[1] [2] [3] [4]

Influence of feed efficiency and physiological state on rumen VFA and microbial profiles in cattle

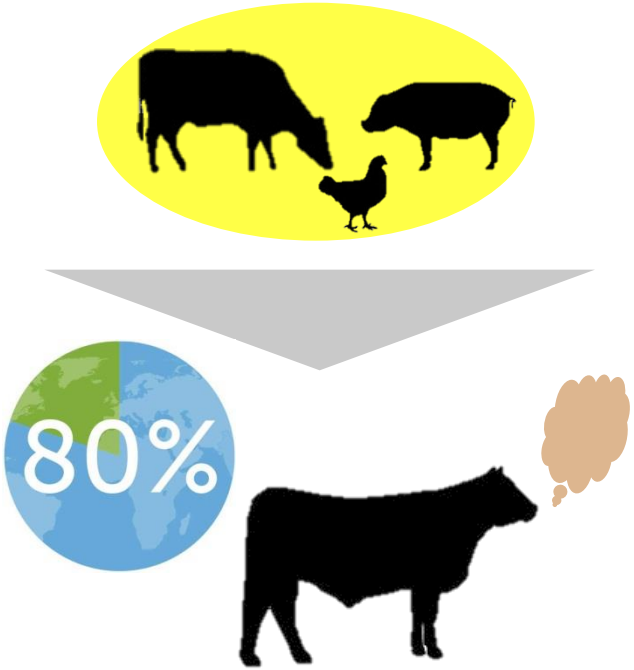
S Lam[1], J Munro[2], J Cant[1], L Guan[3], M Steele[3], F Schenkel[1], S Miller[1,4], Y Montanholi[2]

Outline

- Introduction
- Hypothesis
- Objectives
- Materials and methods
  - Grain-fed study
  - Grass-fed study
- Results and discussion
- Conclusion
- Acknowledgements

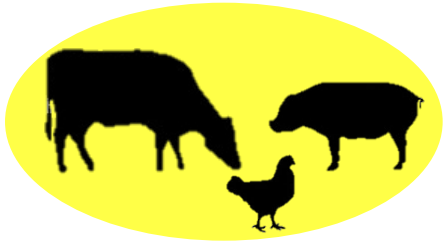
Introduction: Industry challenges

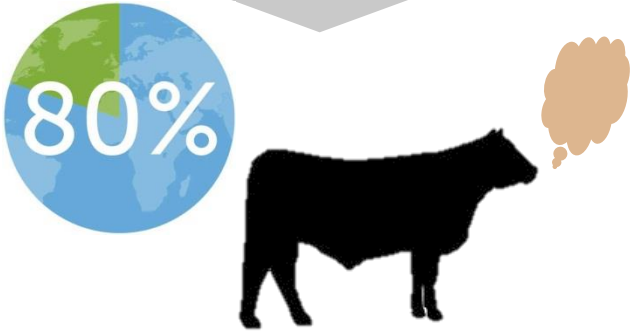
30-50% agriculture GHG



Introduction: Industry challenges

30-50% agriculture GHG



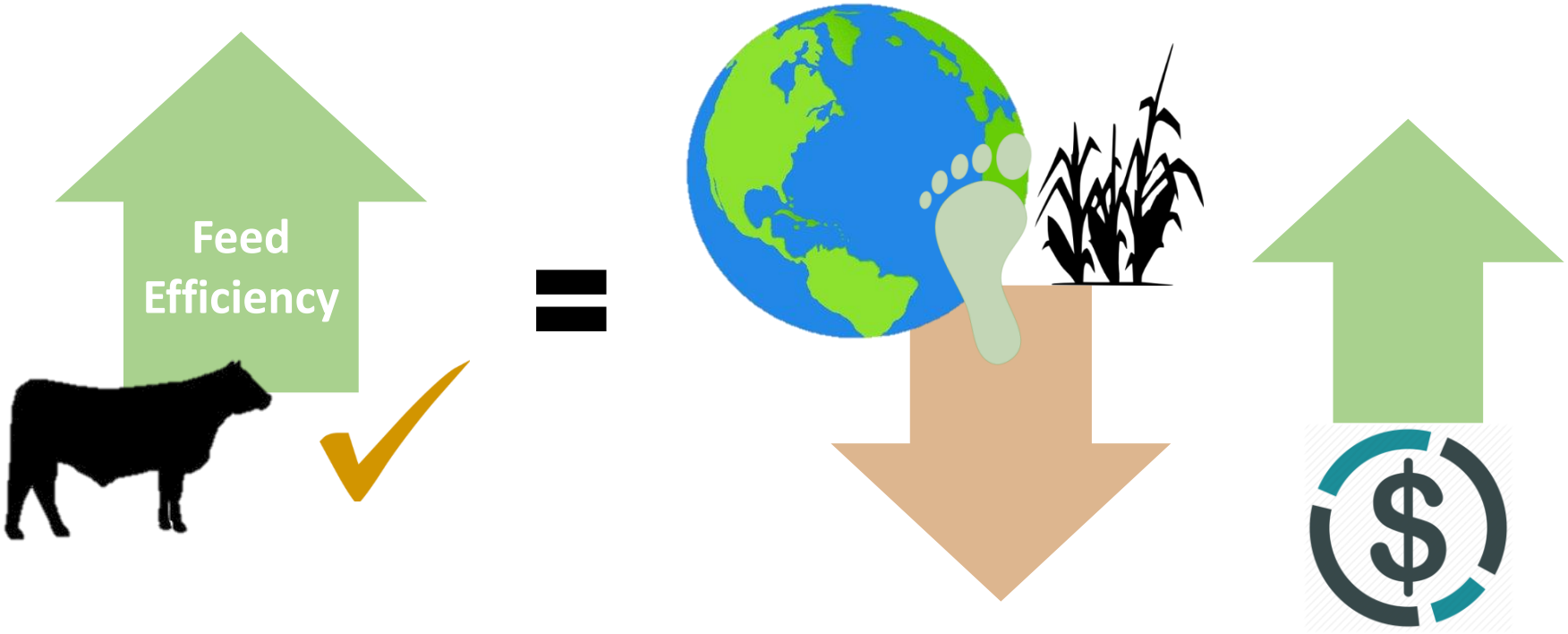


Feed costs

Herd cost variation

Introduction: Feed efficiency

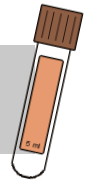
Introduction: Feed efficiency



Introduction: Feed efficiency

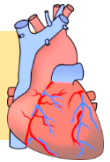
Milk and colostrum composition
(Montanholi et al. 2013)

Blood metabolites and hormones
(Kelly et al. 2011, Gonano et al. 2014)



Fertility traits
(Awda et al. 2013, Fontoura et al. 2015)

Cardiac physiology
(Munro et al. 2016)



Introduction: Rumen metabolism

% 10% of the biological variation of RFI due to digestibility

(Richardson and Herd 2004)

Rumen and reticulum = 75% total digestive tract

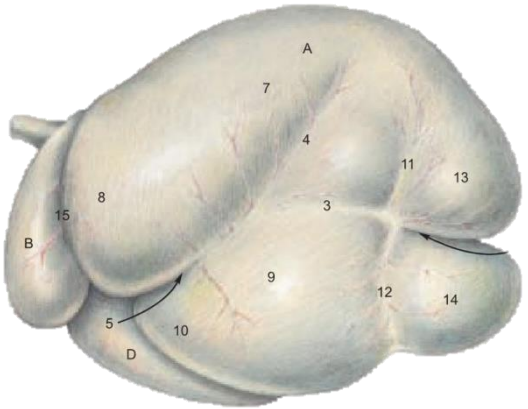
(Baldwin 1980)

Large energetic sink with high energy demand

(Hungate 1960)

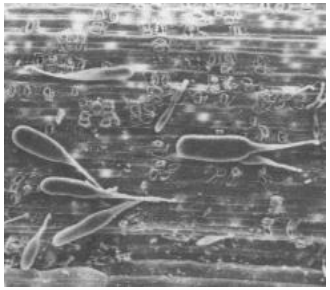
Area of energy absorption - 75% total VFA

(Bergman 1990)

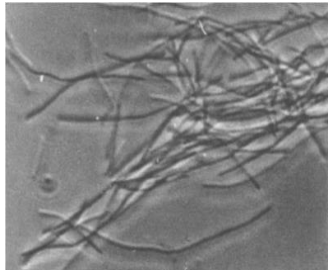


Introduction: Microbiology

Bacteria (10^{11} cells/ml)
75% feed particle digestion



Fungi (10^{3}-10^{4} cells/ml)
Fibrolytic particle digestion

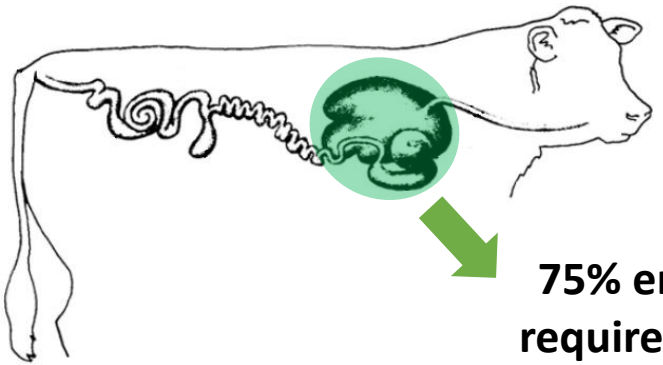


Methanogens (10^{4}-10^{6} cells/ml)
Methanogen ecology associated with methane emissions

Protozoa (10^{4}-10^{6} cells/ml)
Ciliate species digesting suspended and colonized feed particles

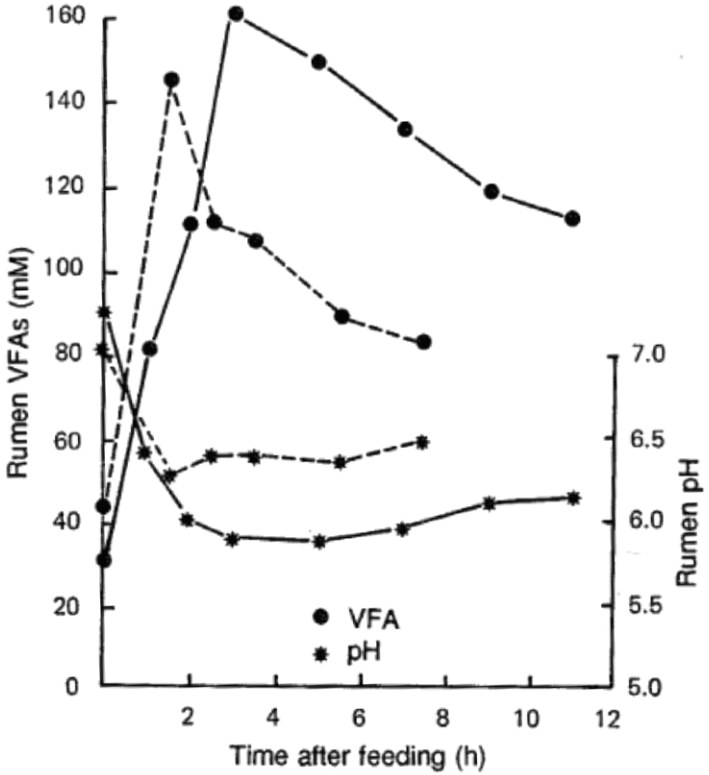
Feed efficiency (Guan et al. 2008, Zhou et al. 2009, Hernandez et al. 2012, Carberry et al. 2014)

Introduction: Volatile fatty acids (VFA)



75% energy requirements

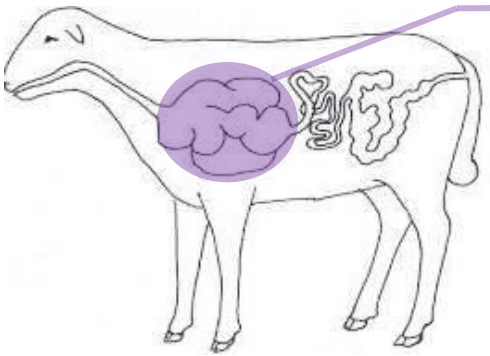
(Guan et al. 2008, Hernandez-Sanabria 2012)



(Briggs et al. 1957, Bergman et al. 1990)

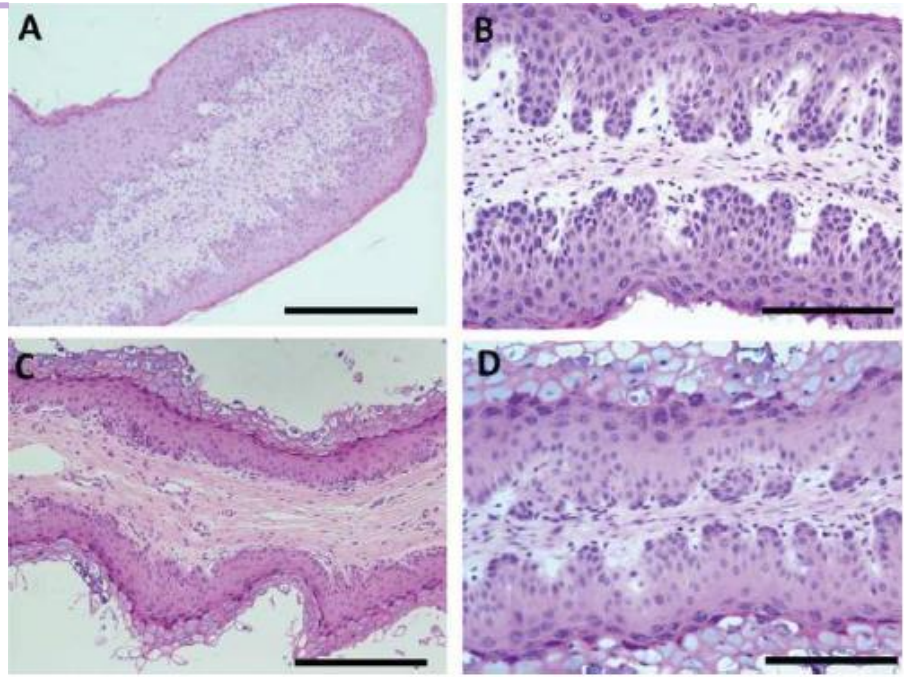
Introduction: Rumen microstructure

Sheep papillae microstructure



Low energy diet:

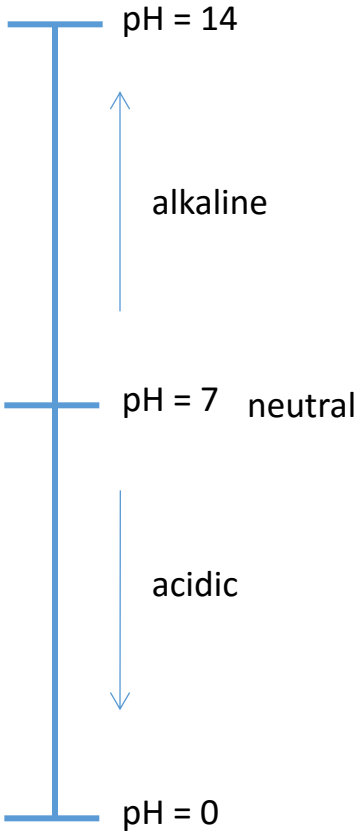
High energy diet:

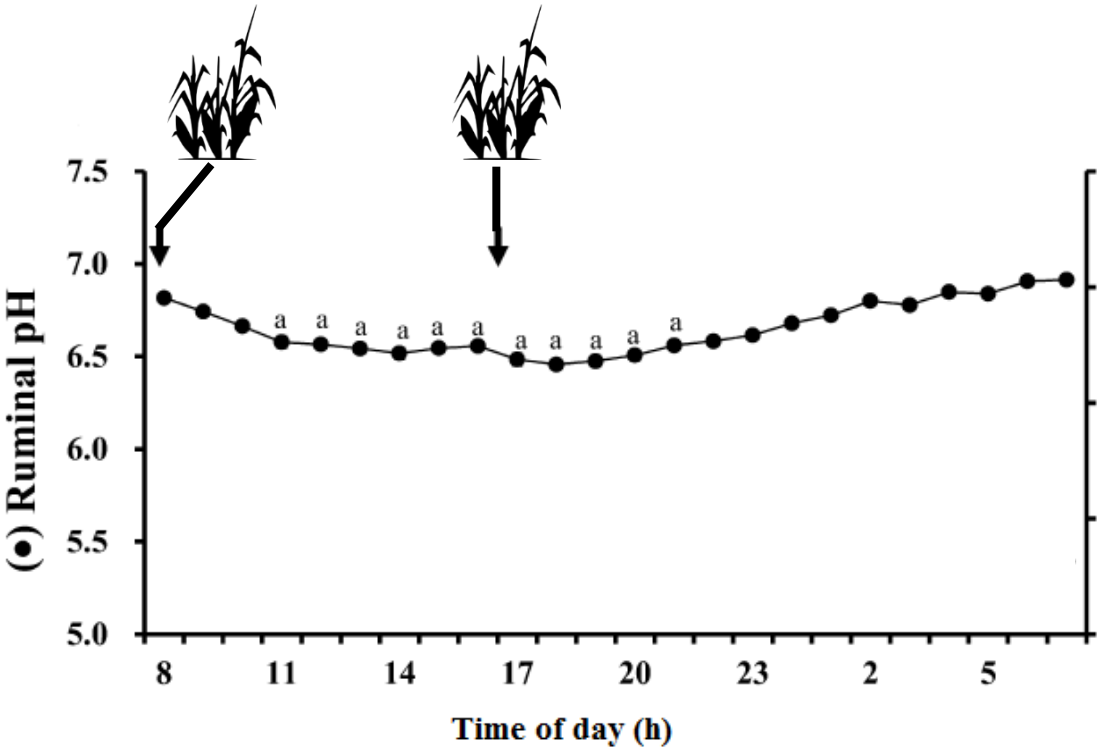


(Steele et al. 2012)

Stratum corneum thickness = Energy in diet

Introduction: Rumen pH





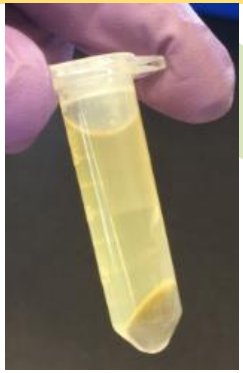
(Kimura et al. 2016)

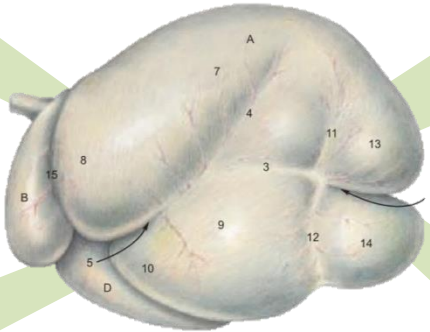
Hypothesis

Feed efficiency is associated with energetic processes and the rumen is a highly metabolically active organ. Therefore, the variability in rumen metabolism across feed efficiency phenotypes and dietary treatments may be featured through rumen functional and structural assessments.

Objectives

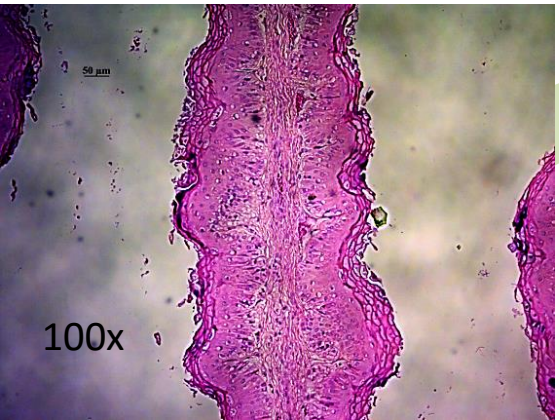
Microbiology





Volatile fatty acids (VFA)

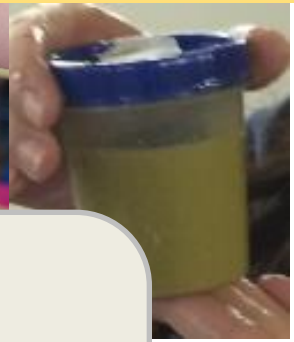
Papillae epithelium



Rumen pH

Objectives

Microbiology



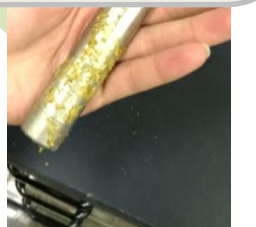
(VFA)

Efficient vs Inefficient

- Grain-fed animals

- Grass-fed animals

Pa



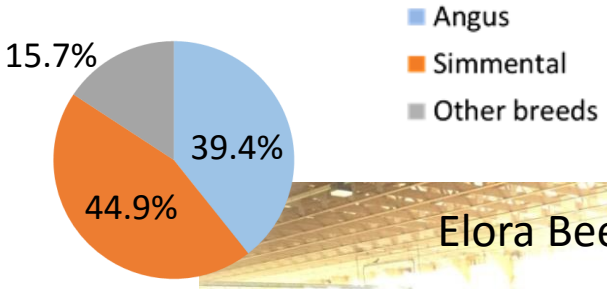
Rumen pH

Materials: Experimental conditions

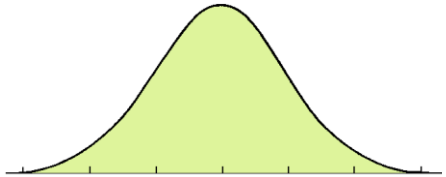
Feedlot study

- 48 crossbred cattle
- Trial length: 112 d

Overall breed composition

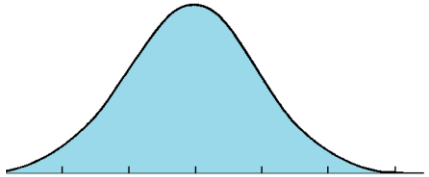


16 Steers



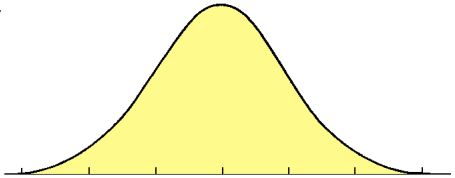
Average BW = 536 ± 43 kg

16 Steers



BW = 506 ± 72 kg

16 Bulls



BW = 531 ± 57 kg

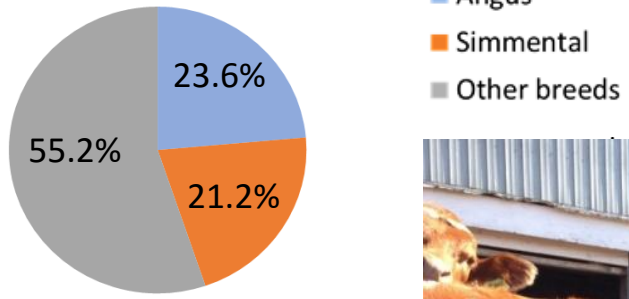
Elora Beef Research Centre

Materials: Experimental conditions

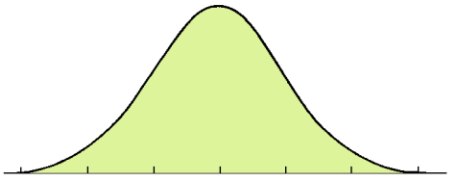
Grass-fed study

- 141 crossbred cattle
- Trial length: 124 d

Overall breed composition



107 heifer calves

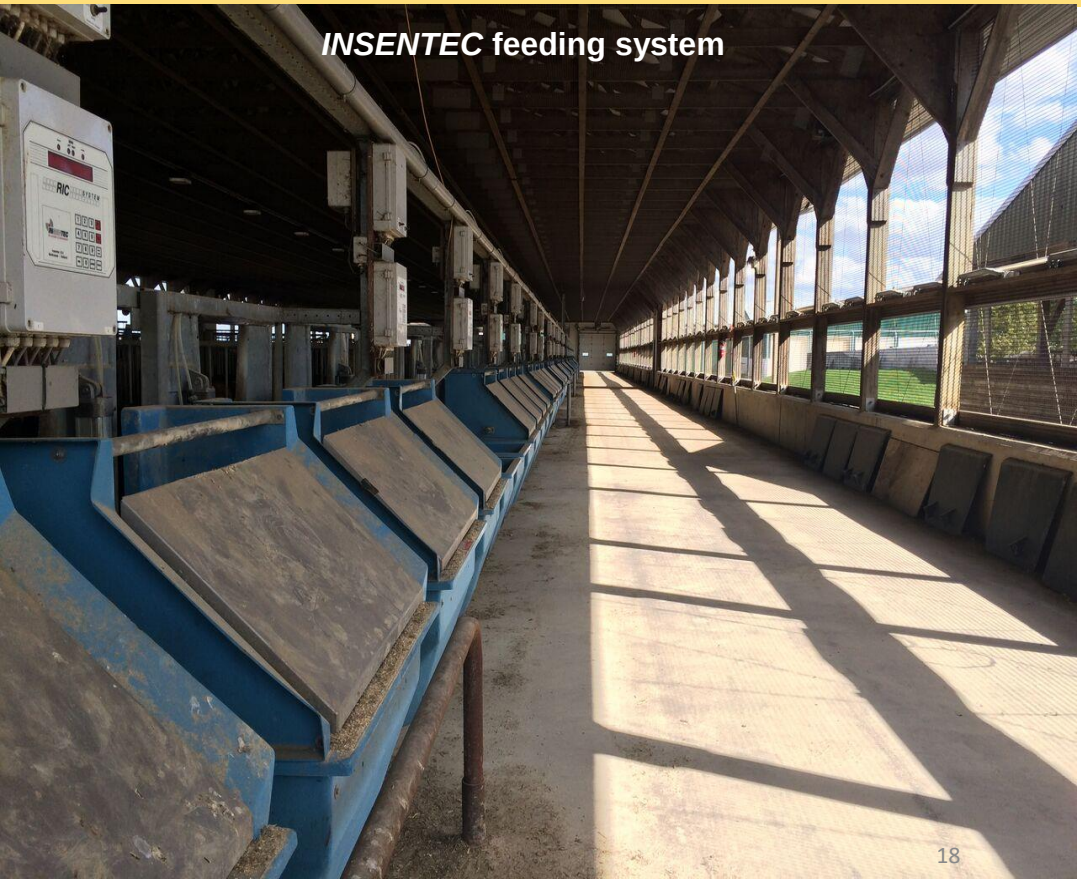


BW = 253 ± 38 kg
Age = 403 ± 27 d

36 pregnant heifers

BW = 406 ± 42 kg
Age = 594 ± 95 d

Methods: Diet



Chemical Composition	***Dry Basis (%)***
Dry Matter	53.8
Crude Protein	13.9
Acid Detergent Fibre	10.9
Neutral Detergent Fibre	22.2
Starch	45.0
Total Digestible Nutrients	86.0
Ingredient Composition	***Dry Basis (%)***
High-moisture corn	52.5
Haylage	42.3
Soybean meal	3.5
Premix*	1.7

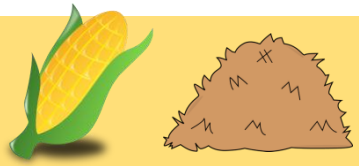
*Contains 40% of calcium phosphate, 60% trace mineralized salt

Methods: Diet

Chemical Composition	***Dry Basis (%)***
Dry matter	36.1
Crude Protein	15.5
Acid Detergent Fibre	29.6
Neutral Detergent Fibre	53.7
Starch	6.5
Total Digestible Nutrients	70.3
Ingredient Composition	***Dry Basis (%)***
Haylage	99.5
Premix*	0.5

*Contains 37.4% of calcium phosphate, 62.7% trace mineralized salt

Methods: RFI models



Grain-fed (R^2 = 0.74):

Body Size *Rate of Gain* *Leanness*

Feed intake = [μ + (β_1 x body weight)] + (β_2*ADG) - (β_3*ribeye area) +

(β_4*back fat) – (β_5*marbling) + subpopulation + RFI

Fatness

Grass-fed (R^2 = 0.61):

Body Size *Rate of Gain* *Leanness*

Feed intake = [μ + (β_1*body weight)] + (β_2*ADG) - (β_3*ribeye area) +

(β_4*rump fat) – (β_5*age) + subpopulation + RFI

Fatness

Methods: Sample collection

5.5±1 d prior slaughter

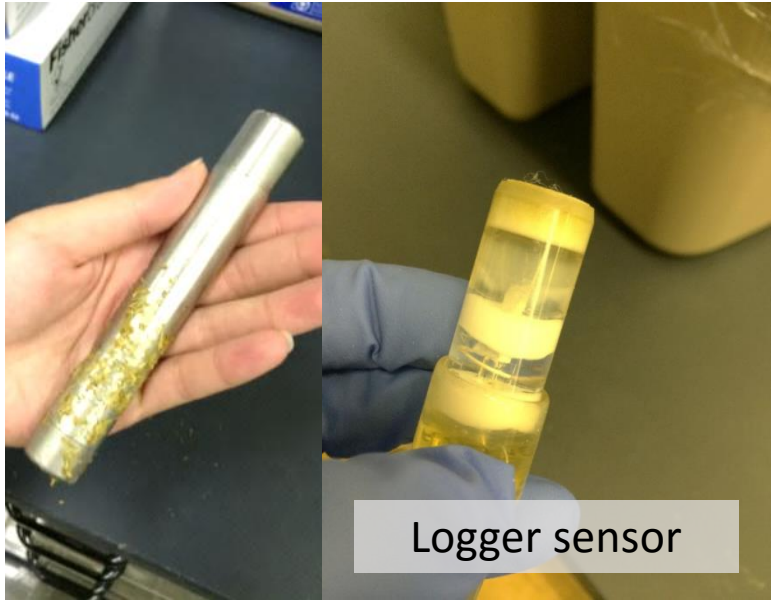
pH logger insertion

End of performance test

Rumen fluid

Rumen tissue

Methods: Logger insertion



Rumen pH loggers

T9 LRCpH Data Logger Dascor

Method: esophageal tubing

Recording: 5 minute intervals (~2,600 data points/animal)

Methods: Rumen fluid collection

Method:

Oro-ruminal probe with suction

Evaluating:

Microbiology

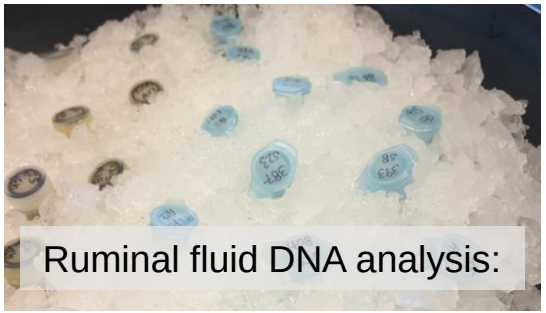
Volatile fatty acid profiles

Methods: Microbiology

Method:

Rumen fluid DNA isolation

RT-qPCR

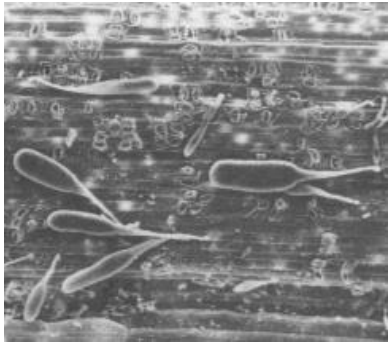


Evaluating:

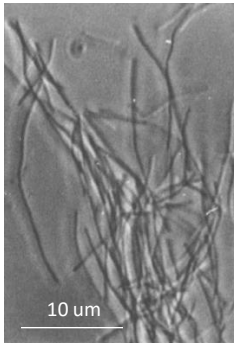
Bacteria

Protozoa

Fungi



Methanogen



(Doddema 1978; Mathers and Miller 1980; Godfried 1980)

Methods: VFA

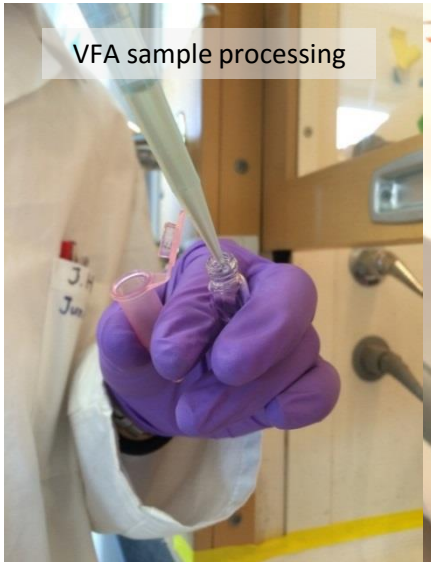
Evaluated:

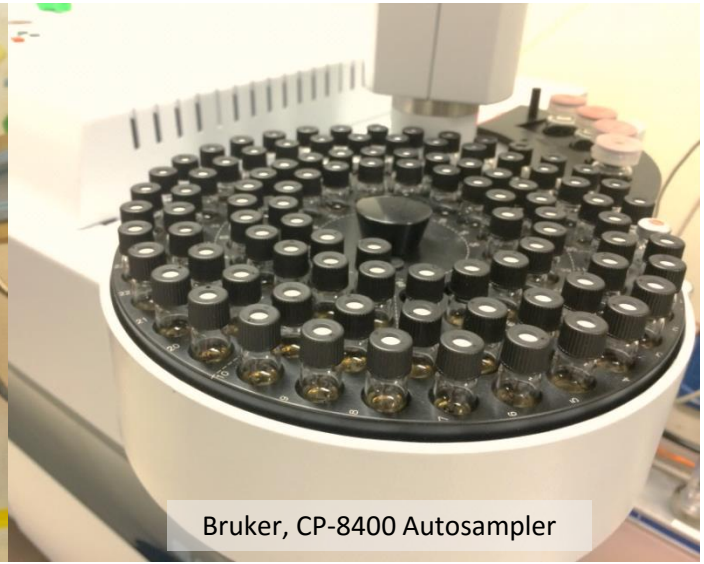
VFA molar concentrations

- **Acetate**
- **Propionate**
- **Butyrate**
- Valerate
- Isovalerate
- Isobutyrate
- Caproate

Total VFA concentration

Method:





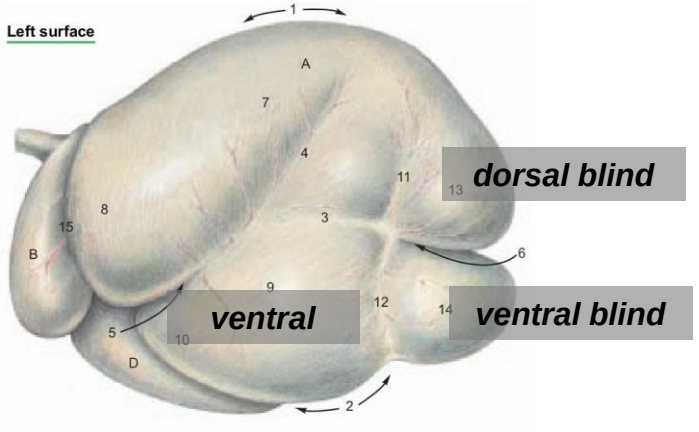
Methods: Rumen tissue collection

Method:

Tissue collection

Processed for histomorphology

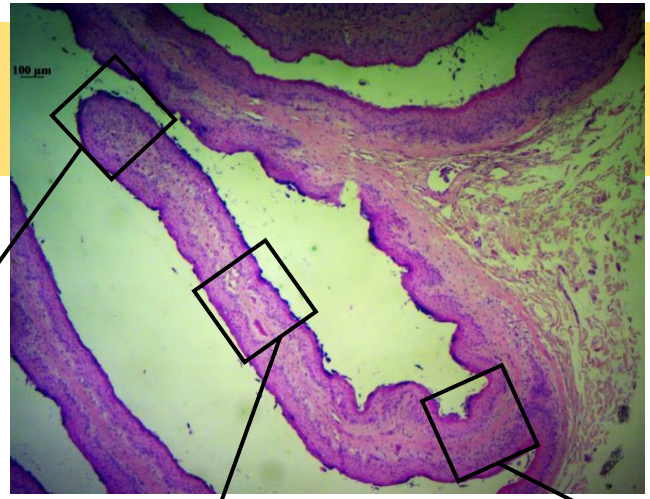
Evaluating: Papillae epithelial thickness

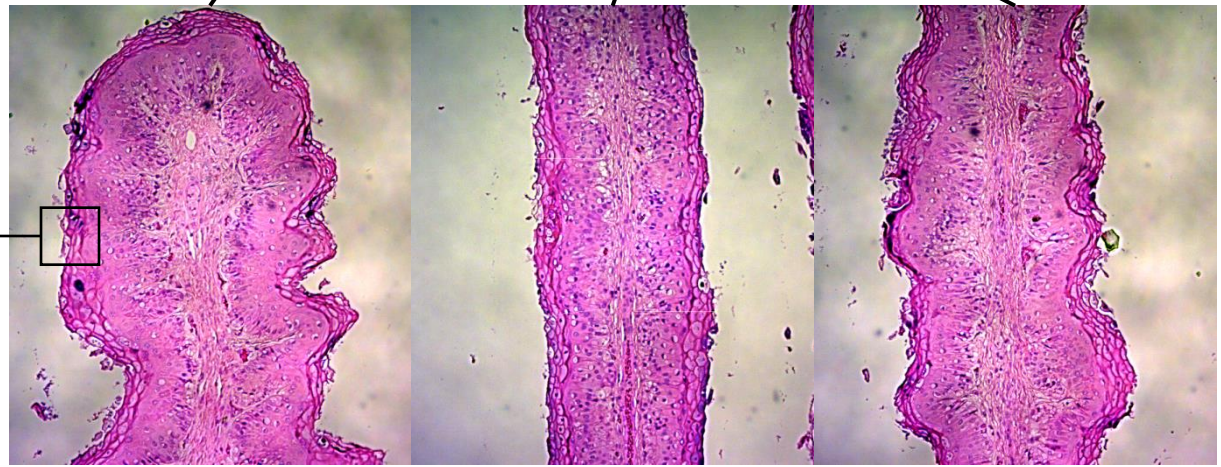


Methods: Histomorphometry

Histology traits:

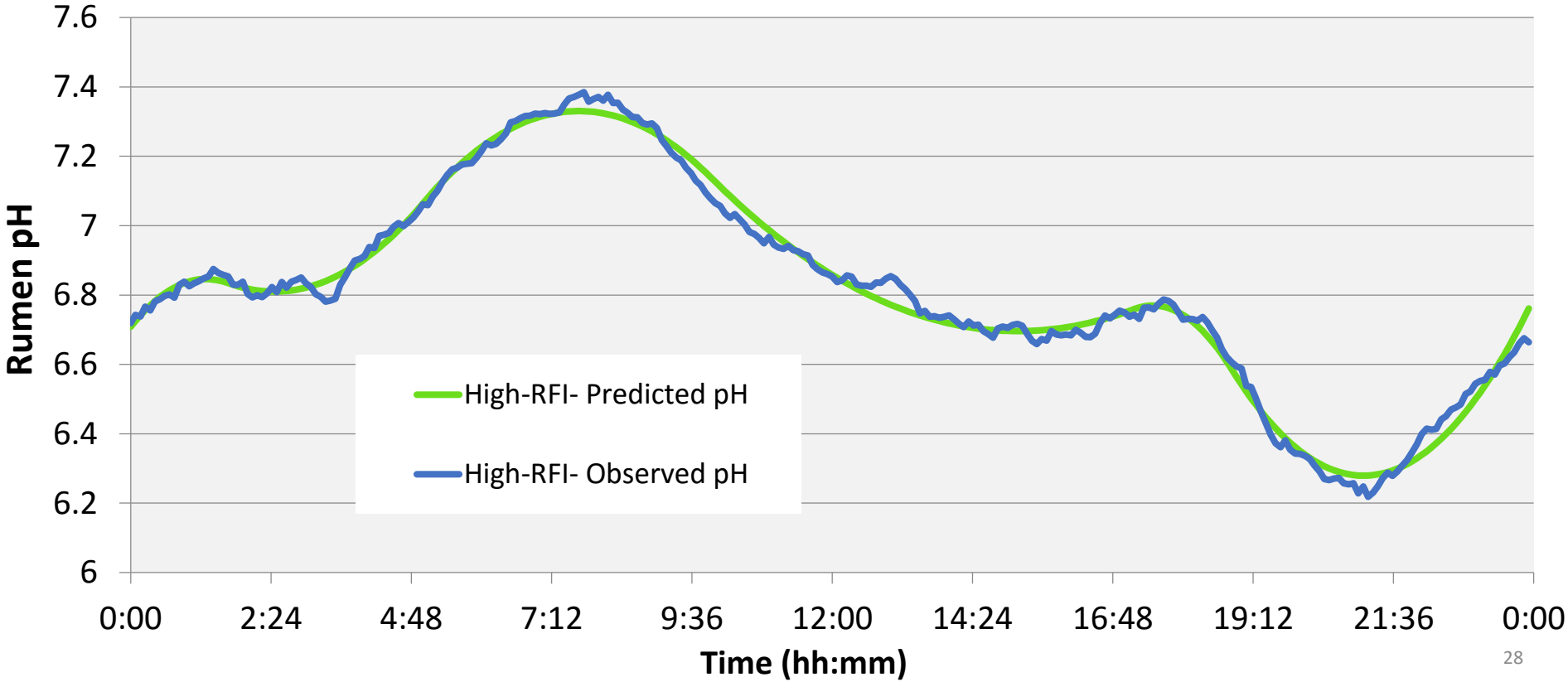
- Stratum corneum
- Papillae width





Tip Middle piece Base

Methods: pH measurements



Methods: Statistical analysis

Univariate Normality Procedure

- Skewness, Kurtosis, Anderson-Darling Test
- Transformations
  - logarithm
  - squared

GLM Select procedure

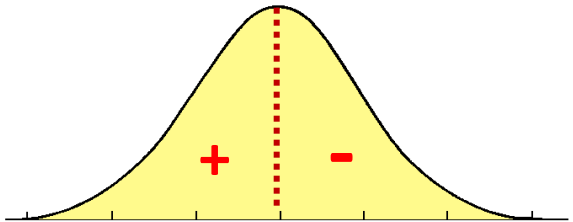
- Determine model effects

General Linear Model (GLM) Procedure

- Rumen traits

Partial Least Square procedure

- Determine % contribution to RFI



50% Efficient *vs.* 50% Inefficient

$$Y_{ijkl} = \mu + \text{efficiency group}_i + \text{subpopulation}_j + \text{breeds}_k + \epsilon_{ijkl}$$

Results: Physiological status

Trait (%/total VFA)	Heifer calves	Pregnant heifers	***P-value***
Acetate	71.68	74.62	**<0.01**
Propionate	18.30	16.53	**<0.01**
Isobutyrate	0.97	0.89	0.051
Butyrate	7.29	6.47	**<0.01**
Isovalerate	0.90	0.90	0.952
Valerate	0.58	0.41	**<0.01**
Caproate	0.28	0.18	**<0.01**
Total VFA (µmol/ml)	43.52	37.39	**<0.01**

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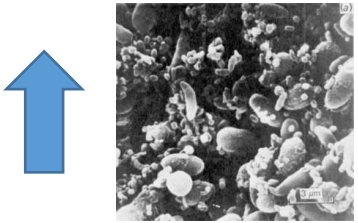
Pregnant heifers



Bacteria population

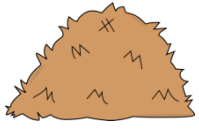
Metabolic activity throughout gestation

VFA metabolism and energy demand

(Church, 1988; Drackley et al. 2001)

Results: RFI – Microbial profiles

Trait (16s rRNA copy/ml)	**Inefficient**	**Efficient**	***P-value***
Total bacteria	$4.3x10^{11}$	$7.6x10^{11}$	**<0.05**
Methanogen	$4.9x10^{9}$	$2.3x10^{9}$	**<0.05**
Protozoa	$4.3x10^{7}$	$1.5x10^{7}$	0.18
Fungi	$6.3x10^{4}$	$3.8x10^{4}$	0.37

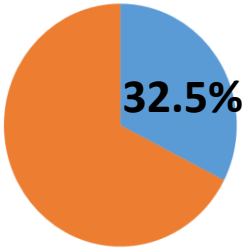


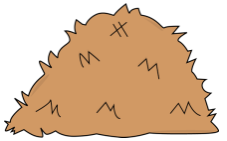
Trait (16s rRNA copy/ml)	**Inefficient**	**Efficient**	***P-value***
Total bacteria	$6.0x10^{10}$	$5.3x10^{10}$	0.16
Methanogen	$2.6x10^{7}$	$3.1x10^{7}$	**<0.05**
Protozoa	$1.2x10^{5}$	$1.6x10^{5}$	0.30
Fungi	$1.3x10^{5}$	$1.9x10^{5}$	**<0.05**

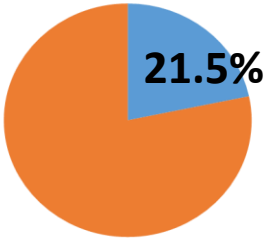
Results: RFI – VFA profiles

Trait (%/total VFA)	**Inefficient**	**Efficient**	***P-value***	**Inefficient**	**Efficient**	***P-value***
Acetate	54.4	54.5	0.97	73.48	72.95	0.55
Propionate	29.0	29.3	0.89	17.25	17.45	0.38
Isobutyrate	1.2	1.0	0.11	0.90	0.95	**<0.10**
Butyrate	8.9	8.6	0.75	6.81	6.91	0.44
Isovalerate	3.0	2.7	0.41	0.87	0.94	**<0.05**
Valerate	2.6	2.9	0.29	0.47	0.49	0.43
Caproate	0.4	0.5	0.40	0.22	0.22	0.87
Total VFA (µmol/ml)	78.0	80.3	0.66	38.94	41.83	**<0.10**

Results: Variance analysis

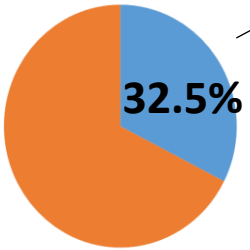


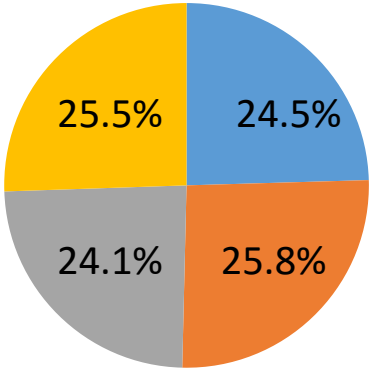




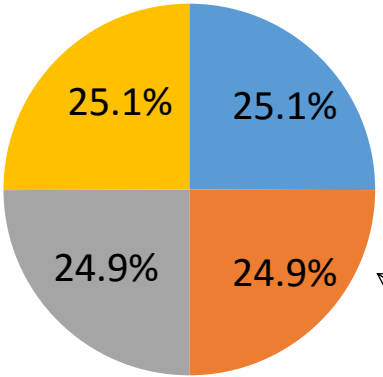
Results: Variance analysis

44.3%

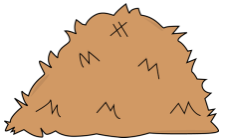


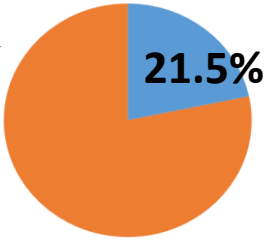


Bacteria
Methanogen
Protozoa
Fungi



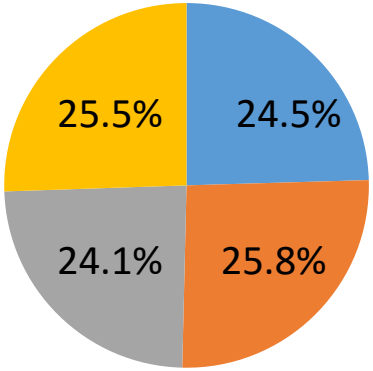
10.0%



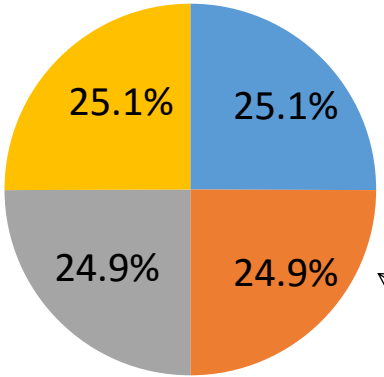


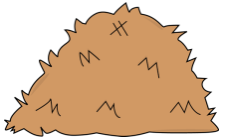
Results: Variance analysis

44.3%

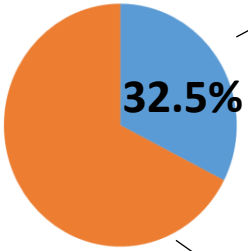


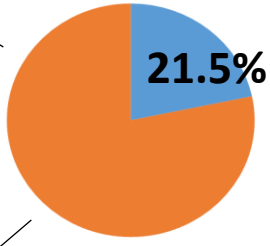
Bacteria
Methanogen
Protozoa
Fungi





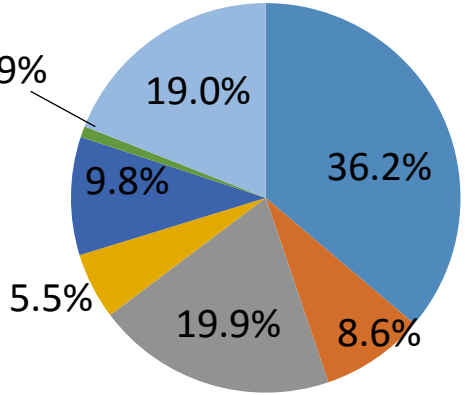
10.0%



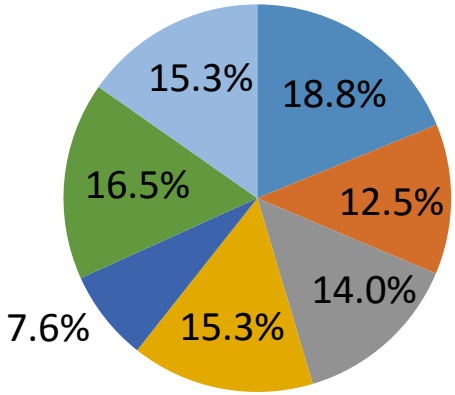


55.7%

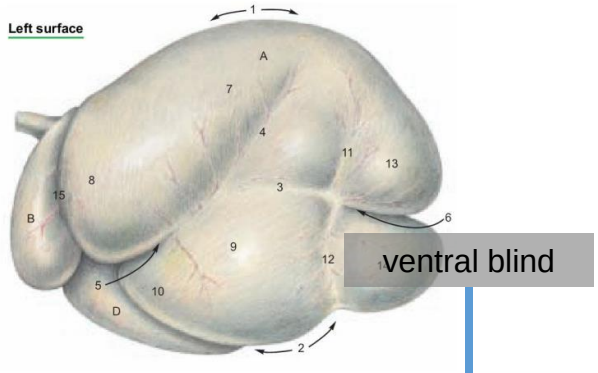
90.0%

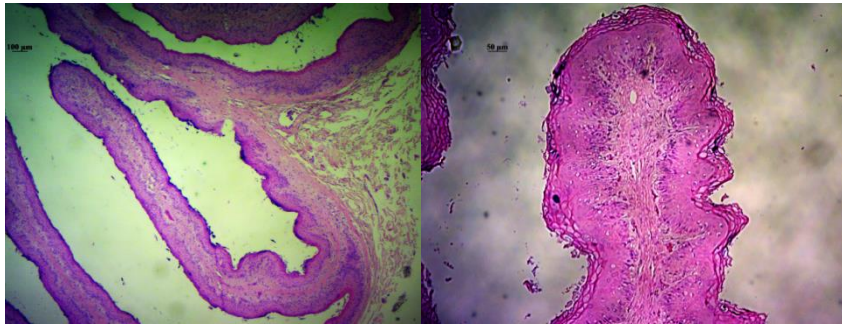


Acetate
Propionate
Isobutyrate
Butyrate
Isovalerate
Valerate
Caproate



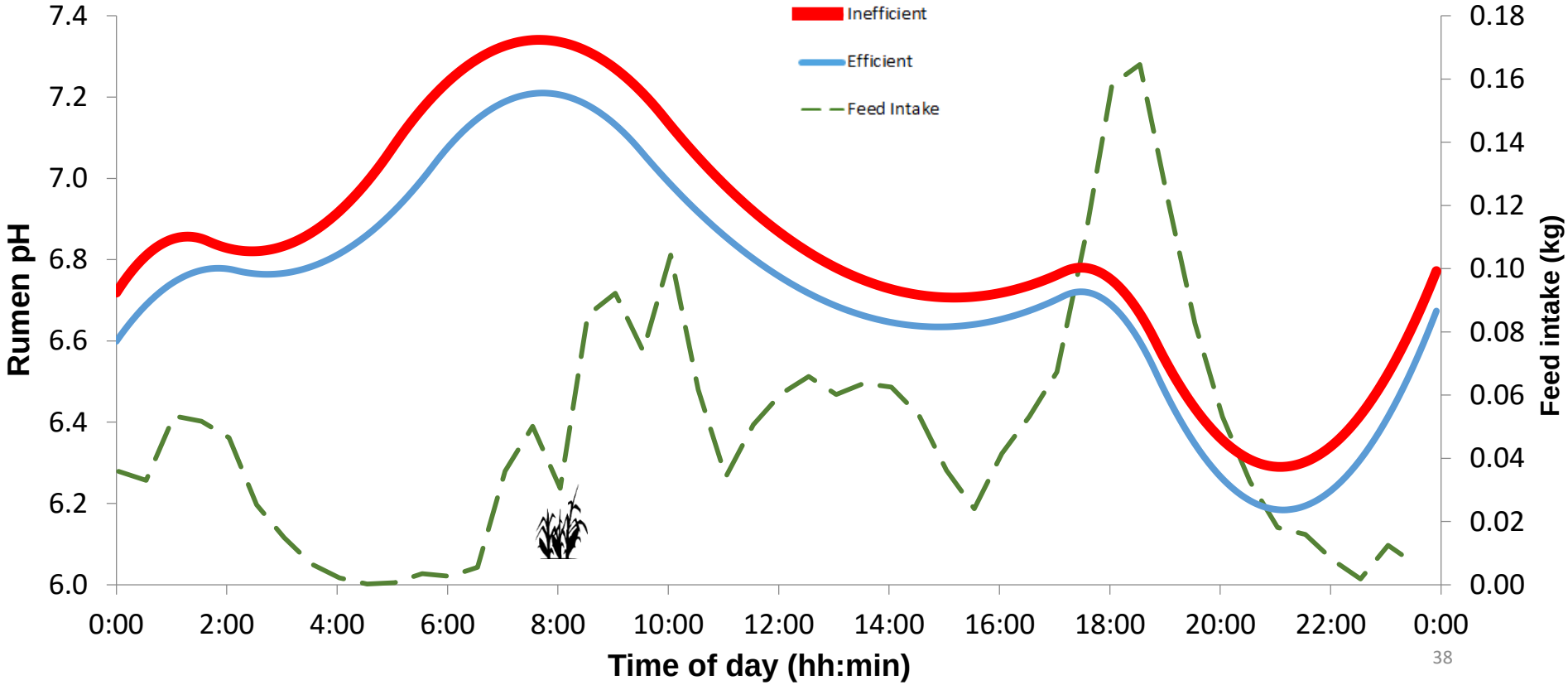
Results: Papillae histomorphometry



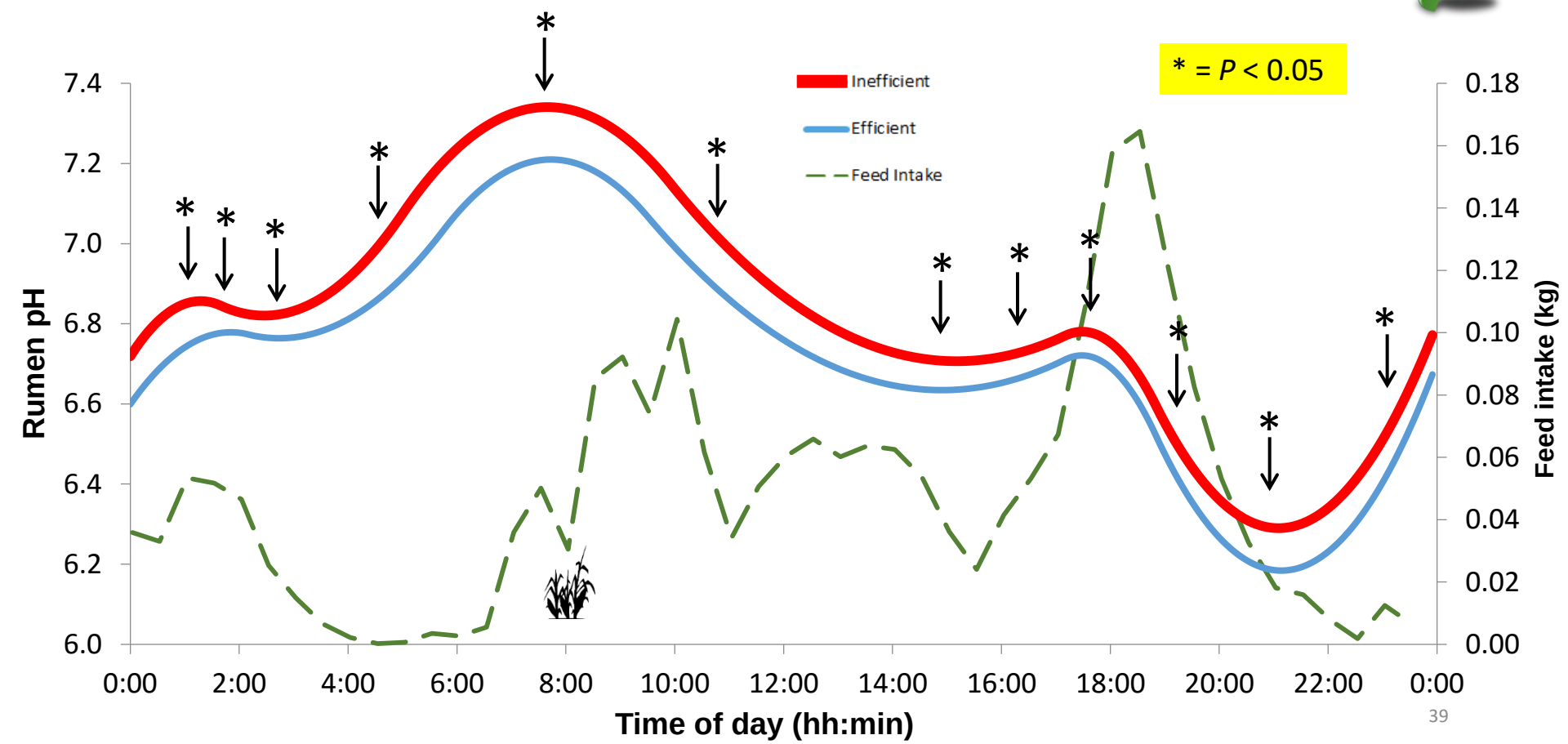


Papillae width	Papillae area	**Inefficient**	**Efficient**	*P*
(µm)	Base	110.1	113.4	0.39
	Middle	119.5	139.4	**<0.05**
	Tip	125.0	148.4	**<0.01**

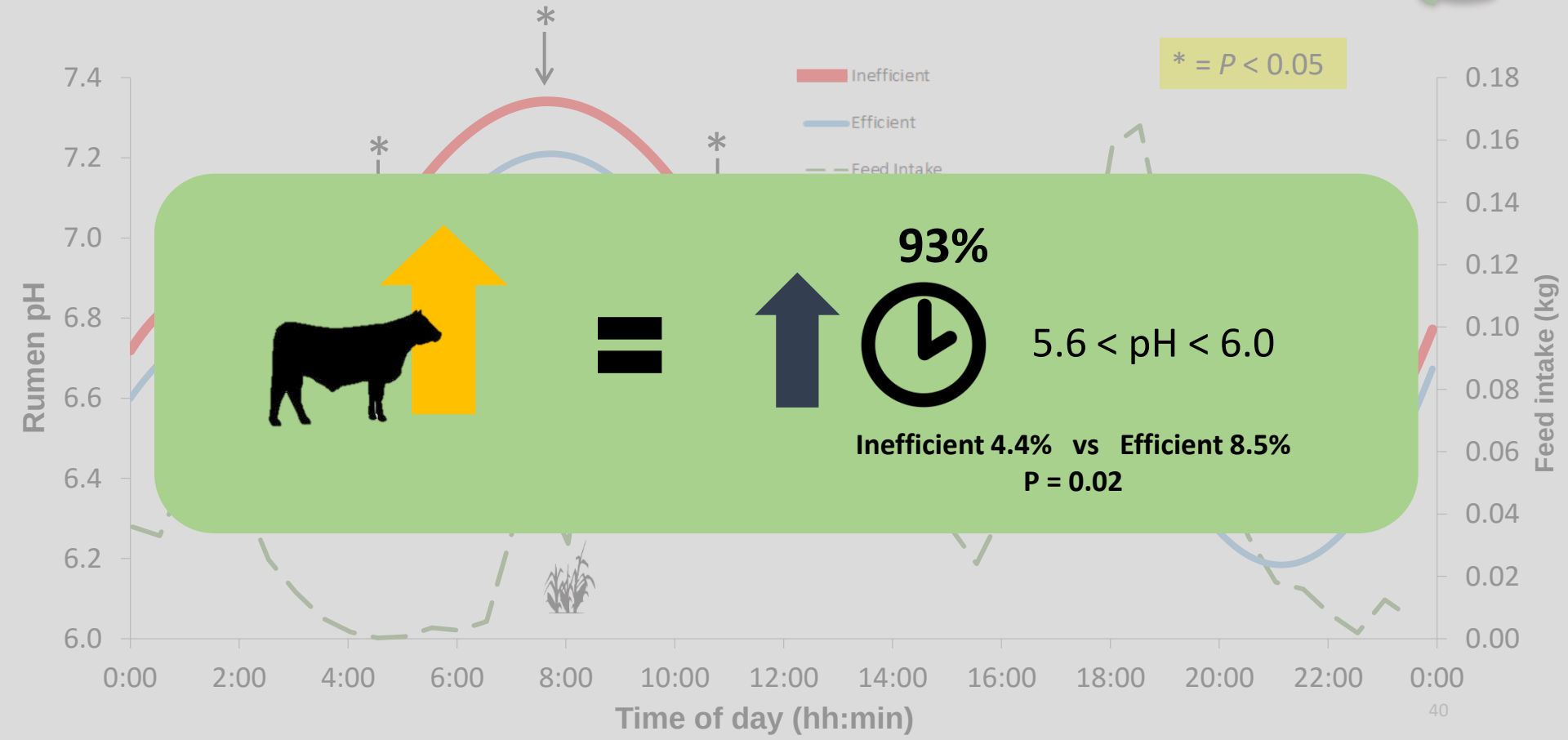
Results: Predicted rumen pH curves



Results: Predicted rumen pH curves

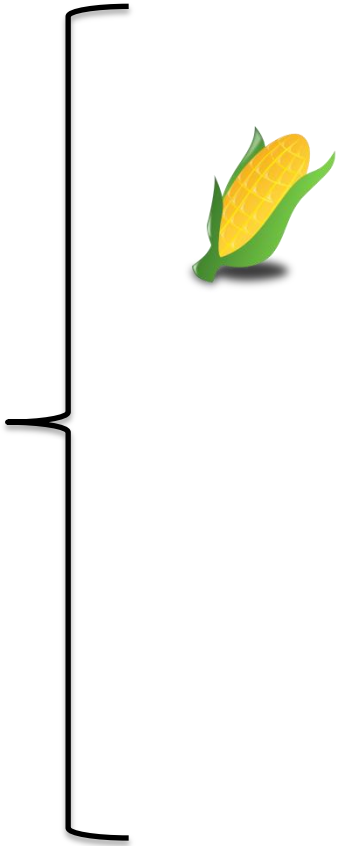


Results: Predicted rumen pH curves



Summary

Feed Efficiency



Bacteria population

Summary

Feed Efficiency

Bacteria population

Methanogen population

Methanogen population

Summary

Feed Efficiency

↑ Bacteria population

↓ Methanogen population

↑ Methanogen population

↑ Total and specific VFA

Summary

Feed Efficiency

- ↑ Bacteria population
- ↓ Methanogen population
  - ↑ Papillae width
  - ↓ Circadian pH

- ↑ Methanogen population
- ↑ Total and specific VFA

Conclusions

- Rumen microbiology, functional and structural parameters are important in assessing the underlying digestive biology of feed efficiency

- Dietary treatment has an impact on the relevance of rumen parameters used for indicating feed efficiency

Acknowledgements

- Advisor: Dr. Yuri Montanholi
- Colleagues and volunteers
- Technical staff
  - Yanhong Chen
  - Tim Caldwell
  - Elora beef research centre
  - Maritime beef testing station