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Mitigation of Greenhouse Gas Emissions from Dairy Farms: the cow, the manure, and the field

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Outline

1. Milk carbon footprint

2. Cow (enteric methane)

3. Manure (methane + nitrous oxide)

4. Field (nitrous oxide + carbon dioxide)

5. Real-world" systems (cow + manure + field)

6. Future

U.S. Milk Carbon Footprint circa 2008

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Thoma et al. (2013). Greenhous gas emissions from milk production and consumption in the United States: A cradle-to-grave life cycle assessment circa 2008. I. Dairy Jrnl. 31:S3-S14.

- 2.05 kg CO_2eq per kg milk consumed (90% CI: 1.77 – 2.4).
- The dairy sector contributes ~1.9% of US GHG emissions.

International Dairy Journal 31 (2013) S3–S14

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ELSEVIER

Greenhouse gas emissions from milk production and consumption in the United States: A cradle-to-grave life cycle assessment circa 2008

CrossMark

Greg Thoma [a,*], Jennie Popp [b], Darin Nutter [c], David Shonnard [d], Richard Ulrich [a], Marty Matlock [e], Dae Soo Kim [a], Zara Neiderman [e], Nathan Kemper [b], Cashion East [a], Felix Adom [d]

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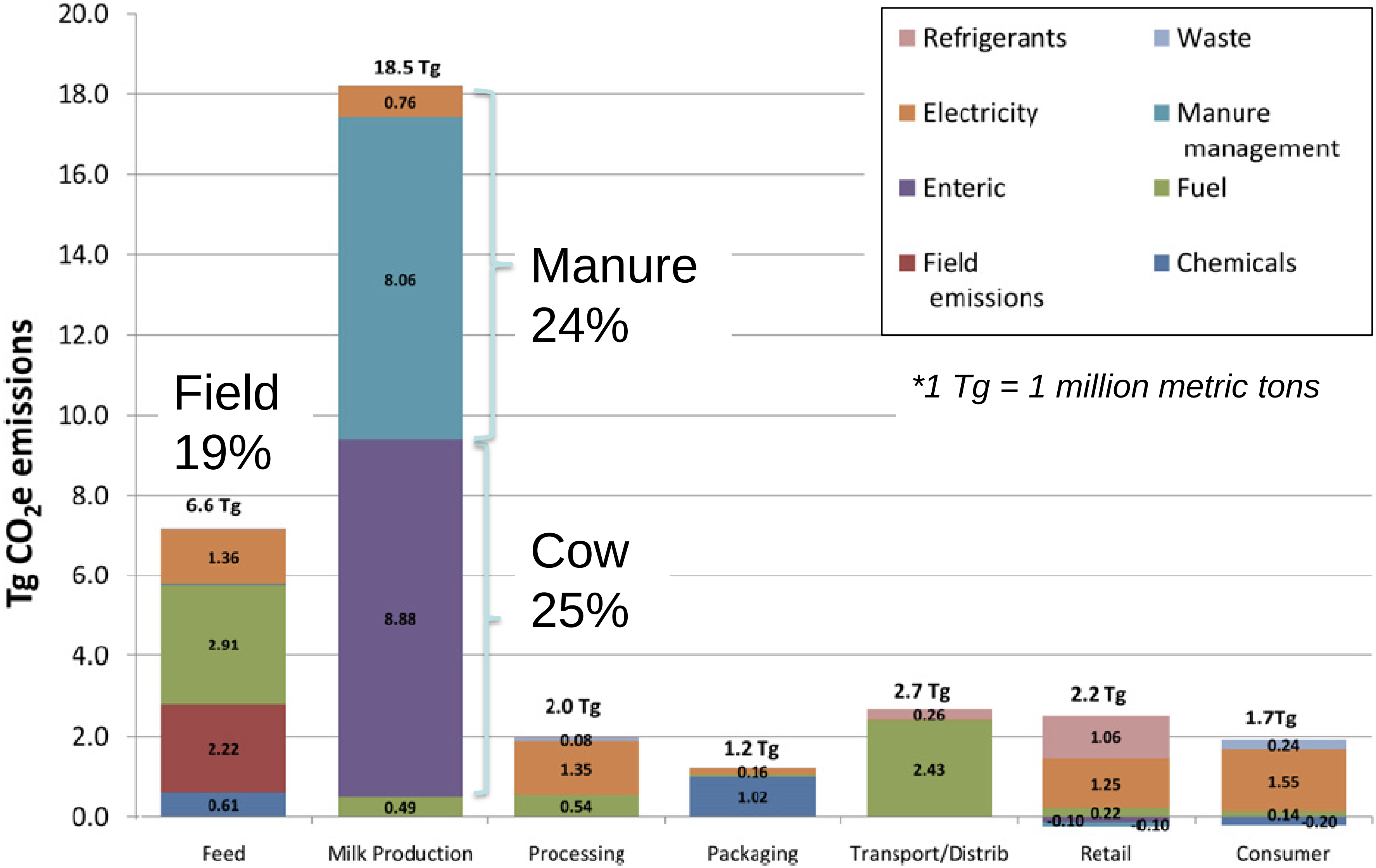
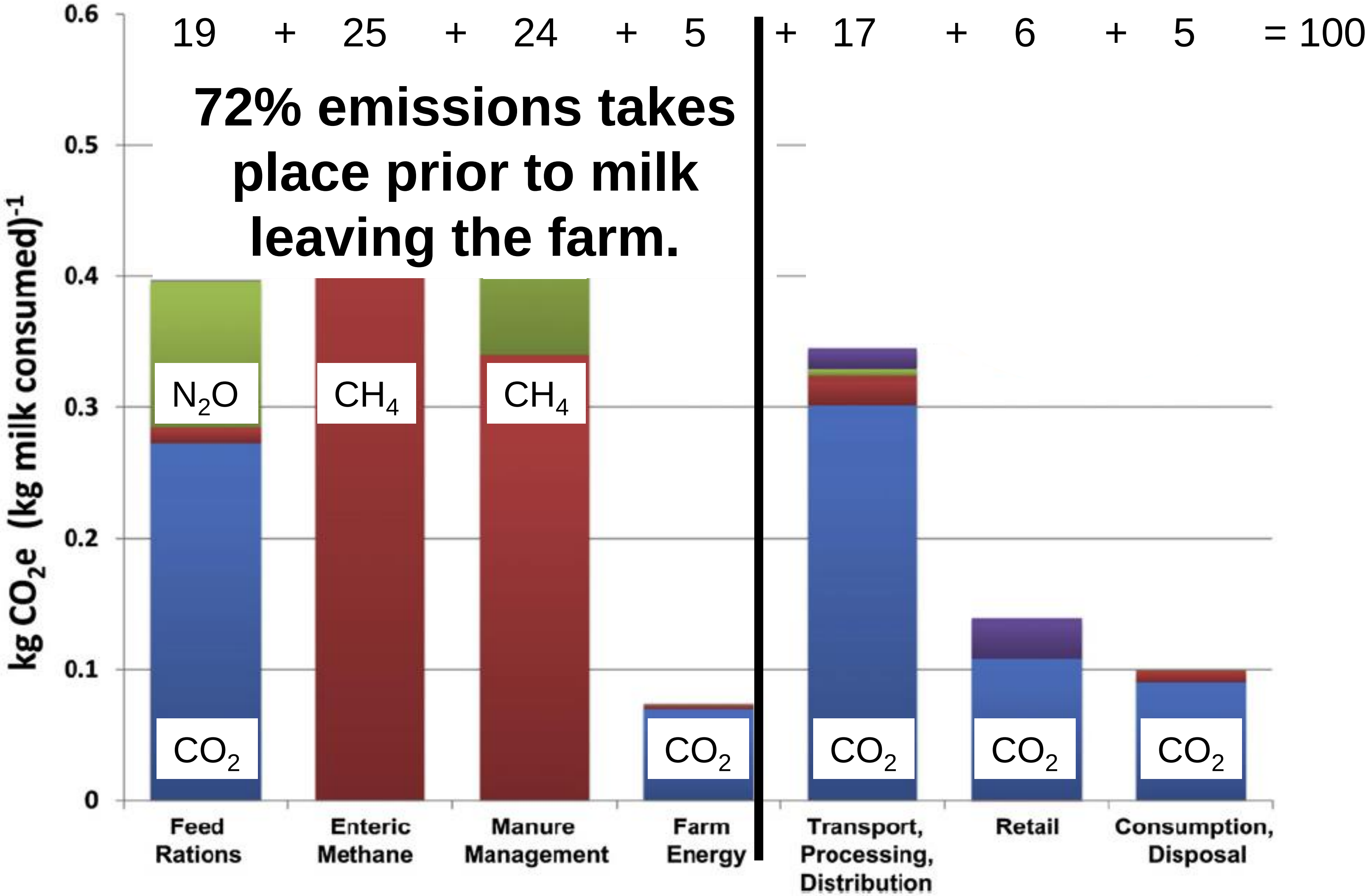
Sources of Emission from Supply Chain: (35 Tg CO2eq; 95% confidence 30 to 45 Tg)



Thoma et al. 2013. Greenhouse gas emissions from milk production and consumption in the United States: A cradle-to-grave life Cycle assessment. International Dairy Journal. 31:S3-S14.

Sources of Emissions: The Main Gases



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Cow: Predicting Enteric CH_4

Moraes et al. 2014. Prediction of enteric methane emissions from cattle. Global Change Biology 20:2140-2148.

Methane emission (MJ/d) from lactating cows

NDF and EE are the main dietary drivers influencing the availability of H_2, the main substrate for CH_4 formation.

Gross energy level

$$CH_4 = 3.247 + 0.043 \times GEI$$

Dietary level

$$CH_4 = 0.225 + 0.042 \times GEI + 0.125 \times NDF - 0.329 \times EE$$

Animal level

$$CH_4 = 9.311 + 0.042 \times GEI + 0.094 \times NDF - 0.381 \times EE + 0.008 \times BW + 1.621 \times MF$$

The more a cow eats the more CH_4 she produces.

Where:

GEI = Gross energy intake (MJ/d);

NDF = Dietary neutral detergent fiber proportion (% of dry matter);

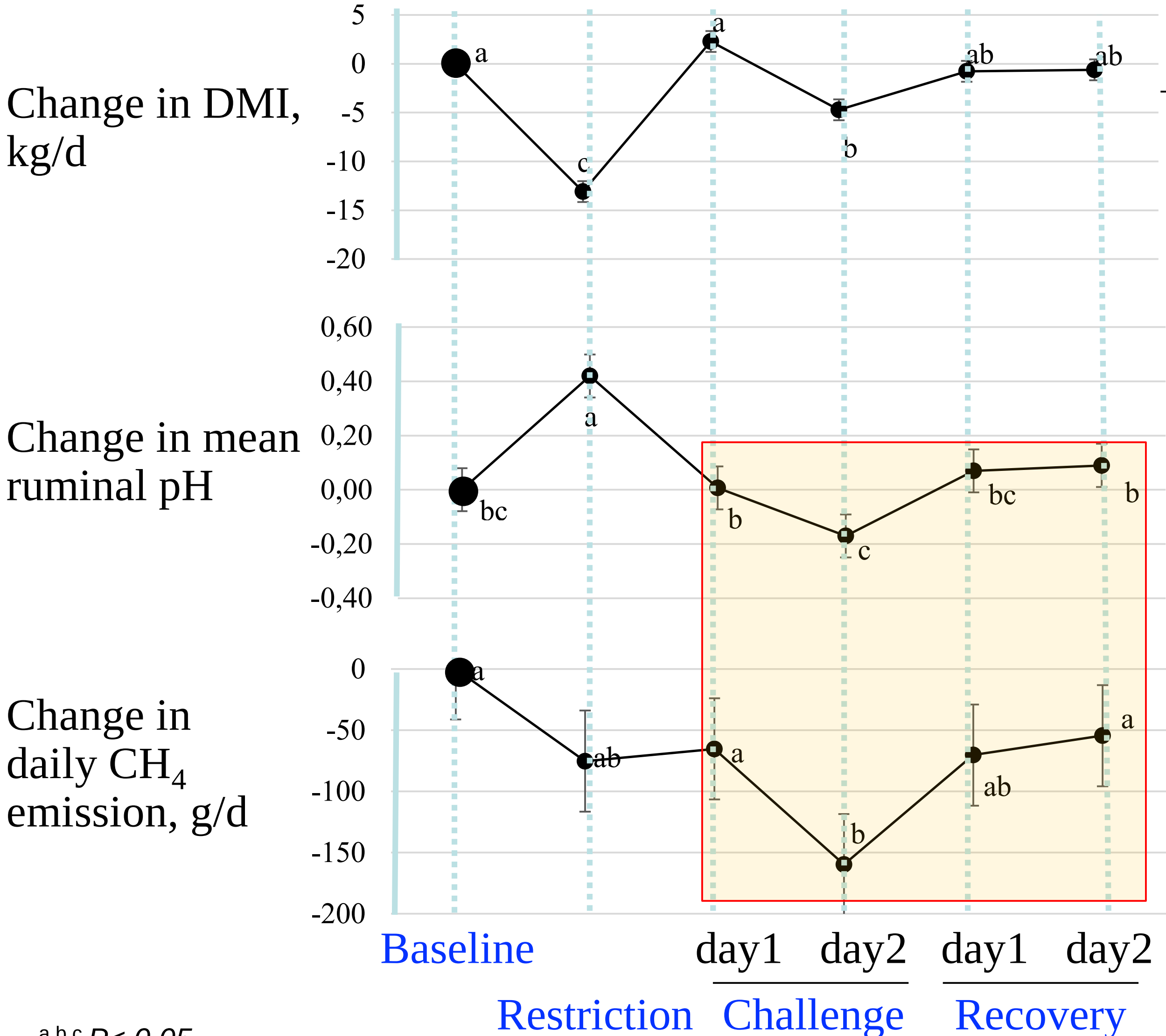
EE = Dietary ether extract proportion (% of dry matter);

BW = Body Weight (kg);

MF = Milk fat (%).

Cow: Ruminal pH and CH_4

Aguerre, Sun et al. unpublished.



Sub Acute Ruminal Acidosis (SARA) inducing protocol

Baseline diets:
67 or 45% forage DM

Feed Restriction:
50% of DMI observed during baseline

Challenge:
Baseline diet with an additional 20% grain pellet offered ad-libitum

Recovery:
Original baseline diet.

[a,b,c] *$P < 0.05$*

Methane production, yield and intensity

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Aguerre et al. (2011)
Forage vs. Concentrate

Arndt et al. (2015)
Alfalfa silage vs. Corn silage

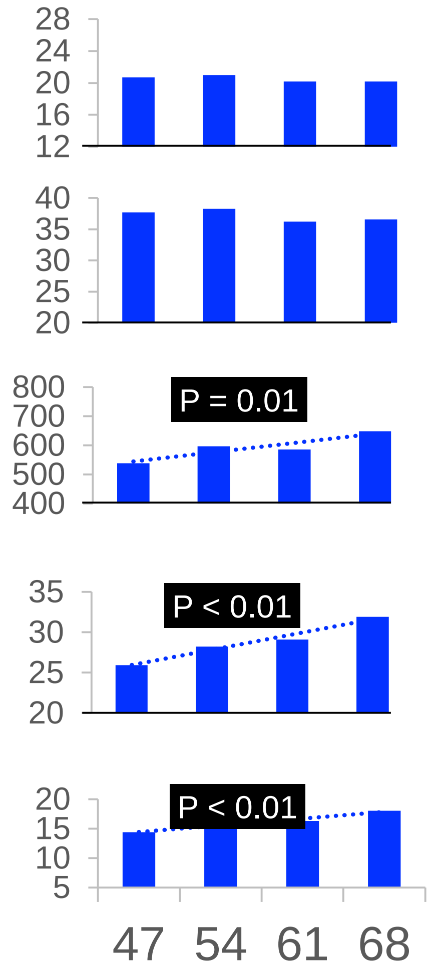
Feed Consumption
(DMI, kg/day)

Milk Production
(ECM, kg/day)

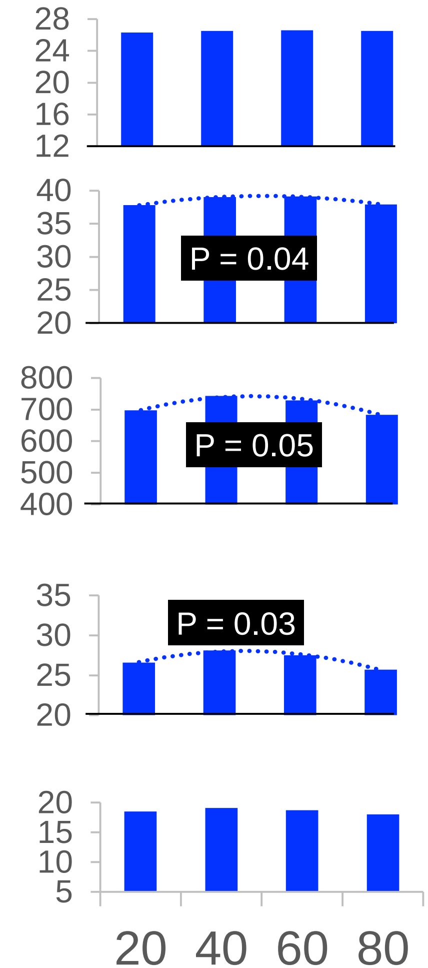
Methane production
(g/day)

Methane yield
(g/ kg DMI)

Methane intensity
(g/ kg ECM)



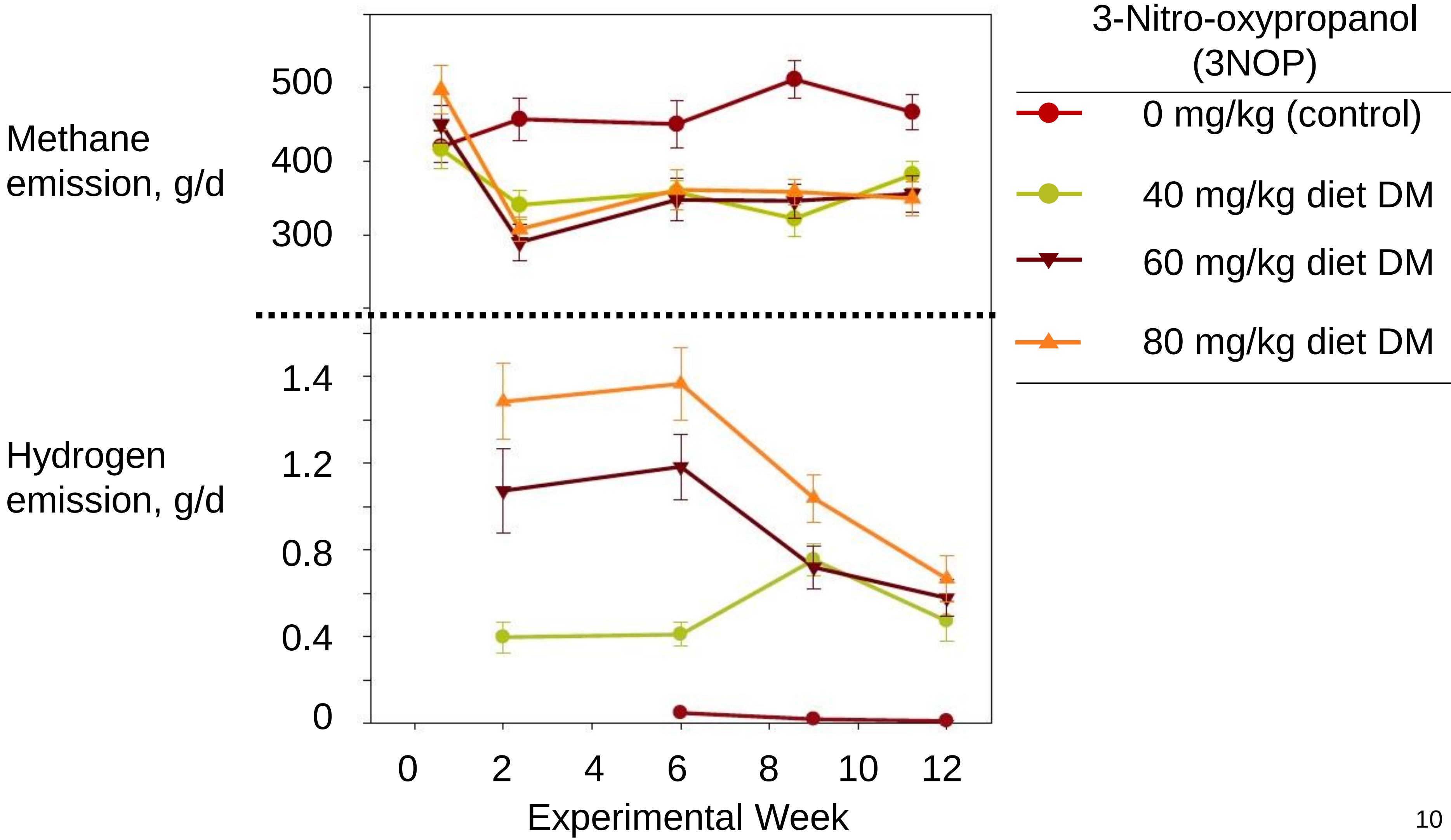
Forage
% dietary DM



Alfalfa silage
% Forage DM in the diet

Cow: Diet (additive)

Hirstov et al. 2015. An inhibitor persistently decreased enteric methan emission from dairy cows with no negative effect on milk production. PNAS. 112:10663-10668.



Cow: Efficiency

Arndt et al. 2013. Feed conversion efficiency in dairy cows: Repeatability, variation in digestion and metabolism of energy and nitrogen, and ruminal methanogens. J. Dairy Sci. 98:3938-3950

	Phenotypic Efficiency			
Item	High[1]	Low[1]	SEM	*P value*
BW, kg	633	696	30	0.18
DMI, kg/d	23.6	19.5	0.96	0.01
FPCM[2], kg/d	39.0	19.7	0.70	0.03
BW gain, kg/d	0.40	0.69	0.13	0.08
NDF Intake, kg/d	6.6	5.4	0.28	0.01
NDF Digestibility, %	46.0	49.7	1.40	0.14
NDF Digested, kg/d	3.0	2.7	0.18	0.22

[1] n = 16 cows in 8 pairs of high and low phenotypic efficiency cows with 16 DIM of each other with average DIM ranging from 106 to 368.

[2] Fat-and-protein corrected milk production.

Cow: Efficiency

Arndt et al. 2013. Feed conversion efficiency in dairy cows: Repeatability, variation in digestion and metabolism of energy and nitrogen, and ruminal methanogens. J. Dairy Sci. 98:3938-3950

	Phenotypic Efficiency			
Item	High[1]	Low[1]	SEM	*P value*
Methane production, kg/d	439	494	32.1	0.26
Methane yield, g/kg DMI	18.6	25.1	0.84	<0.01
Methane intensity, g/kg FPCM	10.6	30.4	3.59	<0.01
Methane / NDFD, g/kg	147	184	4.92	<0.01
% of total methanogens				
Methanosphaera Stadtmanae, LP	1.05	0.59	0.07	0.13
Methanbrevibacter spp. Strain AbM4, LP	1.29	1.36	0.08	0.54
Methanosphaera Stadtmanae, SP	1.39	1.08	0.20	0.32
Methanbrevibacter spp. Strain AbM4, SP	1.14	1.79	0.17	0.01

[1] LP= Liquid phase, SP = Solid phase.

Cow: Efficiency

Arndt et al. 2013. Feed conversion efficiency in dairy cows: Repeatability, variation in digestion and metabolism of energy and nitrogen, and ruminal methanogens. J. Dairy Sci. 98:3938-3950

	Phenotypic Efficiency			
Energy Partitioning	High	Low	SEM	*Valor P*
Gross energy Intake, %	100	100	--	--
Fecal energy, %	28.6	25.9	0.70	0.03
Digestible energy, %	71.4	74.1	0.70	0.03
Urine energy, %	2.76	3.40	0.12	<0.01
Methane energy, %	5.23	6.99	0.24	<0.01
Metabolizable energy, %	63.5	63.7	0.52	0.76
Net $energy_{mlg}$,%	37.5	32.6	1.45	0.01
Heat $energy_{mlg}$, %	26.0	31.1	1.33	0.02

[1] Gross energy intake of high and low efficient cows was 111.5 y 92.8 Mcal/d, respectively.

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3. **Manure (methane + nitrous oxide)**
4. Field (nitrous oxide + carbon dioxide)
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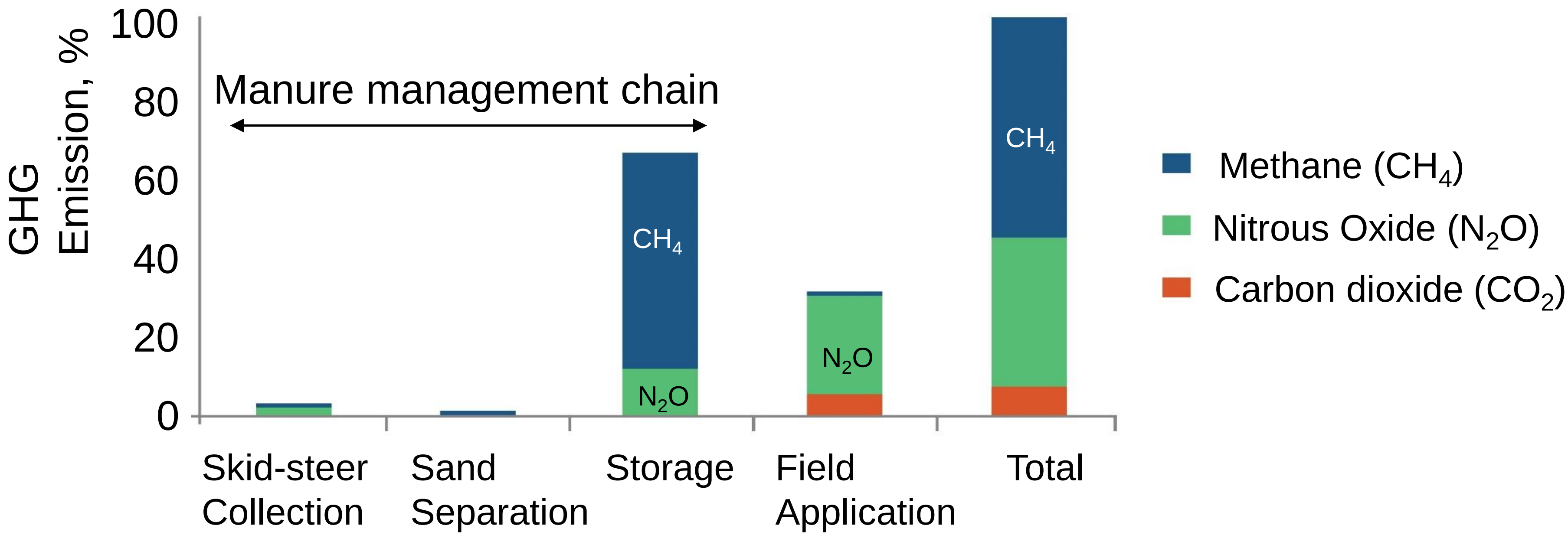
Manure: A Source of Fertilization and a Source of CH_4 & N_2O

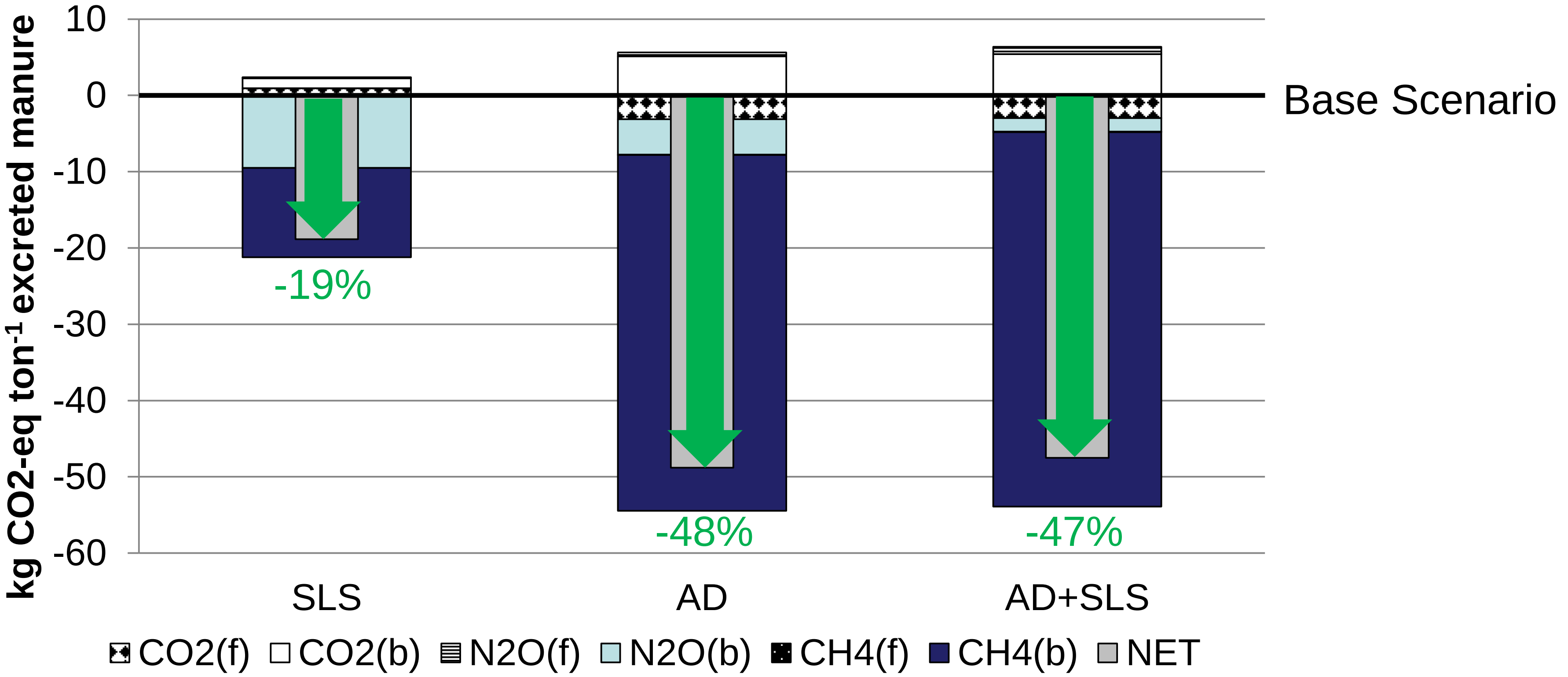
Aguirre-Villegas et al. 2017. Greenhouse gas and ammonia emissions from dairy manure management systems. UW-Extension UWEX A4131-05.

An average dairy cow (~635 kg) produces ~24,500 kg of manure each year including:	Fertilization of 1 ha of corn
• 160 kg N	30-160 kg N
• 18 kg P	20- 60 kg P
• 118 kg K	40-180 kg K



Manure: Solid-Liquid Separation (SLS) and Anaerobic Digestion (AD)

Aguirre-Villegas, H. A., Larson, R. and Reinemann, D. J. (2014), From waste-to-worth: energy, emissions, and nutrient implications of manure processing pathways. Biofuels, Bioprod. Bioref., 8: 770–793. doi:10.1002/bbb.1496



SLS = Solid-Liquid Separation
AD = Anaerobic Digestion

(f) = Fossil fuel emission
(b) = biotic emission

Manure: Solid-Liquid Separation (SLS) and Anaerobic Digestion (AD)

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Per ton of excreted manure in base-case		SLS	AD	SLS+AD	Electric Grid
Global Warming Pot.	101.2 kg CO_2eq	-19%	-48%	-47%	
Depletion fossil fuel[1]	106.1 MJ	+13%	-43%	-40%	
Ammonia emission	2.62 kg	+2%	+40%	+44%	
Plant Available N	2.45 kg	±0%	↙	↙	
FER[2] = Usable $energy_{out}$ / Fossil $energy_{in}$			3.7		0.29
ERIR[3] = Usable $energy_{out}$ / Total $energy_{in}$			0.98-1.80		0.27

SLS = Solid-Liquid Separator   AD = Anaerobic Digestor

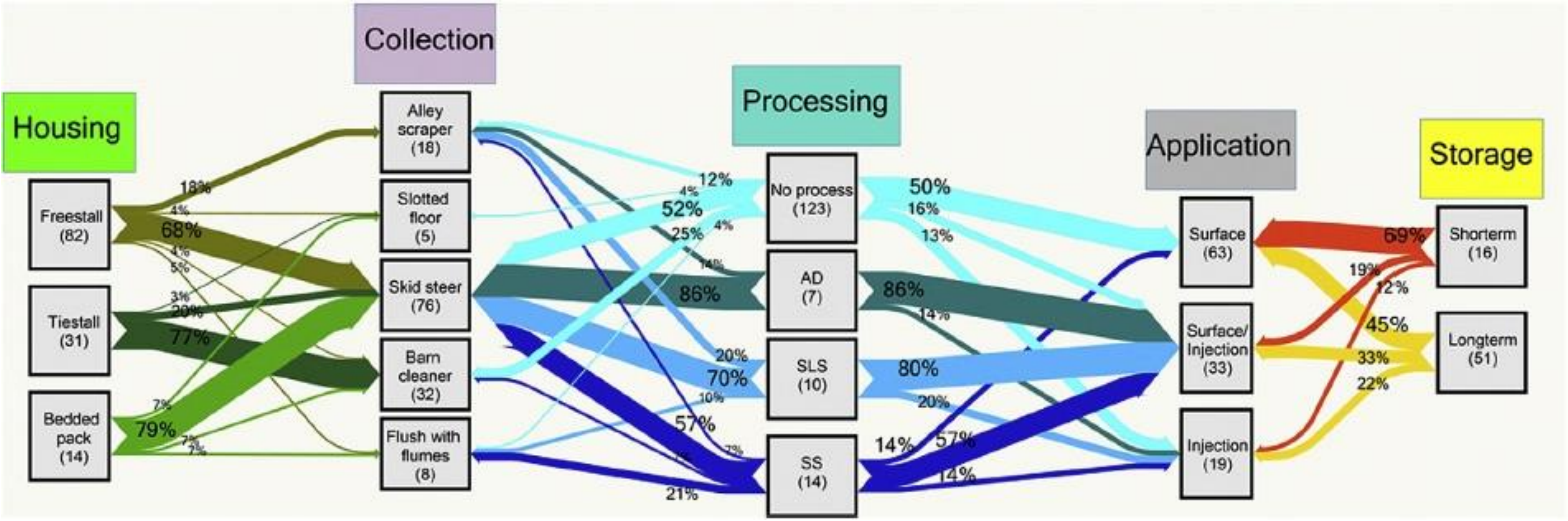
[1]Depletion fossil Fuel = Energy consumed in the production and delivery of that energy product

[2]FER= Fossil Energy Ratio

[3]ERIR = Energy Return on Investment Ratio

Manure: Wisconsin Farm Survey & Modelling

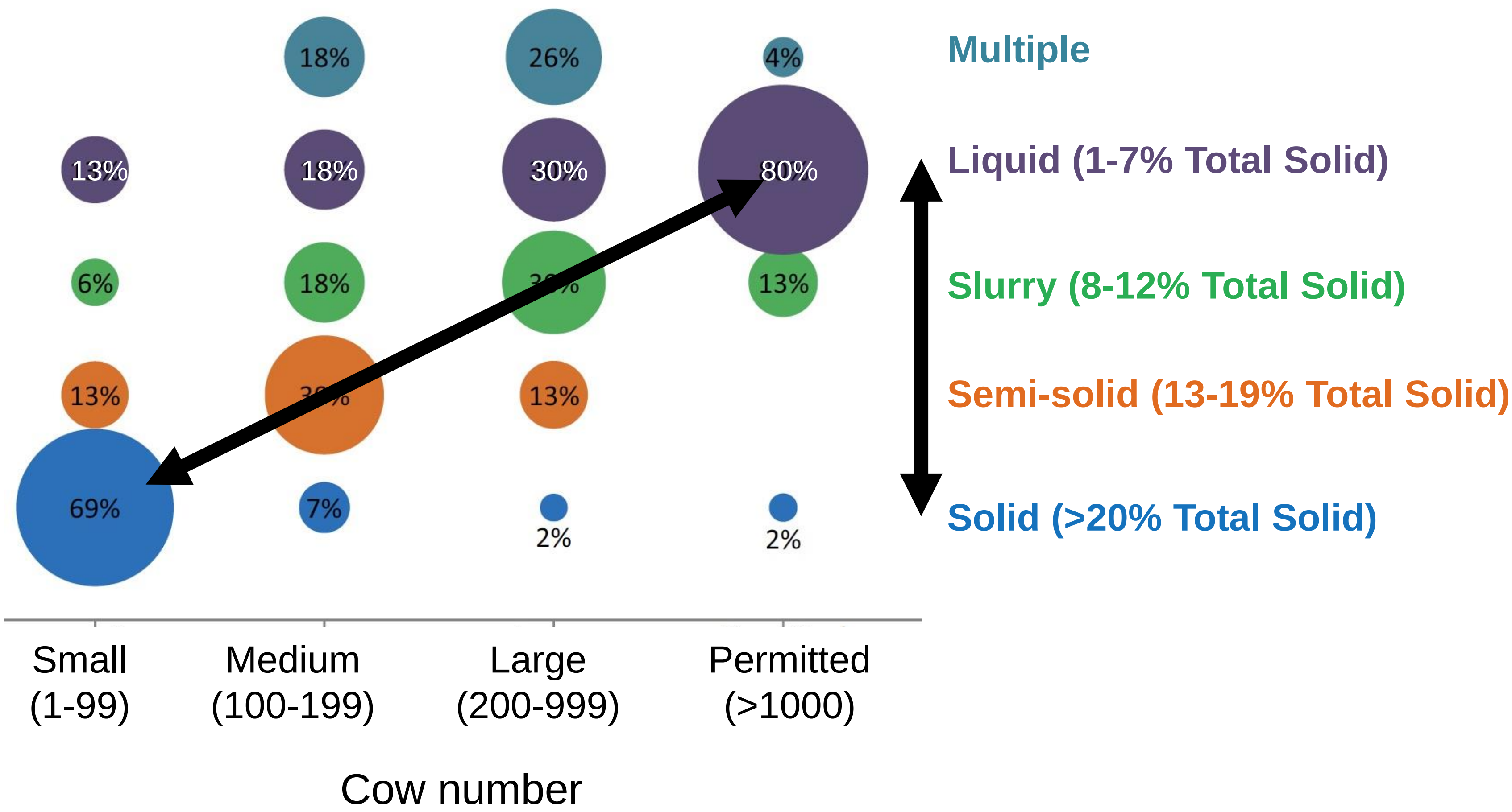
Aguirre-Villegas, H. A., and R. Larson. 2017. evaluating greenhouse gase emissions from dairy manure management practices using survey data and lifecycle tools J. Cleaner Production 143:169-179



Housing	Collection	Processing	Application	Storage
Freestall (82)	Alley scrapper (18)	No processing (123)	Surface (63)	Short term (16)
Tiestall (31)	Slotted floor (5)	Anaerobic Digestor (7)	Surf./Inject (33)	Long term (51)
Bedded pack (14)	Skid steer (76)	Solid-Liquid separator (10)	Injection (19)	
	Barn cleaner (32)	Sand Separation (14)		
	Flush w/flumes (8)			

Manure: Wisconsin Farm Survey & Modelling

Aguirre-Villegas, H. A., and R. Larson. 2017. Evaluating greenhouse gases emissions from dairy manure management practices using survey data and lifecycle tools J. Cleaner Production 143:169-179



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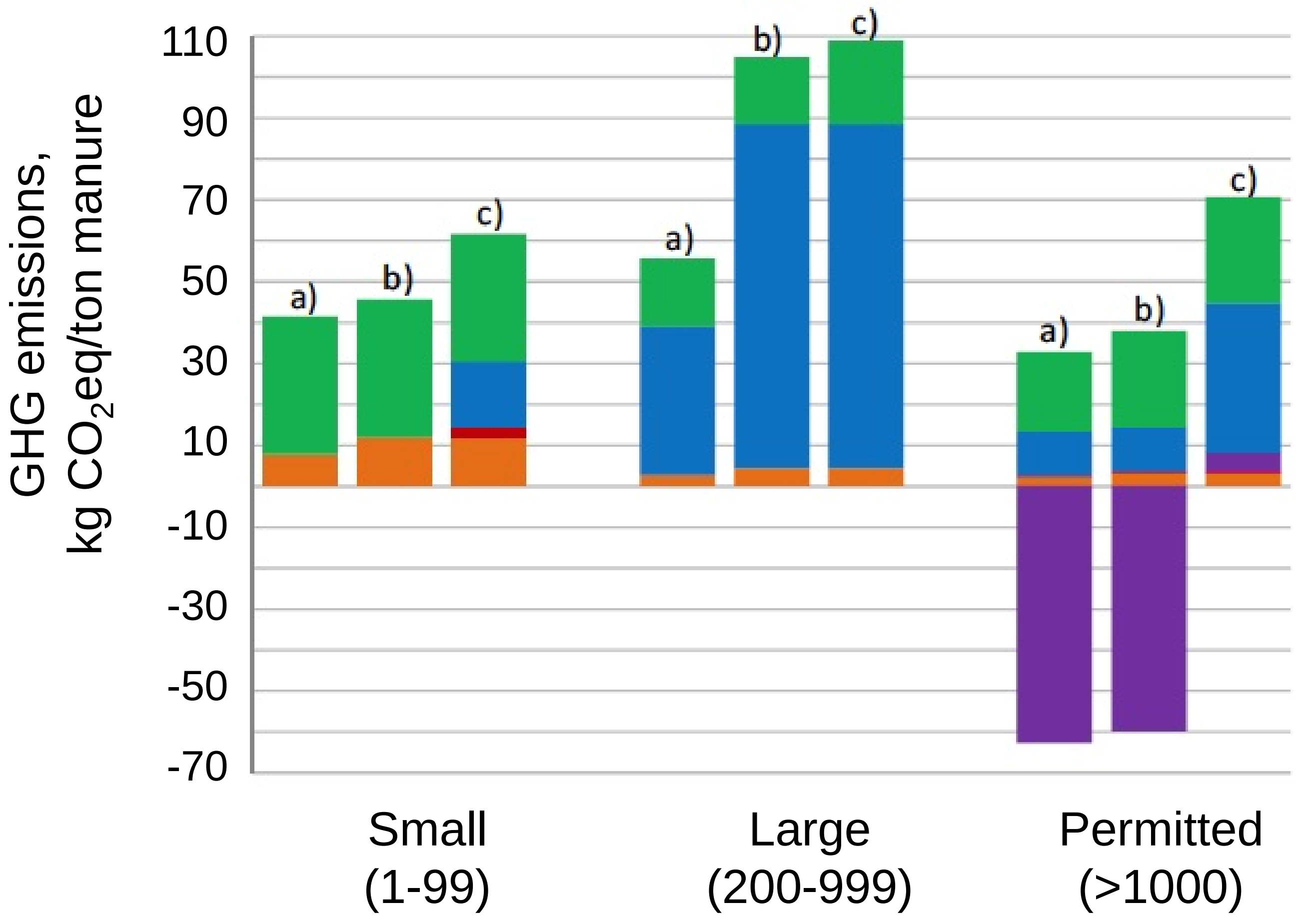

Sources

- Field application
- Storage
- Transport
- Processing
- Collection

Emitting Senarios:

a) low emitting
b) reference
c) high emitting

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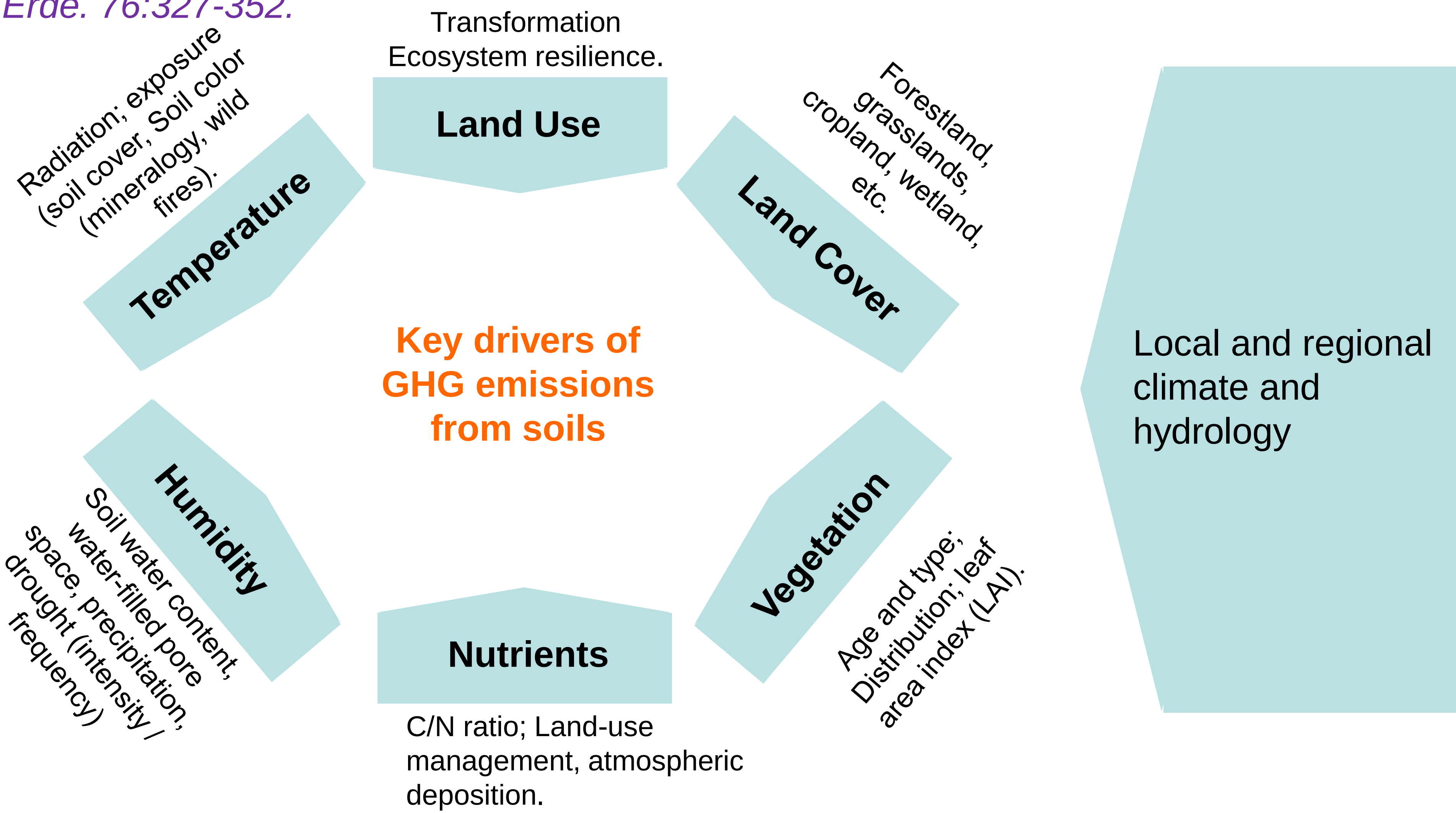
4. **Field (nitrous oxide + carbon dioxide)**

5. Comparison of “real-world” systems (cow + manure + field)

6. Future

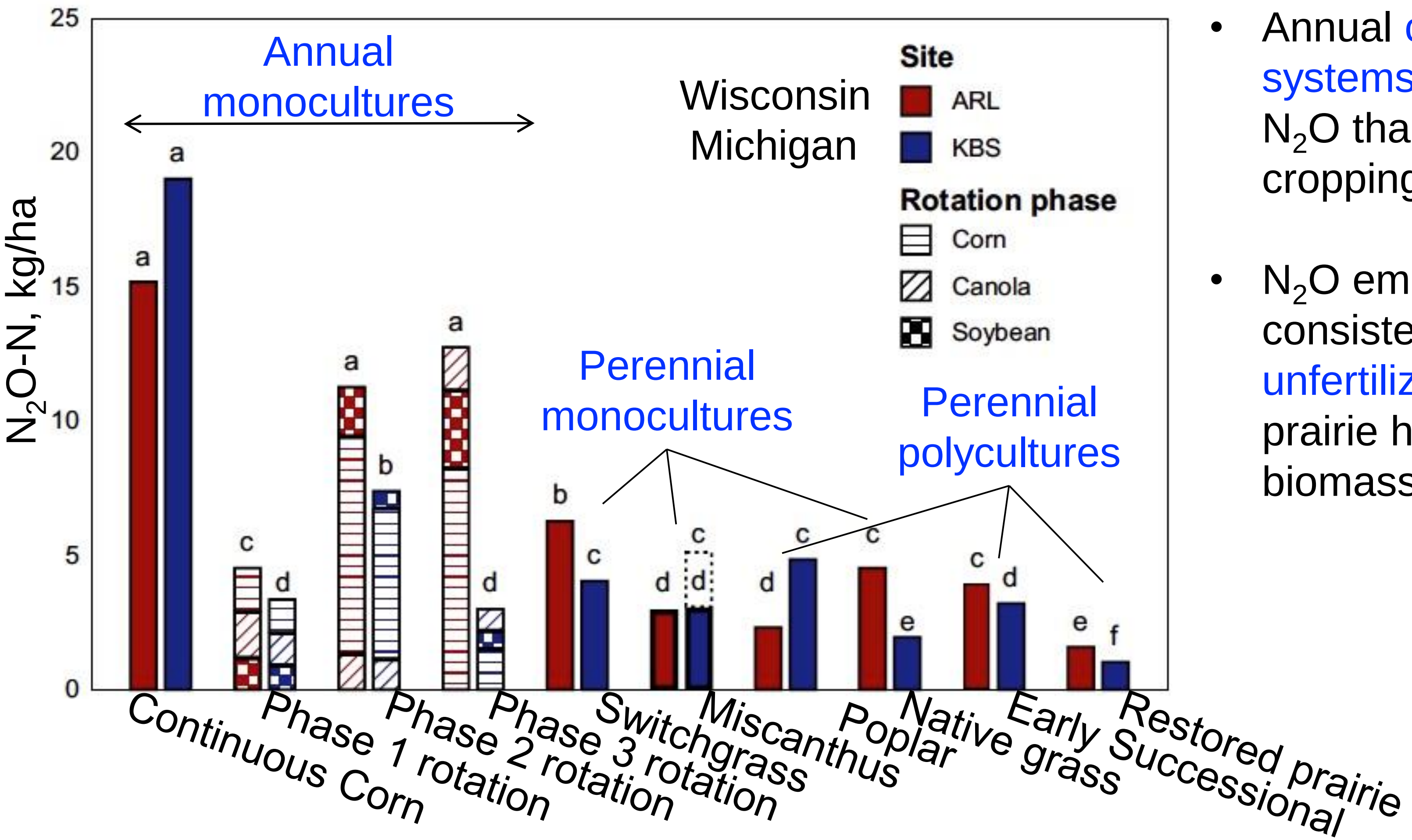
Drivers of GHG Emission from Soils

Cornelius et al. 2016. Greenhouse gas emissions from soils— A review. Chemie der Erde. 76:327-352.



Field: N_2O Emission

Oates et al. 2016. Nitrous Oxide emissions during establishment of eight alternative cellulosic bioenergy cropping systems in the North Central United States. Global Change Biology Bioenergy. 8:539-549.



Authors' Findings

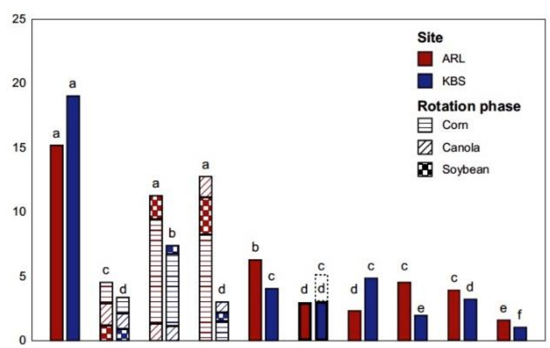
- Annual cropping systems emit more N_2O than perennial cropping systems.
- N_2O emissions were consistently low for unfertilized, restored prairie harvested for biomass.

Field: N_2O Emission

Oates et al. 2016. Nitrous Oxide emissions during establishment of eight alternative cellulosic bioenergy cropping systems in the North Central United States. Global Change Biology Bioenergy. 8:539-549.

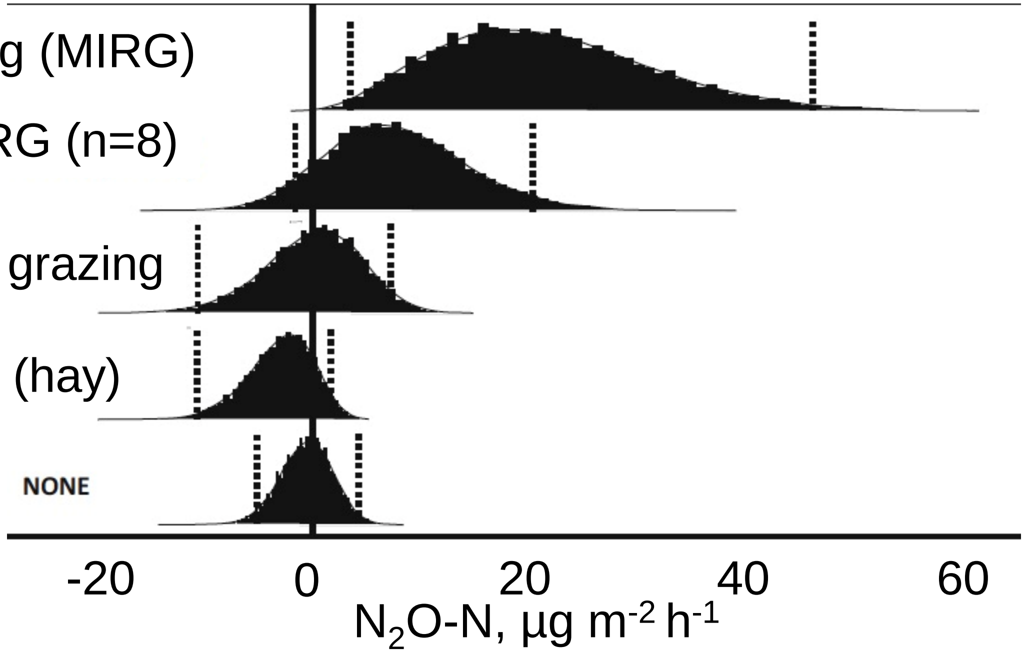
Authors' Findings (cont'd)

- Weather conditions: N_2O peak fluxes typically were associated with precipitation events that closely followed fertilization.
- Soil type: Highly productive mollisols had higher N_2O emissions than moderately productive alfisols.
- Rotations: Diversifying (annual) rotations reduces N_2O.
- Fertilization: Perennial grasslands emit some N_2O, more when fertilized, less when more diverse.



Field (Pasture): N_2O Emission

Jackson et al. 2015. Nitrous Oxide emissions rom cool-season pastures under managed grazing. Nutr. Cycl. Agroecosyst. 101:365-376.



Authors' Findings

- Grazing management of perennial grasslands influence N_2O emission.
- Rainfall: Significant spikes of N_2O emission occurred immediately following grazing and precipitation events.
- If you wish to stop all N_2O emission, remove cattle: Perennial grasslands continuously grazed or harvested for hay are essentially not emitting any N_2O.

Field: Wisconsin Integrated Cropping System Trial (WICST)

WICST, located at the UW-Madison experimental research station at Arlington, offers 60 acres of land and 29 years of data available for use in long-term studies on the productivity, profitability, and environment impact of organic and conventional agricultural (https://wicst.wisc.edu)

Field: The 6 WISCT Cropping Systems (CS)

Cash-grain CS:

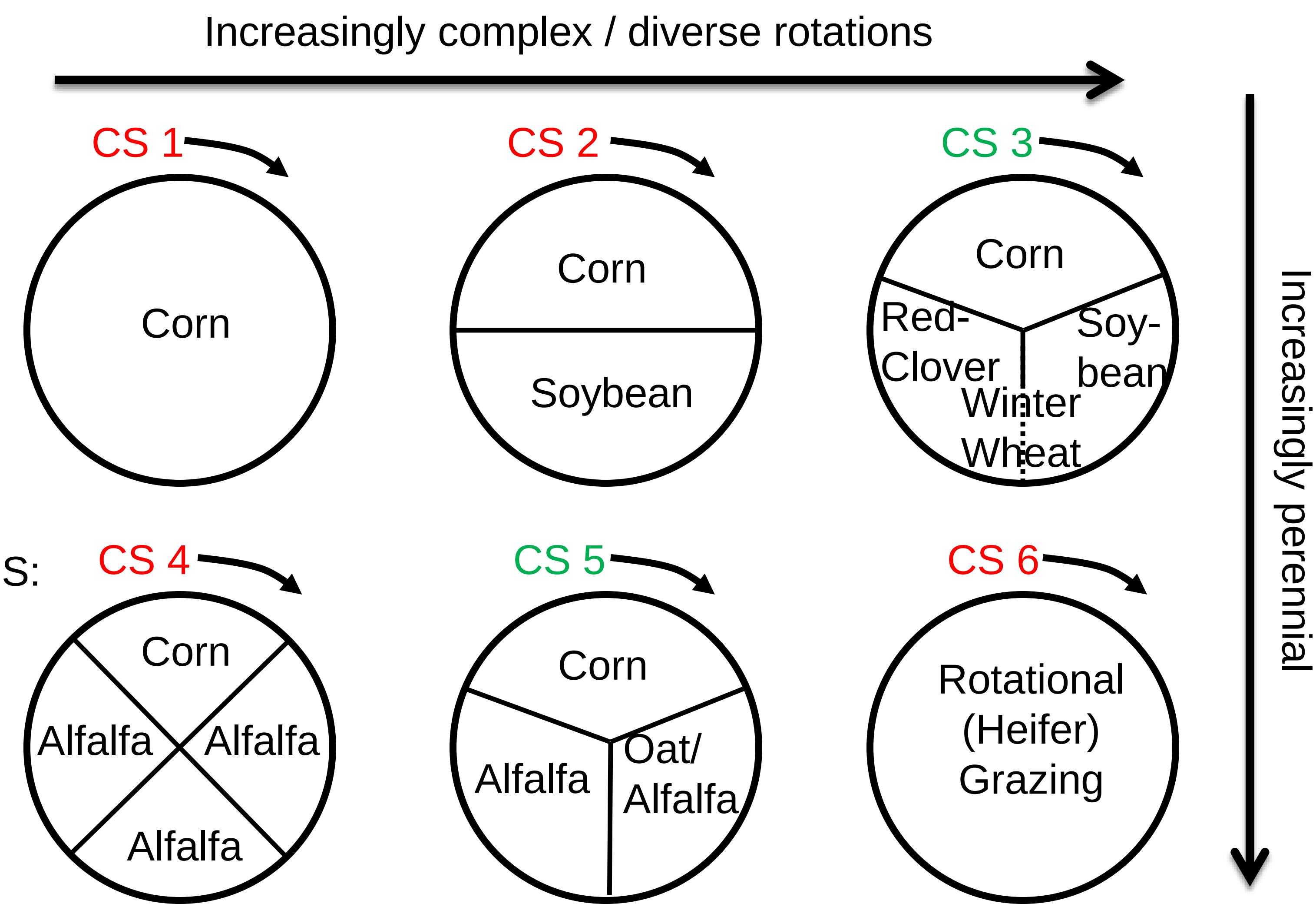
Conventional

Organic

Dairy Forage CS:

Conventional

Organic



Field: WISCT Results (Carbon sequestration?)

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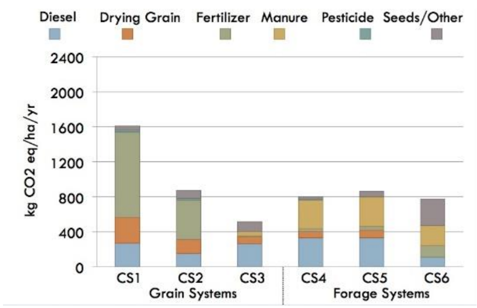
A) Embedded emissions

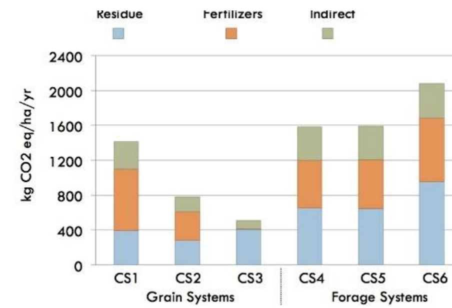


- Diesel
- Drying grain
- Fertilizer
- Manure
- Pesticide
- Seeds
- Other

Regardless of cropping system the soil emits CO_2.

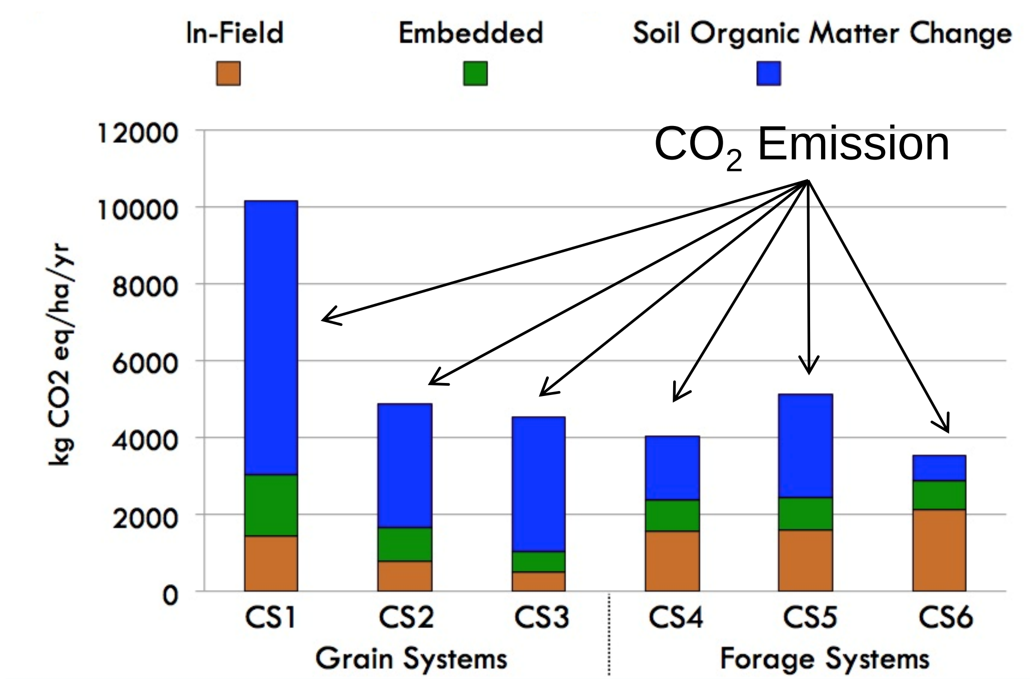
However, the rate of CO_2 emission vary considerably among cropping systems.

B) In-field emissions



- Residue
- Fertilizers
- Indirect

C) Embedded, in-field emissions and soil organic matter change



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Grass-based vs. Indoor
(New Zealand vs. Sweden)

Flysjö et al. 2013. The impact of various parameters on the carbon footprint of milk in New Zealand and Sweden. Agricultural Systems 104:459-469

New Zealand

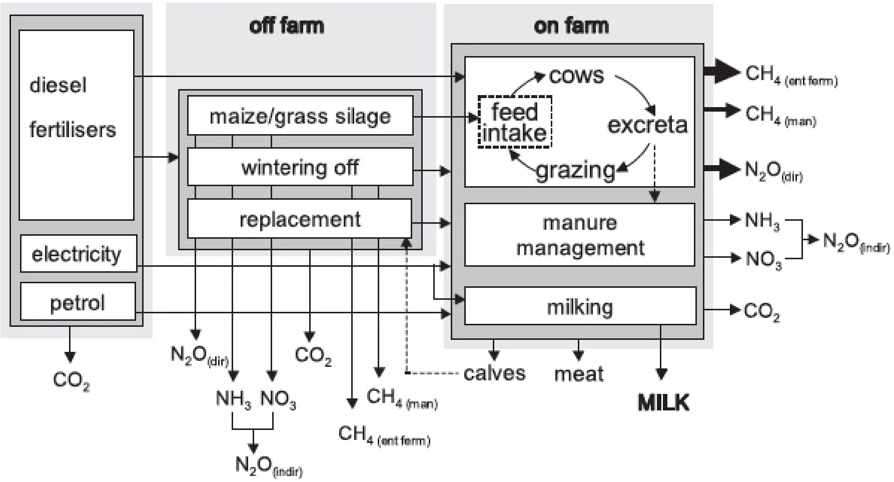
Outdoor, grass-based

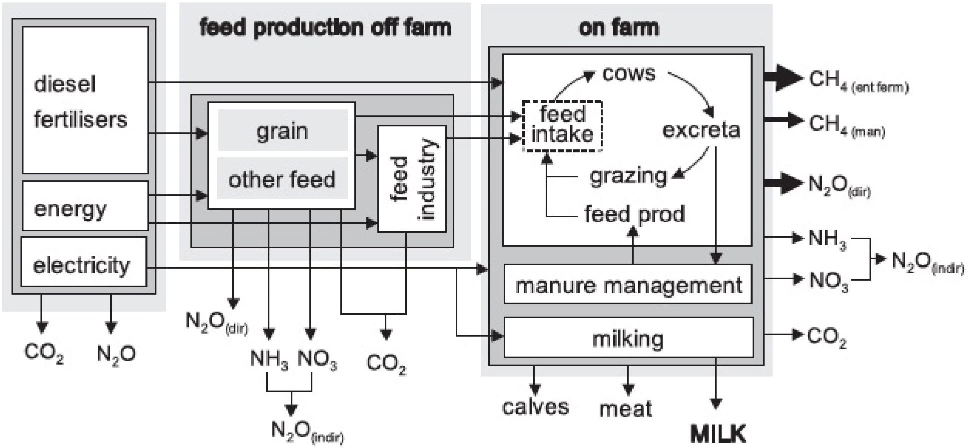
1.00 CO_2eq / kg ECM

Sweden

Indoor, mixed ration

1.16 CO_2eq / kg ECM





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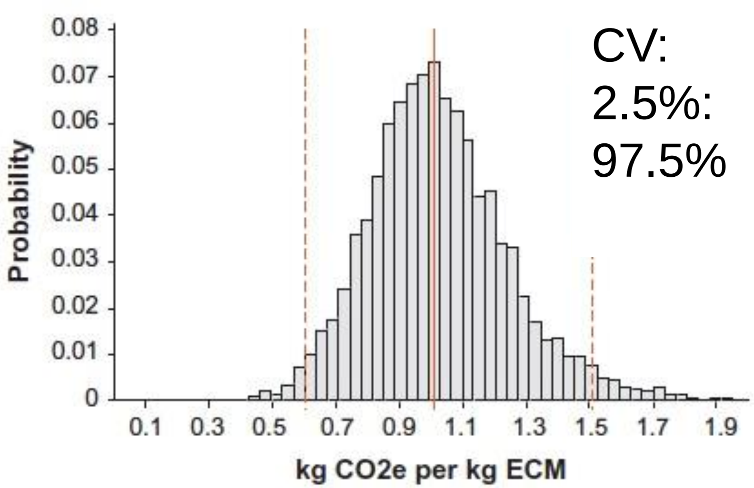
New Zealand

Outdoor, grass-based

1.00 CO_2eq / kg ECM

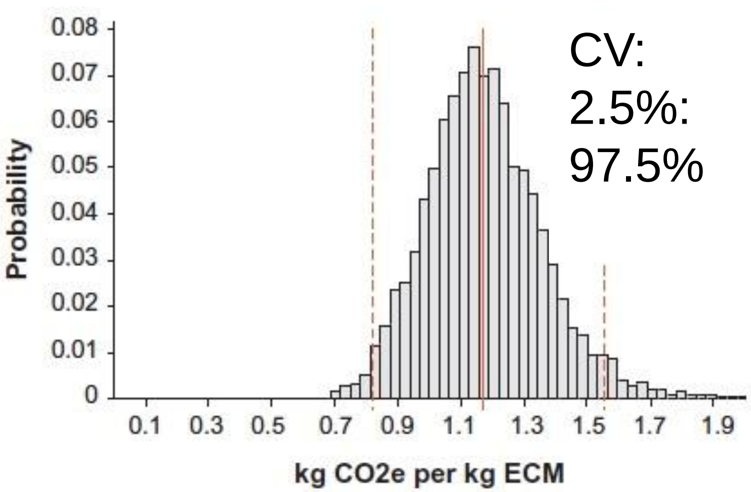


CV: 25.8%
2.5%: 0.60
97.5% 1.52

Sweden

Indoor, mixed ration

1.06 CO_2eq / kg ECM



CV: 16.2%
2.5%: 0.83
97.5% 1.56

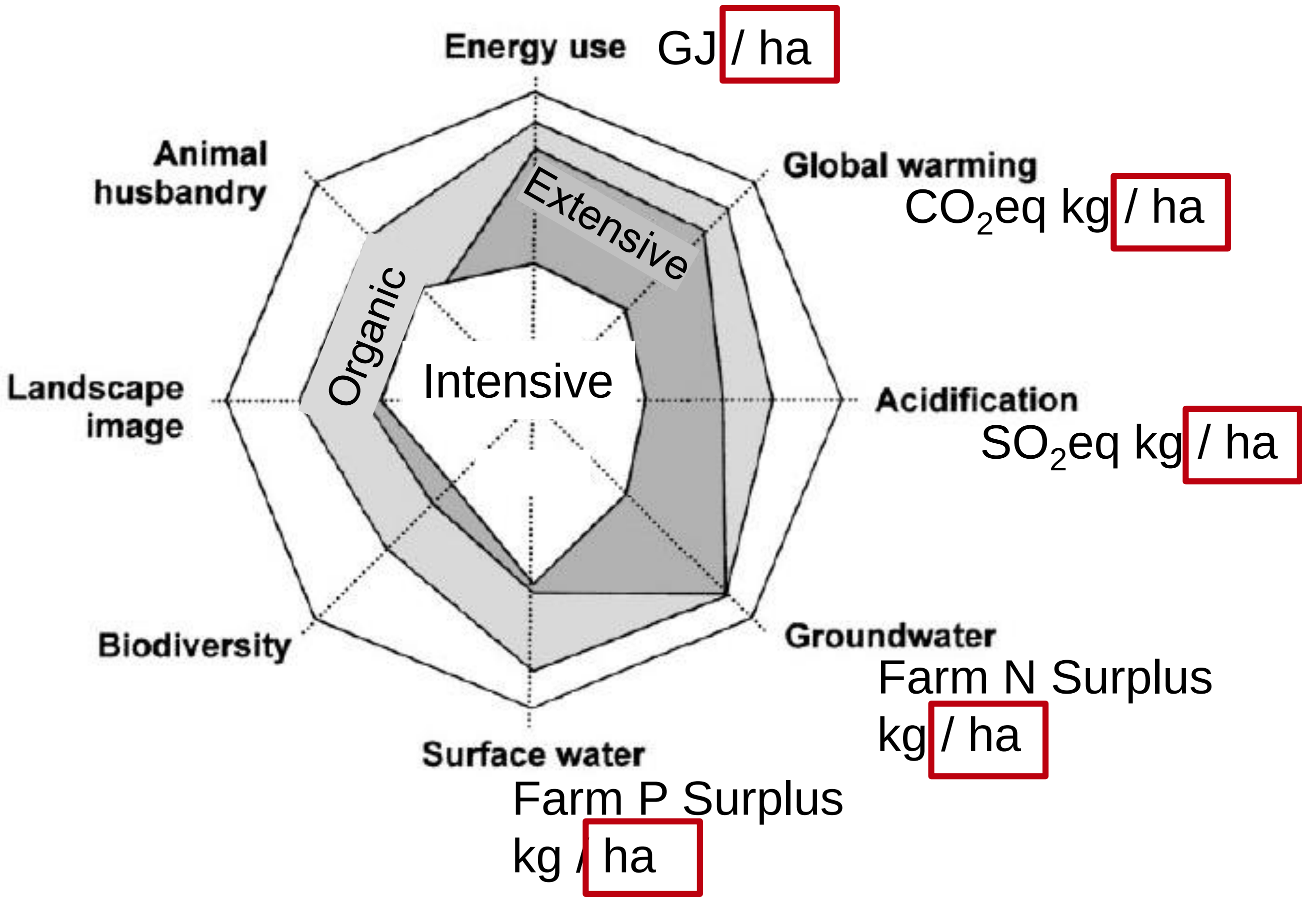
Intensive, Extensive, Organic (Germany)

Haas et al. 2001. Comparing intensive, extensified and organic grassland farming in southern Germany by process life cycle assessment. Agric., Ecosy., and Envir. 83:43-53.

"Ameba" graph showing 8 dimensions (indicators) of sustainability.

Values closer to the outer edge are more desirables.

Notice the functional unit (denominator) used by the authors (Agronomists?!)



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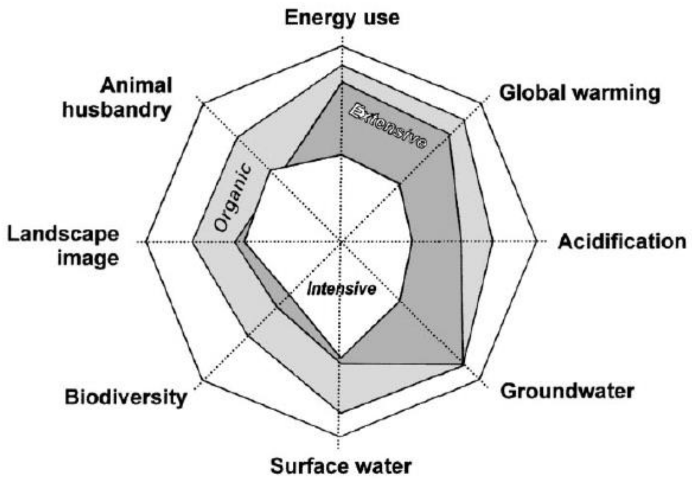


Authors' Conclusions

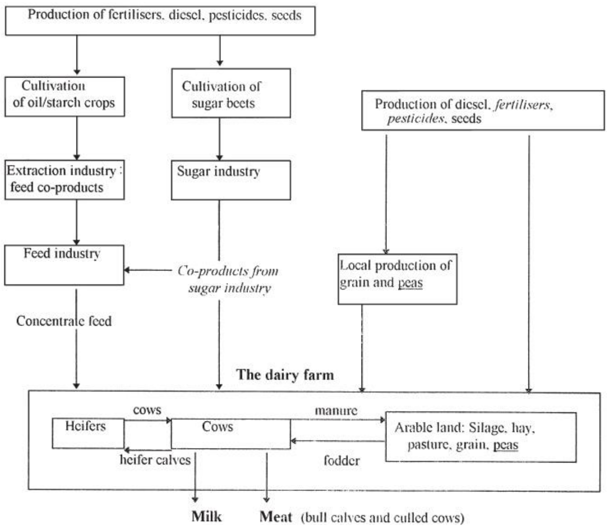
- *Renouncing mineral nitrogen fertilizer could reduce negative effects in the abiotic impact categories of:*
  - *energy use,*
  - *global warming potential, and*
  - *ground water.*
- *Basis of evaluation should be what?*
  - *reference data,*
  - *limiting values,*
  - *critical load limits*
  - *Index ?*

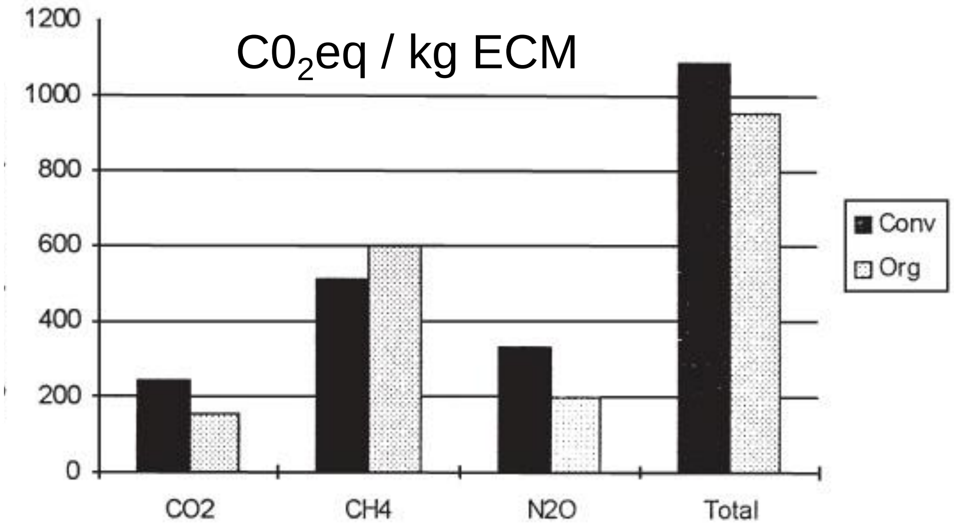
- *Estimations made in the biotic and aesthetic subranges are more or less subjective.... Experts and local people should achieve consensus if further LCAs on a broader base will be undertaken in the region.*

Conventional vs. Organic (Sweden)

Cederberg and Mattsson. 2000. Life cycle assessment of milk production — a comparison of conventional and organic farming. J. Cleaner Production 8:49-60.

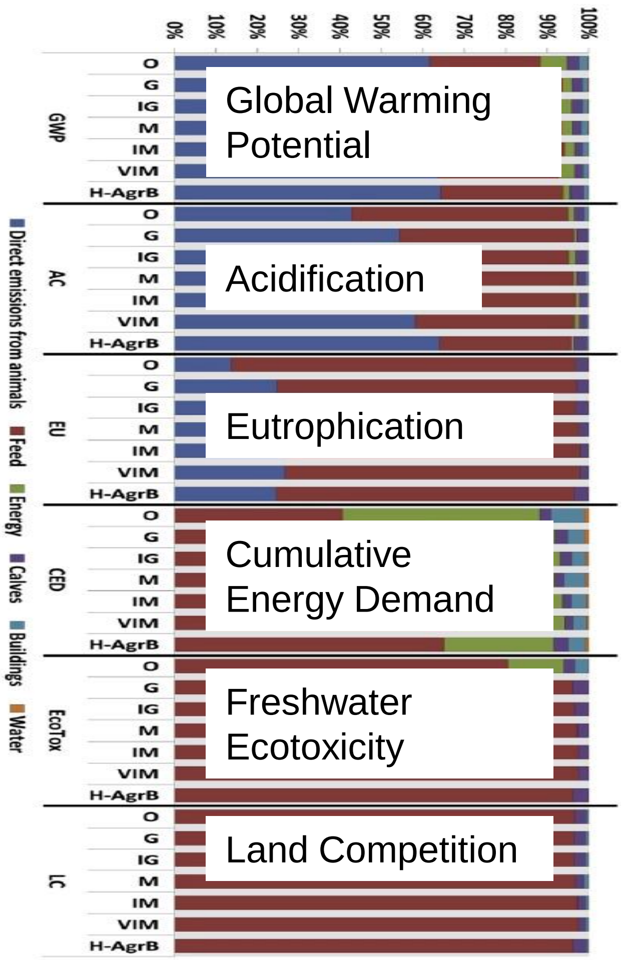
Item	Conventional	Organic	O : C
CO_2eq kg / kg ECM	1.20	0.96	**0.80**: 1:00
Energy, MJ / kg ECM	3550	2511	**0.71**: 1:00
Farmland, m^2/ kg ECM	1925	3464	**1.80**: 1:00
Farm N Surplus, kg/ ha	198	65	**0.33**: 1:00
Farm P Surplus, kg/ ha	10.3	1.1	**0.11**: 1:00
Farm K Surplus, kg/ ha	32.0	3.0	**0.09**: 1:00





Intensification (France)

Salou et al. 2017. Environmental impacts of dairy system intensification: the functional unit matters! J. Cleaner Production. 140:445-454.



Authors' Conclusions

- *The evaluation of the impact of dairy systems intensification depended upon the functional unit (kg milk vs. hectare of land).*
- *Current LCA practice (mass based functional unit) seem blind to the negative environmental consequences of agricultural system intensification.*
- *We recommend the use of both mass-based and area-based functional units in LCA of agricultural goods.*

Outline

1. Milk carbon footprint
2. Cow (enteric methane)
3. Manure (methane + nitrous oxide)
4. Field (nitrous oxide + carbon dioxide)
5. Comparison of “real-world” systems (cow + manure + field)
6. **Future**

Future: 1-Understanding variability at the system's level

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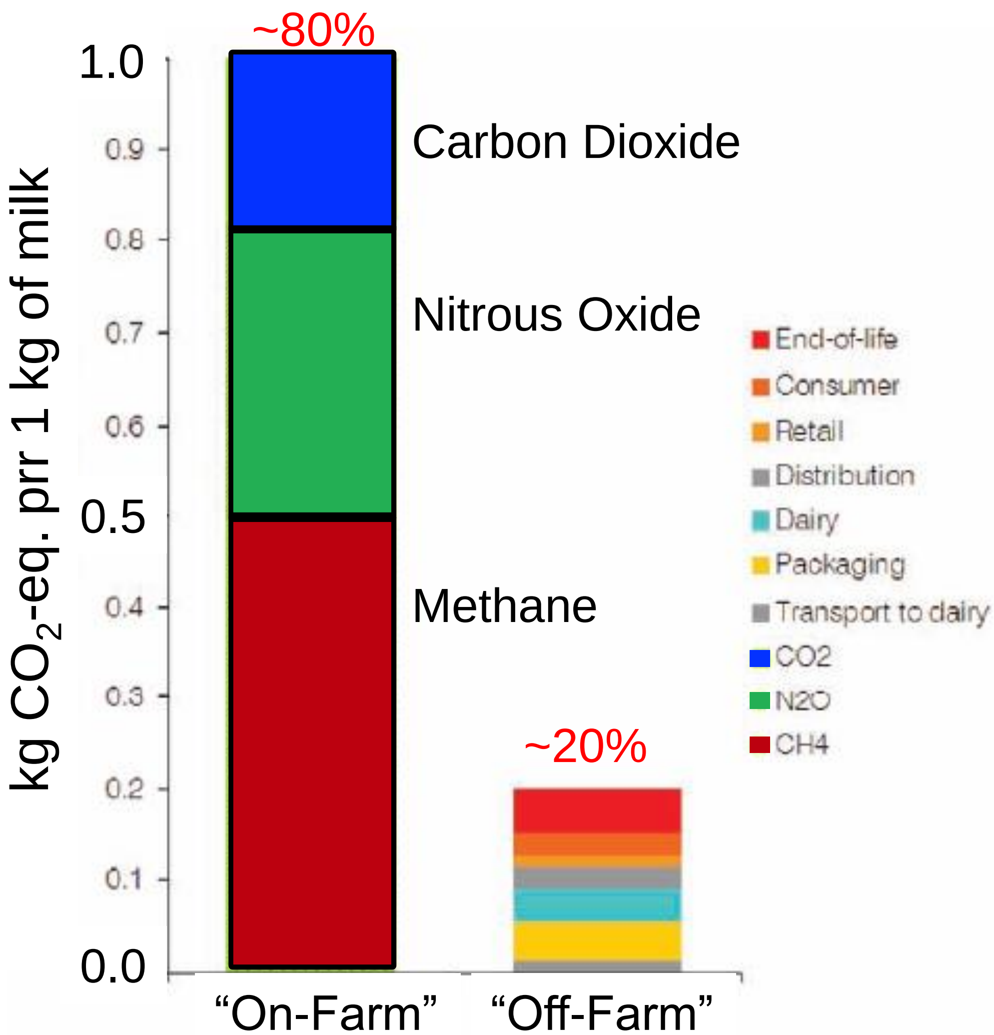
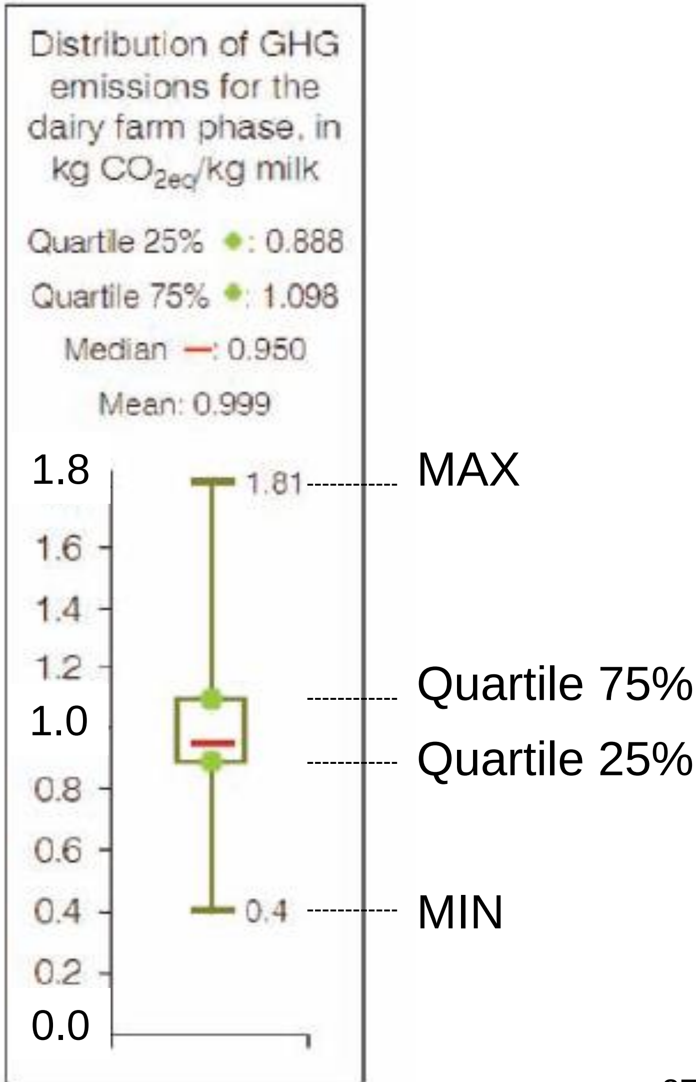
Means and Percentages are deceiving … … but variability is an opportunity





Guinard et al., 2009

Future: 2- As a research method, LCA is still a "work-in-progress"

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Questions to address about milk LCA: $\frac{CO_2eq}{\text{kg milk}}$?

- What is our ultimate goal?
  - Reducing emissions of the cow, manure and field or the "whole-farm"?
  - Contribute to solving climate change? (Analytical solution)
  - Contribute to consumer's demand/satisfaction? (Value-based solution)

- Functional Unit:
  - Should there be a denominator?
  - If so, what should it be (kg milk, cow, hectare, human edible nutrient)?
- System's boundaries: Attributional vs. consequential LCAs?
- System's boundaries and allocation of co-products:
  - Input side: Recycling of industrial by-products
  - Output side: Meat, manure nutrients, cereal crops
- Interactions among system's components?

Future: 3- Learn how to hold contradictory concept as equally true

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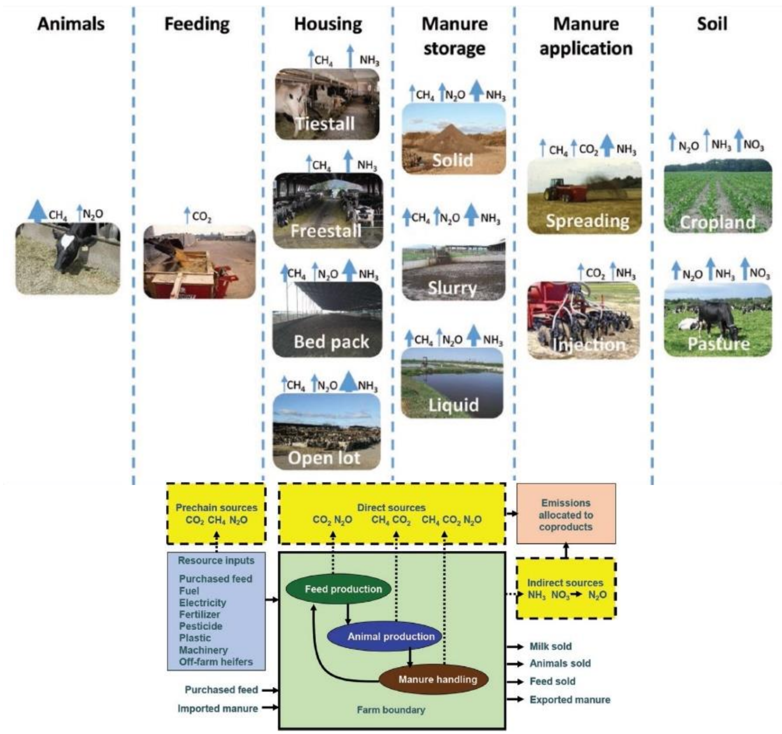
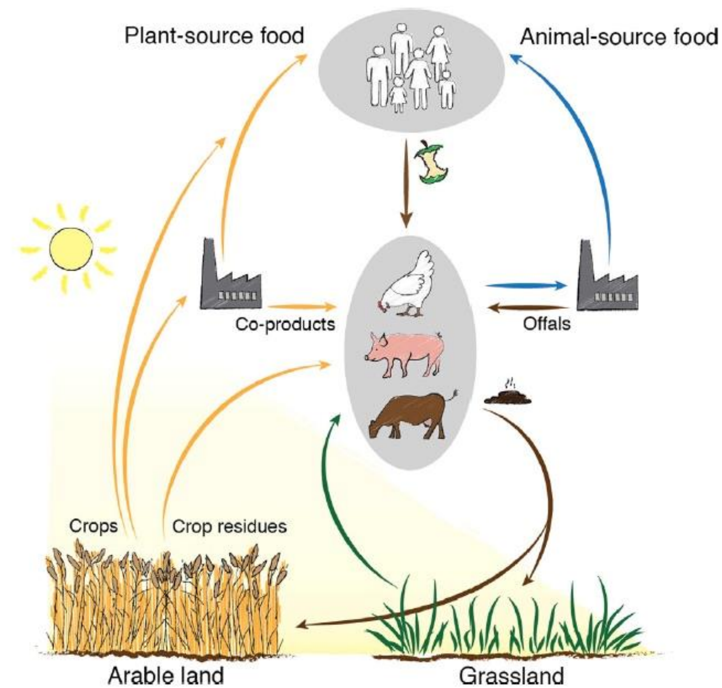
Rotz, A. 2018. Symposium review: Modeling greenhouse gas emissions from dairy farms. J. Dairy Sci. 101:6675-6690.

Van Zanten et al. 2018. Defining a land boundary for sustainable livestock consumption. Global Change Biology May 2018.

Making our producer more "efficient"	Making our consumer feeling better
Analytical solution: Solvable problems based on "hard" science	Value-based solution: "Wicked" problems (inclusive of people's choices and values)






¡ MUCHAS GRACIAS !

Cow: Predicting Enteric CH_4

Ramin and Huhtanen. 2013. Development of equations for predicting methane emissions from ruminants. J. Dairy Sci. 96:1-18.

Methane, Liters per day

CH_4 (L/d) = –64.0 + 26.0 x DM intake (kg/d) – 0.61 x $DMI^2_{(centered)}$ + 0.25 x OMDm (g/kg) – 66.4 x EE intake (kg of DM/d) – 45.0 x NFC/(NDF + NFC)

Where:

DMI intake = Dry matter intake

OMDm = Organic matter digestibility estimated at the maintenance level of feeding

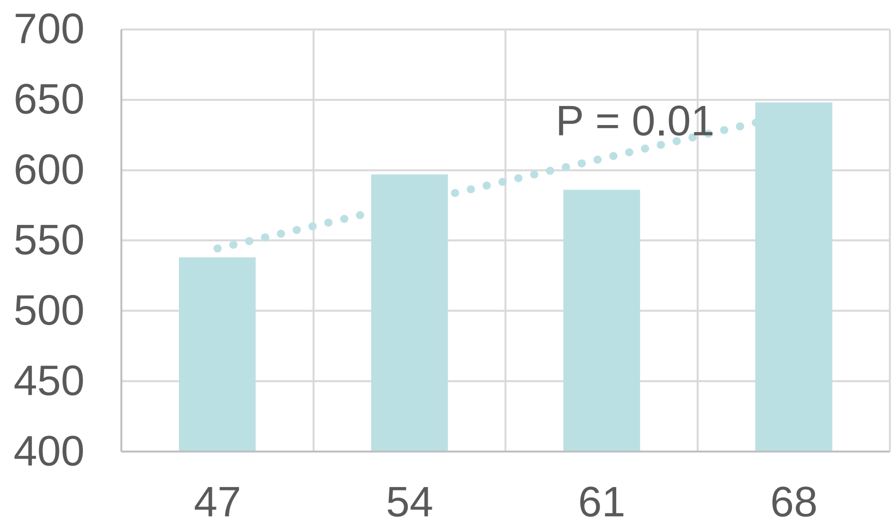
EE intake = Ether Extract intake

NFC/(NDF + NFC) = Ratio of NFC to total CHO

Cow: Diet (Forage to Concentrate ratio)

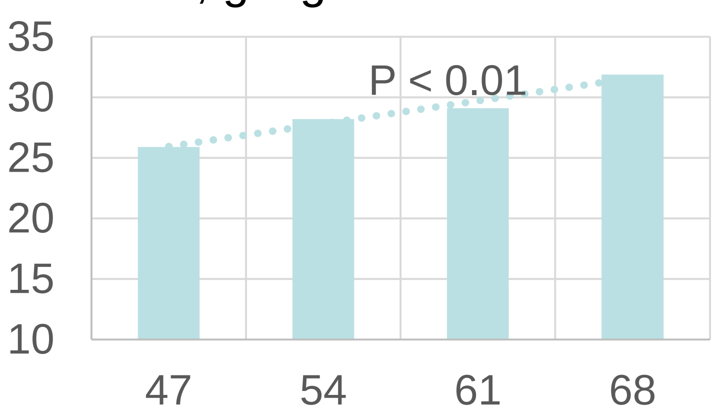
Aguerre et al. 2011. Effect of Forage to concentrate ratio in dairy cow diets on emission of methane, carbon dioxide, and ammonia, lactation performance, and manure excretion. J. Dairy Sci. 94:3081-3093.

Methane, g/ d

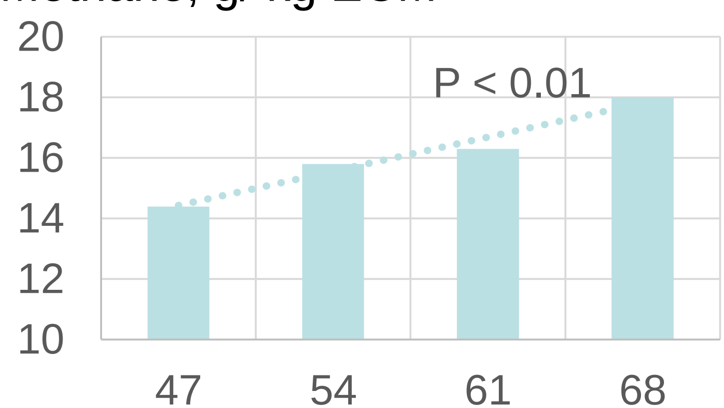


Forage (% of diet DM)	NDF (% of diet DM)
47	31.3
54	33.4
61	36.0
68	38.3

Methane, g/ kg DMI



Methane, g/ kg ECM



Cow: Diet (Alfalfa silage vs. Corn silage)

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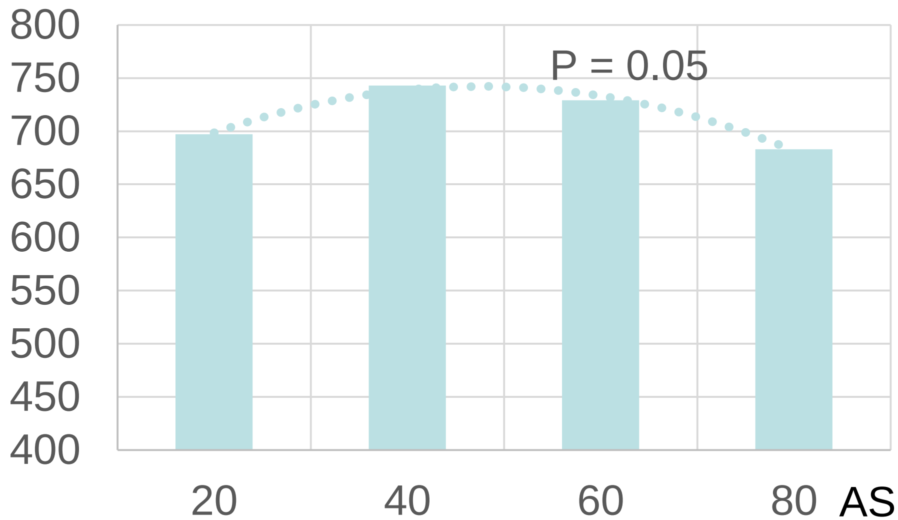
Arndt et al. 2015. Performance, digestion, nitrogen balance, and emission of manure ammonia, enteric methane, and carbon dioxide in lactating cows fed diets with varying alfalfa silage-to-corn silage ratios. J. Dairy Sci. 98:418-430.

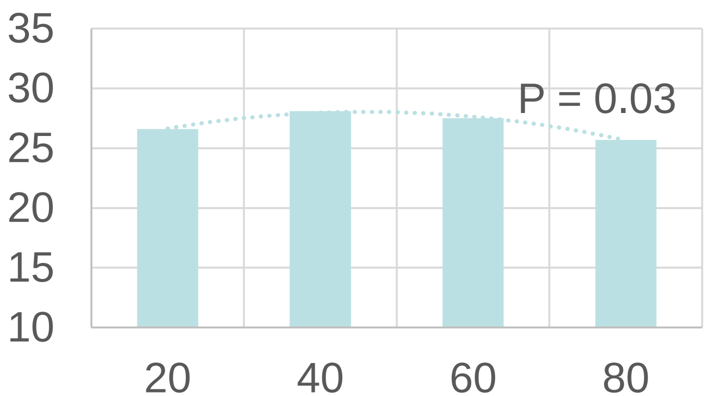
Diet DM,%		
Alfalfa Silage AS	Corn Silage CS	AS:CS
11	44	20:80
22	33	40:60
33	22	60:40
44	11	80:20

Methane, g/ d

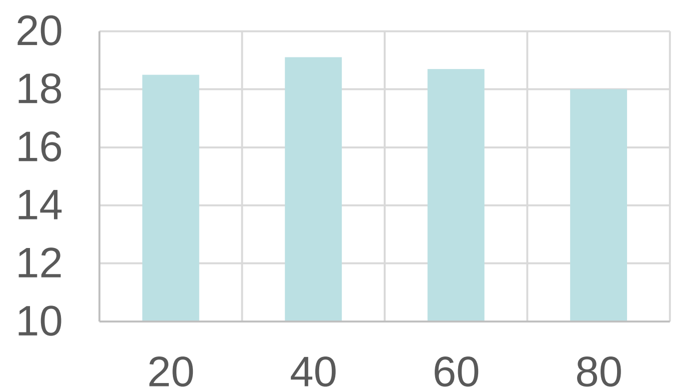


AS (% of Forage DM)

Methane, g/ kg DMI



Methane, g/ kg FPCM



Conventional vs. Organic (Sweden)

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Cederberg and Mattsson. 2000. Life cycle assessment of milk production — a comparison of conventional and organic farming. J. Cleaner Production 8:49-60.

Abstract

An LCA was performed on organic and conventional milk production at the farm level in Sweden. In the study, special focus was aimed at substance flows in concentrate feed production and nutrient flows on the farms. The different feeding strategies in the two forms of production, influence several impact categories. The import of feed by conventional dairy farms often leads to a substantial input of phosphorus and nitrogen. Organic milk production is a way to reduce pesticide use and mineral surplus in agriculture but this production form also requires substantially more farmland than conventional production. For Swedish conditions, however, a large use of grassland for grazing ruminants is regarded positively since this type of arable land use promotes the domestic environmental goals of biodiversity and aesthetic values.

Keywords: LCA; Milk production; Organic farming

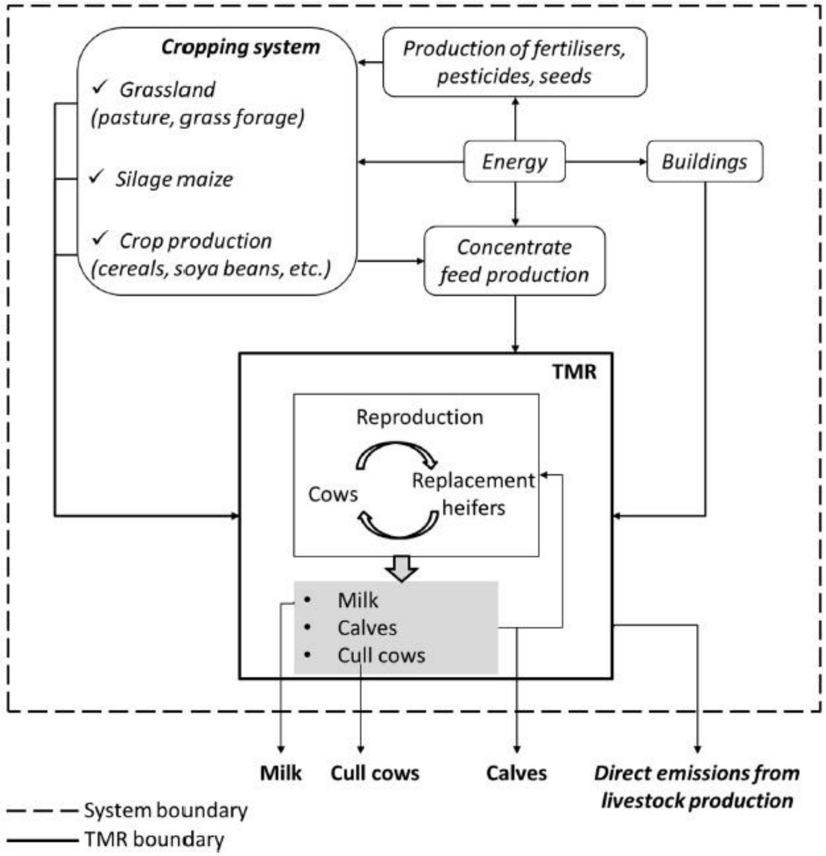
The import of feed by conventional dairy farms often leads to a substantial input of phosphorus and nitrogen.

Organic milk production is a way to reduce pesticide use and mineral surplus in agriculture but it also requires substantially more farmland than conventional production.

For Swedish conditions, however, a large use of grassland for grazing ruminants is regarded positively since this type of arable land use promotes the domestic environmental goals of biodiversity and aesthetic values.

Intensification (France)

Salou et al. 2017. Environmental impacts of dairy system intensification: the functional unit matters! J. Cleaner Production. 140:445-454.



Objective

To use LCA to assess a range of impacts of contrasting dairy systems that represent a wide diversity of management practices and intensification levels.

Technological management routes (TMR)

- *Concentrate feed intake (kg/c/y)*
- *Corn silage intake (kg/c/y)*
- *Grass (silage and pasture, kg/c/y)*
- *Grazing (yes/no)*
- *Grazing area (ha)*
- *Grazing duration (d/y)*
- *Breed*
- *Age at first calving*
- *Seasonal calving (yes/no)*
- *Replacement rate (%)*
- *Milking parlor technology*
- *System (conventional/organic)*

Intensification (France)

Salou et al. 2017. Environmental impacts of dairy system intensification: the functional unit matters! J. Cleaner Production. 140:445-454.

LI = Least intensive
I = Intensive
VI = Very Intensive

		Grass-based		Corn silage			High land
	Organic	LI	I	LI	I	VI	
CO_2eq kg / kg Milk	0.92	0.98	0.99	0.93	1.17	1.12	1.40
CO_2eq ton / ha	4.39	6.86	7.56	9.28	8.95	9.62	5.44

Rank	Per unit of milk	Per unit of land
1 (lowest)	Organic	Organic
2	LI- Corn silage	Highland
3	LI- Grass based	LI- Grass based
4	I- Grass based	I- Grass based
5	I- Corn silage	I- Corn silage
6	VI- Corn silage	LI- Corn silage
7 (Greatest)	Highland	VI- Corn silage

Cow: Diet (Alfalfa silage vs. Corn silage)

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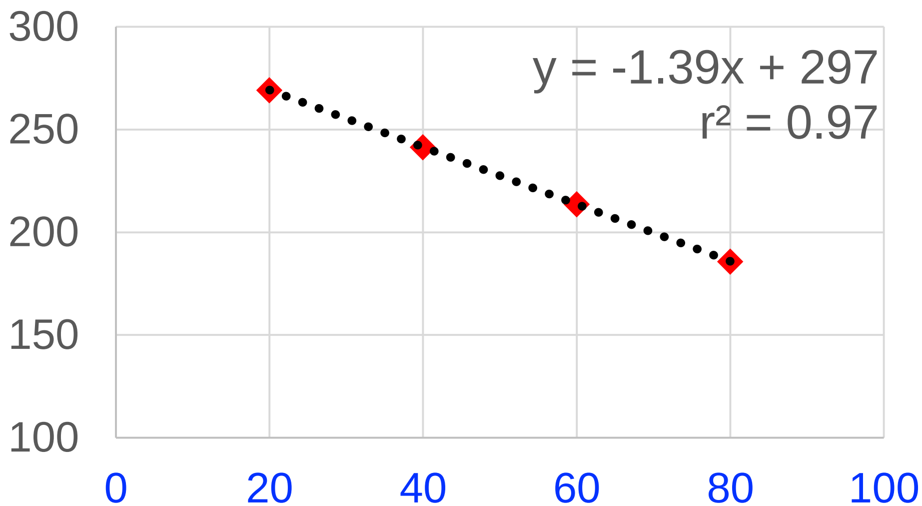
Arndt et al. 2015. Performance, digestion, nitrogen balance, and emission of manure ammonia, enteric methane, and carbon dioxide in lactating cows fed diets with varying alfalfa silage-to-corn silage ratios. J. Dairy Sci. 98:418-430.

Diet DM,%		
Alfalfa Silage AS	Corn Silage CS	AS:CS
11	44	20:80
22	33	40:60
33	22	60:40
44	11	80:20

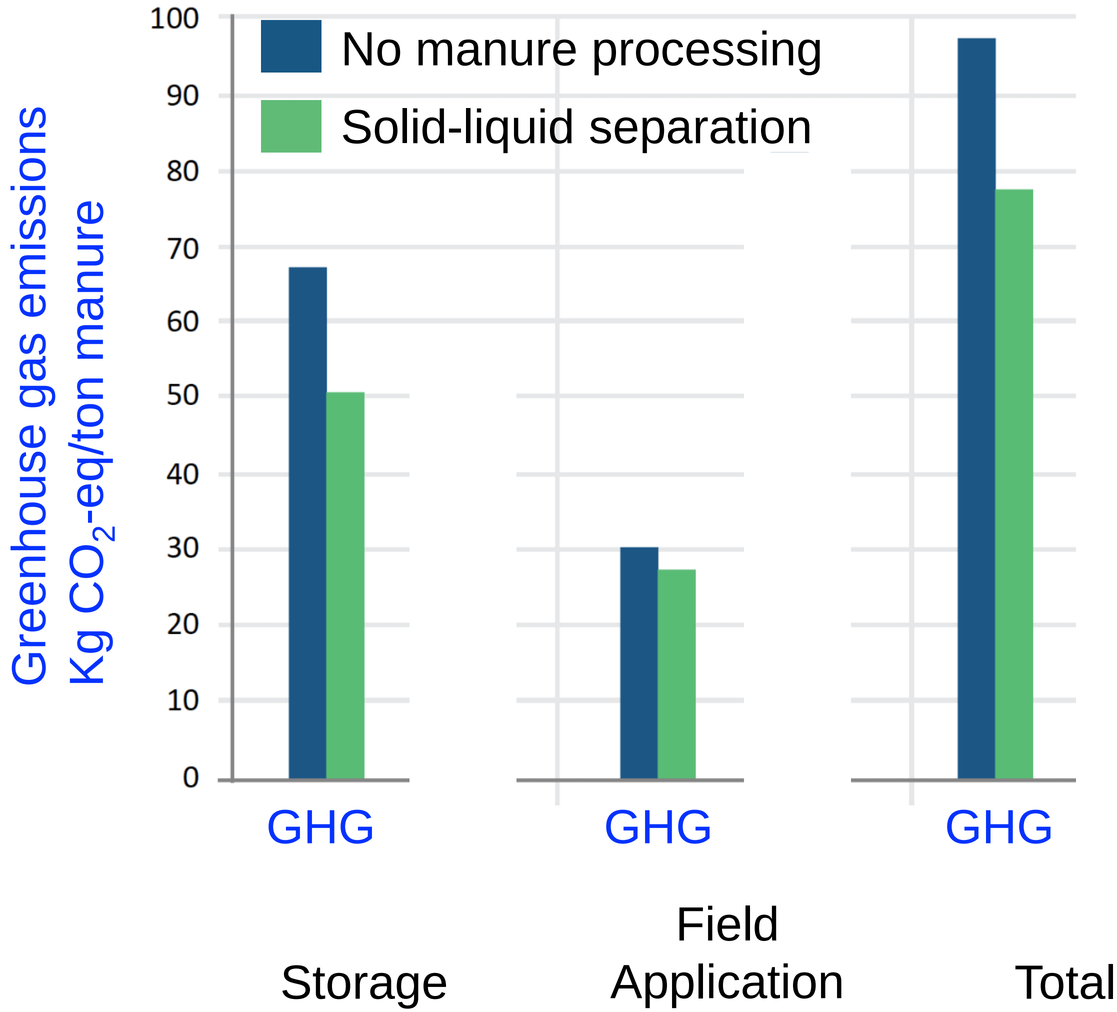
Methane, g/ kg of digested NDF



AS (% of Forage DM)

Manure: Solid-Liquid Separation (SLS)

Aguirre-Villegas et al. 2017. Solid-Liquid separation of manure and effects on greenhouse gas and ammonia emissions. UW-Extension UWEX A4131-04.



Intensive, Extensive, Organic (Germany)

Haas et al. 2001. Comparing intensive, extensified and organic grassland farming in southern Germany by process life cycle assessment. Agric., Ecosy., and Envir. 83:43-53.

	Intensive	Extensive	Organic
Characteristics			
Mineral N Fertilizer	Yes	No	No
Purchasing fodder	Yes	Yes	Limited
Grassland, ha	32.7	34.7	25.8
Grassland yield, t DM/ha	11.8	10.5	10.7
Animal Unit / ha	2.2	1.9	1.9
Milk production (annual), kg/cow	6758	6390	5275
Environmental Performance			
CO_2eq kg / kg Milk	1.30[a]	1.0[b]	1.30[a]
CO_2eq kg / ha	9400[a]	7000[b]	6300[b]
Farm N Surplus, kg/ ha	80.1[a]	31.4[b]	31.1[b]
Farm P Surplus, kg/ ha	5.3	4.5	-2.3

[a,b]*Tukey test, P<0.05 (n= 6 farms per group.*