Nutrition, efficiency and emissions

Pekka Huhtanen

Swedish University of Agricultural Sciences

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Why feed efficiency is important?

- Global challenges to livestock production
- Competing of resources – increasing demand of animal products
- Reduced environmental emissions (N, P, CH_4, CO_2) per unit of product
- Improved economy
- Tools to improve efficiency
  - Nutrition
  - Management
  - Selection / breeding

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Definitions of feed efficiency; FE (1)

- Efficiency = Output / Input
- FE = Milk kg/ DM intake (kg)
  - Energy corrected milk (ECM) a better biological measure of milk production
  - ECM/unit of metabolisable energy (ME); OK with feed table values, but not if true ME determined
    - Excludes between animal variation in digestibility and converting DE to ME

- Feed conversion efficiency (FCE) = Unit of feed / unit of product; e.g. FEC = kg DM/kg ECM

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Definitions of feed efficiency; FE (2)

- Residual Feed Intake (RFI)
- Used mainly for growing cattle
- Compares observed intake and intake predicted according to energy requirements
- $RFI = DMI - (a * ECM + b * BW^{0.75} + c * BWC)$
  - Positive values mean that the animal has used more feed expected according to requirements
  - Negative values mean that the animal has used less feed than expected = more efficient

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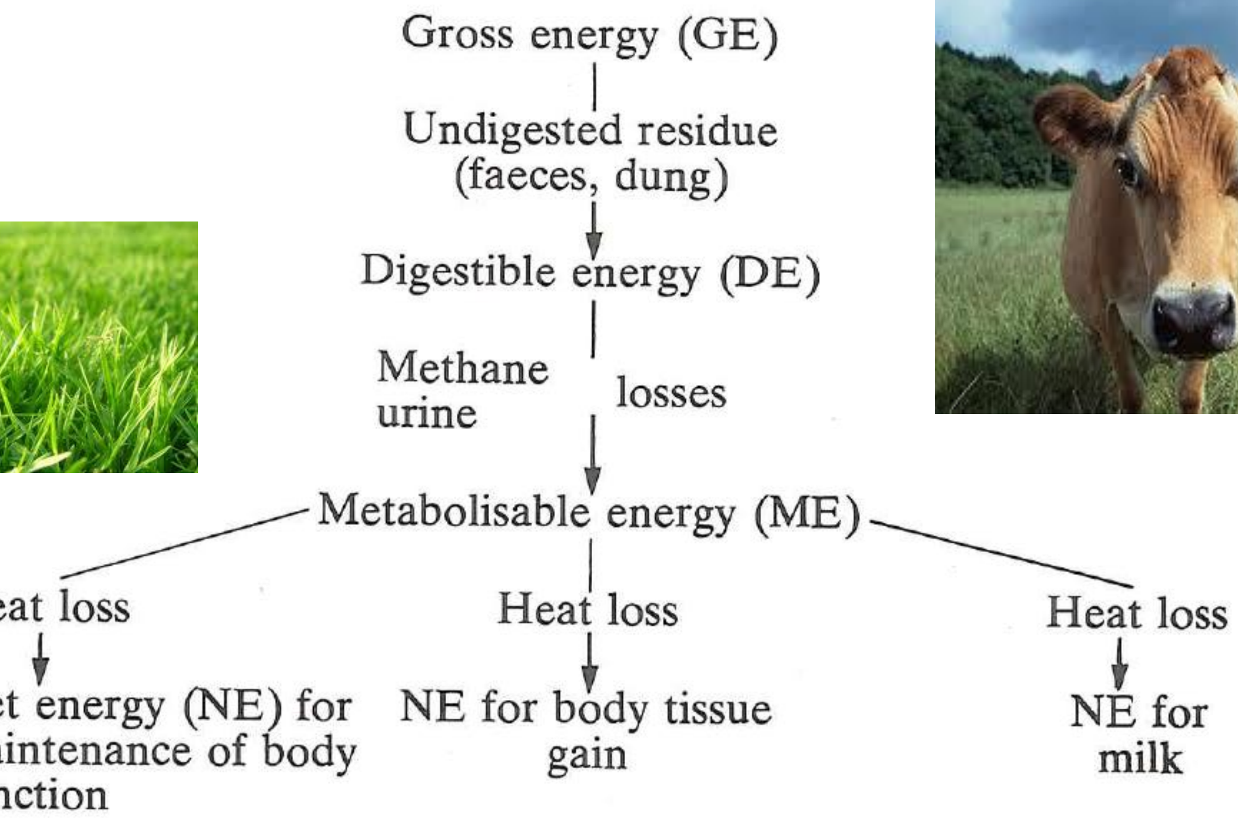
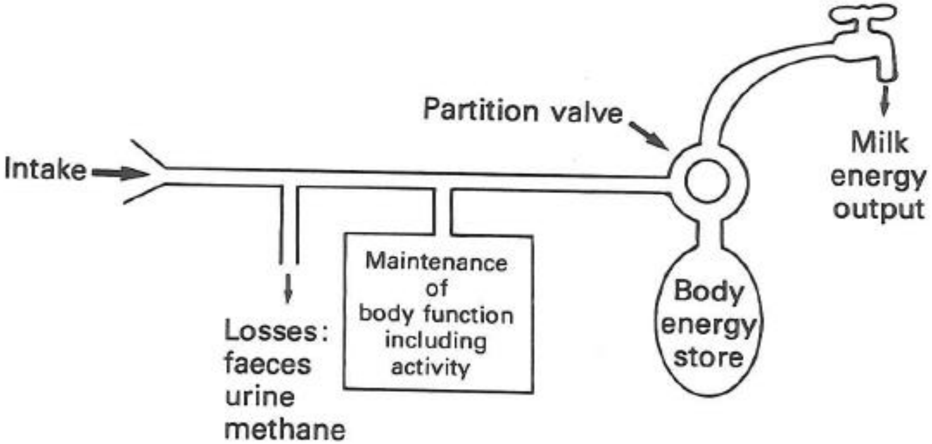
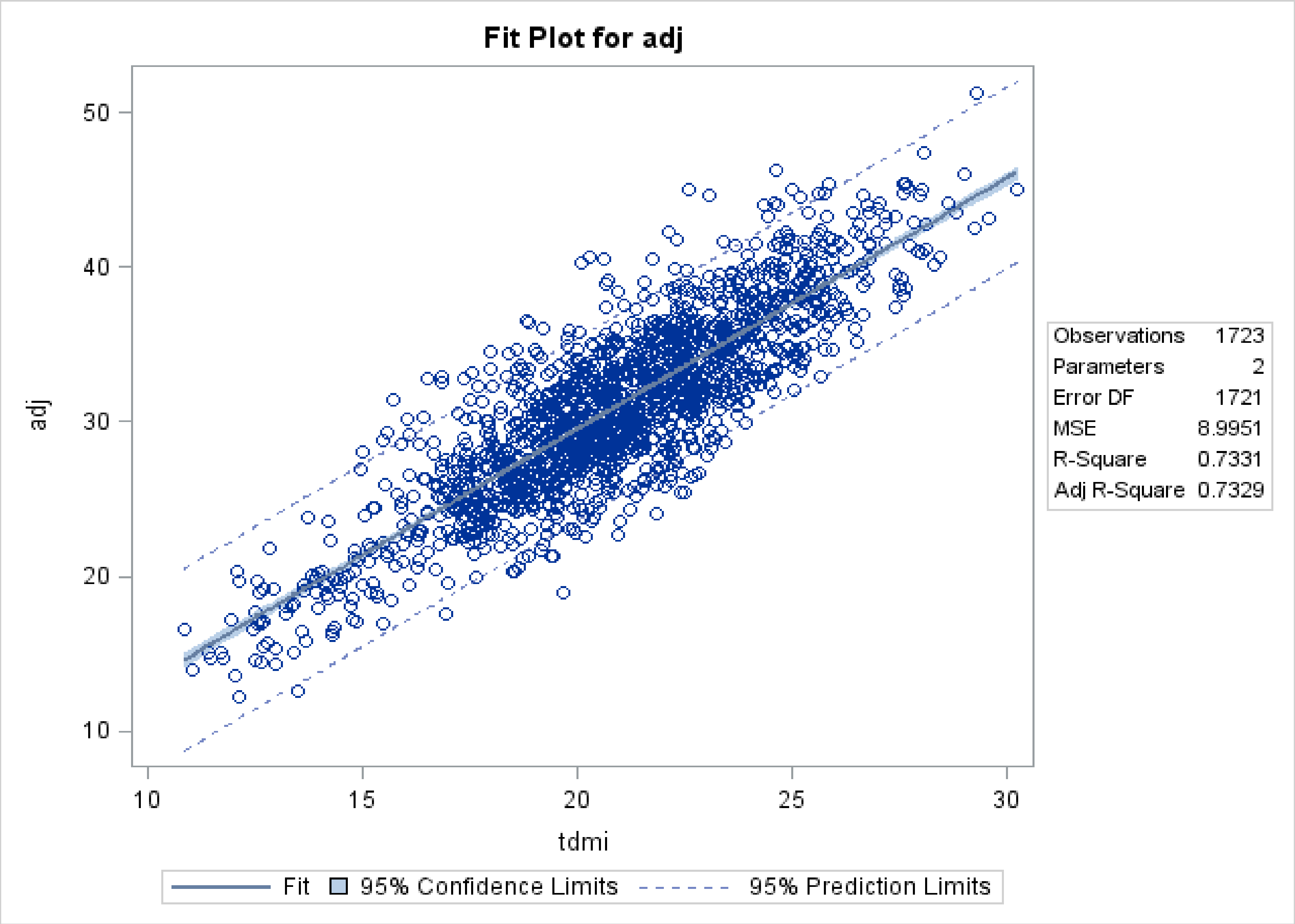




Partition of feed energy in the cow
(Owen, 1991)

Relationship between total DM intake and energy corrected milk yield



Effects of diet and period within Exp removed

Variation between cows in production

- ECM = DMI + BW + DIM; Diet(Exp) random
- Residual variance = 6.14 → between cow SD in ECM yield when the effects of diet, intake, body weight and stage of lactation removed was 2.48 kg/day (n = 1804 cow/period observations)
- This indicates that there are other factors than diluting maintenance requirement that cause variation in FE
- 2.48 kg ECM = 7.8 MJ milk energy and 12.5 MJ ME (k_l = 0.62)
- Example DMI = 20 kg/d, GE = 18.5 MJ/kg DM, GED = 0.70, CH_4 = 6.5% of GE, ME maintenance 60 MJ/d, k_l = 0.62

Variation between cows in production

- Production requirement = 156 MJ ME; 7.8 MJ milk energy = 0.05 improvement in k_l (CV in kl = ?)
- Maintenance requirement = 60 MJ → 12.5 MJ ME = 0.21 reduction in maintenance (CV = 0.076 in FHP; Yan et al.)
- Digestibility 0.70; DE intake = 259 MJ; 12.5 MJ ME = 14.7 MJ DE (q = 0.85); 0.057 improvement in digestibility (CV ~ 0.02)
- Methane 6.5% of GE intake = 24 MJ; 12.5 MJ = 0.51 reduction in CH_4 (CV 0.08 – 0.10)
- Variation in the efficiency of ME utilisation for milk production (k_l) and/or maintenance requirement (FHP and/or k_m) most likely greatest contributors to variation in efficiency

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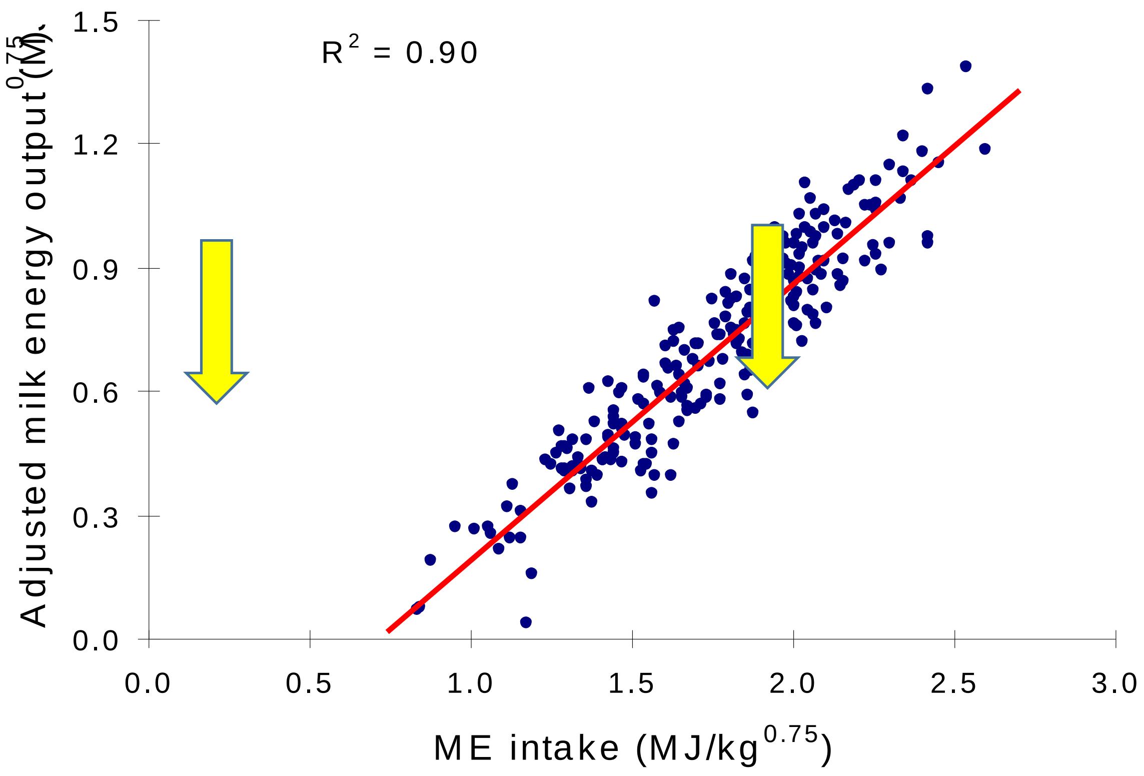
Large between cow variation in milk energy adjusted for zero energy balance



Data obtained from calorimeter chambers at AFBI Hillsborough

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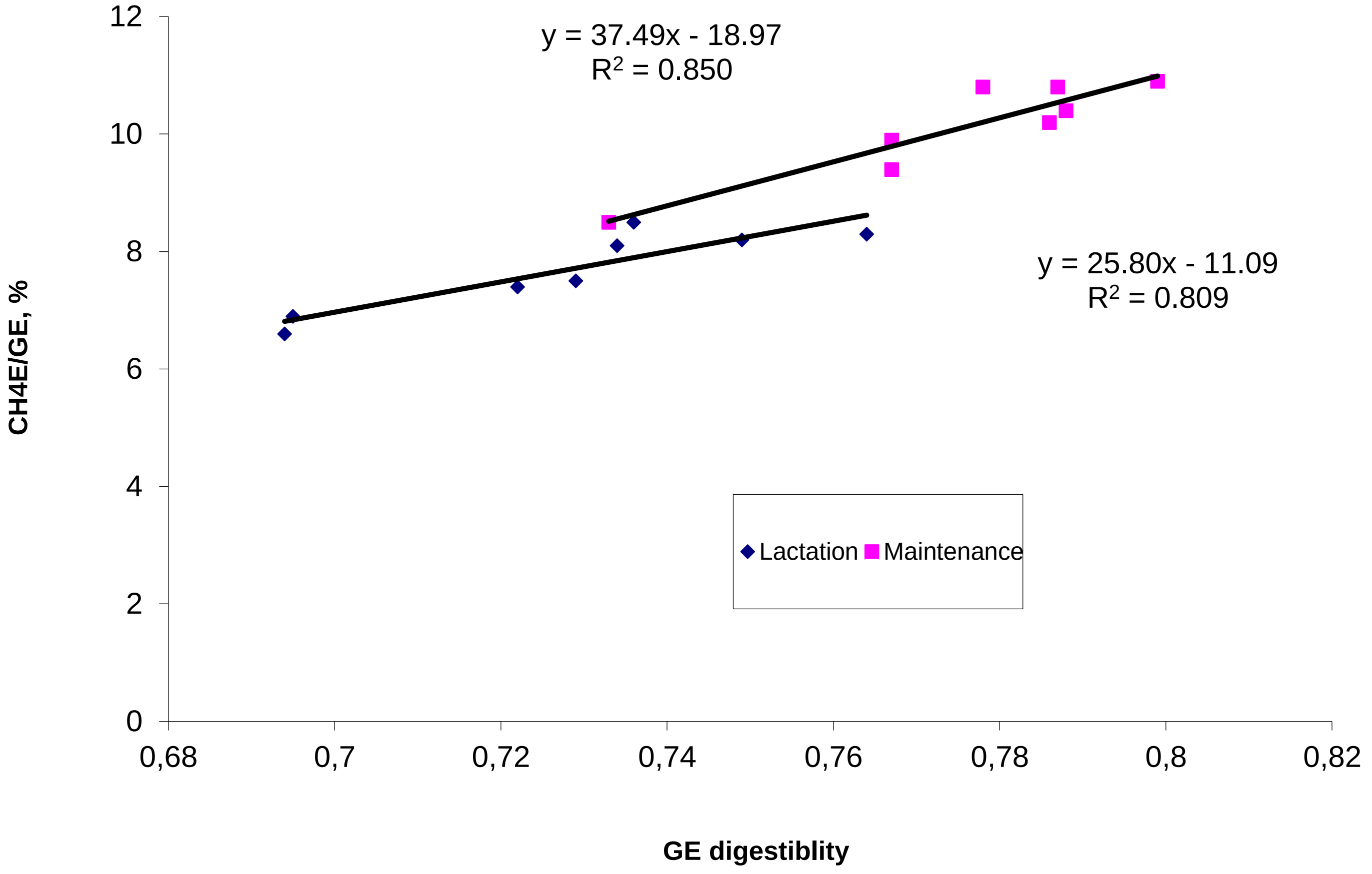
Digestibility / methane / efficiency

- The effects are digestibility and CH_4 on efficiency are likely to be smaller than calculated, since they are positively correlated
  - Methane is produced only from fermented material
  - Variation in digestibility at least partly due to variation in retention time in the rumen
  - Increased digestibility mainly from slowly digestible NDF that produce more CH4
  - With increased retention time (slower passage) more fermented C portioned to VFA and gasses and less to microbial cells that are more reduced than fermented CHO

Observed relationship between digestibility and methane (Schiemann et al. 1971)



Schieman et al. 1971

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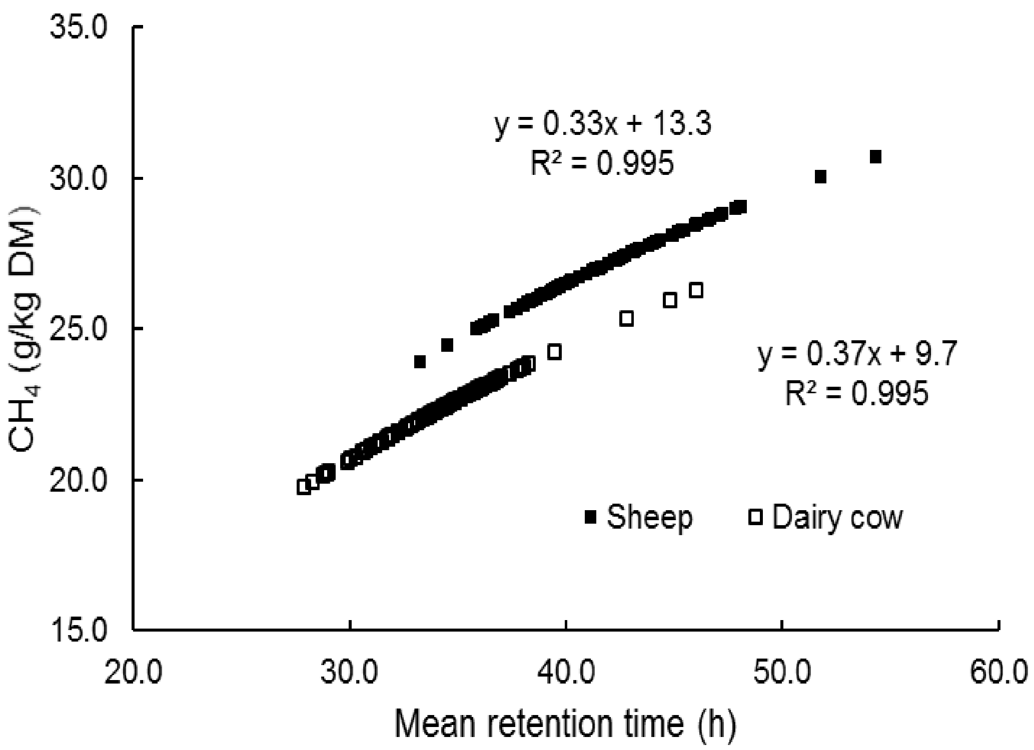
Relationships between rumen retention time and CH_4 or OM digestibility



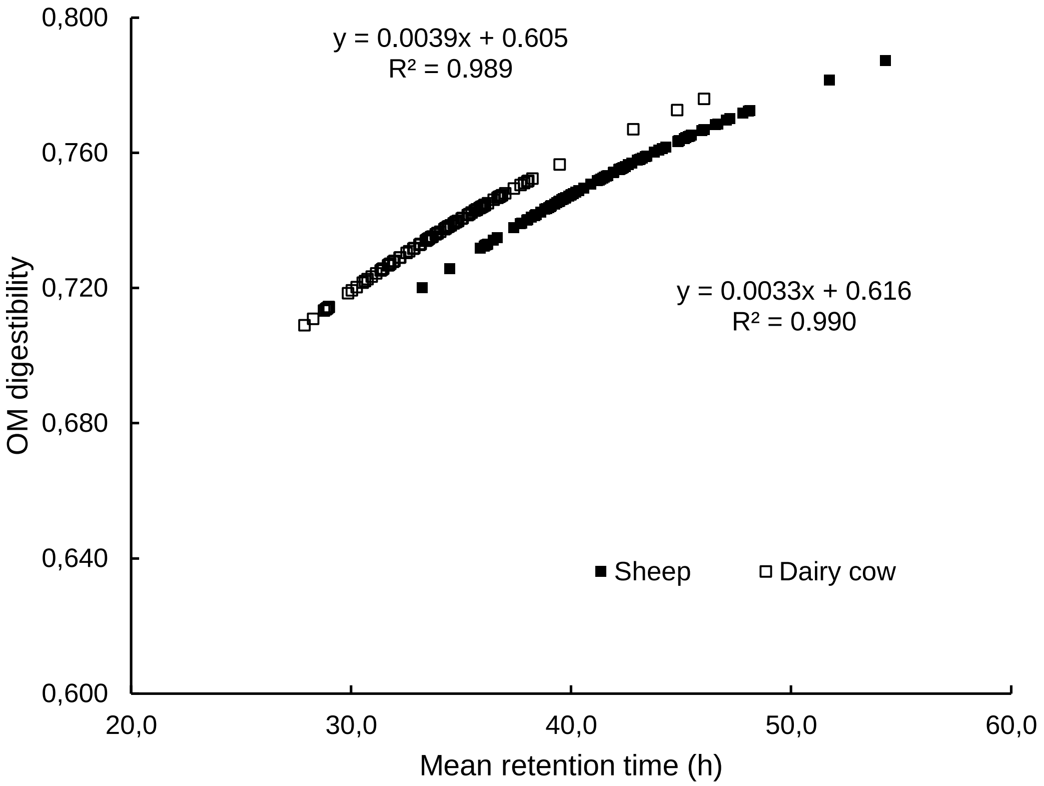
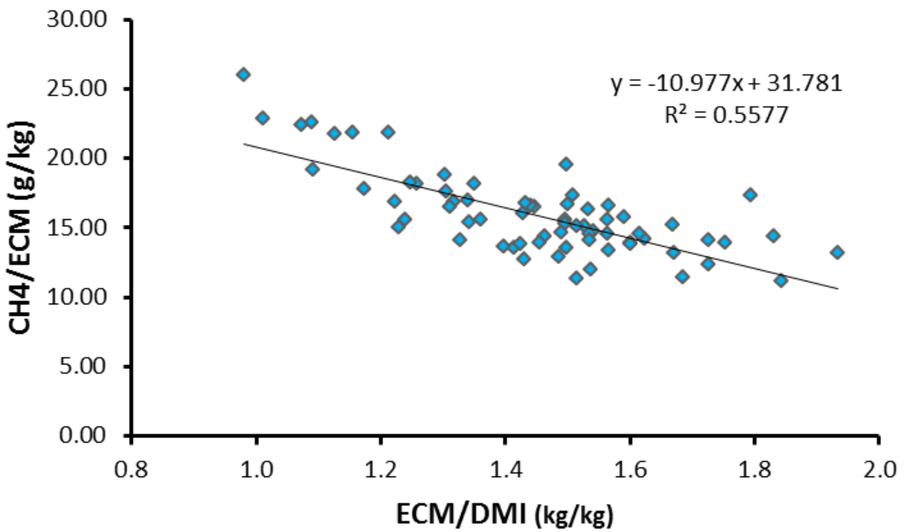
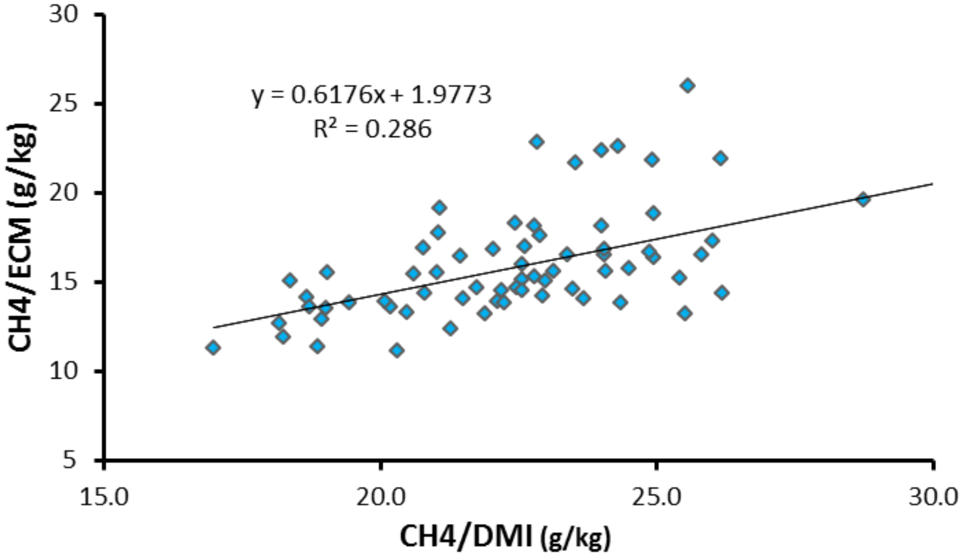


Table 1. Methane emissions, DM intake (DMI), energy corrected milk production (ECM) and feed efficiency (ECM/DMI) for cows ranked low and high according to different criteria. Selection criterion is bold font on gray background.

Selection criterion		CH_4 (g/d)	CH_4 (g/kg DMI)	CH_4:CO_2	CH_4/ECM (g/kg)	DMI (kg/d)	ECM (kg/d)	ECM/DMI (kg/kg)
Total CH_4 (g/d)	Low	**386**	21.3	0.0372	15.3	18.3	26.5	1.44
	High	**513**	23.0	0.0406	15.9	22.4	32.9	1.47
CH_4 (g/kg DMI)	Low	439	**19.1**	0.0378	13.5	23.0	32.6	1.42
	High	476	**25.6**	0.0394	18.0	18.7	27.2	1.47
CH_4:CO_2	Low	411	21.0	**0.0356**	15.5	19.8	27.8	1.39
	High	488	23.6	**0.0412**	16.2	20.9	30.9	1.48
CH_4/ECM (g/kg)	Low	428	19.8	0.0377	**12.7**	21.6	33.8	1.57
	High	458	24.1	0.0383	**20.2**	19.2	23.1	1.22
ECM (kg/d)	Low	440	24.0	0.0386	20.1	18.4	**22.1**	1.22
	High	489	21.3	0.0395	13.7	23.2	**35.9**	1.56
ECM/DMI (kg/kg)	Low	457	22.6	0.0377	20.1	20.3	23.3	**1.14**
	High	456	24.1	0.0389	14.3	19.1	32.1	**1.69**

Improved FE reduce CH4 emission per kg milk (ECM)





Mechanisms of efficiency and methane emissions per unit of product

1. Maintenance requirement is diluted with increased production → Less CH_4 per kg milk or gain
2. Although total CH_4 increases with increased intake, emissions decrease per unit of intake
   i. Digestibility decrease
   ii. Repartitioning of fermented C to microbial cells instead of VFA and gasses
   iii. Microbial cell are H_2 sink – more reduced than CHO in the diet
   iv. Changes in rumen fermentation pattern

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Nutrition and methane emissions

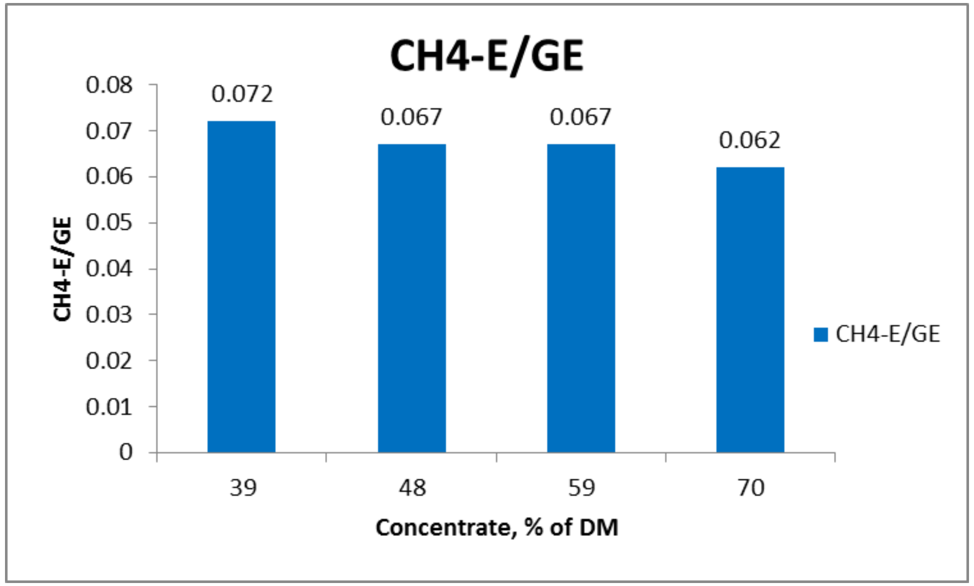
1. High concentrate diets decrease CH_4, but within typical dairy cow diets the effects not very large (much lower with feed-lot diets >90% concentrate)
    i. Emissions from manure increase
2. Fat supplements reduce CH_4
    i. Replace CHO in the diet
    ii. Biohydrogenation
    iii. Changes in rumen fermentation pattern

Prediction of methane production as a proportion of GE (kJ CH_4-E / MJ GE); n = 298

Variable	**Estimate**	**SE**	***P*-value**
Intercept	-0.60	12.7	0.96
DMIBW, g/kg	-0.70	0.072	<0.01
OMD, g/kg	0.076	0.0118	<0.01
EE, g/kg DM	-0.13	0.02	<0.01
NDF, g/kg DM	0.046	0.0097	<0.01
NFC, g/kg DM	0.044	0.0094	<0.01

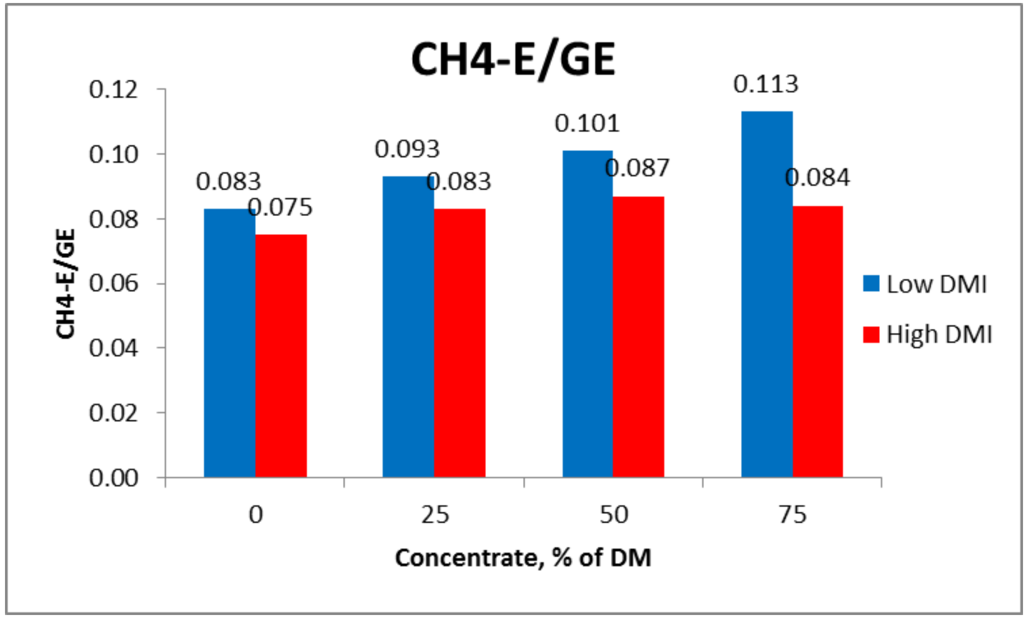
RMSE adj. for random study effect 3.26 (CV 4.65%)

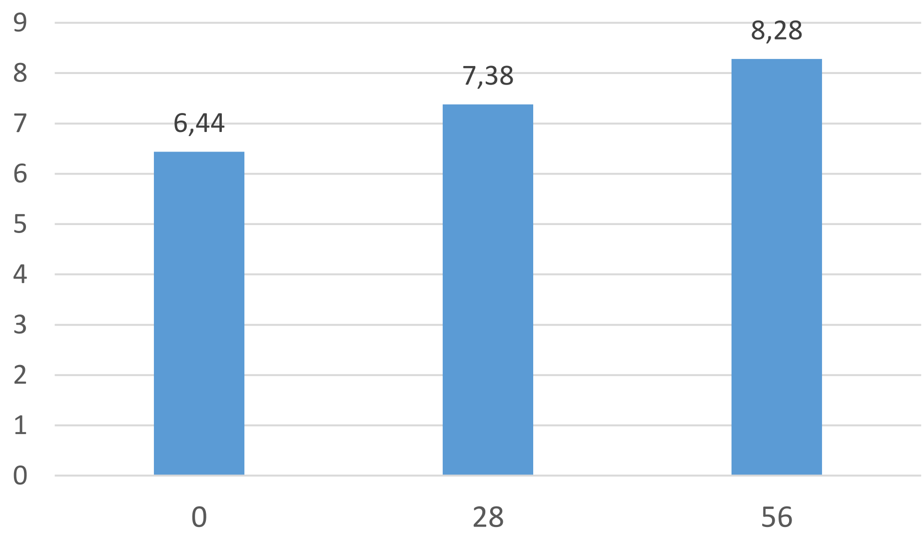
Effect of proportion of concentrate on CH_4 emissions in dairy cows, growing cattle and sheep



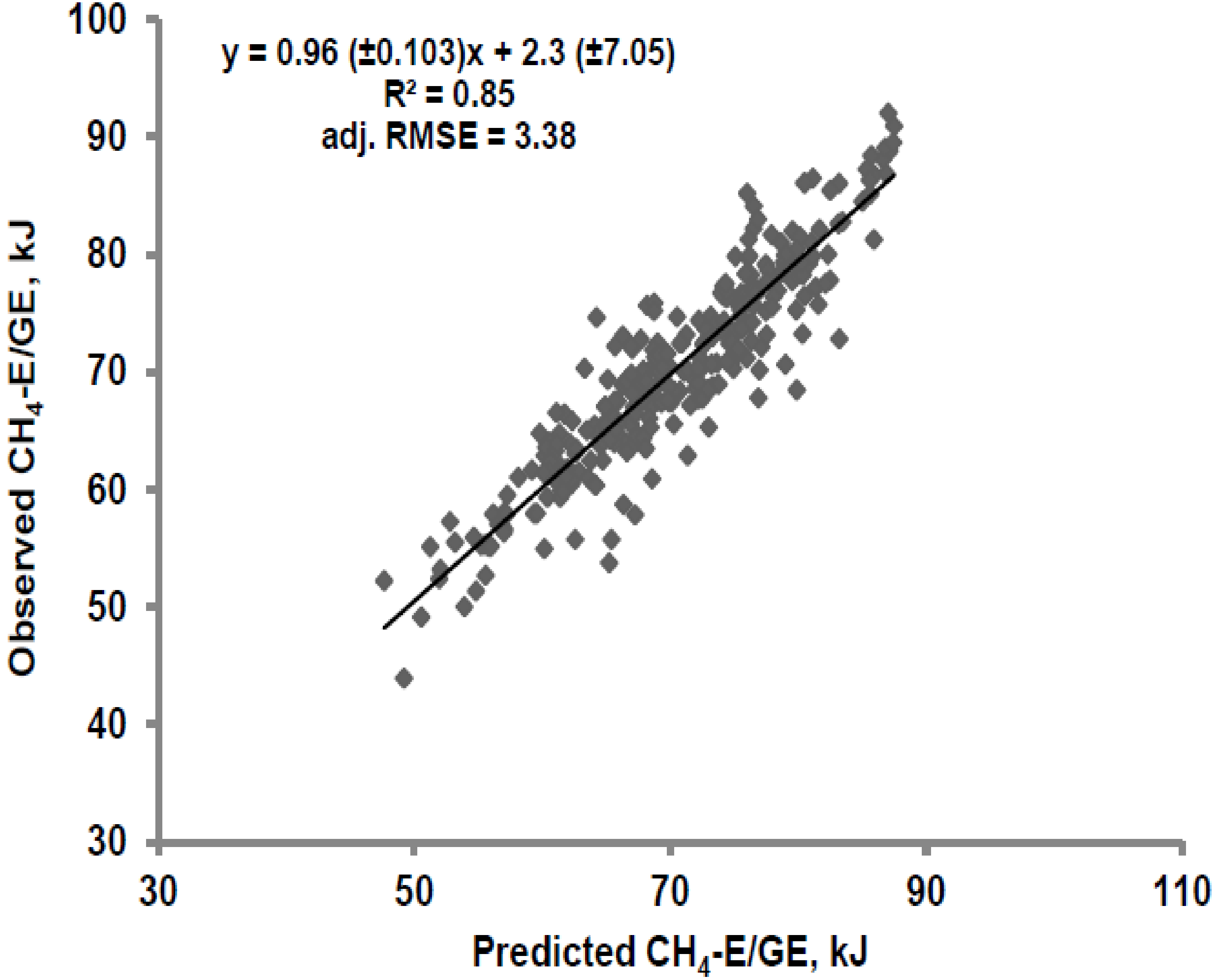
Ferris et al., 1999

Moss et al. 1995





Beever et al. 1988



y = 0.96 (±0.103)x + 2.3 (±7.05)
R² = 0.85
adj. RMSE = 3.38
Observed CH4-E/GE, kJ
Predicted CH4-E/GE, kJ
100
90
80
70
60
50
40
30
30
50
70
90
110

Prediction of methane production as a proportion of GE (kJ CH_4-E / MJ GE) in studies in which rumen fermentation was measured; n = 127

X_1	X_2	X_3	Intercept	$Slope_1$	$Slope_2$	$Slope_3$	RMSE
DMIBW	OMD_m	Acetate (C_2)	-31.6	-0.97	0.088	93	5.86
DMIBW	OMD_m	Propionate (C_3)	90.2	-0.86	0.054	-190	5.08
DMIBW	OMD_m	Butyrate (C_4)	46.5	-1.16	0.041	169	5.42
DMIBW	OMD_m	C_2/C_3	11.0	-0.88	0.068	9.6	5.32
DMIBW	OMD_m	$(C_2 + C_4)/C_3$	18.0	-0.90	0.058	8.3	5.21
DMIBW	OMD_m	CH_4VFA	-29.6	-0.96	0.050	262	4.93

$CH4VFA = 0.5 \times C_2 - 0.25 \times C_3 + 0.5 \times C_4$

Power function model

n = 207, CH_4 = a × $DMI^{b,}$
adj. RMSE = 22.4 L/d (CV = 5.9 %)

Parameter	**Estimate**	**SE**	***P-value***
Constant (a)	50.0	3.75	<0.001
Power			
b	0.877	0.0367	<0.001
EE (kg/kg)	-0.850	0.1125	<0.001
$cOMD_m$ (kg/kg)	0.258	0.064	<0.001
NFC/CHO	-0.105	0.0343	<0.001

Dietary variables adjust the exponent (b)

EE: ether extract.
$cOMD_m$: organic matter digestibility at maintenance intake centred to mean digestibility (0.736).

Additives

- Ionophores banned in EU; effect at least partially temporary.
- Plant extracts; some positive results in vitro, but doses often unfeasible (expensive) in practise
- Nitrate
  - Has consistently decreased CH_4
  - Health problems? Very little evidence from recent studies
  - Increase N emissions unless used to replace urea to meet N requirements of rumen microbes
  - More expensive than urea
- 3-nitrooxypropanol decreased CH_4 about 30% without adversary effects on intake or production (Hristov et al., 2015)

Nitrogen emissions

- Average efficiency of N utilization for milk production (MNE) has been 25-30% in large datasets
- Large variation from about 15 to 40%
- Environmental effects: ammonia evaporation, nitrate leaching, nitrogen oxides
- Urine N much more harmful than faecal N; more susceptible for both evaporation and leaching

Nitrogen economy of the lactating cow

N intake

503 g/d

N Urine

37%

N Faeces

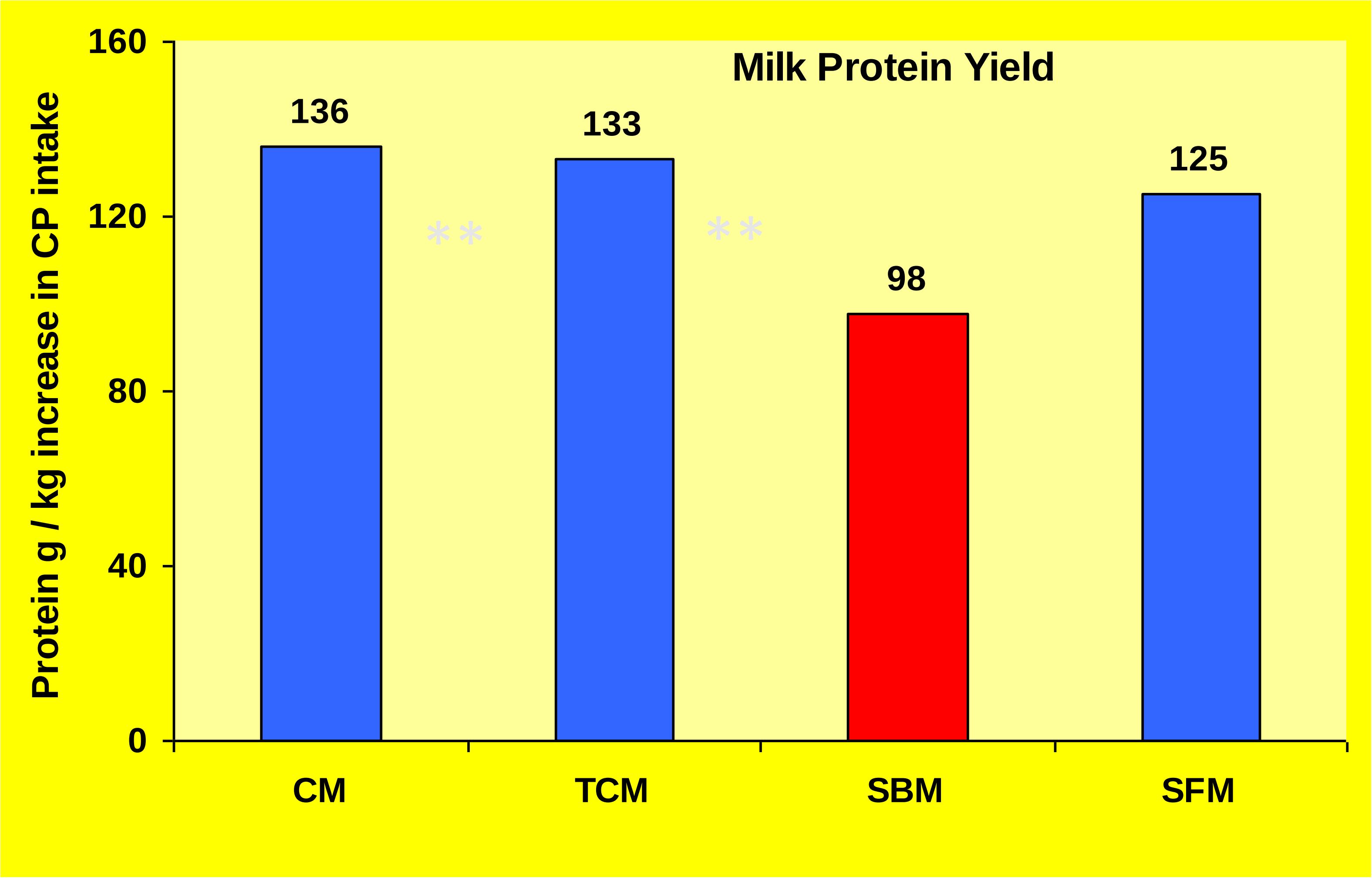
33%

N Milk

28%

Mills et al., 2009

Effects of protein supplements on milk protein yield (g per kg increase in CP intake)



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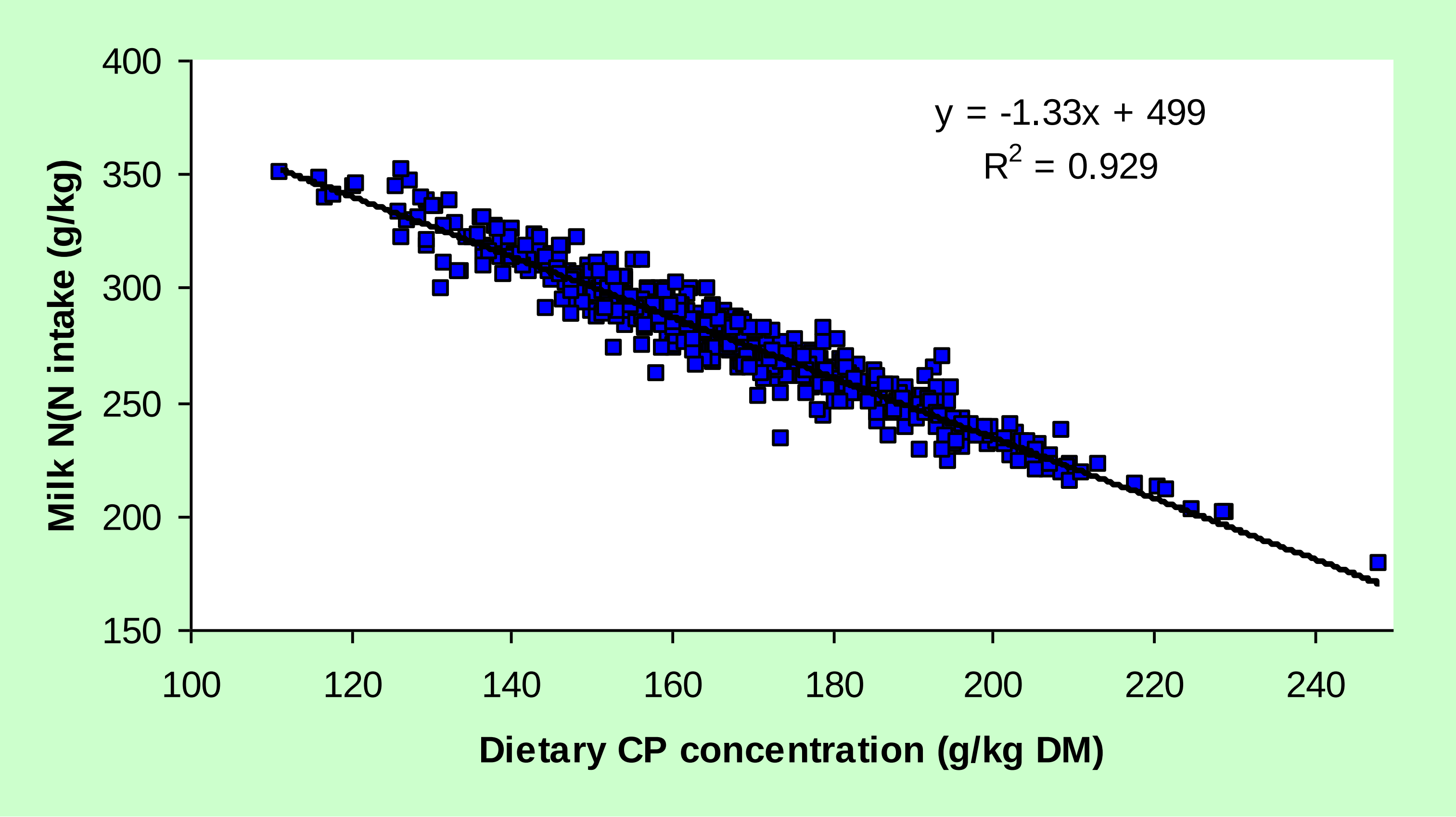
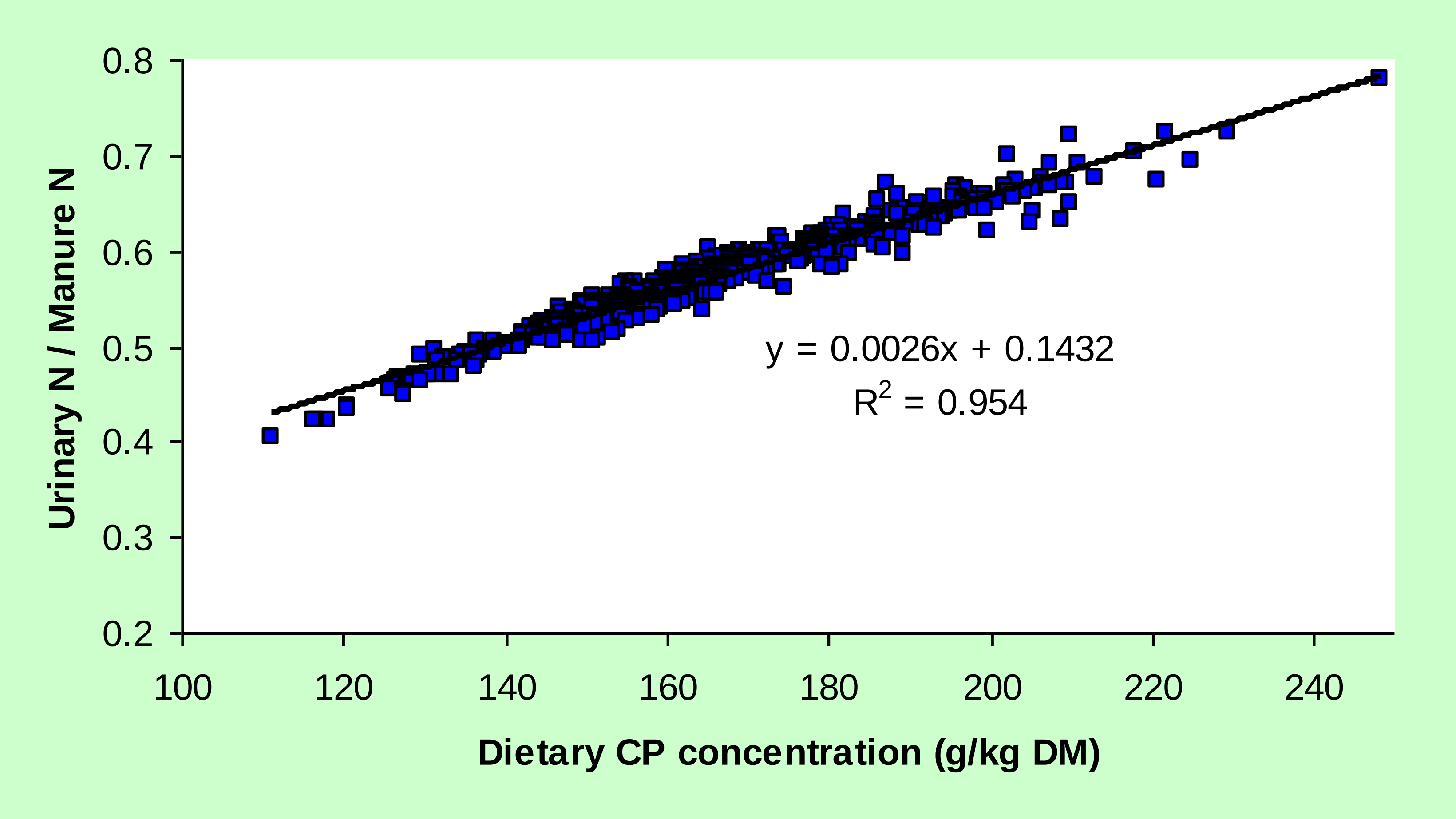
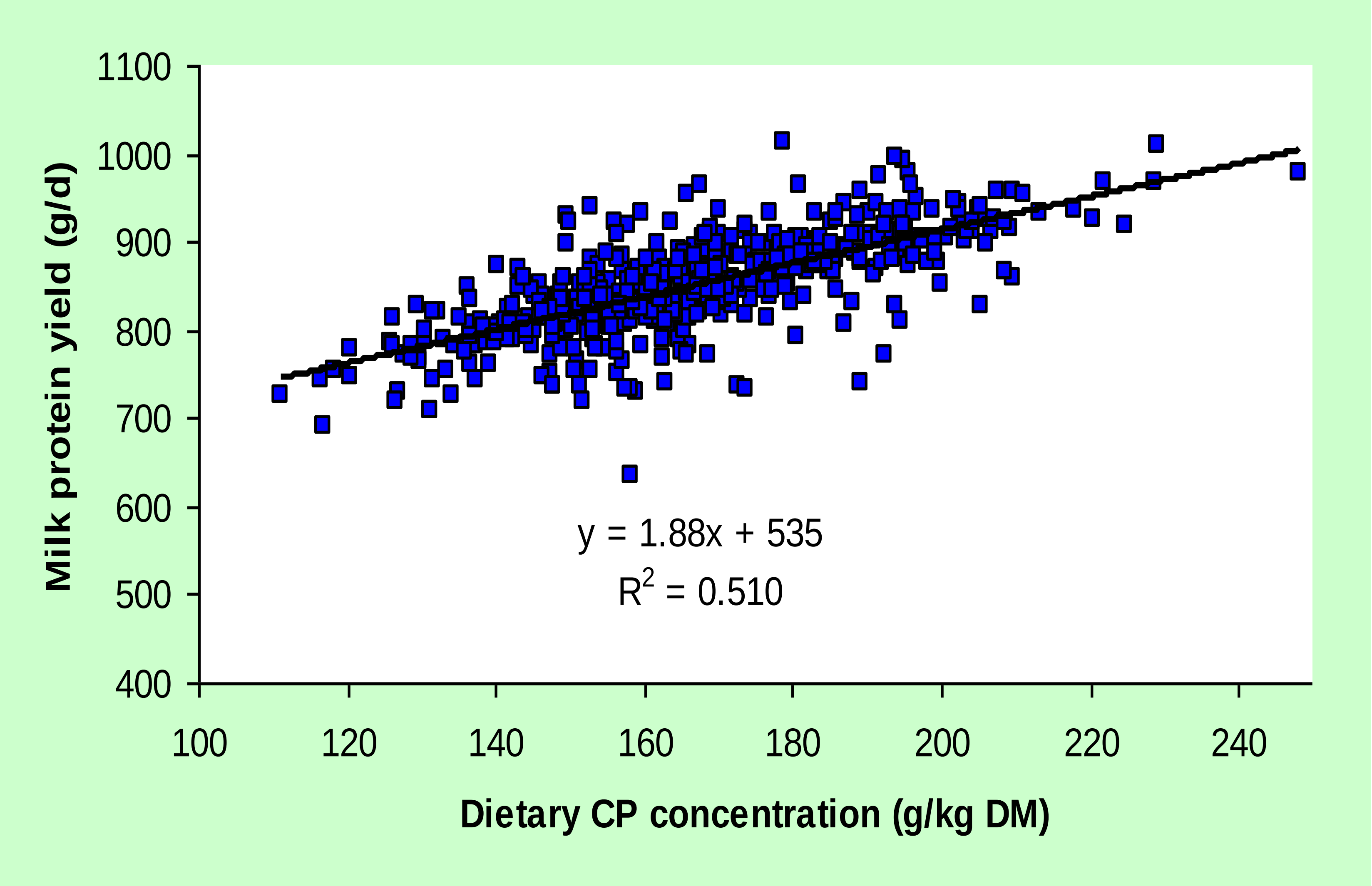
Increased dietary protein decrease the efficiency of N utilisation



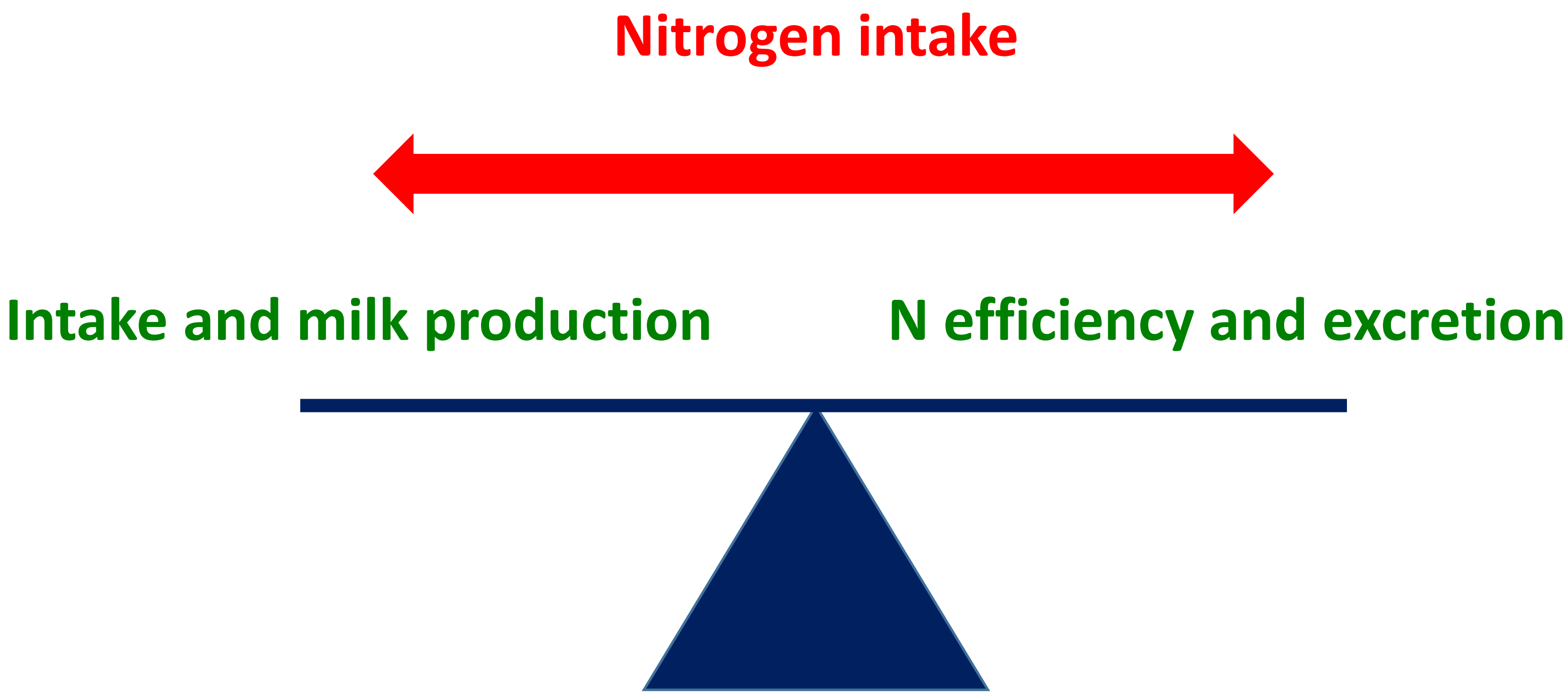
AND increased urinary in manure N that is more harmful to the environment



…BUT increased dietary protein also increase production



Fundamental conflict between performance and efficiency responses to dietary protein supplementation



Nutritional strategies to improve MNE

(other than dietary CP concentration)

- Reduce ruminal protein degradability
  - Effects much smaller than degradability values based on in situ method predict
  - RUP "overvalued"
- Amino acid supplementation
  - Positive results with low CP diets
  - Positive results when RUP imbalanced (low in Met and/or Lys)
  - With typical forage + grain + RSM/SBM diets AA composition rather well balanced
- Optimizing microbial protein synthesis

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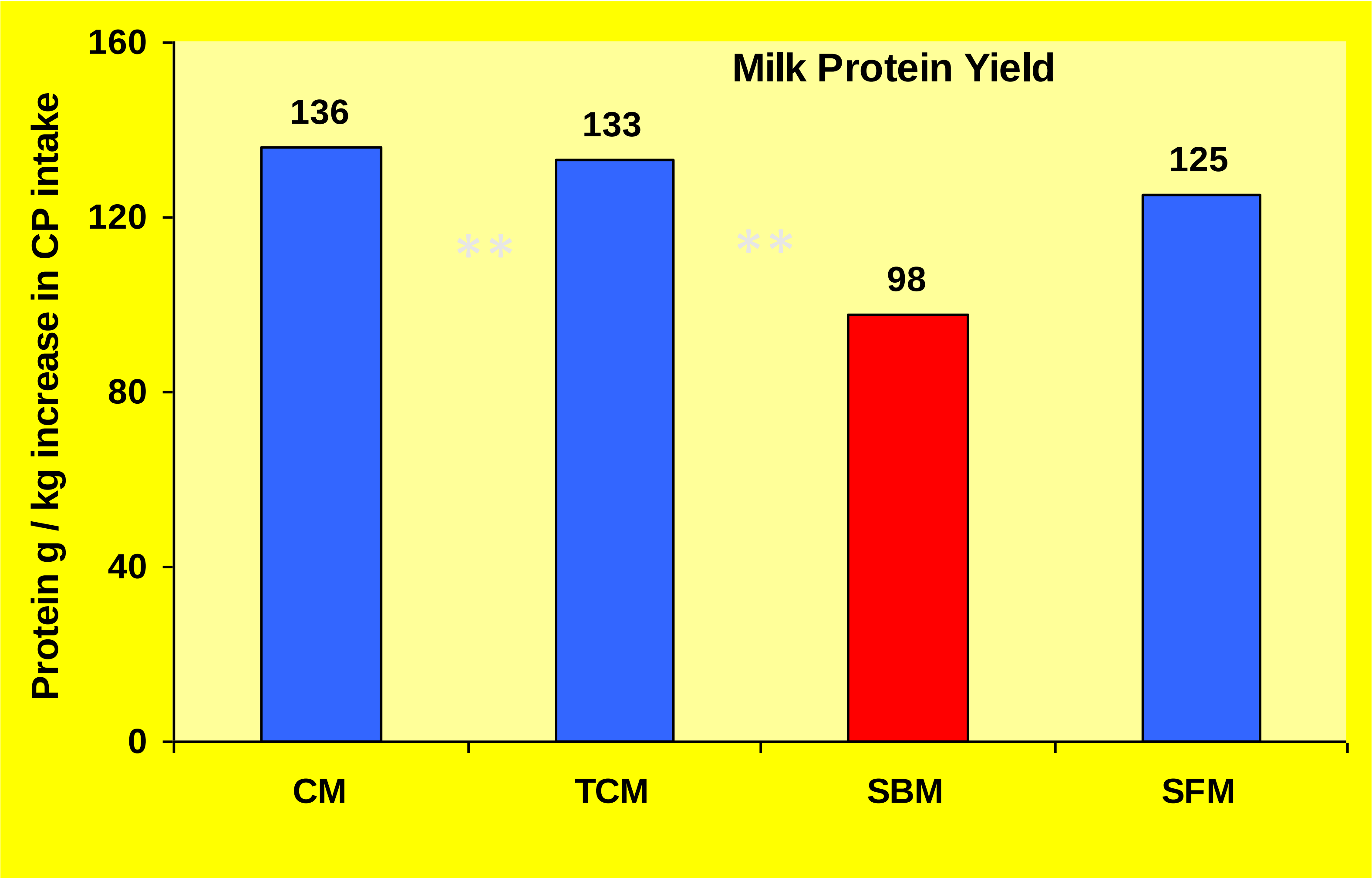
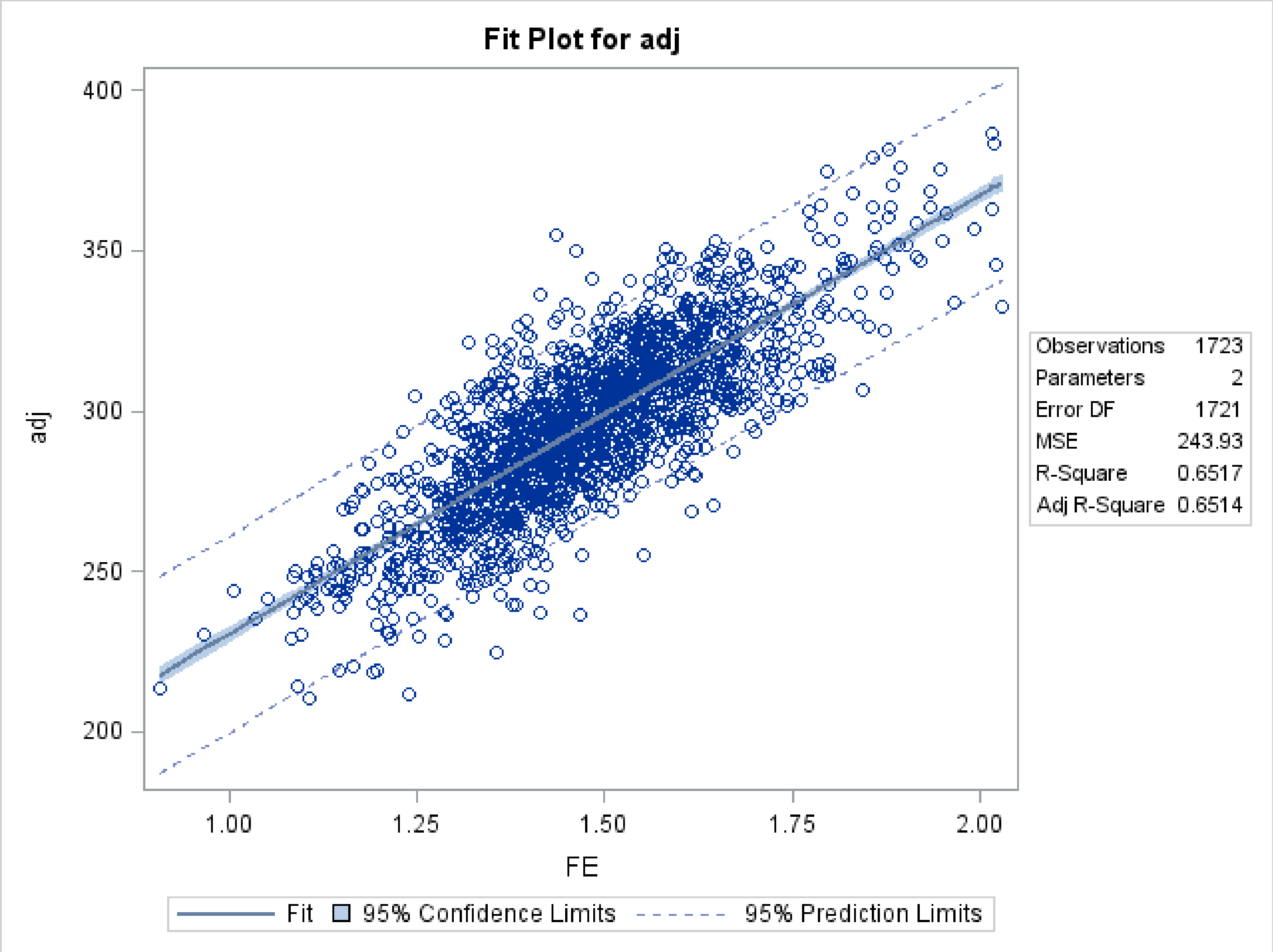
Effects of protein supplements on milk protein yield (g per kg increase in CP intake)



Relationship between feed efficiency (FE) and milk N efficiency (Milk N / N intake; g/kg)



Conclusions

- To decrease methane emissions per unit of product
  - Balanced rations with optimal (economy) level of fat
  - Longevity at least important as production level for lifetime CH_4/kg
  - Improving FE by breeding most sustainable method in a long run to improve utilization of resources and reduce emissions
  - Improve FE decrease CH_4, but decreased CH_4 may not improve FE
- To decrease N emissions per unit of product
  - Dietary CP concentration clearly the most important factor in a short run
  - Longevity and FE important in a long run

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