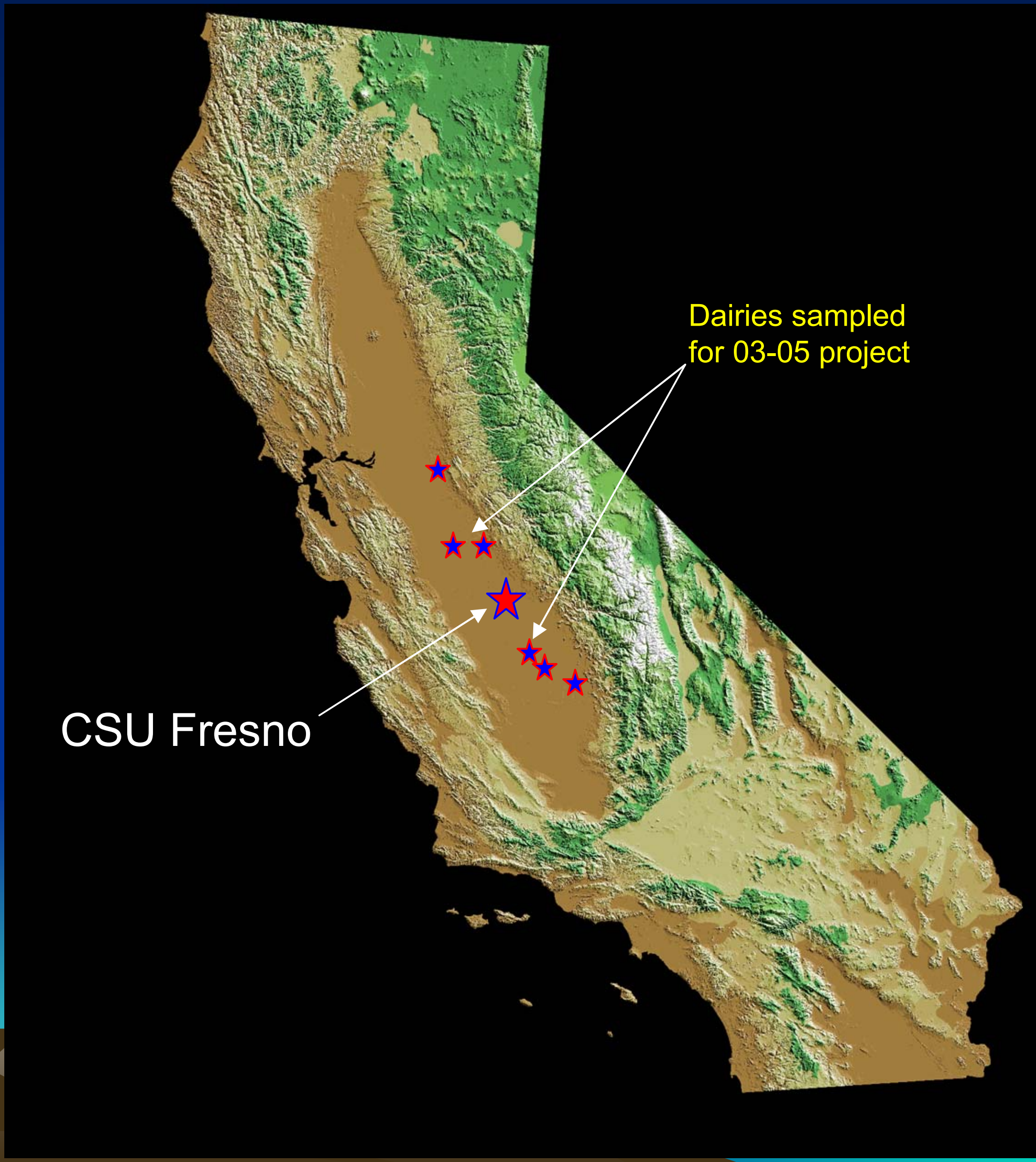
Original Grant Title: Dairy Operations - An Evaluation and Comparison of Baseline and Potential Mitigation Practices for Emissions Reductions In the San Joaquin Valley


Primary Funding: California Air Resources Board

- Funded by the CA Air Resources Board, 4/06 - 6/09 to CSU Fresno with a sub-contract to UC Irvine.
  - Select five dairies with different manure handling systems because the primary source of ROG was assumed to be lagoons and flush-lanes.
  - Year-1: Develop a preliminary sampling plan, determine the significant ozone reactive VOC's (ROG) and the appropriate methods to monitor them.
  - Year-2: Develop a monitoring program to be used at each dairy for three sampling periods (fall, winter, early summer)
  - Compare emissions from the various practices at the different dairies to identify those that may reduce emissions of significant ROG's
- Additional funding from CSU-ARI, UNH, and USDA were added to extend the scope and duration of the study. These additions have augmented the monitoring program to include various N compounds, alcohols, photosynthetic lagoons, land applications, and GHG's.

## CSU-Fresno Dairy Air Quality Projects in the Central Valley of California

- An initial study was done at two dairies from 2003-05. Upwind and downwind canister samples were collected and used to calculate an emission rate using dispersion modeling.
- That preliminary study was augmented in 2005 by ARB to include cooperation with UC Irvine for speciation of VOC's and to identify the dominant ROG's from specific operations.
- This current study focuses on the relative ROG fluxes from various operations at six dairies as well as ammonia, other N compounds, and correlation with surface materials.



Dairy A.  A 2000 cow dairy in Kings County.  The dairy utilizes “free stall” management where the cows are fed on gently sloping concrete that is flushed with a large flow of water several times a day to remove the waste.  Solids in the flush water are separated from the liquid which is stored in a series of lagoons for subsequent flushing of the free stalls and eventually is part of the irrigation water for the surrounding cropland.

The dairy is surrounded by sorghum and alfalfa fields that are used to recycle nutrients from the dairy waste and to produce forage for the dairy herd.

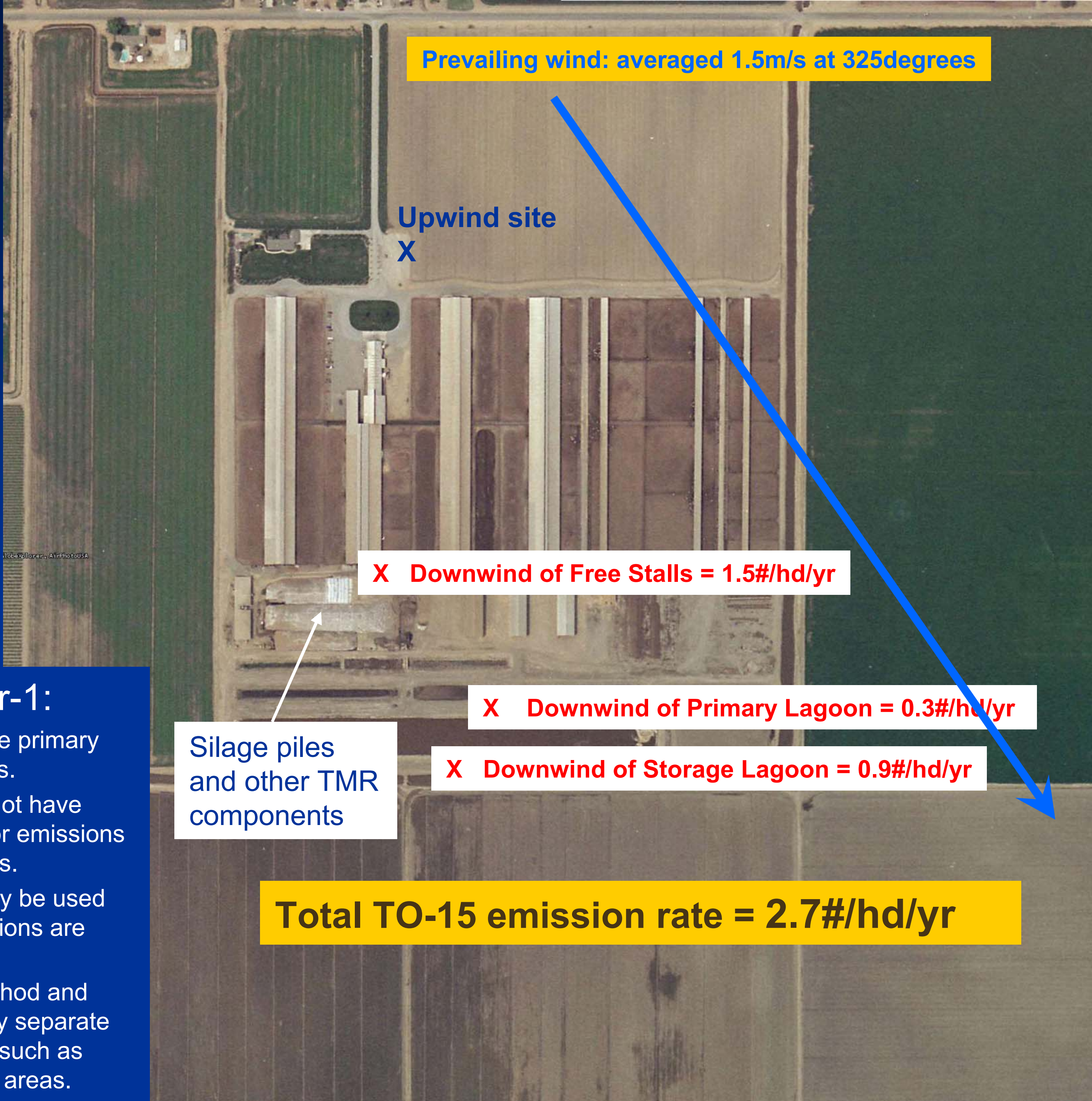
Up Wind Fenceline site (DW1). Looking SE, downwind.

# Dairy A

July 22, 2004

1330 to 1600

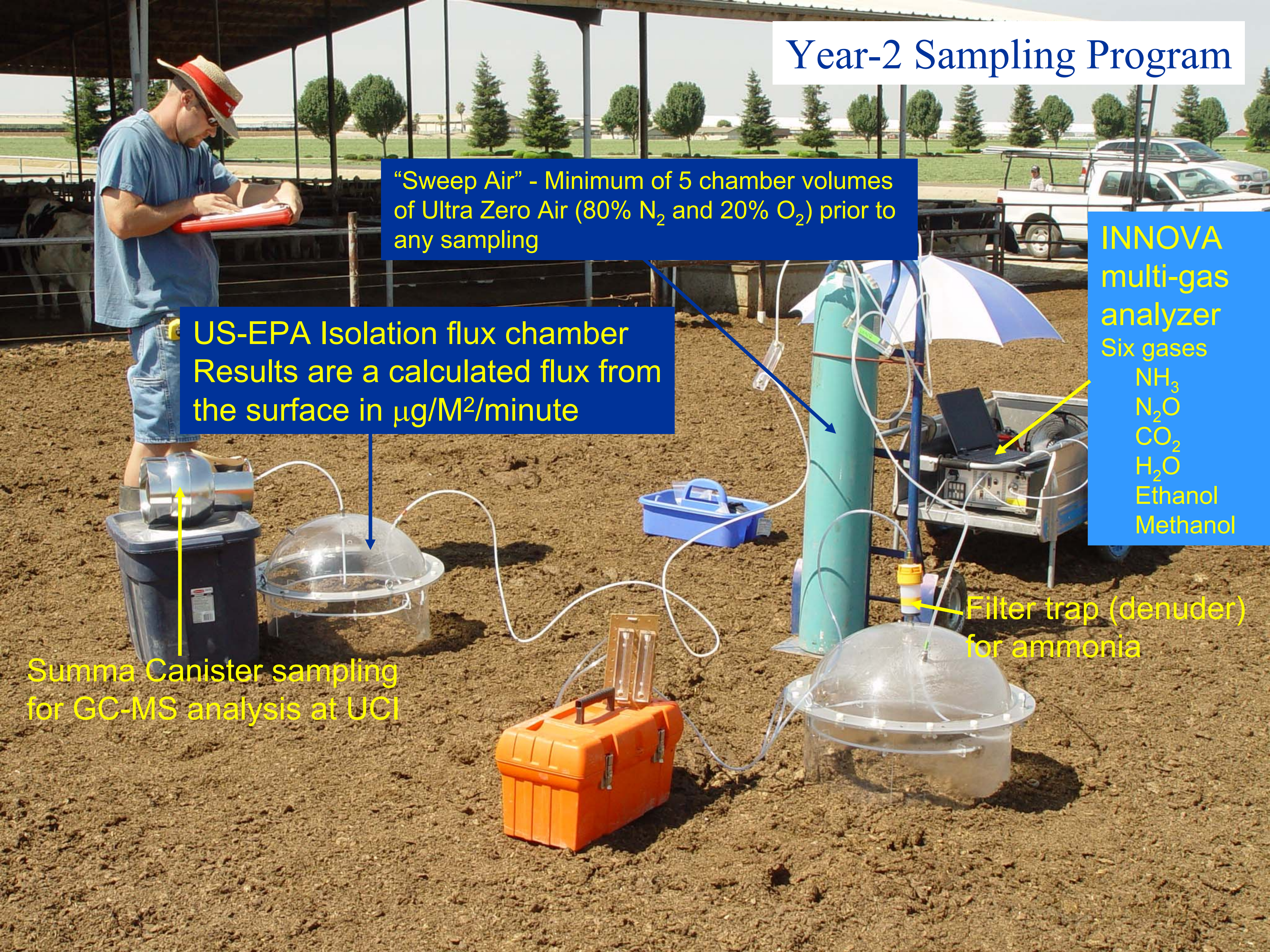
Summer wind direction (325) and speed (1.5m/s) were typical for this location. Wind speed in the early afternoon was less than at other locations but the direction was sufficiently consistent for modeling.




## Conclusions from Year-1:

1. Lagoons are probably not the primary source of ROG's from dairies.
2. The sampling method may not have sufficient precision to monitor emissions from specific dairy operations.
3. Dispersion modeling can only be used when the proper wind conditions are obtained.
4. This sampling/analytical method and dispersion modeling can only separate large scale dairy operations such as lagoons and animal housing areas.

# Year-2 Sampling Program

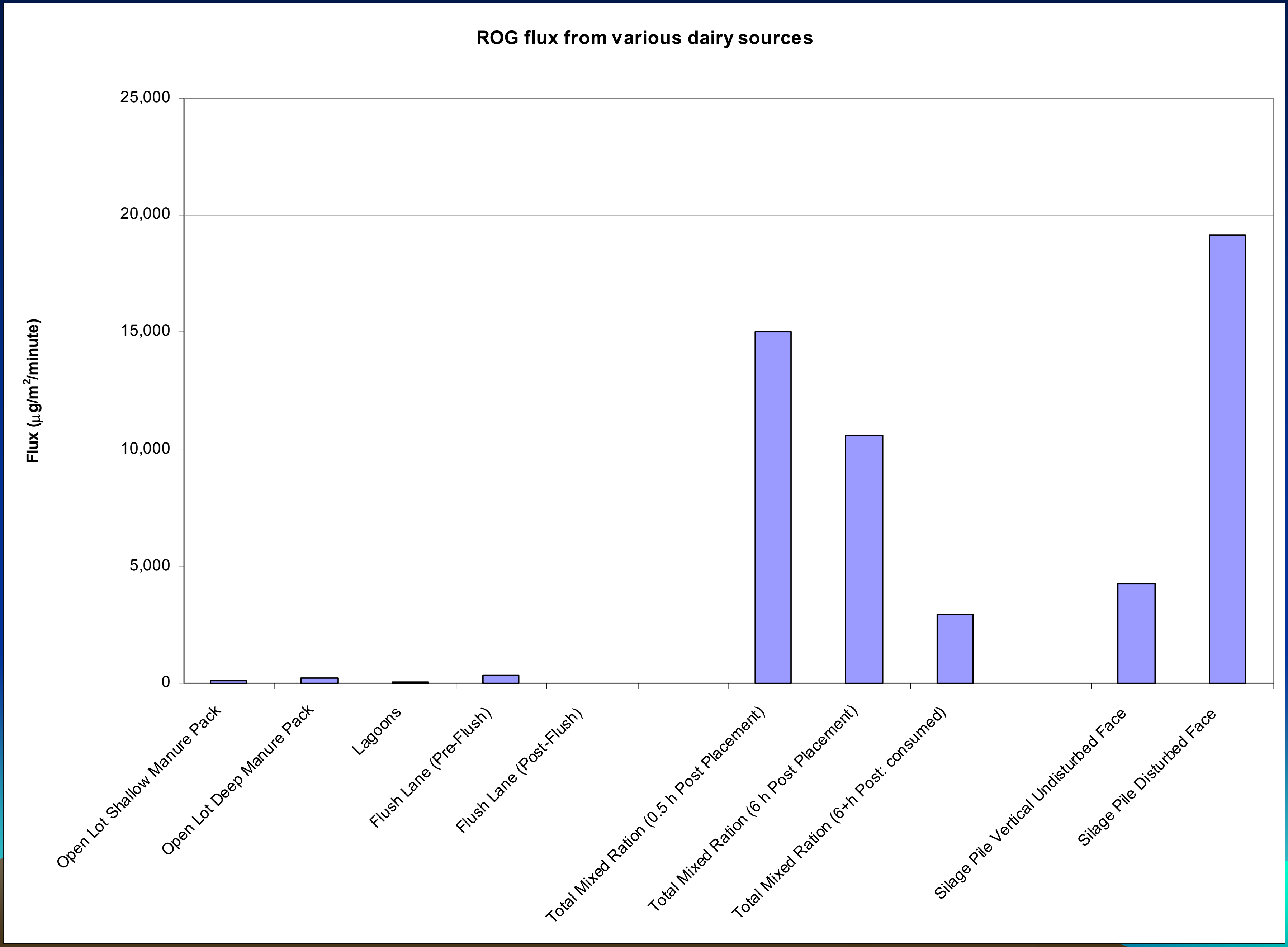


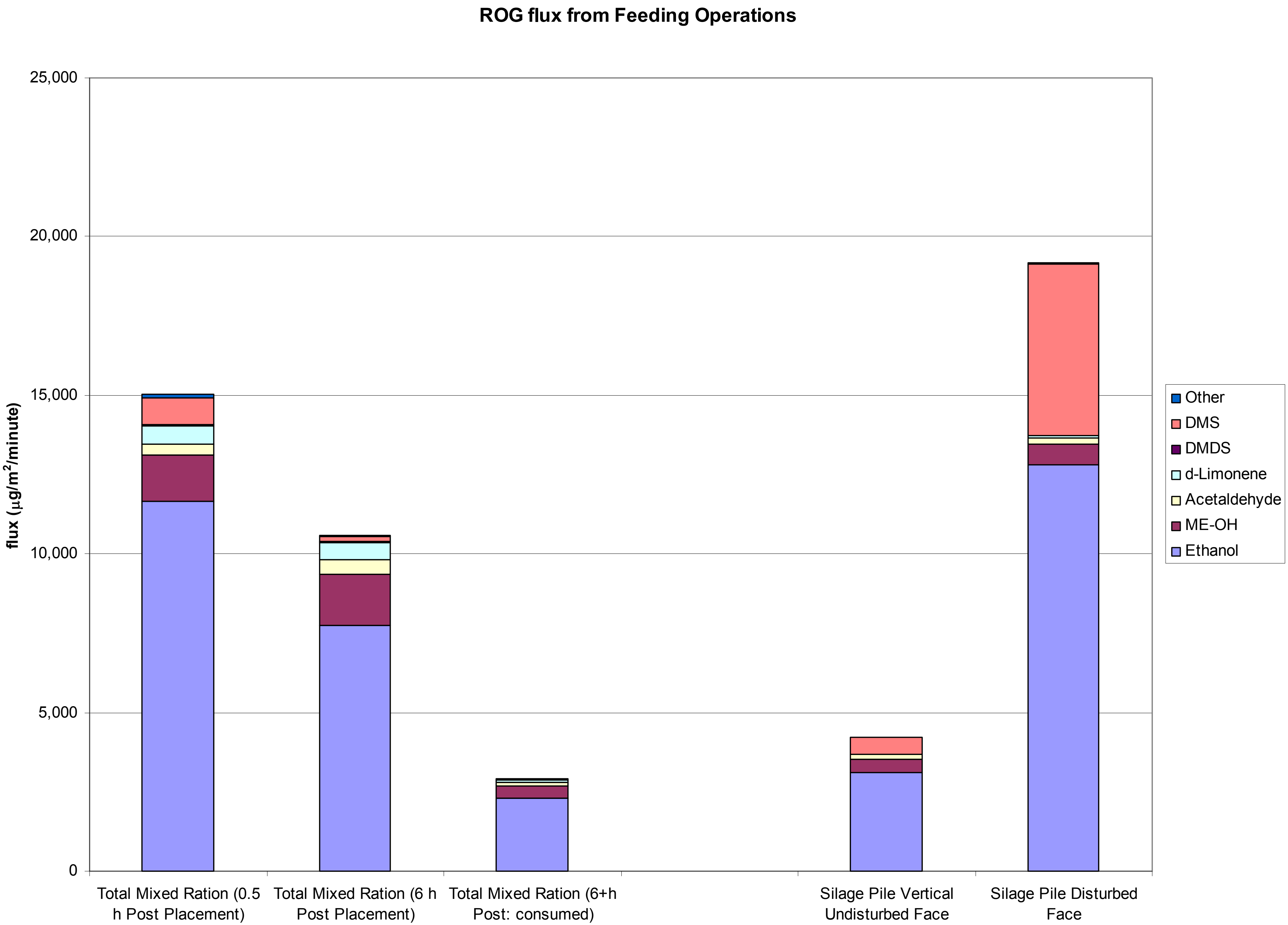
Fluxes from the silage pile face compared to disturbed silage at Dairy A

Flux Chamber monitoring of flush lane at Dairy B

Sampling ethanol, methanol, ammonia, $N_2O$ and ROG's from Total Mixed Ration (TMR) using flux chambers at Dairy A.

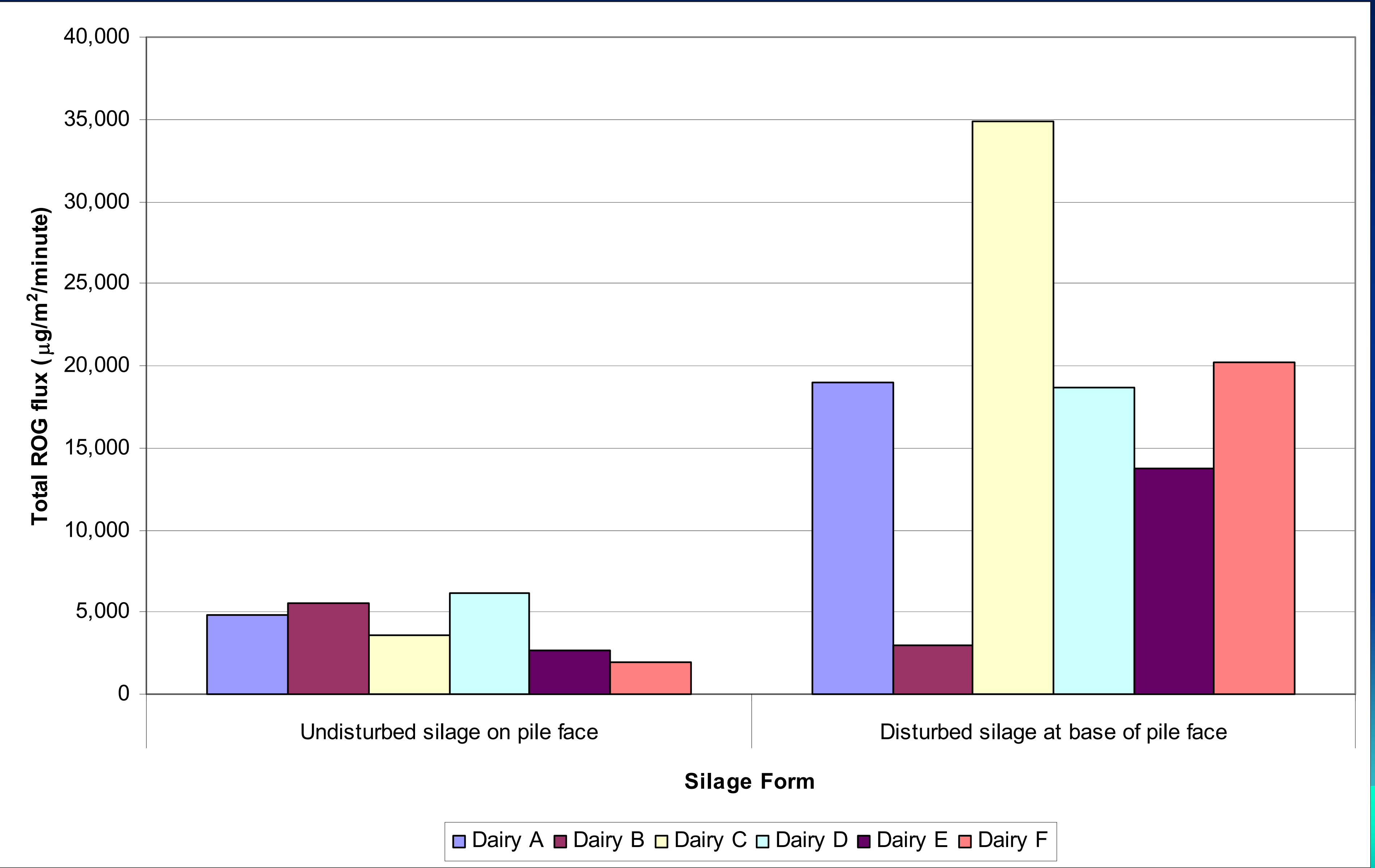
# ROG fluxes ($\mu g/m^2$/minute) from various sources at six valley dairies in 2007-08




ROG flux from Feeding Operations
flux (µg/m²/minute)
25,000
20,000
15,000
10,000
5,000
0
Total Mixed Ration (0.5 h Post Placement)
Total Mixed Ration (6 h Post Placement)
Total Mixed Ration (6+h Post: consumed)
Silage Pile Vertical Undisturbed Face
Silage Pile Disturbed Face
Other
DMS
DMDS
d-Limonene
Acetaldehyde
ME-OH
Ethanol

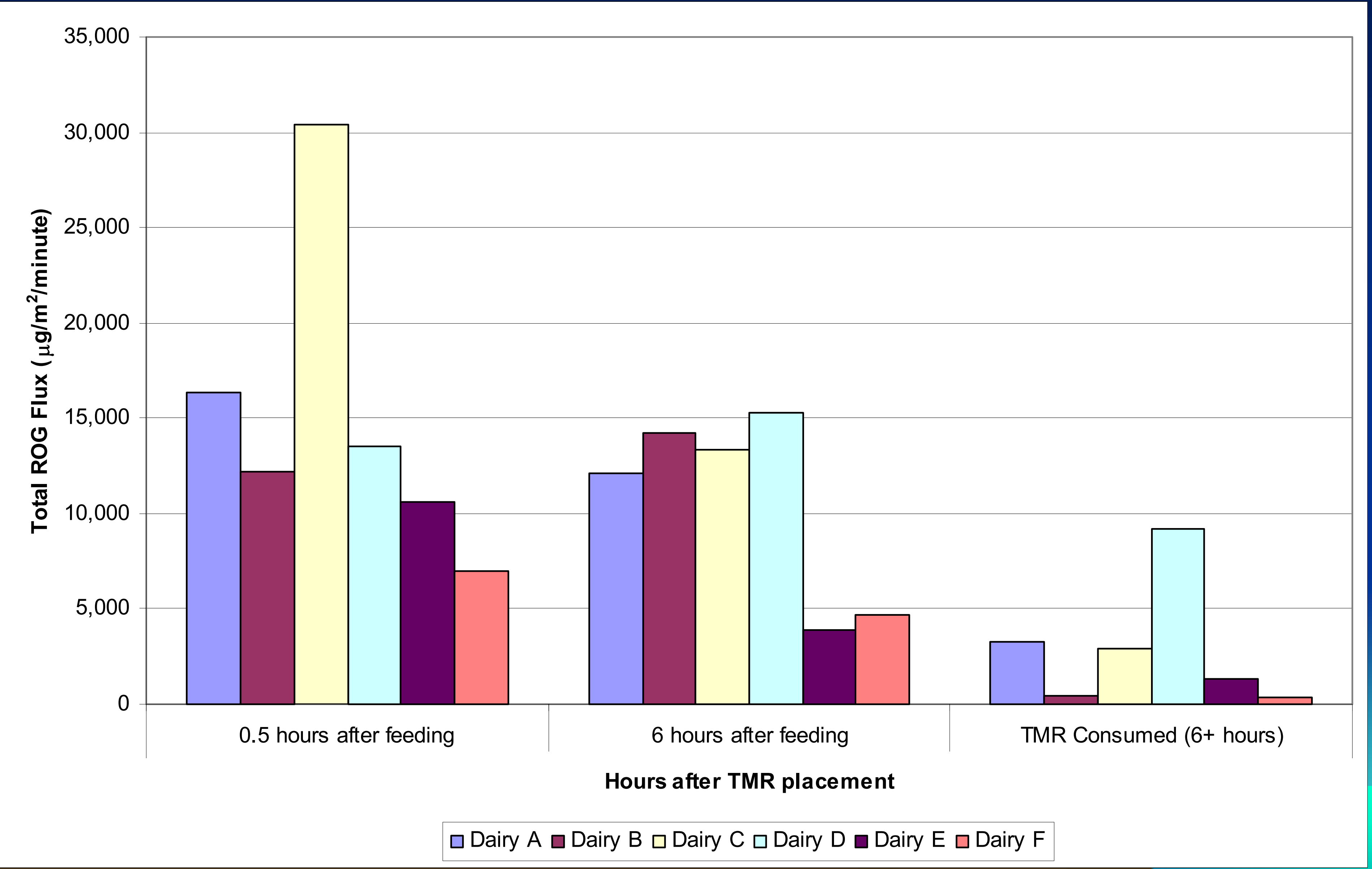
# Silage fluxes for each sampled dairy

**(Each value is an average of 3 to 5 samples over a period of a year)**



# TMR fluxes for each sampled dairy over the feeding cycle

## (Each value is an average of 3 to 5 samples over a period of a year)



# ROG fluxes from various manure handling practices (Note low flux values compared to feed)

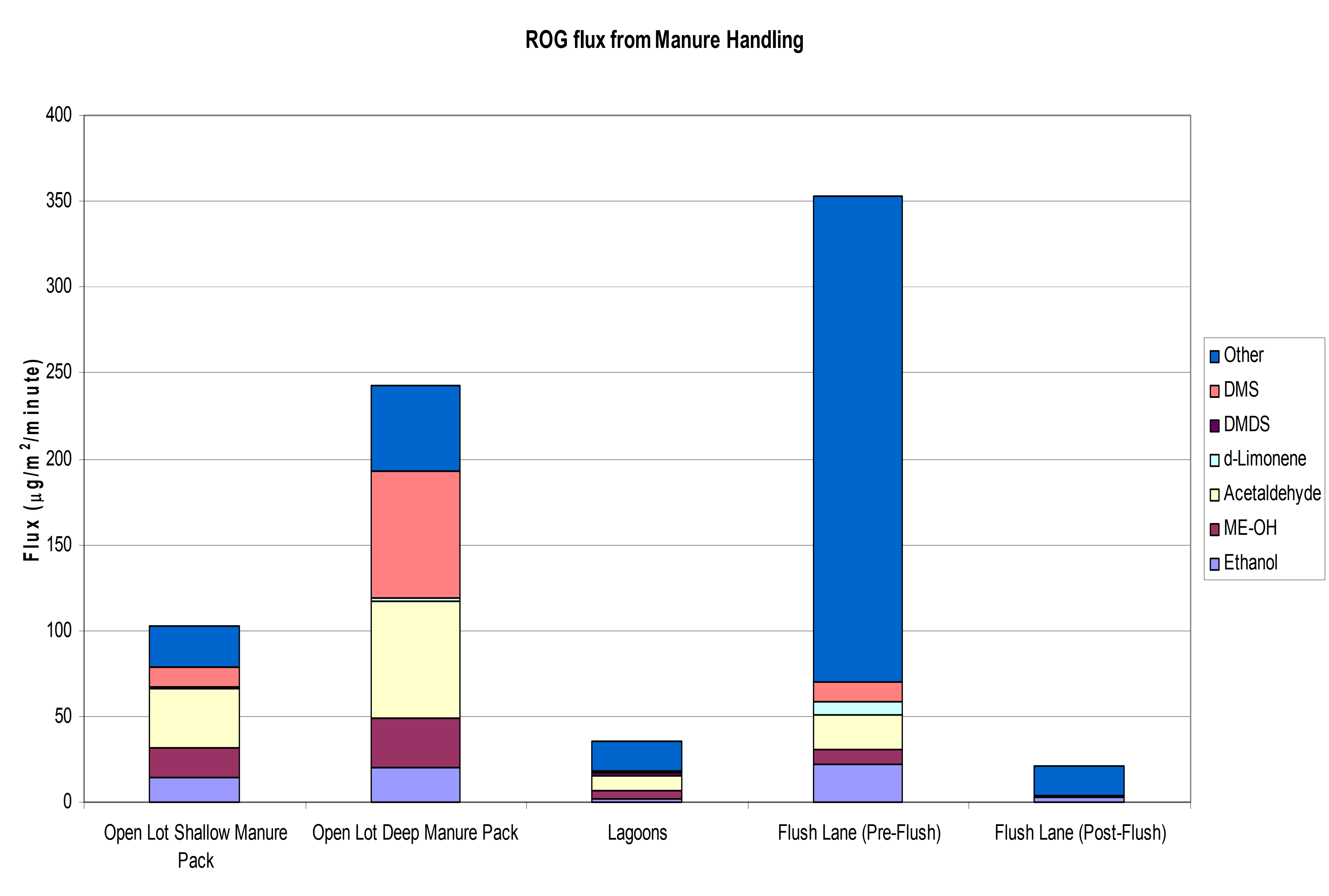


**Table 10.** Average flux rates for all dairies, all dates and each dairy operation included in the regular sampling program for Year-2. The 6 major components of ROG are reported here. The UC Irvine analysis included ROG components from a list of 64 gasses identified in the analytical procedure. Values are in μg/m$^2$/minute and are corrected by the subtraction of Field Blank values.

**Flux Rate in μg/m$^2$/minute**

| | **Total ROG** | Ethanol | Ethanol | Metanol | Metanol | **Total Alcohols** | **Total Alcohols** | Acetaldehyde | Acetaldehyde | d-Limonene | d-Limonene | DMDS | DMDS | DMS | DMS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Open Lot Shallow Manure Pack | 102 | 15 | 22% | 17 | 24% | 45 | 56% | 35 | 19% | 1 | 1% | 0 | 0% | 12 | 10% |
| Open Lot Deep Manure Pack | 243 | 20 | 22% | 28 | 25% | 60 | 57% | 69 | 14% | 1 | 1% | 0 | 0% | 74 | 14% |
| Flush Lane (Pre-Flush) | 353 | 22 | 9% | 9 | 8% | 108 | 47% | 20 | 11% | 7 | 6% | 0 | 0% | 12 | 2% |
| Flush Lane (Post-Flush) | 21 | 3 | 34% | 1 | 13% | 6 | 53% | 0 | 2% | 0 | 3% | 0 | 0% | 0 | 1% |
| Total Mixed Ration (0.5 h Post Placement) | 15,022 | 11,668 | 75% | 1,460 | 11% | 13,141 | 86% | 336 | 3% | 584 | 4% | 26 | 0% | 831 | 5% |
| Total Mixed Ration (1.5 h Post Placement) | 4,507 | 3,394 | 78% | 547 | 12% | 3,941 | 90% | 15 | 0% | 459 | 7% | 34 | 2% | 12 | 0% |
| Total Mixed Ration (6 h Post Placement) | 10,582 | 7,747 | 69% | 1,591 | 18% | 9,350 | 87% | 469 | 5% | 557 | 5% | 9 | 0% | 152 | 1% |
| Total Mixed Ration (6+h Post: consumed) | 2,929 | 2,289 | 69% | 389 | 19% | 2,683 | 89% | 106 | 5% | 102 | 4% | 3 | 0% | 32 | 2% |
| Silage Pile Vertical Undisturbed Face | 4,229 | 3,095 | 76% | 416 | 10% | 3,524 | 86% | 164 | 4% | 6 | 0% | 1 | 0% | 532 | 11% |
| Silage Pile Disturbed Face | 19,170 | 12,814 | 75% | 632 | 8% | 13,461 | 84% | 214 | 3% | 49 | 0% | 1 | 0% | 5,413 | 13% |

## Flux values for various sources multiplied by the area represented by those sources at a "composite diary" averaged from the six sites sampled in the study.

Disturbed Silage
Average flux (Table 10) = 19,170 $\mu g/m^2$/minute
Estimated area at the fictitious dairy = 25 $m^2$
Estimated emission = 19,170 $\mu g/m^2$/minute X 25 $m^2$ X 1440 min/day = 0.7 kg/day

Undisturbed Silage
Average flux (Table 10) = 4,229 $\mu g/m^2$/minute
Estimated area at the fictitious dairy = 250 $m^2$
Estimated emission = 4,229 $\mu g/m^2$/minute X 250 $m^2$ X 1440 min/day = 1.5 kg/day

TMR (average of all sample periods)
Average flux (Table 10) = 8,260 $\mu g/m^2$/minute
Estimated area at the fictitious dairy = 1600 $m^2$ (1m wide x 400m long x 4 bunkers)
Estimated emission = 8,260 $\mu g/m^2$/minute X 1600 $m^2$ X 1440 min/day = 19.0 kg/day

Flush lanes (average of pre-flush and post-flush)
Average flux (Table 10) = 187 $\mu g/m^2$/minute
Estimated area at the fictitious dairy = 9600 $m^2$ (3m wide x 400m long x 8 lanes)
Estimated emission = 187 $\mu g/m^2$/minute X 9600 $m^2$ X 1440 min/day = 2.6 kg/day

Open Lots (average of deep and shallow manure pack)
Average flux (Table 10) = 172 $\mu g/m^2$/minute
Estimated area at the fictitious dairy = 32,000 $m^2$ (20m wide x 400m long x 4 lots)
Estimated emission = 172 $\mu g/m^2$/minute X 32,000 $m^2$ X 1440 min/day = 7.9 kg/day

## Emission rates estimated from the fluxes monitored in the study and applied to estimated source sizes at a "composite dairy" averaged from the six sites monitored in 2005-08.

ROG emissions from the fictitious dairy and their relative percentages of the total:

Disturbed Silage…... 0.7 kg/day (2%)
Undisturbed Silage... 1.5 kg/day (5%)
TMR……………….. 19.0 kg/day (60%)
Flush lanes……..….. 2.6 kg/day (8%)
Open Lots……….… 7.9 kg/day (25%)
Total ………………..31.8 kg/day (100%)

The composite dairy milked 2000 cows so conversion of the 31.8 kg/day to the units used for regulation by the local air district gave a value of 12.8 lb./head/yr. Additional monitoring and further data analysis will provide a more accurate range of emission rates for these sources.

# Cautionary Disclaimer

- The EPA Isolation Flux Chamber samples the emissions from the surface it covers by excluding ambient air. Fluxes calculated from this sampling method may be higher than actual surface fluxes of some or all gases sampled because:
  - Equilibrium exchange processes between the surface and the atmosphere are affected by the replacement of the ambient air by sweep air in the chamber.
  - Exchange processes and adsorption by other surfaces at the dairy are not sampled by the flux chamber and so the actual facility emission is likely to be lower than these estimates.

**Consequently, data from this study should be used for comparing relative emissions from different practices and conditions at the dairies rather than determining facility emission rates or factors.**

# Collaborative Projects funded by Additional Support

- USDA-CSREES funding added Ammonia and other N compound monitoring for UNH (Salas and Li) as well as further study of alcohols with UCD (Mitloehner et al).
- Land Application fluxes were monitored for Sustainable Conservation Inc.
- Photosynthetic lagoon fluxes were compared to traditional lagoon systems for the CA Dairy Campaign.
- CSU Agricultural Research Initiative funding matched many of these externally funded projects to extend their terms and expand their scope.

# Fluxes from lightly loaded, photosynthetic lagoons for the CDC

# Summary of Lagoon Emissions

| | Ammonia NH3-N | Nitrous Oxide (NO2-N) | Carbon Dioxide | Methane | Acetic Acid | Ethanol | Methanol | Tri-methylamine | 2-Propanol |
|---|---|---|---|---|---|---|---|---|---|
| Magnussen (6) | 258 | 55 | 9,269 | 84 | 1,120 | U | 58 | 298 | 315 |
| Hilltop Holsteins (6) | 315 | 1 | 61,286 | 18,879 | 1 | 16 | 246 | 992 | 1,066 |
| Verburg (8) | 183 | 7 | 20,489 | 10,806 | 3 | 7 | 186 | 686 | 1,159 |
| Dairy A (8) | 209 | 3 | 88,531 | 45,668 | 31 | U | 366 | 1,518 | 890 |
| Dairy B (4) | 219 | 2 | 65,538 | 30,994 | U | U | 330 | 1,241 | 1,563 |
| Dairy D (8) | 475 | 5 | 46,162 | 15,914 | 12 | U | 418 | 1,212 | 3,856 |
| | | | | | | | | | |
| Photosynthetic Lagoons | 252 | 21 | 30,348 | 9,923 | 375 | 12 | 163 | 659 | 847 |
| Conventional Lagoons | 317 | 3 | 66,985 | 30,831 | 19 | U | 379 | 1,340 | 2,211 |

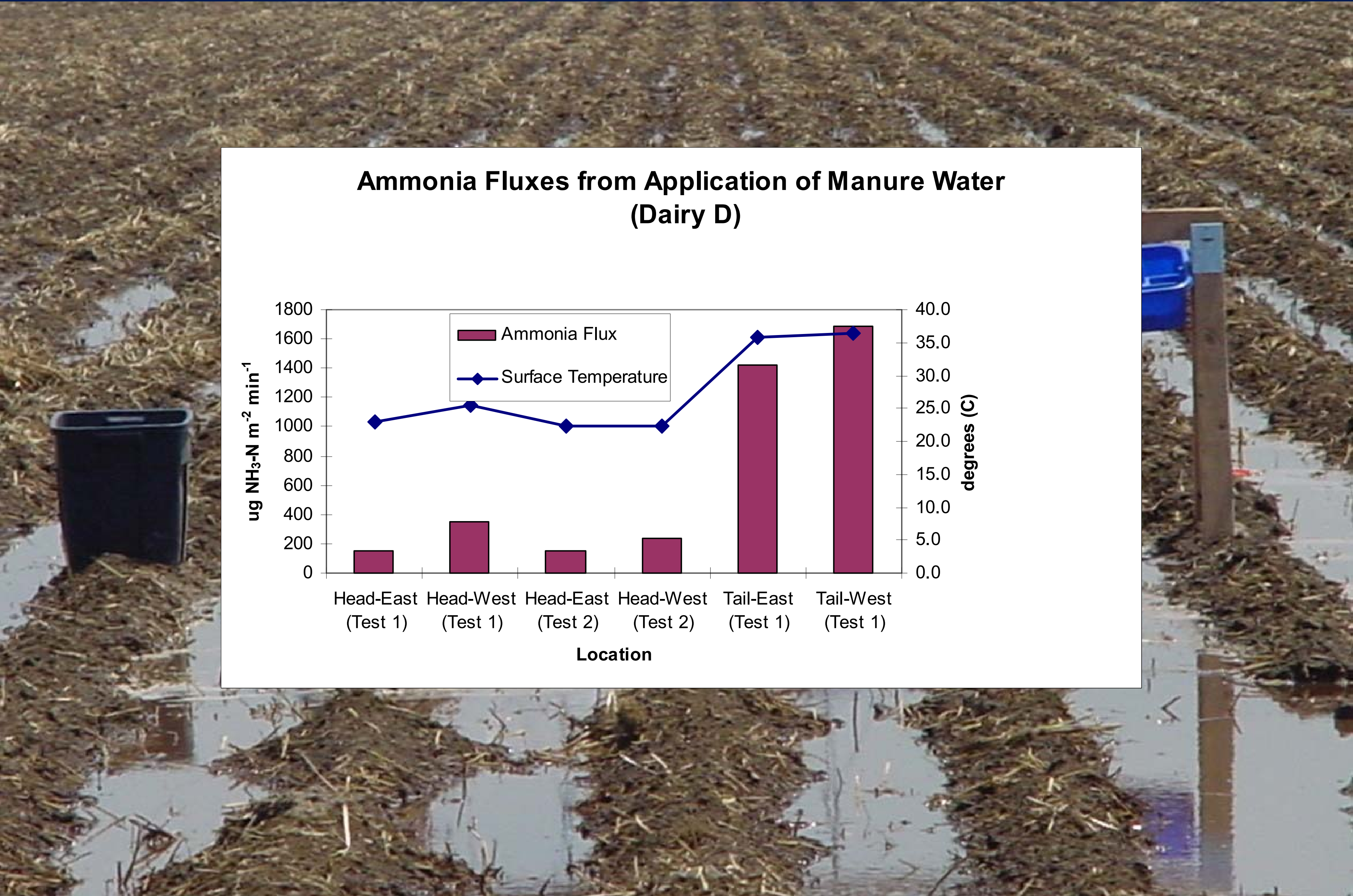
Values in the table are “flux rates” in $\mu g/M^2$/minute.

“U” indicates a value below the detection limit of the INNOVA analyzer.

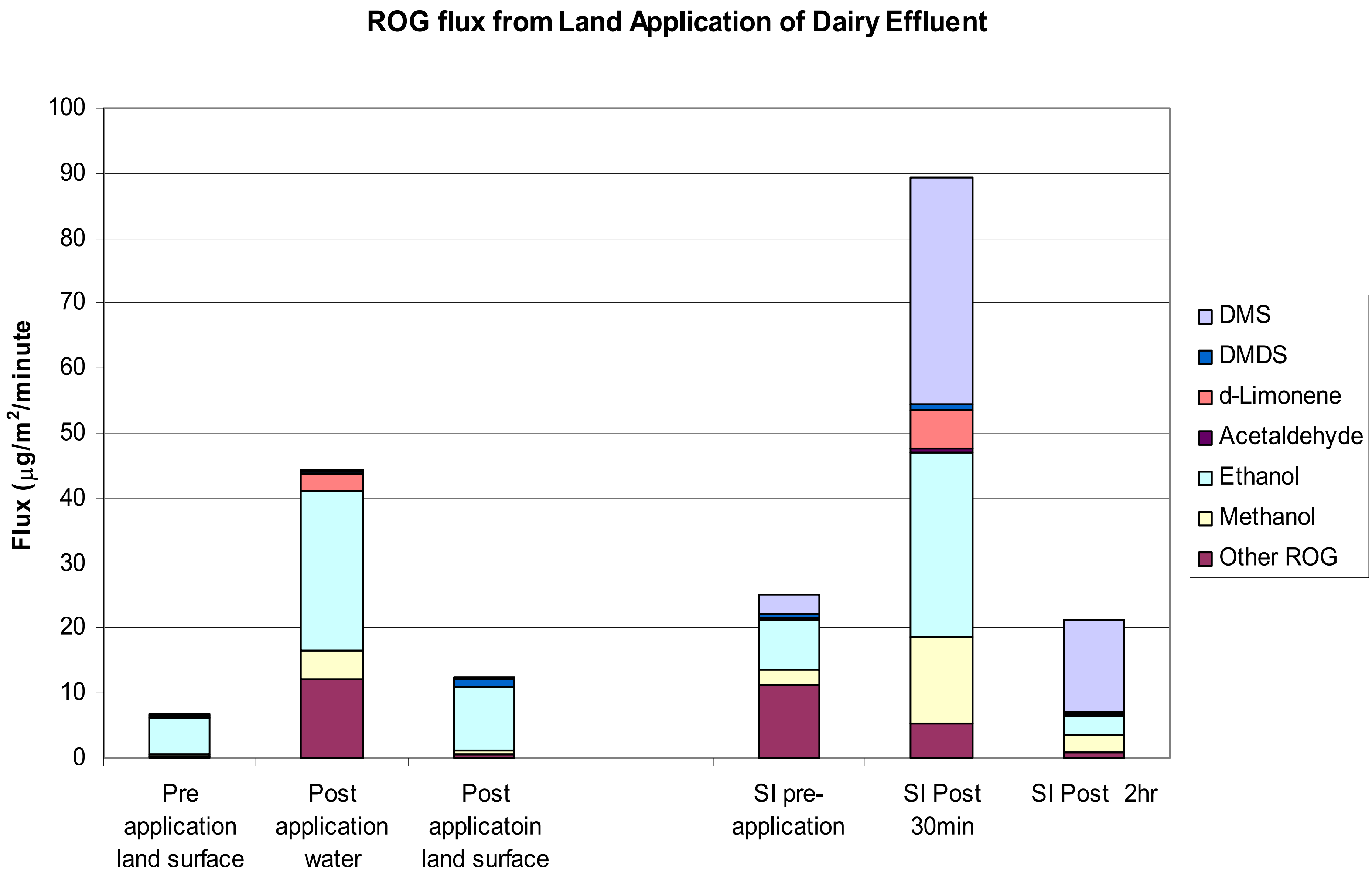
The values are corrected by subtracting the field blank from the measured value.

The number of samples averaged for each dairy is shown in parenthesis.

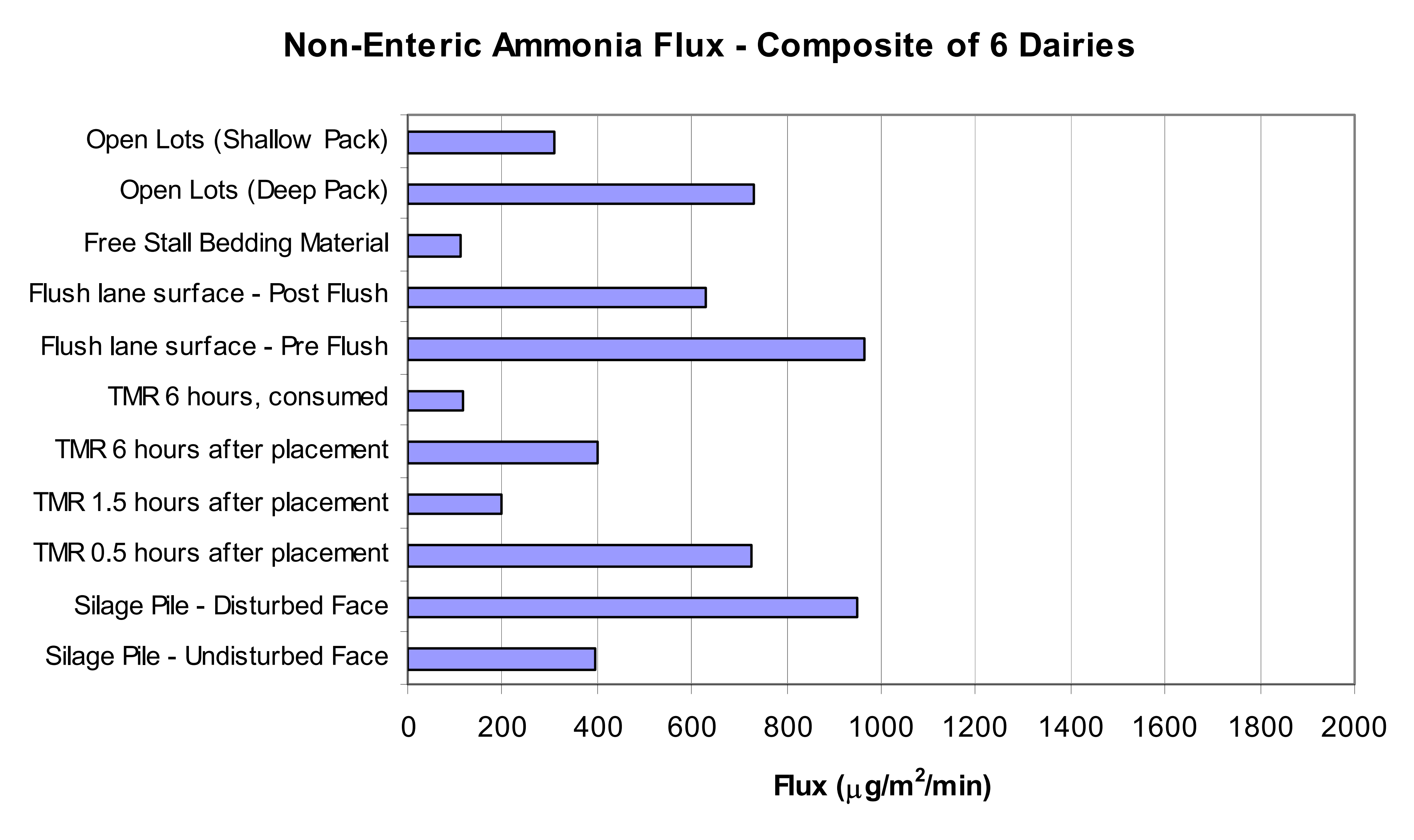
# Land Application of Lagoon Effluent at Dairy D (June, 2006)



## ROG fluxes from various land applications. SI indicates injection of manure slurry. Fluxes not labeled SI are irrigations mixed with lagoon water.

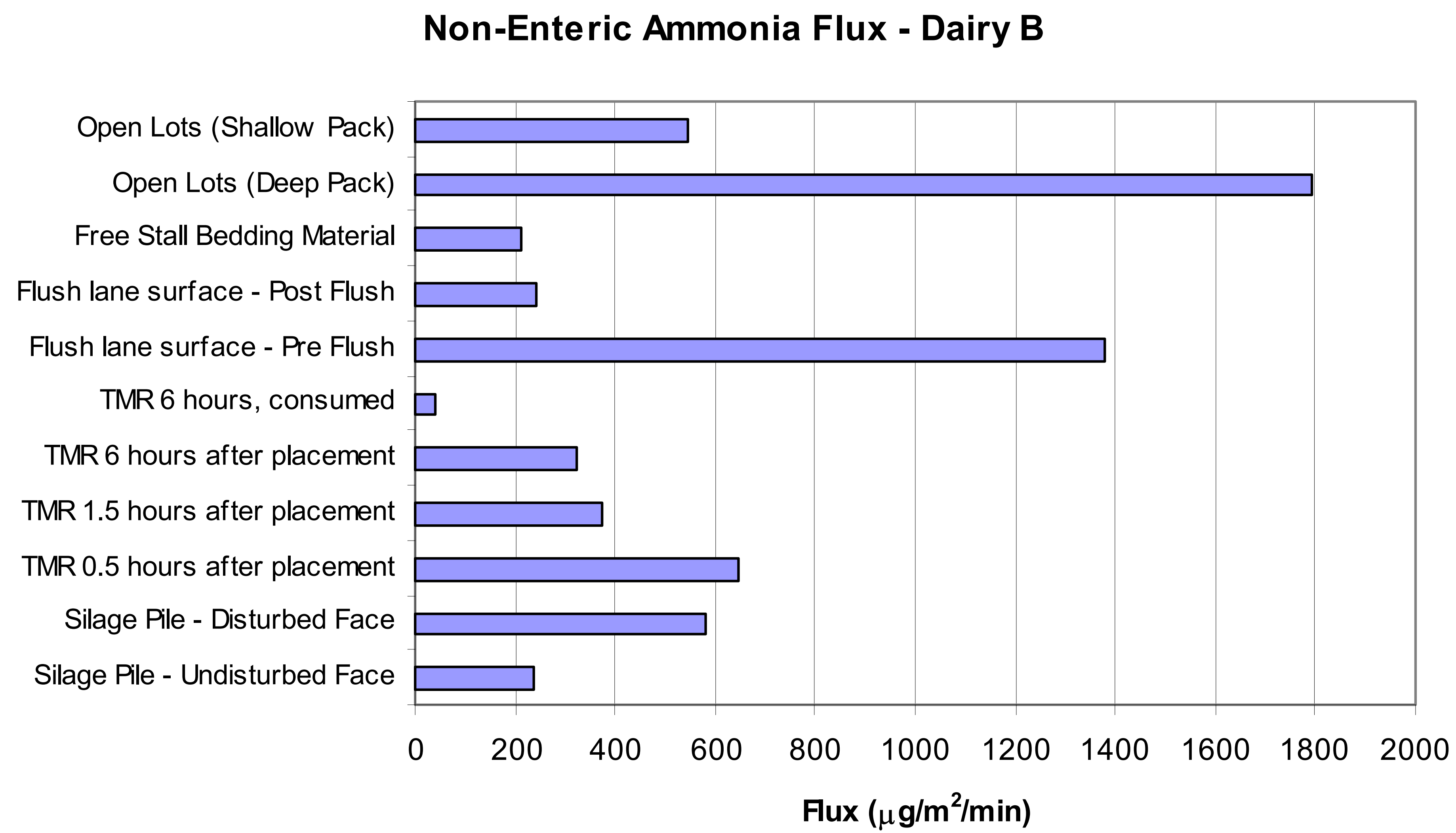


# Ammonia and other N fluxes for DNDC model validation USDA-CSREES subcontract for U New Hampshire (Salas and Li)



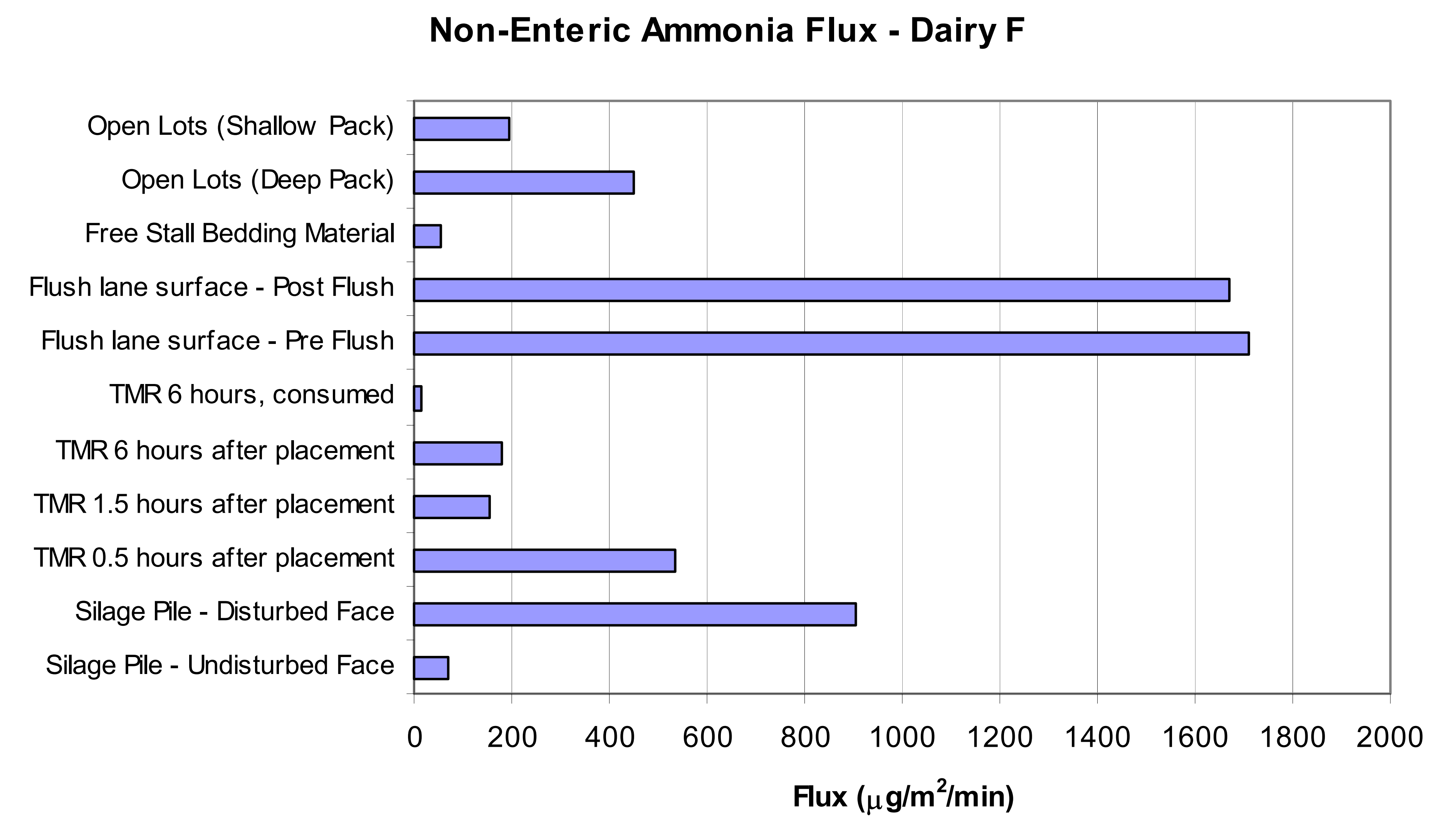
# Ammonia and other N fluxes for DNDC model validation USDA-CSREES subcontract for U New Hampshire (Salas and Li)

Dairy B has a single lagoon and manages the manure pack in the corrals infrequently



# Ammonia and other N fluxes for DNDC model validation USDA-CSREES subcontract for U New Hampshire (Salas and Li)

Dairy F scrapes the manure slurry rather than flushing it and intensively manages the small corrals



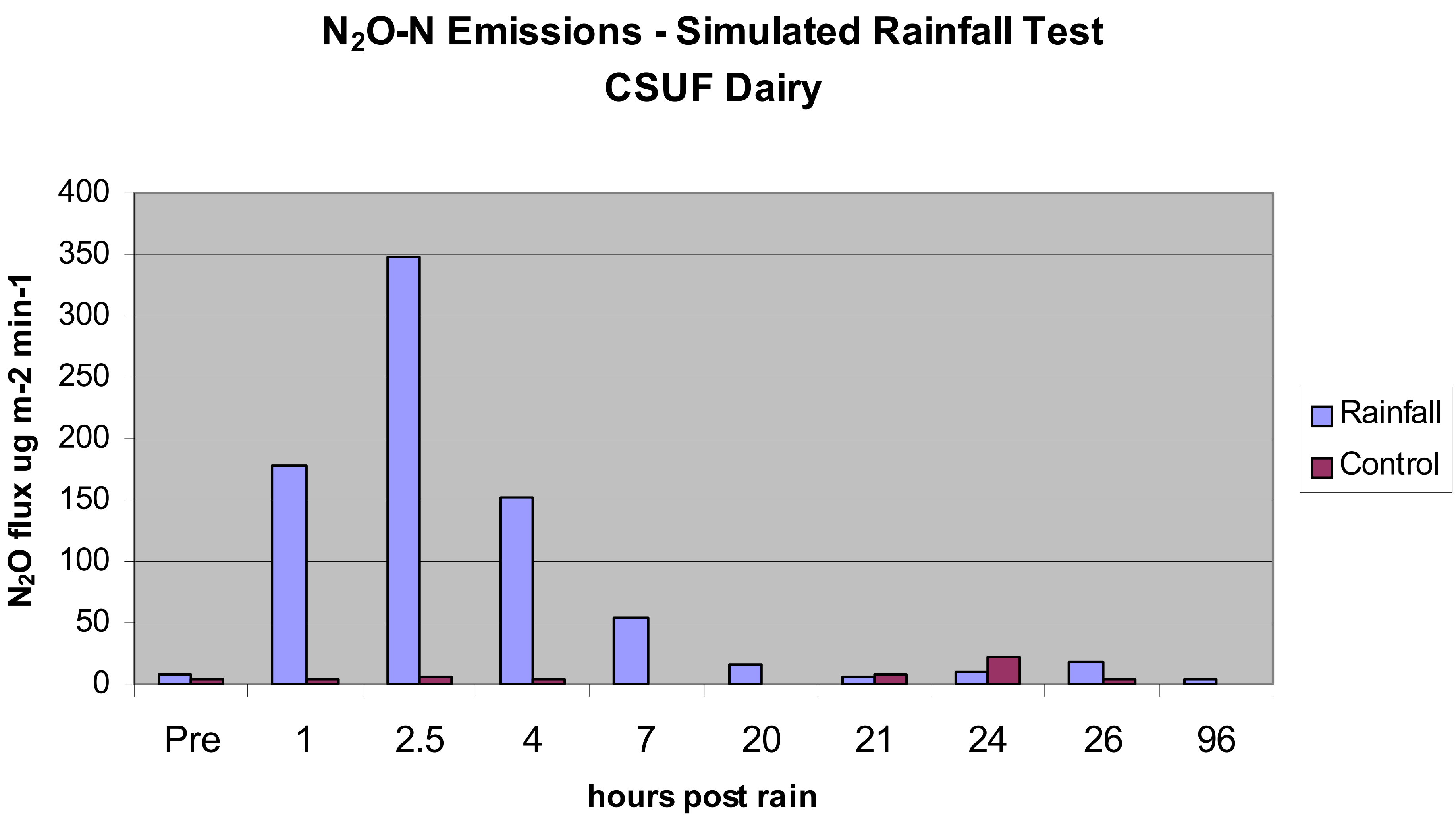
# Ammonia and other N fluxes for DNDC model validation
# USDA-CSREES subcontract for U New Hampshire (Salas and Li)

**Estimated Ammonia Flux for the Composite of 6 Dairies**

| **SOURCE** | Estimated Unit Area ($m^2$) | Number of Units | Ammonia Flux $\mu g/m^2/min$ | Time Fraction per Day | Estimated Emission (kg/day) | Fraction of the total | | |
|---|---|---|---|---|---|---|---|---|
| Silage Pile - Undisturbed Face | 250 | 1 | 395 | 100% | 0.14 | 0.5% | | |
| Silage Pile - Disturbed Face | 25 | 1 | 948 | 100% | 0.03 | 0.1% | 0.6% | Total Silage |
| TMR 0.5 hours after placement | 800 | 2 | 725 | 13% | 0.21 | 0.7% | | |
| TMR 1.5 hours after placement | 800 | 2 | 197 | 38% | 0.17 | 0.6% | | |
| TMR 6 hours after placement | 800 | 2 | 400 | 25% | 0.23 | 0.8% | | |
| TMR 6 hours, consumed | 800 | 2 | 117 | 25% | 0.07 | 0.2% | 2.3% | Total TMR |
| Flush lane surface - Pre Flush | 4800 | 2 | 966 | 50% | 6.67 | 22.7% | | |
| Flush lane surface - Post Flush | 4800 | 2 | 631 | 50% | 4.36 | 14.9% | 37.6% | Total Lanes |
| Free Stall Bedding Material | 3600 | 2 | 114 | 100% | 1.18 | 4.0% | | |
| Open Lots (Deep Pack) | 800 | 4 | 733 | 100% | 3.38 | 11.5% | | |
| Open Lots (Shallow Pack) | 7200 | 4 | 312 | 100% | 12.92 | 44.0% | 55.5% | Total Lots |
| | | | | **Sum =** | **29.4** | | | |
| | | | | Dairy A | 10.9 | | | |
| | | | | Dairy B | 98.9 | | | |
| | | | | Dairy C | 3.1 | | | |
| | | | | Dairy D | 69.3 | | | |
| | | | | Dairy E | 32.5 | | | |
| | | | | Dairy F | 59.9 | | | |

A rain event was simulated at the CSU Fresno Dairy to test the hypothesis that temporary anaerobic conditions in the manure pack would elevate $N_2O$ emissions in the highly organic matrix.

- A sprinkler was set up to apply 20mm of water in 4 hours to simulate the initial Central Valley winter storm on an exercise corral at the CSUF dairy.
- An area was covered by a tarp to maintain a control area.
- Flux chambers were set up to measure the emission flux from the manure surface before and after the simulated rain.
- A spike of $N_2O$ occurred for about 8 hours following the end of the “rain event”.



N2O-N Emissions - Simulated Rainfall Test
CSUF Dairy
N2O flux ug m-2 min-1
400
350
300
250
200
150
100
50
0
Pre
1
2.5
4
7
20
21
24
26
96
hours post rain
Rainfall
Control

A rain event was simulated at the CSU Fresno Dairy to test the hypothesis that temporary anaerobic conditions in the manure pack would elevate $N_2O$ emissions in the highly organic matrix.

- A sprinkler was set up to apply 20mm of water in 4 hours to simulate the initial Central Valley winter storm on an exercise corral at the CSUF dairy.
- An area was covered by a tarp to maintain a control area.
- Flux chambers were set up to measure the emission flux from the manure surface before and after the simulated rain.
- A spike of $N_2O$ occurred for about 8 hours following the end of the “rain event”.
- **A real rain event a month later did not show elevated $NO_2$ flux. That may have been due to the fact that the temperatures were much colder by the time of the real rain in December.**


QUESTIONS?