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Monitoring air quality: Relationship of air components with management, handling, and animal welfare

Diego Manriquez DVM PhD

November 21st, 2024

Outline

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- Definition of Air Quality
- Air Quality in dairies: state of art
- Ongoing research
  - Methods
  - Findings
  - Limitations
  - Future

Air Quality

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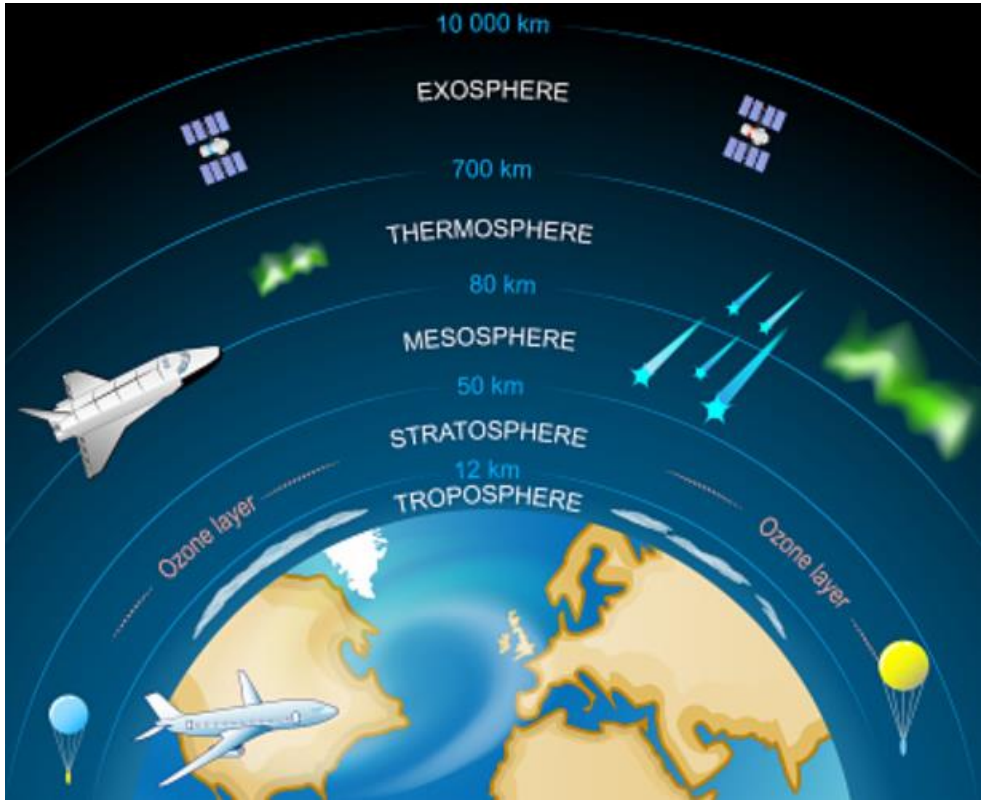
- Air is our medium



What does air quality (AQ) mean?

- Air is our media

What can affect water (medium) quality?

Water composition

Filtration rate (ventilation)

Number of fish

Fish diet (refusal and excretion)

Tank size and cleaning

Fish type

Air Quality (AQ)

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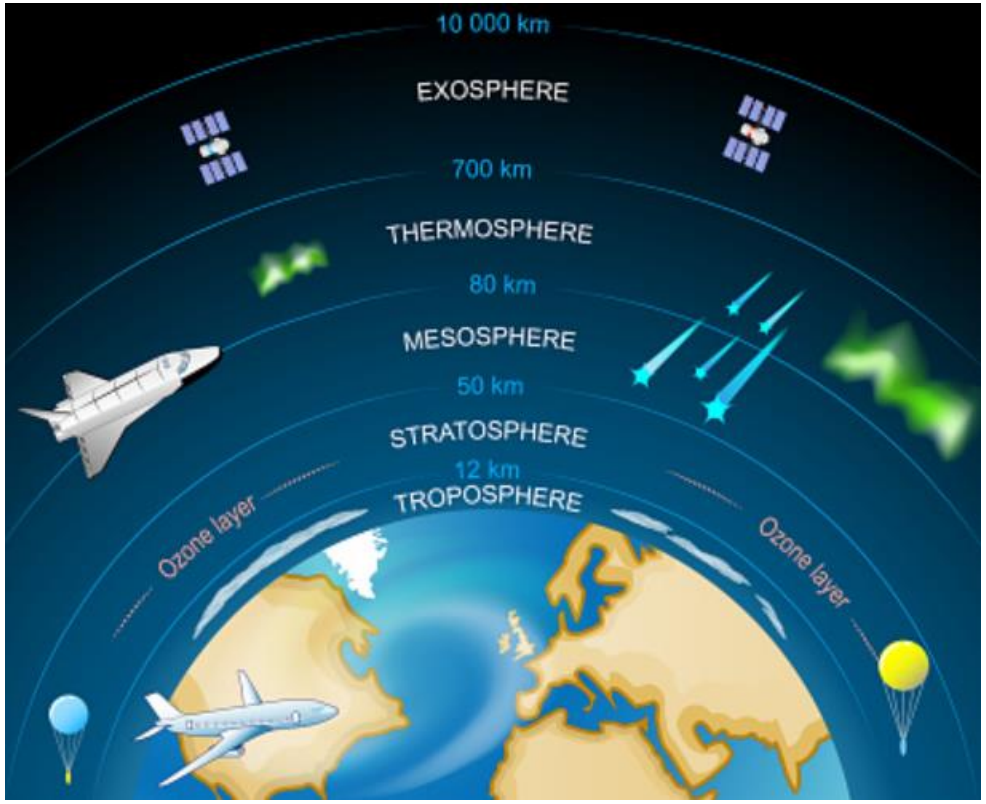
- Air is our medium



AQ is determined by the **amount** of **pollutants** present in our **medium** which can be harmful for **health and the environment**

Air Quality (AQ)

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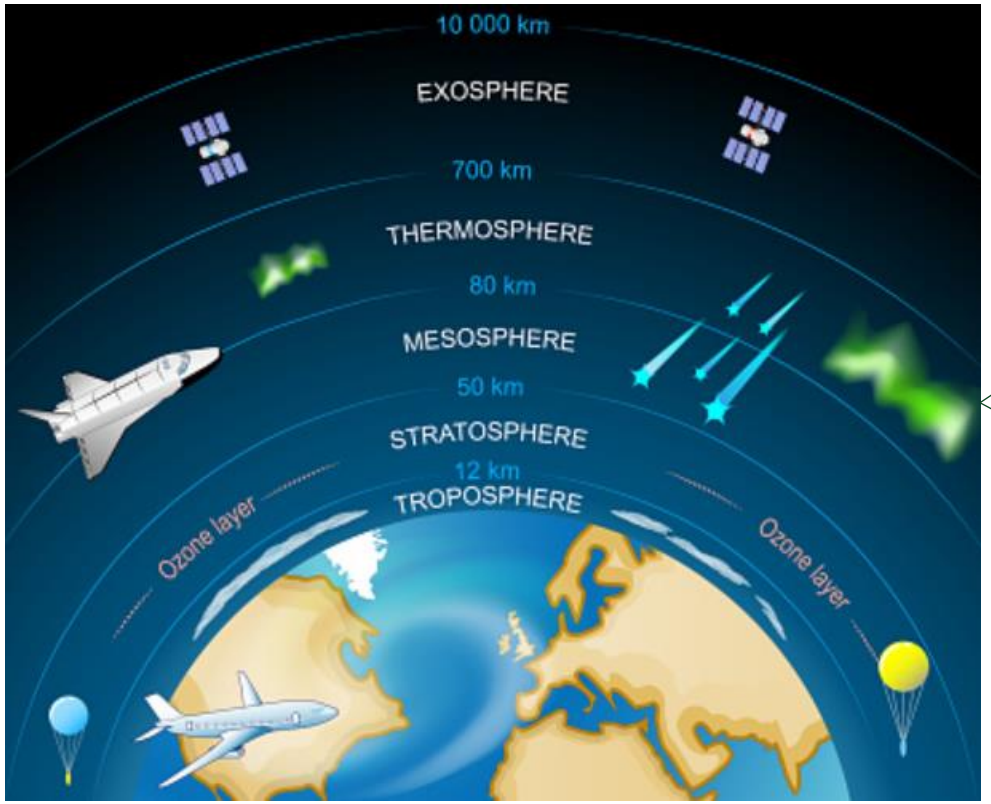

Define our medium

- Outdoor AQ
- Indoor AQ

Air Quality (AQ)

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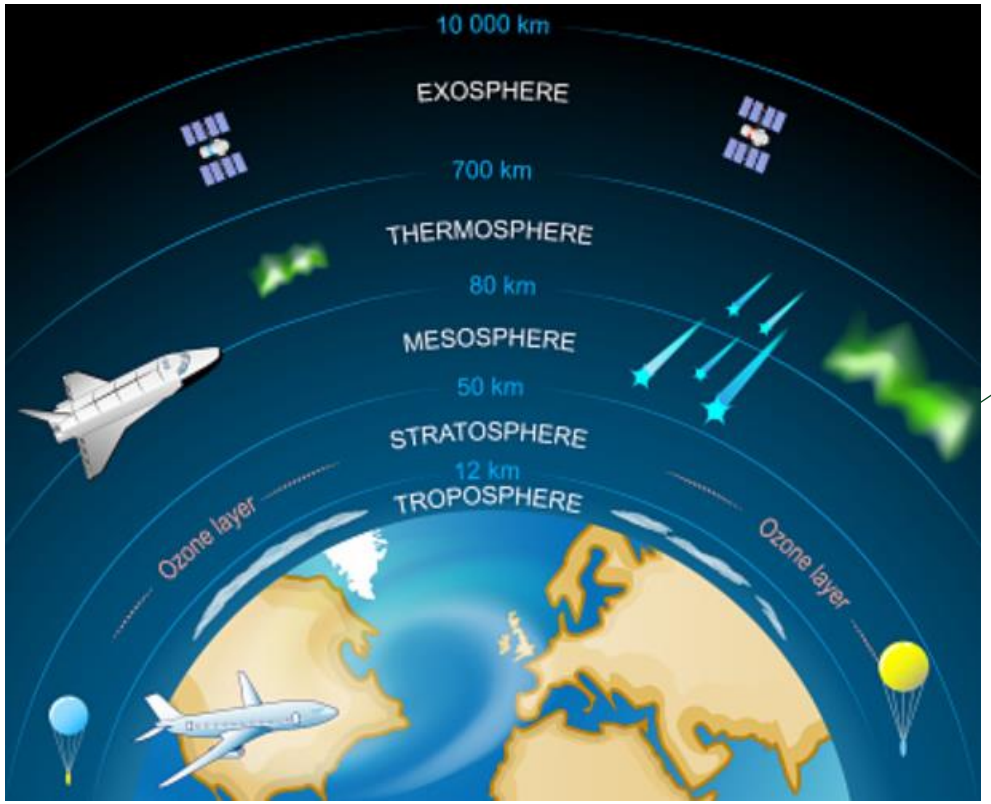
- Air is our medium



Define our medium

Outdoor AQ

- Urban and rural areas → Chronic exposure
- Emergencies → Acute exposure

Air Quality (AQ)

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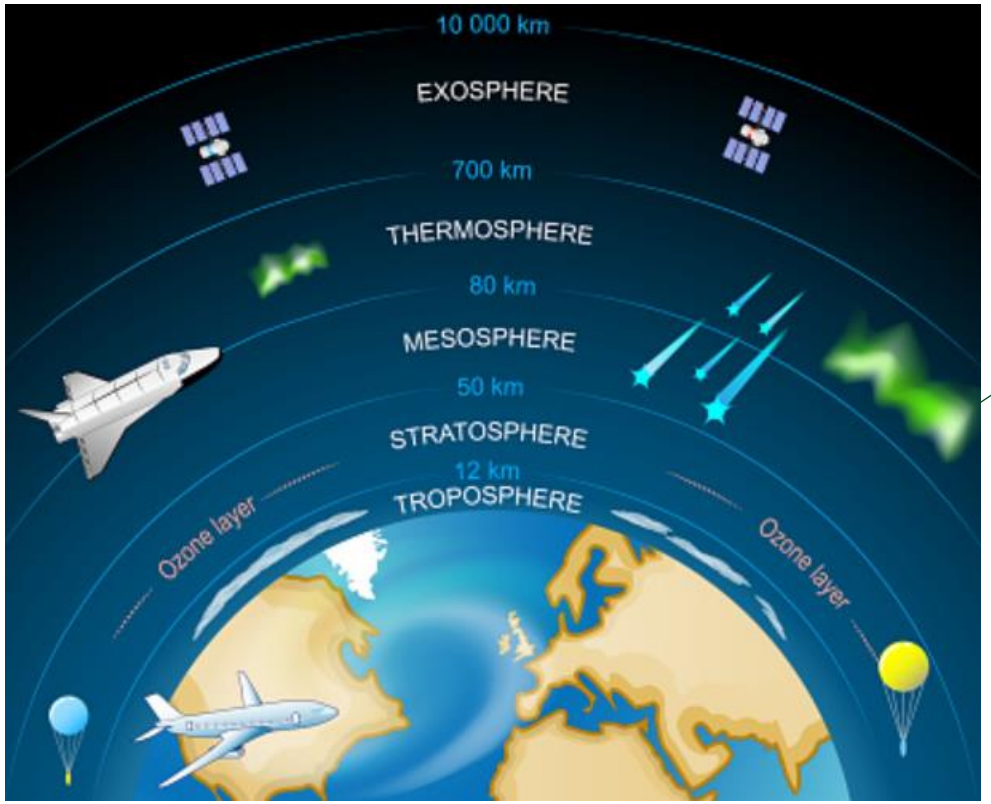
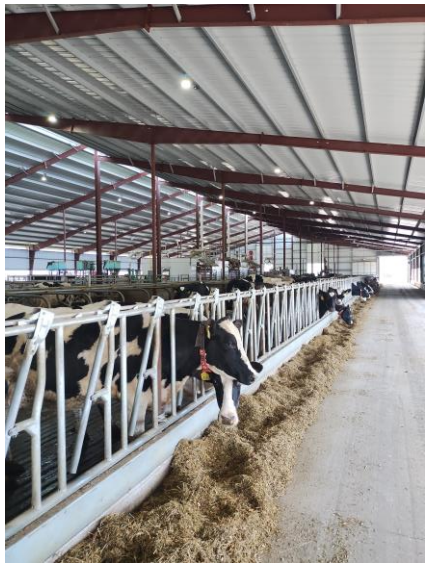
- Air is our medium



Define our medium

Indoor AQ

- Households
- Industrial settings → Acute/Chronic exposure



AQ Standards for dairies?

AQ standards

- Air composition
  - Gases
  - Chemicals
  - Particulates
  - Physical
  - Microbes

Important

✓Air components variate significantly depending on the place and time of the day

✓Humidity can affect the density of the air composition

Air pollutants

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- Health and environment risks

Gases	Chemical	Particulates	Physical	Microbes
• Carbon monoxide • Carbon dioxide • Sulfur dioxide • Hydrogen sulfide • Nitrogen dioxide • Methane • Ozone	• Ammonia • Volatile organic compounds • Lead	• Particulate matter 2.5 &10 (ug/m^3)	• Temperature • Humidity • THI • Solar radiation	• Bacteria • Virus • Fungi

Air pollutants

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- Health and environment risks for dairy operations?

Measure then mitigate

AQ in dairy environments

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- Complex, semi-closed environment, daily human-animal interaction
- Air pollutants have been described

<u>Milking parlor</u>
Chemical
Gases
VOC
Milk cooling systems

<u>Barns</u>
Ammonia
Methane
Hydrogen sulfide
Microbes
Particulates

<u>Vehicles</u>
Ozone
VOC
CO, CO_2

<u>Manure</u>
Ammonia
Methane
Sulfides
Microbes
Nitrogen dioxide

Cammalleri et al., 2022; Islam et al., 2022; Place and Mitloehner, 2010; EPA, 2024

AQ in dairy environments

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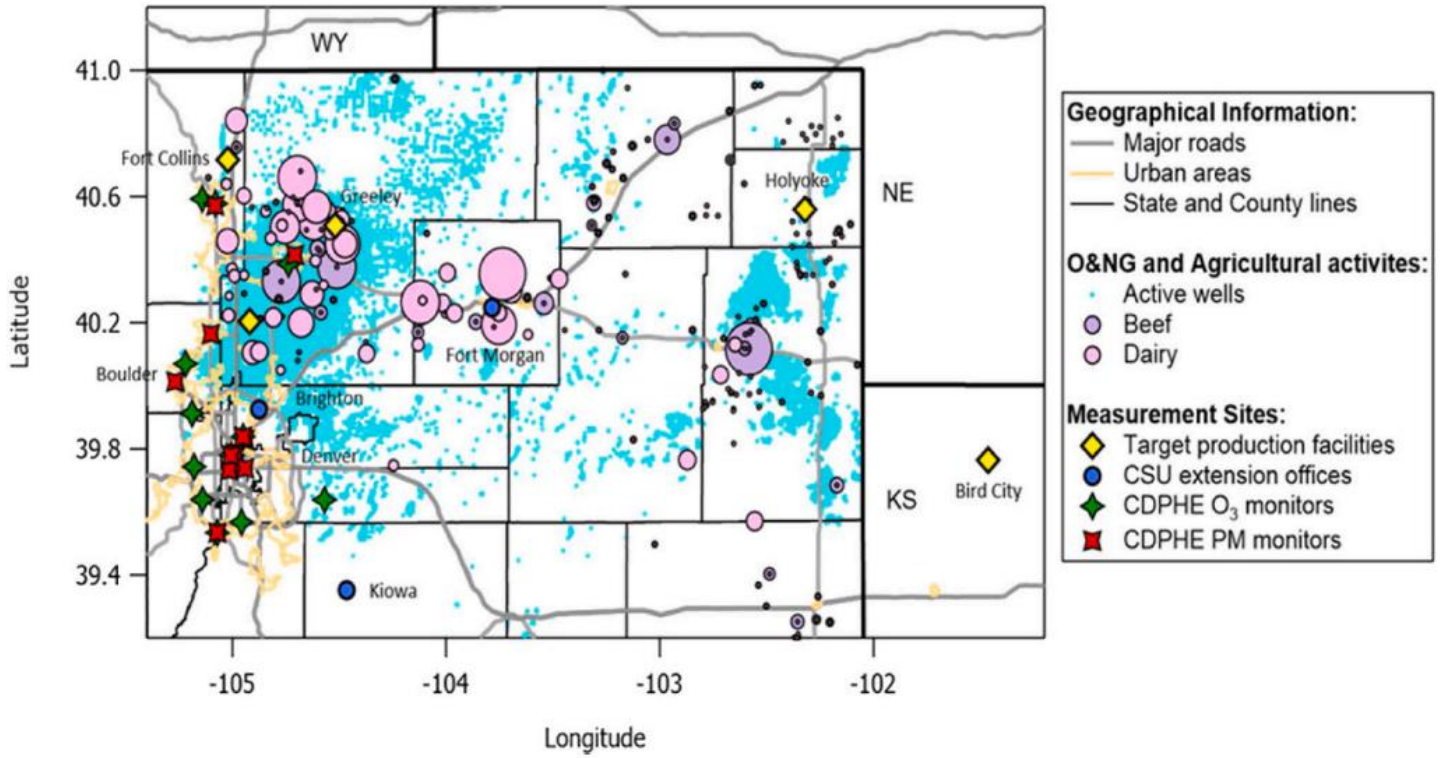
- AQ affects milk production and worker health
  - Acute, chronic, subclinical effects?
- Cow as canaries study (Beaupied et al., 2022)

Local EPA AQ monitors Located between 20 to 42 km from 3 Dairies



AQ in dairy environments

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- Cow as canaries study (Beaupied et al., 2022)
- Bulk tank Somatic Cell Counts (SCC)
  - 10 unit increase daily average THI increase SCC by 14,500 cells/mL
  - 10 ug/m^3 daily average $PM_{2.5}$ increase SCC by 105,500 cells/mL
- Daily milk production
  - 10 unit increase daily average THI reduced milk yield by 1.2 lb./cow/day
  - 10 ug/m^3 daily average $PM_{2.5}$ reduced milk yield by 3.5 lb./cow/day

AQ in dairy environments

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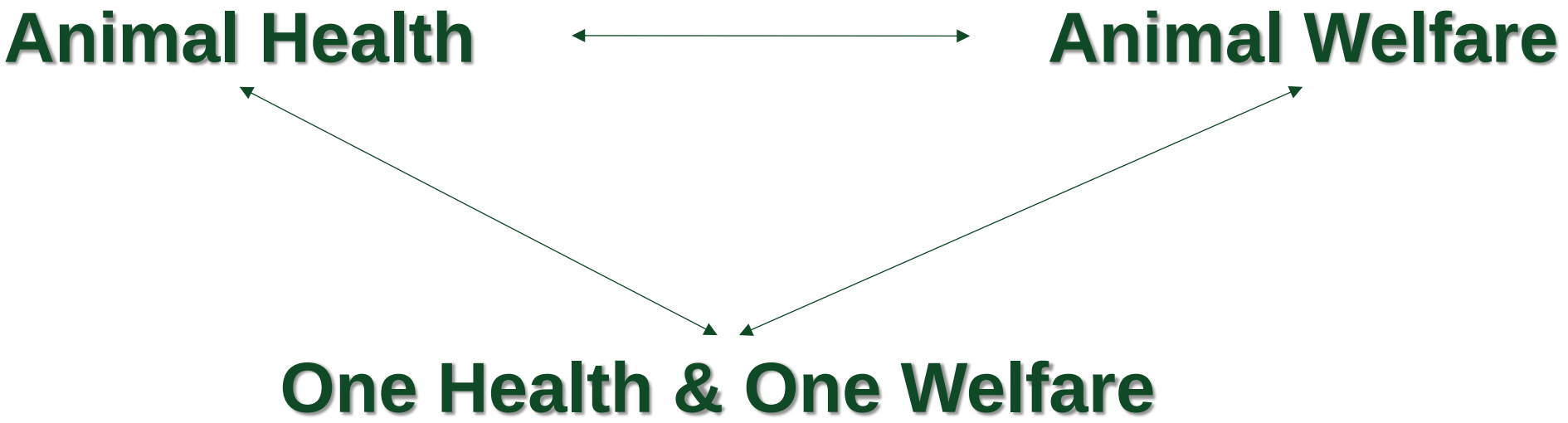
- Research opportunities



Dairy worker exposure

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Published in final edited form as:
J Occup Environ Hyg. 2018 March ; 15(3): 182–193. doi:10.1080/15459624.2017.1403610.

Personal exposure of dairy workers to dust, endotoxin, muramic acid, ergosterol, and ammonia on large-scale dairies in the high plains Western United States

Margaret E. Davidson[a,b,f], Joshua Schaeffer[a,b], Maggie L. Clark[a,b], Sheryl Magzamen[a,b], Elizabeth J. Brooks[a,b], Thomas J. Keefe[a,b], Mary Bradford[a,b], Noa Roman-Muniz[a,c], John Mehaffy[a,b], Gregory Dooley[a,b], Jill A. Poole[d], Frank M. Mitloehner[e], Sue Reed[f], Marc B. Schenker[e], Stephen J. Reynolds[a,b,f]

Published in final edited form as:
J Occup Environ Med. 2015 January ; 57(1): 79–87. doi:10.1097/JOM.0000000000000304.

Particulate Matter, Endotoxin, and Worker Respiratory Health on Large Californian Dairies

Diane C. Mitchell, PhD,
Tracey L. Armitage, MS,
Marc B. Schenker, MD, MPH,
Deborah H. Bennett, PhD,
Daniel J. Tancredi, PhD,
Chelsea Eastman Langer, PhD, MPH*,
Stephen J. Reynolds, PhD,
Greg Dooley, PhD,
John Mehaffy, PhD,
Frank M. Mitloehner, PhD

Published in final edited form as:
J Occup Environ Hyg. 2023 January ; 20(1): 14–22. doi:10.1080/15459624.2022.2137297.

Preliminary investigation of a hypertonic saline nasal rinse as a hygienic intervention in dairy workers

Grant Erlandson[1], Sheryl Magzamen[1,2], Julia L. Sharp[5], Sanchayita Mitra[3], Kenneth Jones[3,4], Jill A. Poole[8], Mary Bradford[1], Matthew Nonnenmann[9], Stephen J. Reynolds[1,6,7], Joshua W. Schaeffer[1,6]

AQ in dairy environments

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- Most studies rely on cross-sectional data
- On-site real time monitoring is rare
- Technological opportunity
  - Multiple sensor platform used in other industrial settings
  - **Group scale emissions**

Ongoing AQ research

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- Assessment of AQ continuous monitoring systems in dairy farms

- Study hypothesis:

Air components can be **detected** and continuously monitored in the milking parlor and in a tunnel ventilated barn and their concentrations have **specific** daily dynamics that might be associated with farm operations

Multiple sensor platform

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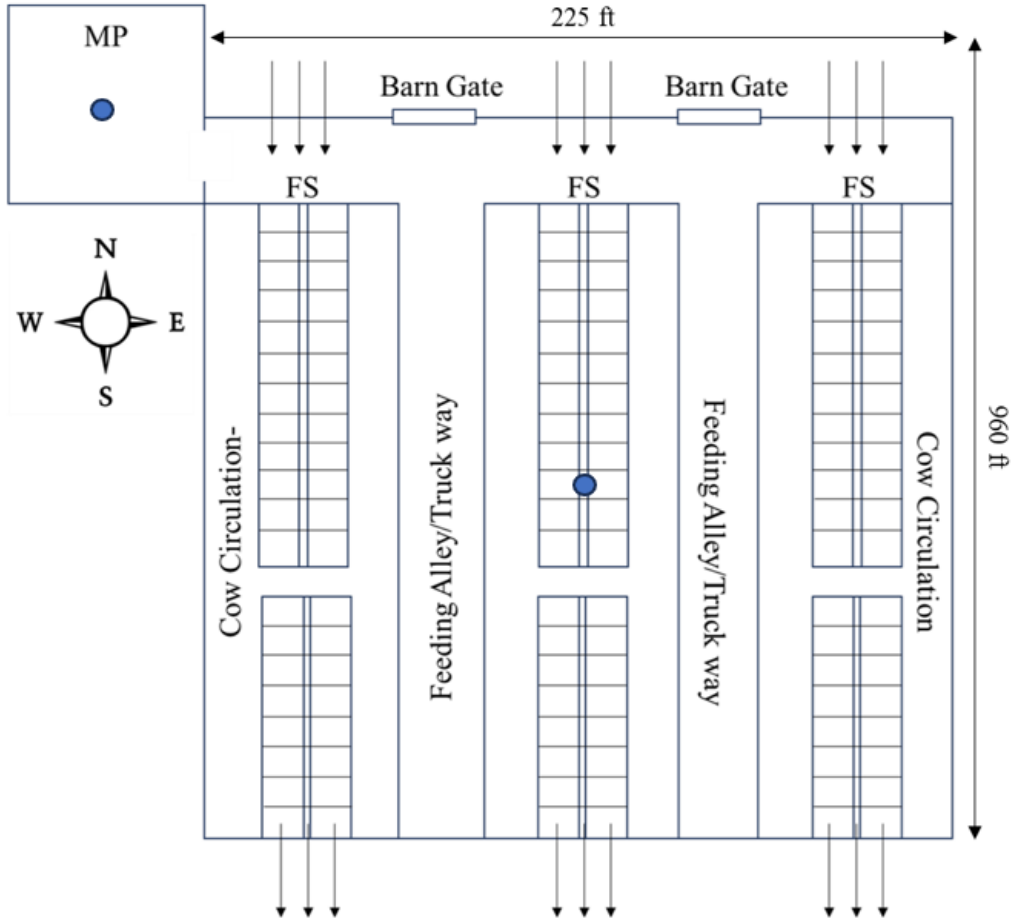
- One-minute sampling rate

Air component	Characteristics	Unit	Sensor type	Range
Gas	Carbon monoxide	ppm	Photoacoustic NDIR	2-1000 ppm
	Carbon dioxide	ppm	Electrochemical	400-2000 ppm
	Methane	ppm	Metal oxide	2-5000 ppm
Chemicals	Ammonia	ppm	Electrochemical	0.5-50 ppm
	Volatile Organic Compounds	ppm	Electrochemical	5-800 ppm
Particulates	Particulate Matter 2.5	ug/m^3	Optical	max 5000
Physical	Temperature	^oC	Electrical	-10 to 80
	Relative Humidity	%	Resistive	0 to 100
	$THI = (1.8 \times T + 32) - [(0.55 - 0.0055 \times RH) \times (1.8 \times T - 26)]$	Units	-	-



Study design

- Study farm
  - 6,000 lactating Holstein cows
  - Northern Colorado, USA
  - Milking 3x day
  - Sand bedding free-stall (FS)
  - Rotary milking parlor (MP)

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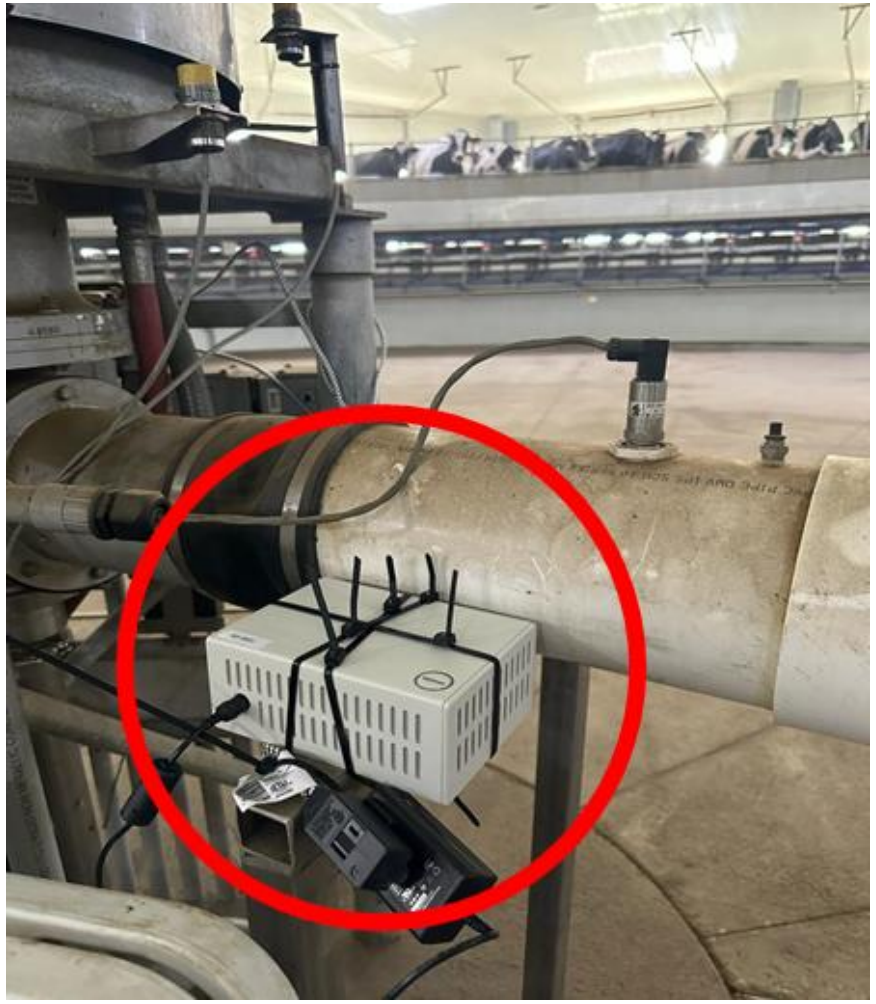

Study design

- Study farm
  - 6,000 lactating Holstein cows
  - Northern Colorado, USA
  - Milking 3x day
  - Sand bedding free-stall (FS)
  - Rotary milking parlor (MP)
- Sensor installation
  - Center of milking parlor
  - Barn 13 ft from the ground
  - **August-December 2023**

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Study design

- Study Barn
  - ~2000 lactating cows
  - 5 pens of 400/heads
  - Fresh and mid-lactation cows
  - Feeding Schedule:
  - **Morning 6 – 10 am**
  - **Afternoon 2 – 3 pm**
  - **Night 10 – 11 pm**

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Statistical analysis

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- ~70,000 readings were averaged by hour by date per location
- Hours LSM estimates were compared between the parlor and the barn using proc mixed.
  - Covariates:
    - Location
    - Hour
    - Date
    - Hour*Location

Results

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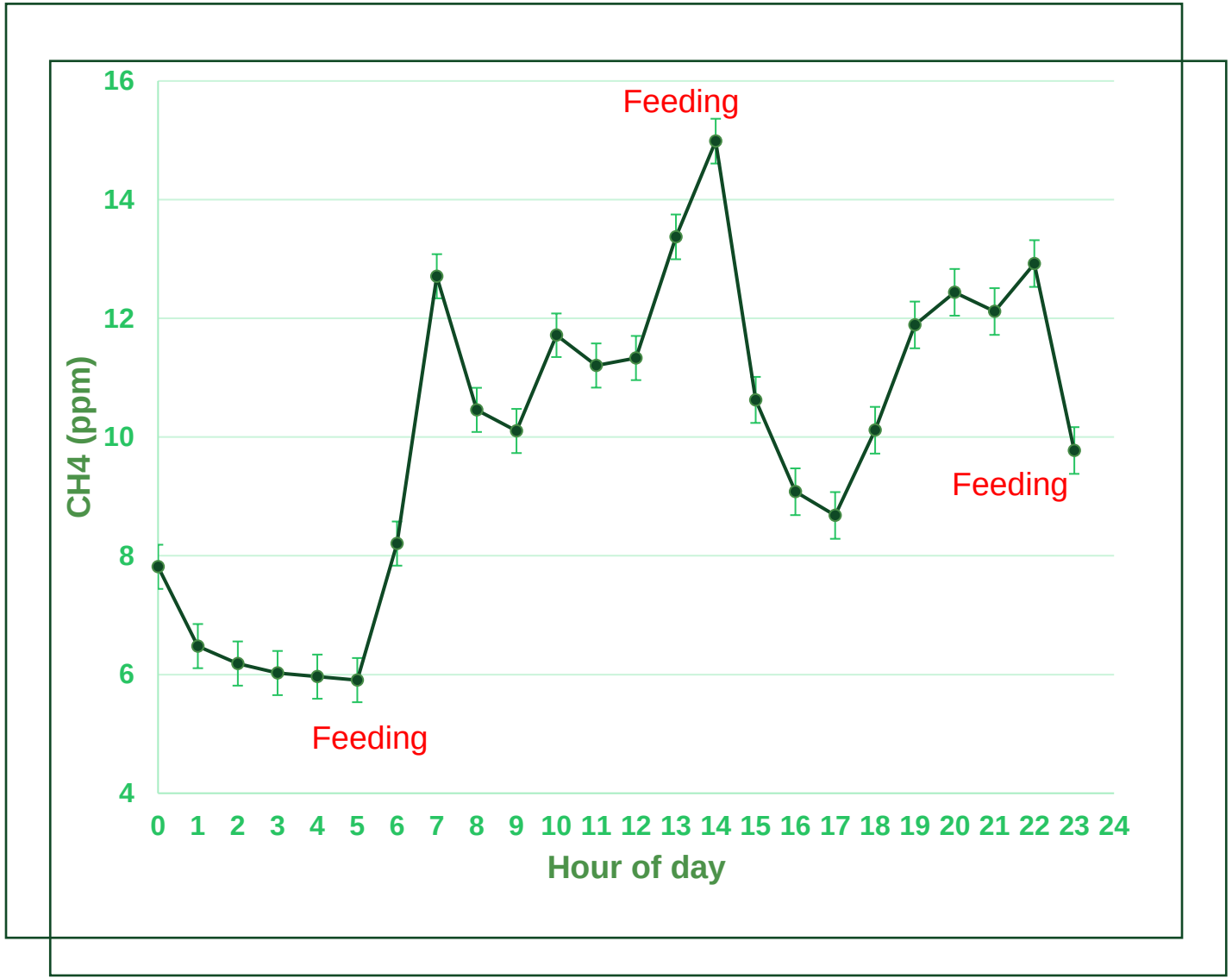
- Overall LSM (SEM) by location (MP: milking parlor)

Variable	LSM (SEM)			Maximum Level		Hour of day	
	MP	Barn	P-value	MP	Barn	MP	Barn
Ammonia	-	6.3 (3.8)	-	-	7.8 (0.2)	-	23h
Carbon monoxide	**1.1 (0.1)**	0.4 (0.1)	<0.01	1.8 (0.4)	2.5 (0.3)	15h	10h
Carbon dioxide	609.9 (1.9)	**655.5 (1.9)**	<0.01	642.6 (9.2)	729.9 (9.3)	0h	1h
Methane	10.2 (0.2)	10.1 (0.2)	0.5	27.1 (0.8)	15.5 (0.8)	13h	7h
Particulate mater 2.5	**5.2 (0.06)**	3.1 (0.07)	<0.01	7.4 (0.3)	5.3 (0.2)	17h	15h
THI	55.6 (0.05)	55.5 (0.04)	0.5	56.3 (0.2)	60 (0.18)	16h	14h
Volatile Organic Coumpounds	143.2 (1.4)	**150.9 (1.3)**	<0.01	246.0 (6.5)	400.7 (6.5)	5h	7h



Results
AQ dynamics

- Barn methane

Mean	STD	Max	Min
10	2.63	14.98	5.9

Natural air levels: 1800 ppb (1.8 ppm)

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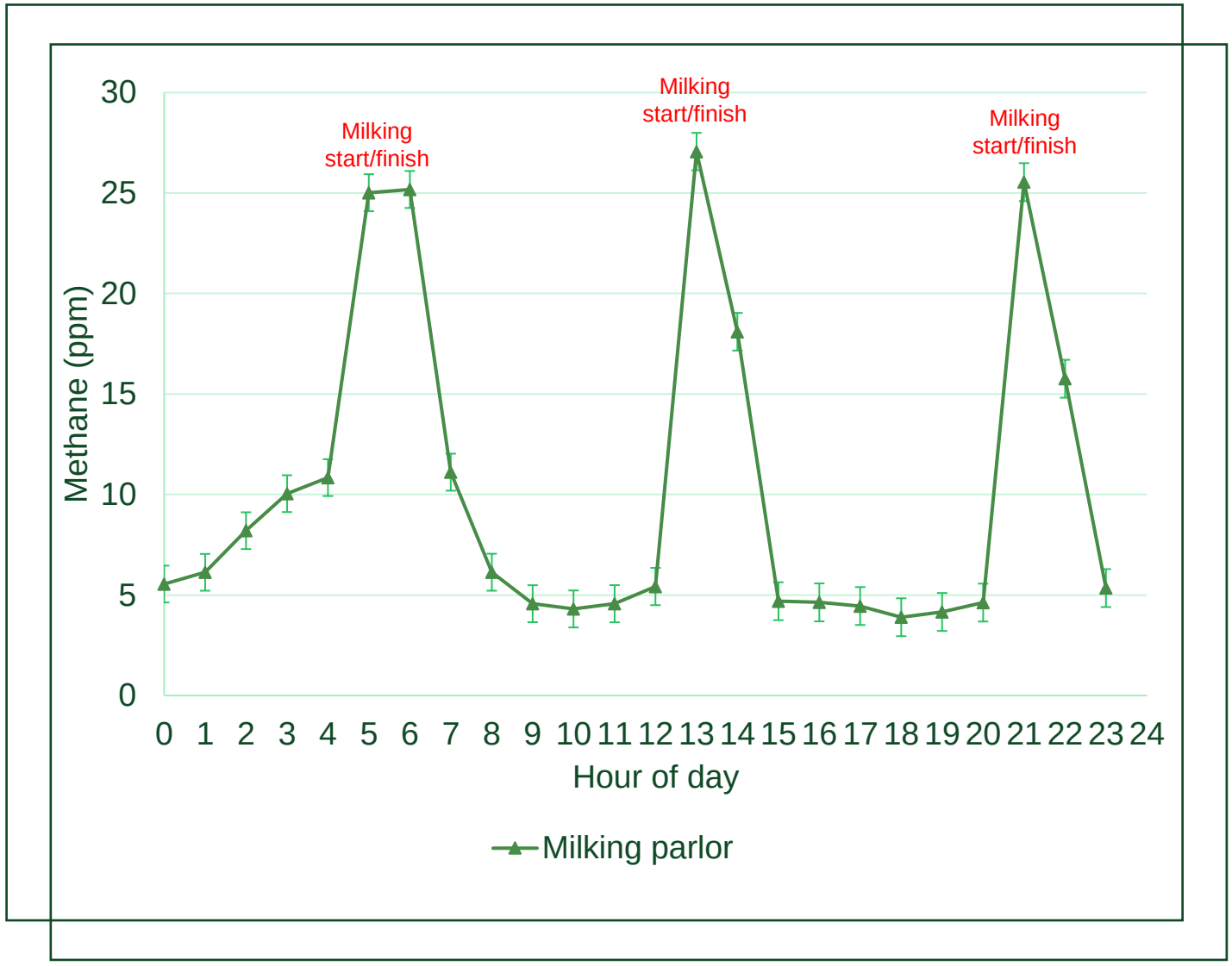
1. https://climate.nasa.gov/vital-signs/methane/?intent=121

Results
AQ dynamics

- MP methane



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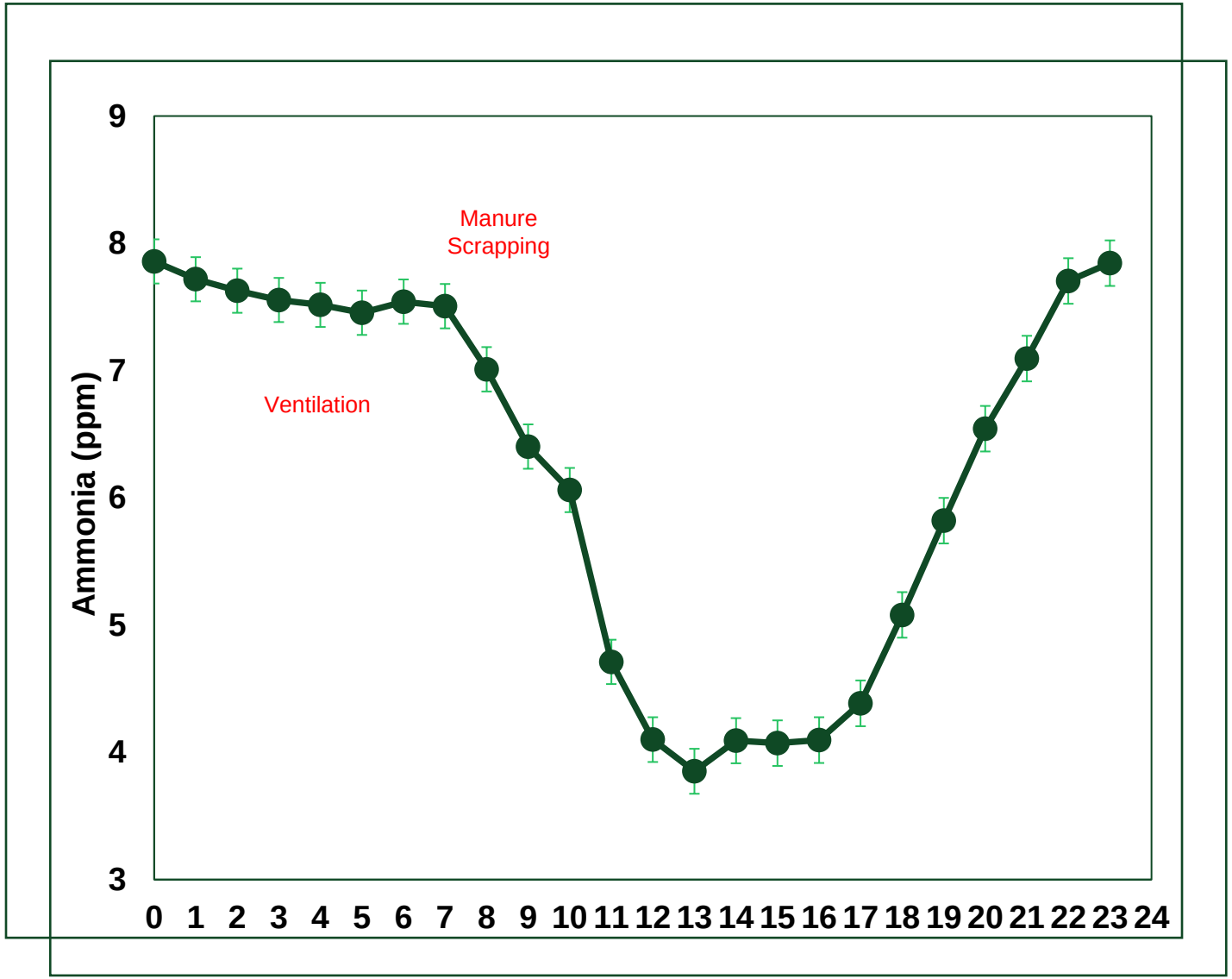

AQ dynamics Ammonia

- Not detected in the milking parlor

Average	STD	Maximum	Minimum
6.73	2.1	9.56	3.52

Natural air levels: 1-5 ppb (0.001-0.005 ppm)
Soil levels: 1-5 ppm[1]

>10 ppm associated with animal health risks[2]

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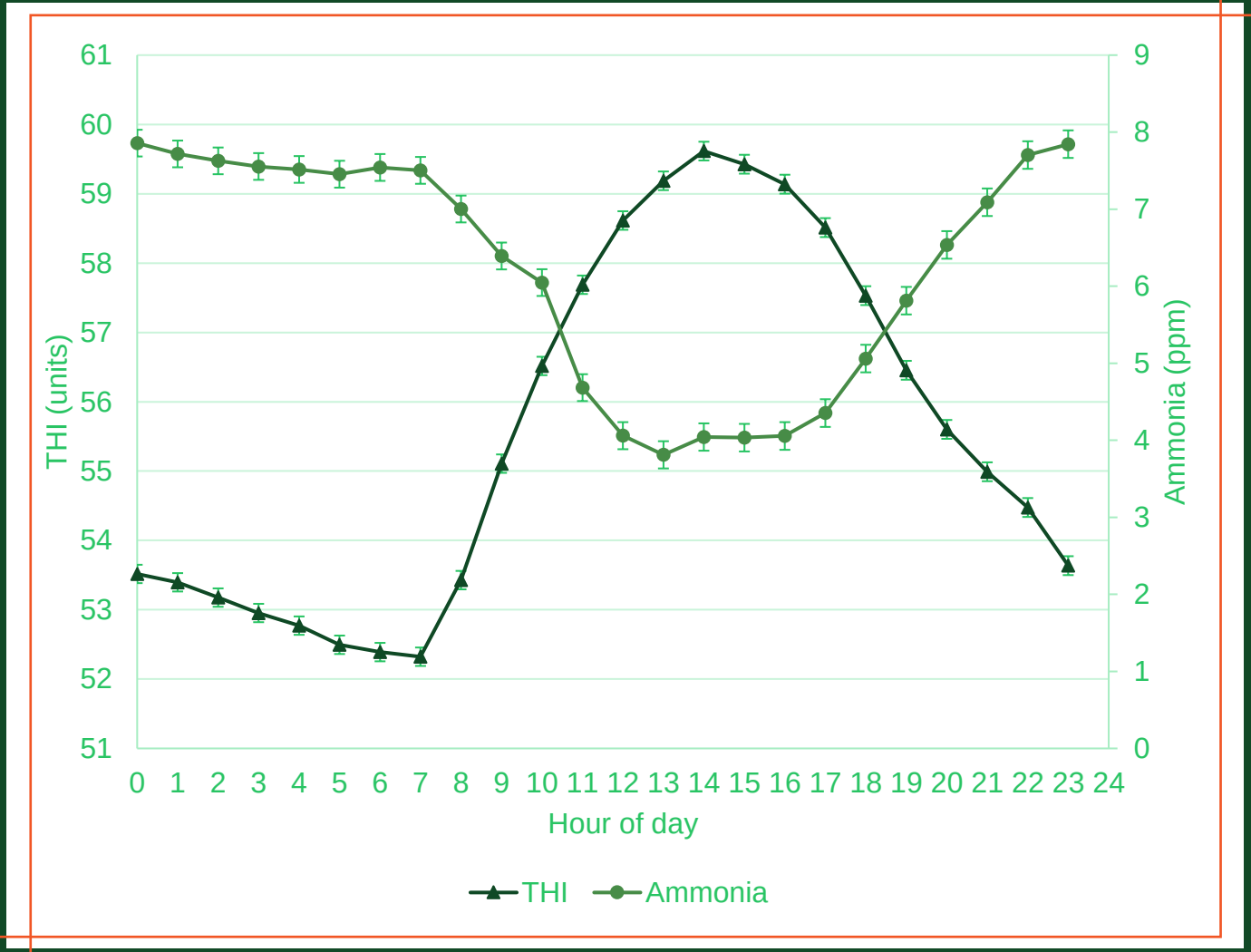
1.https://www.atsdr.cdc.gov/toxprofiles/tp126-c1-b.pdf
2. https://doi.org/10.3390/ani12172286

Results

- Ammonia and THI
- Cross-correlation analysis?
- Effects of ventilation



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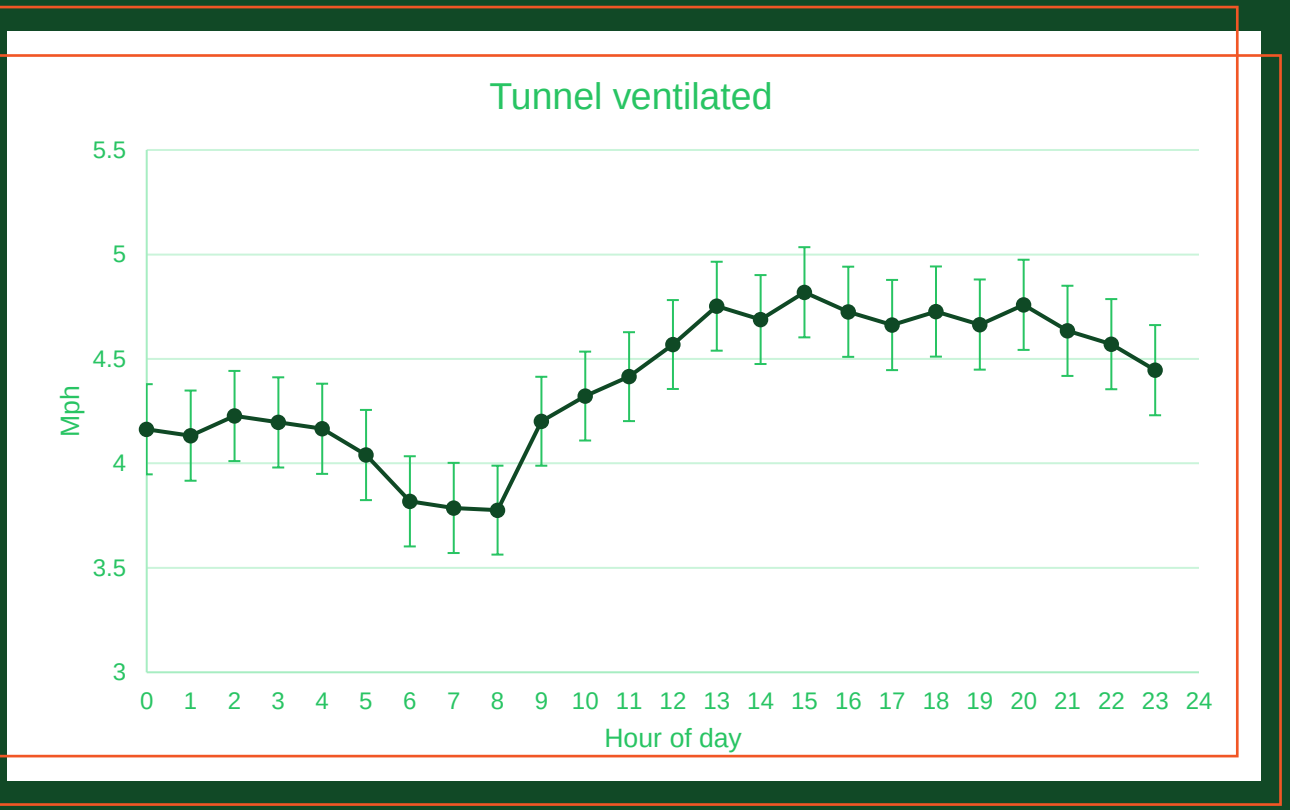
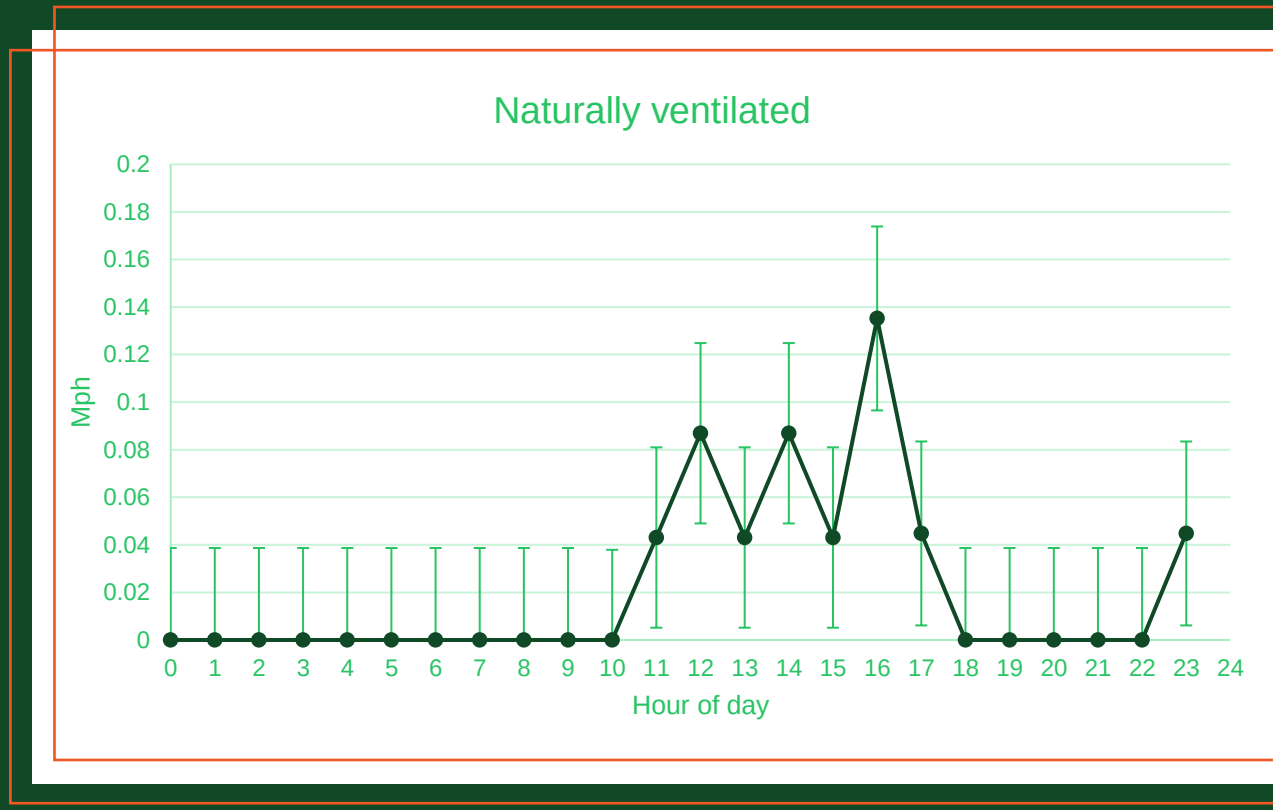
Wind speed in housing barns





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Carbon dioxide

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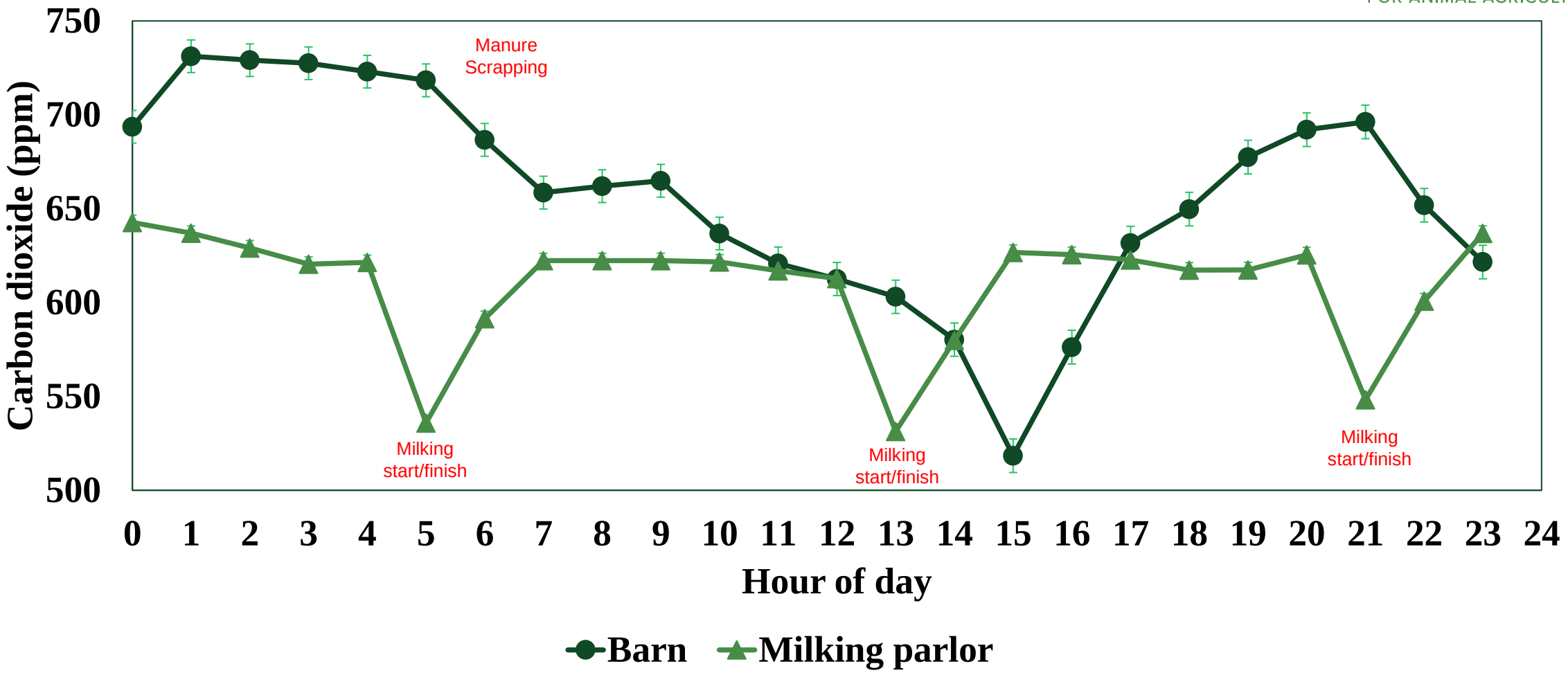

Location*Hour P <0.0001

Carbon dioxide

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- CO_2 levels seem to be high
  - 350 – 450 ppm: outdoor air
  - 450-600 ppm: well ventilated indoor air
  - 600-800 ppm: Acceptable but increased ventilation might be needed
  - 800 - >1000 ppm: Poor ventilation, health risks

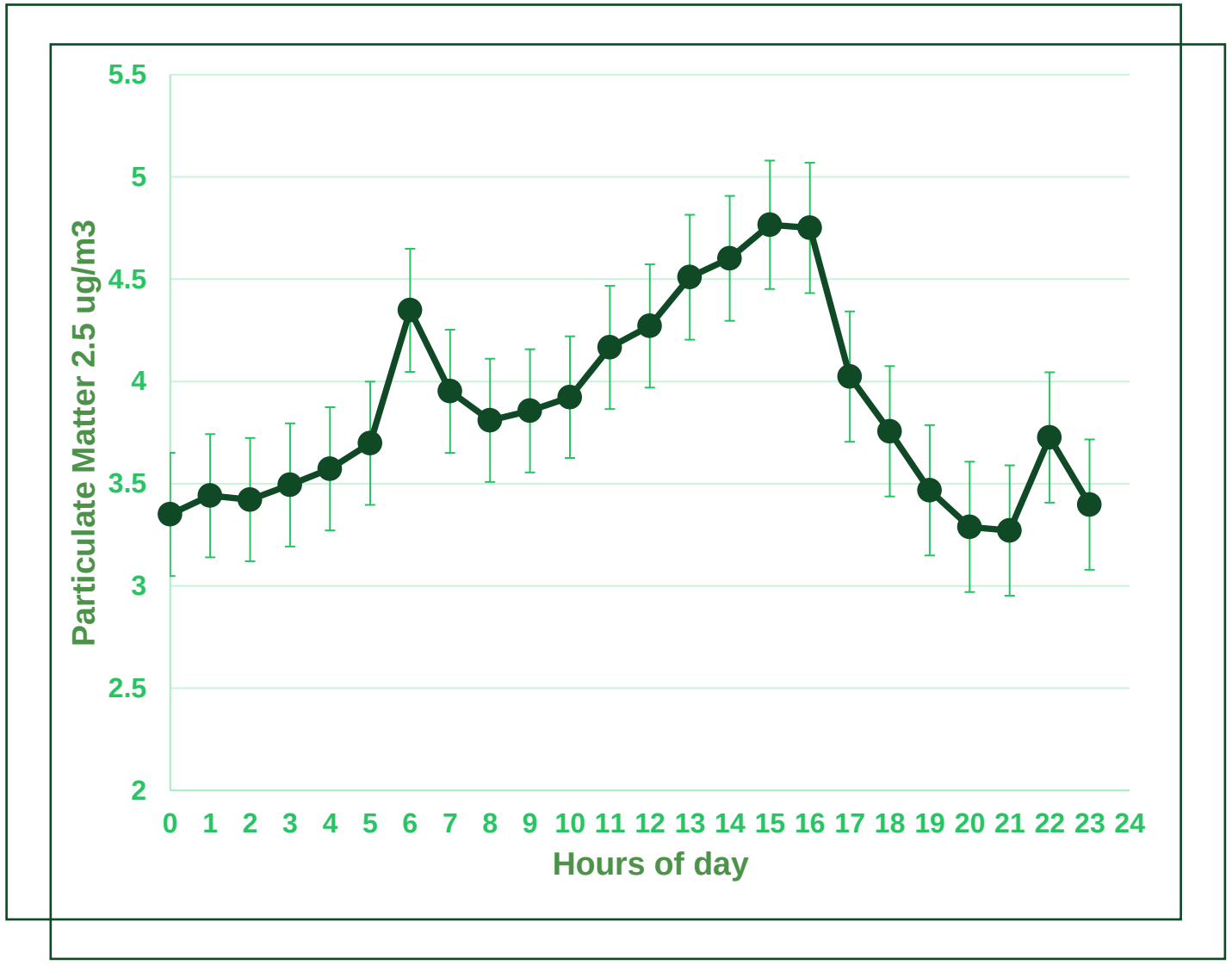
- What are the risks of chronic exposure?

AQ dynamics PM 2.5

Tunnel-ventilated barn

Average	STD	Maximum	Minimum
4.2	4.8	30.7	1.6

- EPA National AQ standard for 24 h PM 2.5 = 12 ug/m^{3*}



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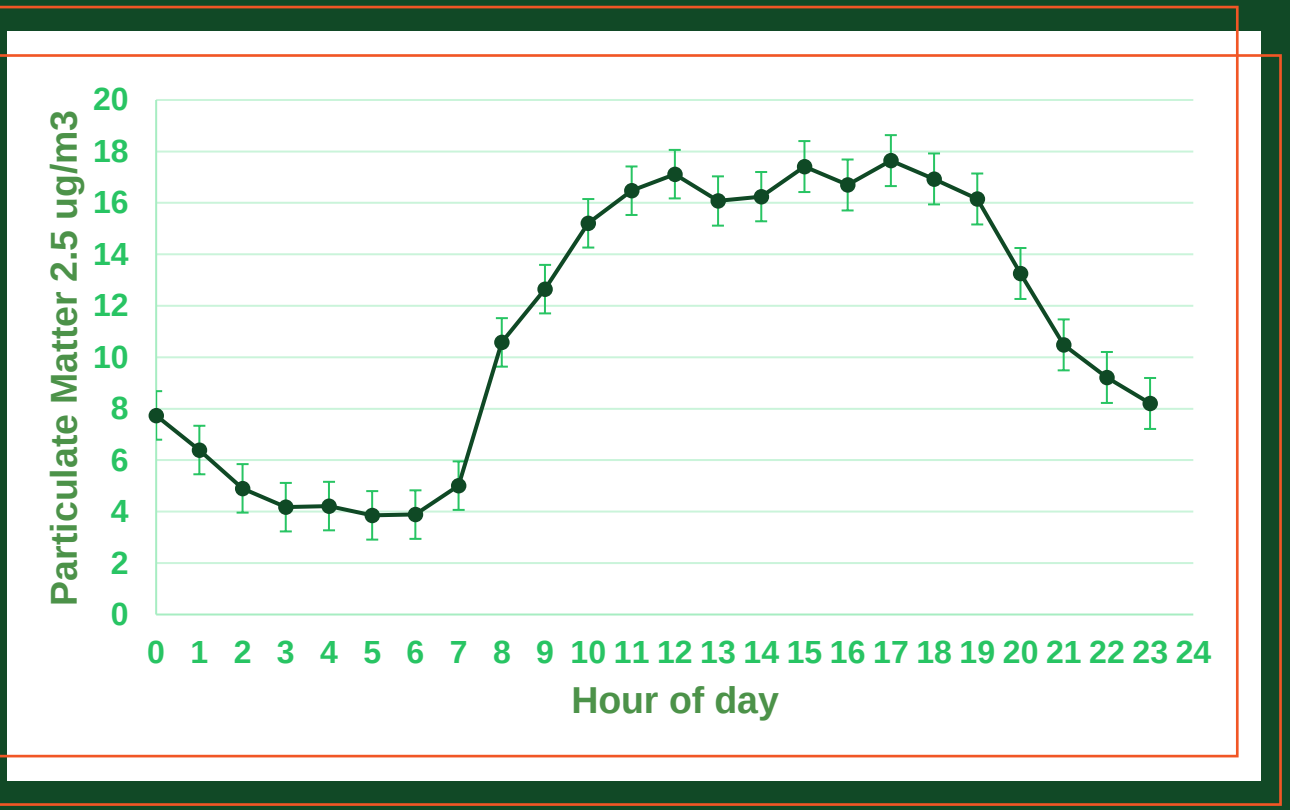
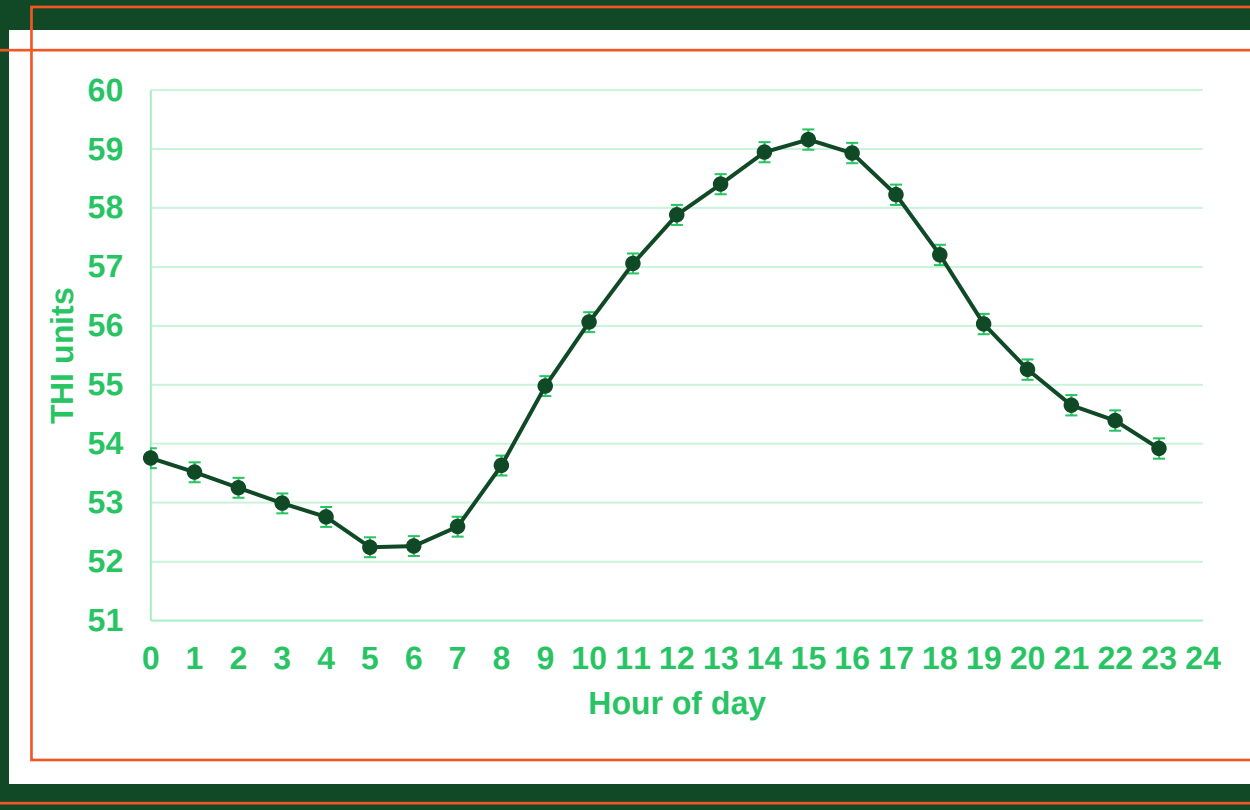
*Beaupeid et al., 2022. doi.org/10.1016/j.envres.2021.112197
*EPA: Federal Register :: Reconsideration of the National Ambient Air Quality Standards for Particulate Matter

Relationship between PM 2.5 and THI in the milking parlor





p = 0.94; P <0.0001
Increase 1-unit THI increase PM 2.5 by 0.7 ug/m^3
Adj. R^2 0.88

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Ammonia and Barn milk yield

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- Effects of AQ on production
- Ongoing work
  - Animal welfare (cow comfort, resting behavior)
  - Animal health
- Objective:
  - Assess the relationship between maximum ammonia concentrations and group milk yield

Ammonia and Barn milk yield

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Detrend ammonia data

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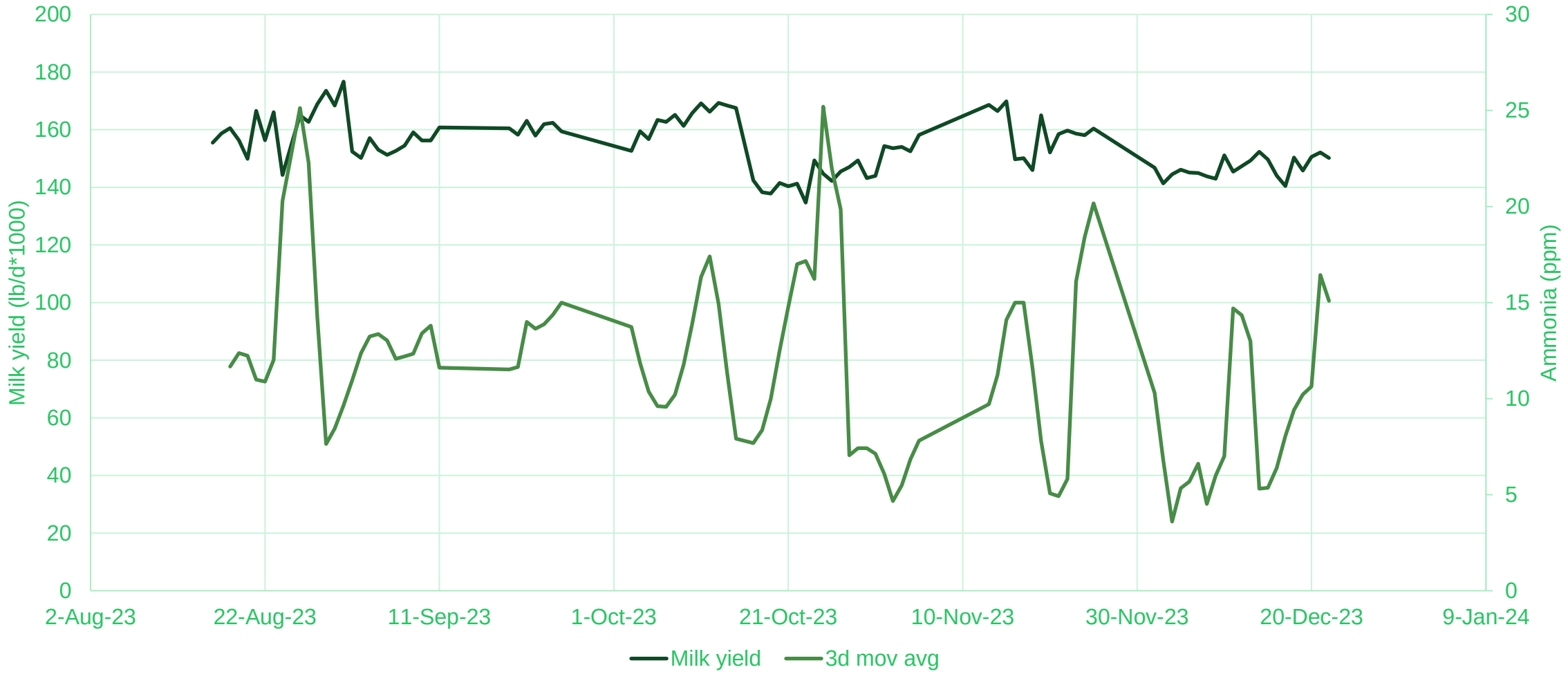
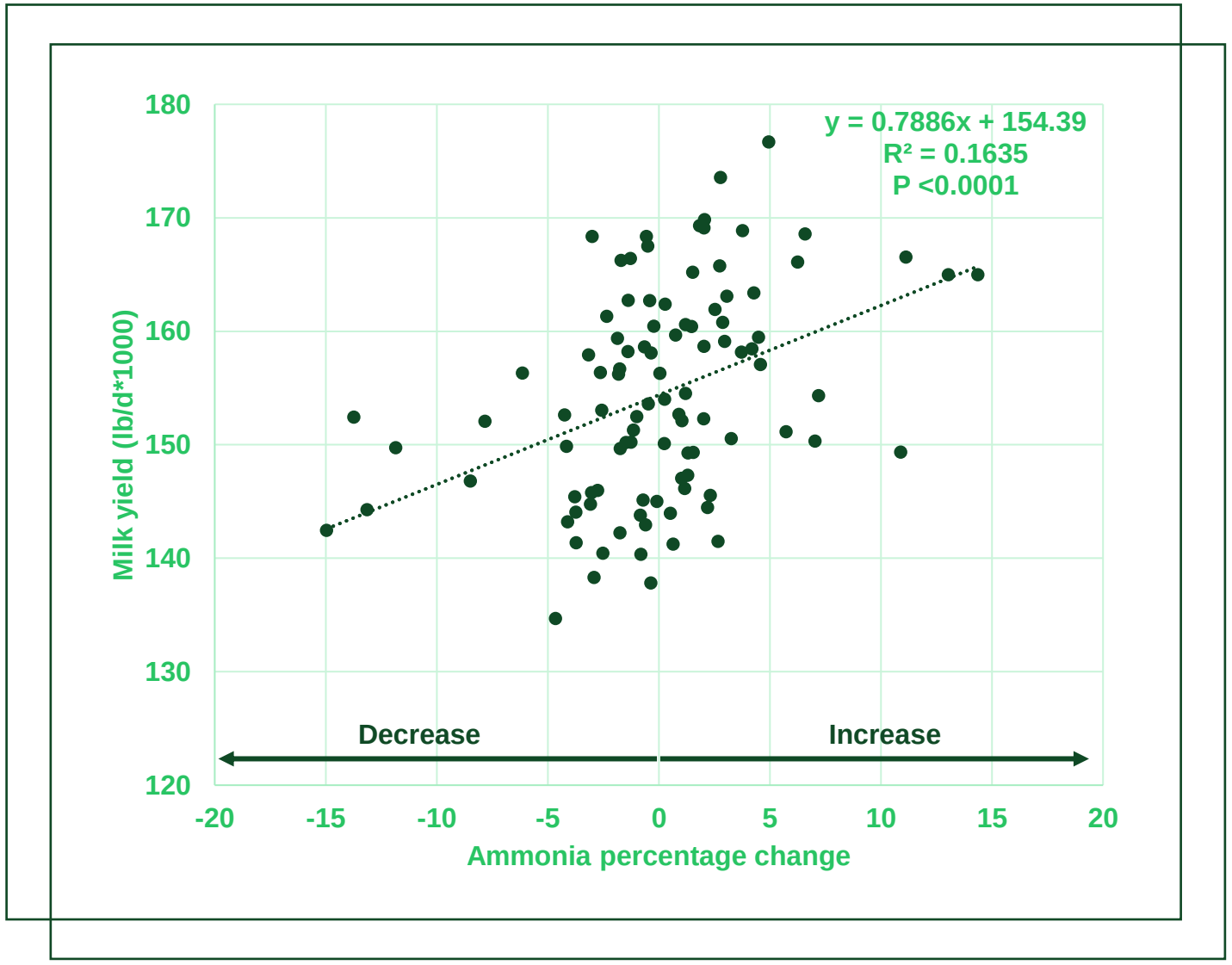


Daily ammonia change

- ↑ Daily Δ Ammonia
- ↑ Group milk yield
- ↑ 1000 lb./d milk yield
- ↑ ammonia by 2%

Increases in ammonia do not affect group milk yield



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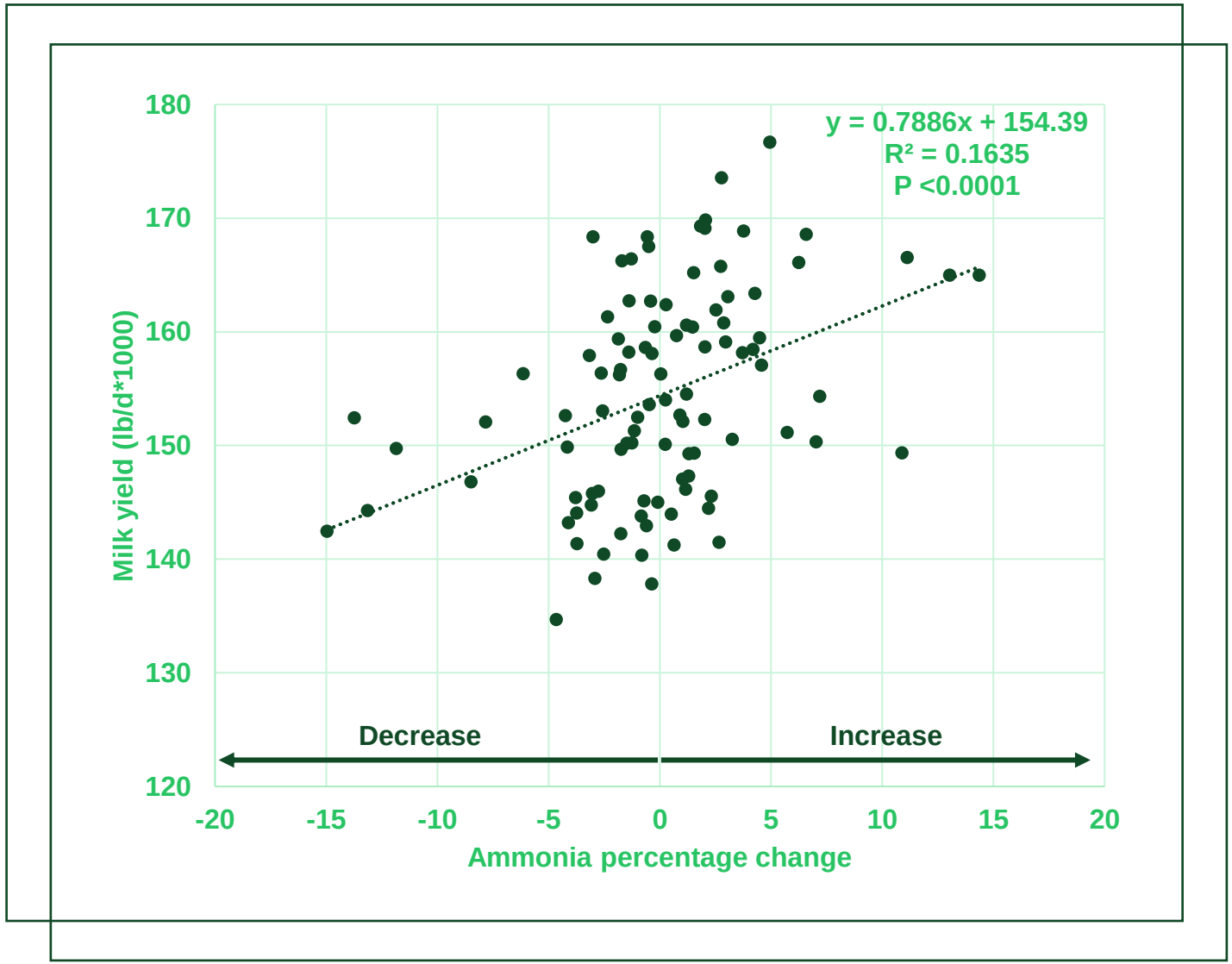
Daily ammonia change

- Can we use ammonia monitoring as a proxy of protein intake efficiency?
- How ammonia affects individual welfare?



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Farm activities & air component levels

- Visited the farm twice a week (7:30 to 10:00 am)
- 15 days of observation (24 august to 12 oct)
- Morning activities list:
  - ✓ Moving the cows to the parlor
  - ✓ Cleaning the barn
  - ✓ Feeding the cows
  - ✓ Cleaning the manure
  - ✓ Movement of different vehicles

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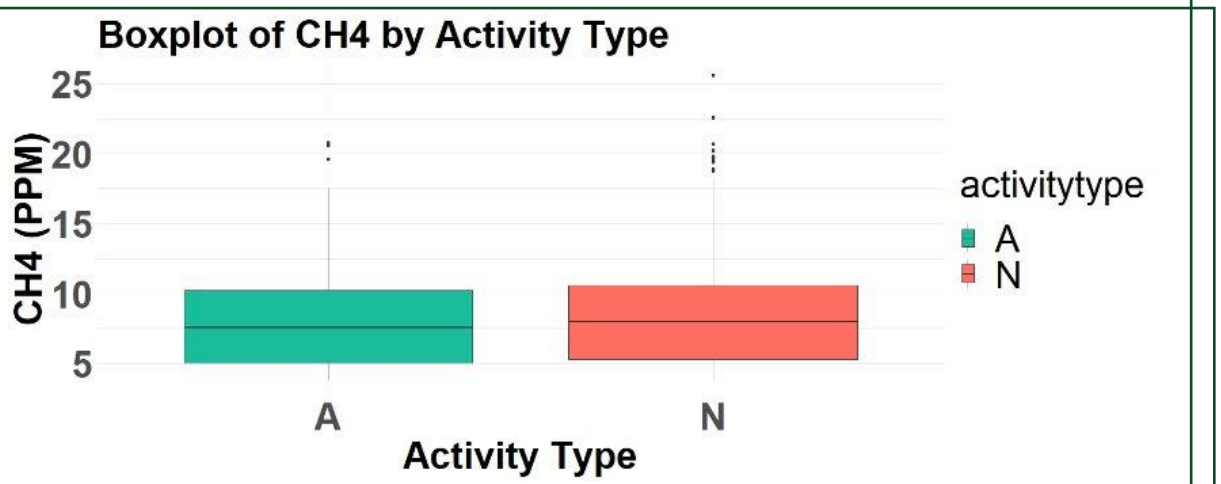
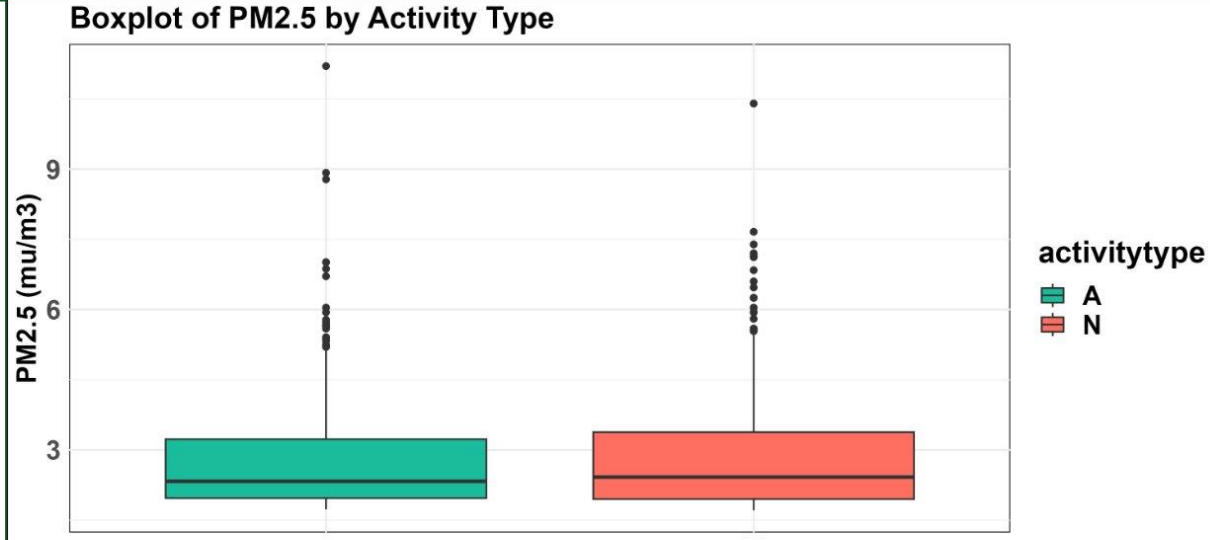
Farm activities & air component levels



Activity Type	Mean	SE	P-value
Activity	9.23	± 0.12	0.40
Non-activity	9.09	± 0.09	



Activity Type	Mean	SE	P-value
Activity	2.76	±0.05	0.61
Non-activity	2.79	±0.04	

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Limitations

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- Significant sensor degradation after 5 months
- ~10% out of detection range
- Location limited to power outlets
- “Insects attack”
- Lack of calibration protocols

Conclusions

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- Key air pollutants can be detected with this technology
- Patterns of AQ were observed and could be attributed to specific operations

Future research

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SUSTAINABLE SOLUTIONS
FOR ANIMAL AGRICULTURE

- Estimate sensor reliability & optimal sensor allocation
- Forced ventilation vs. natural ventilation
- Impact of specific farm activities
- Targeted interventions
  - Cleaning, curtains, bedding management.
- Defining air quality standards
  - Production
  - Animal welfare → Behavior cow comfort
  - Animal health

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SARE Western Sustainable Agriculture Research and Education

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DairyMAX YOUR Local Dairy Council

Dairy Cattle Welfare Council

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