Feed Efficiency in Sheep What, why, how? What now?

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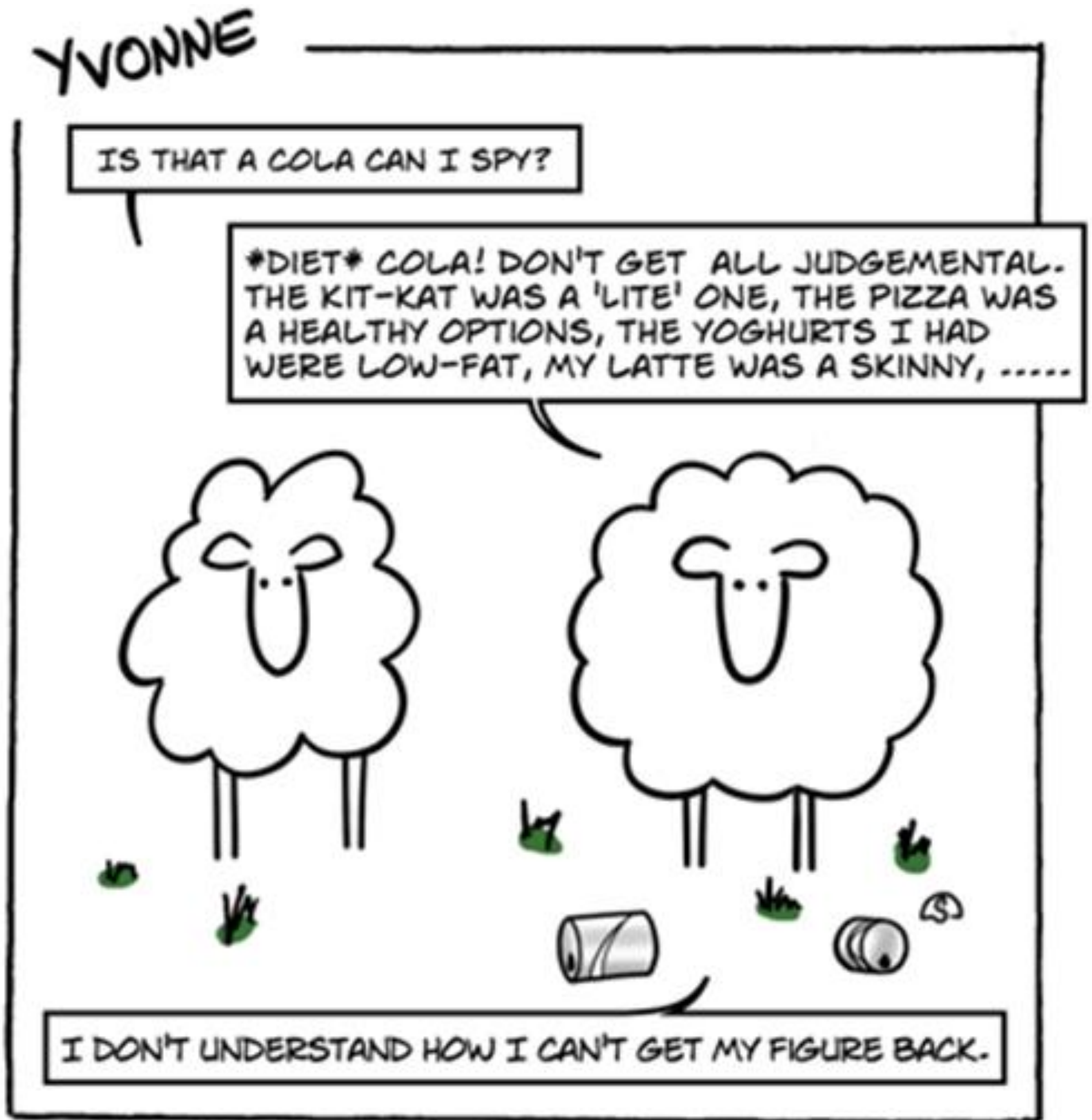

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Definitions

Feed Conversion Efficiency (FCE)

- Efficiency of conversion of feed to product (growth, meat, milk, wool)

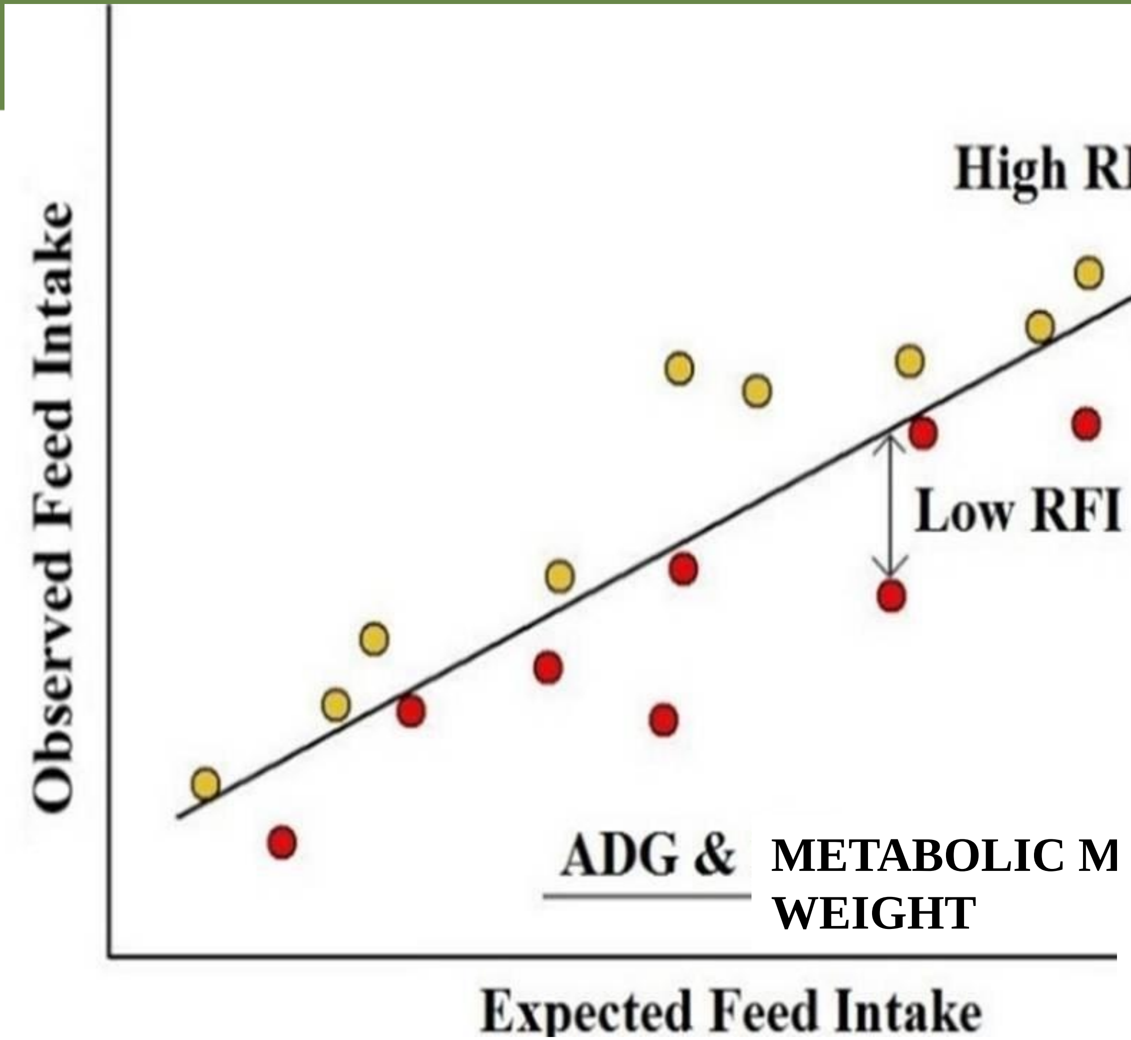
Feed Conversion Ratio (FCR)

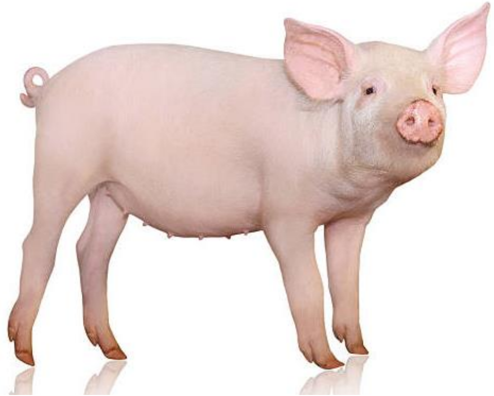
- Ratio of feed consumed to live weight gain (kg feed DM consumed/ kg live weight gain)

Residual Feed Intake (RFI)

- Difference between actual and predicted intake based on size and growth
- Not correlated with mature size or growth rate, can use at any age or growth stage

Residual Feed Intake





http://porkgateway.org/resource/selection-residual-feed-intake-rfi-affected-grow-finish-pigs-ability-cope-stress/

Why is feed conversion efficiency important?

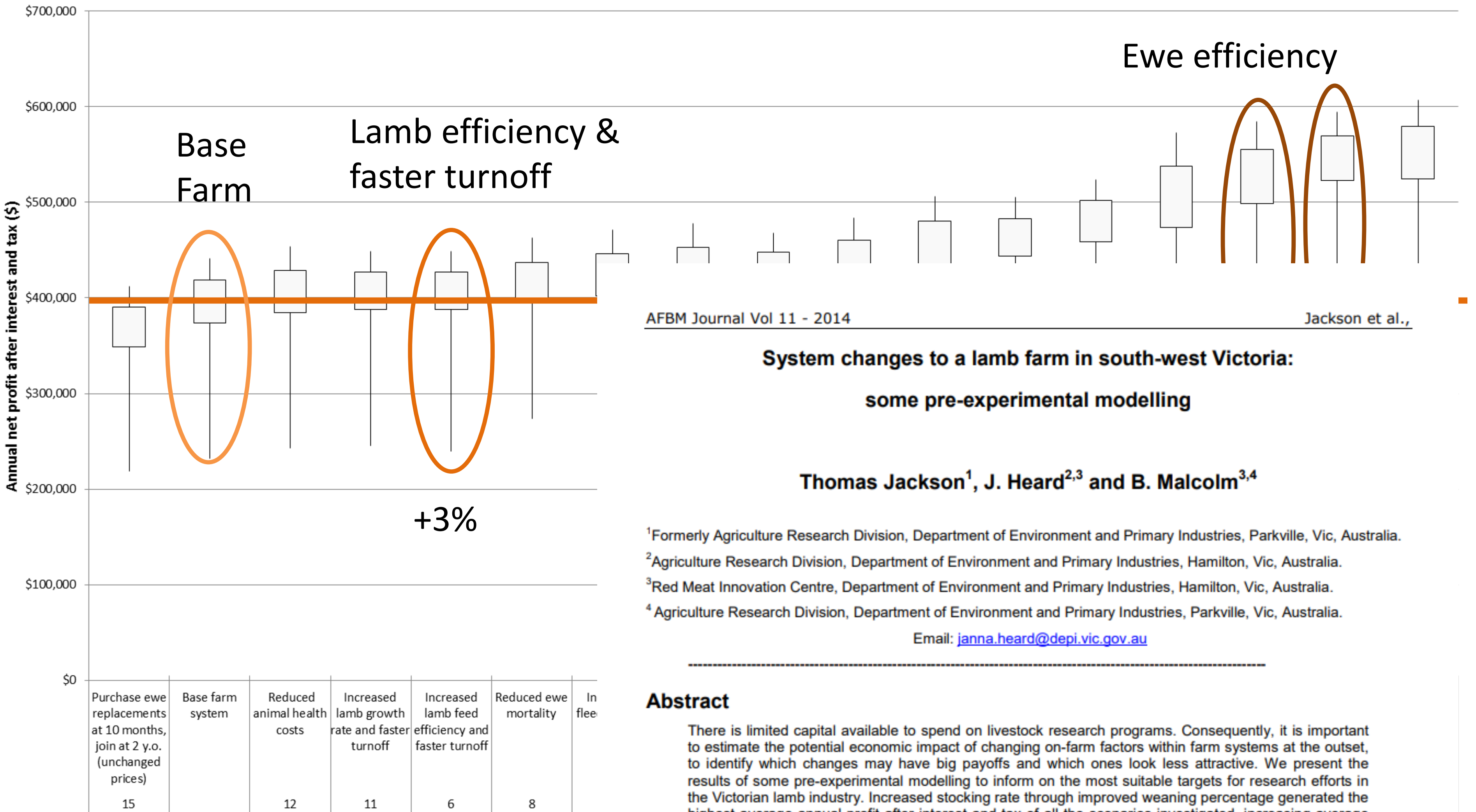
Why?

Feed is a significant cost in animal production

Feed costs for the maintenance of the ewe flock and replacements accounts for about 60% of the total feed required for the production of lamb.

Modelling has shown that improving the Feed Conversion Efficiency (FCE) can increase farm productivity and profitability

Impacts on farm profit – high performing case study farm



AFBM Journal Vol 11 - 2014 Jackson et al.,

System changes to a lamb farm in south-west Victoria: some pre-experimental modelling

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Abstract

There is limited capital available to spend on livestock research programs. Consequently, it is important to estimate the potential economic impact of changing on-farm factors within farm systems at the outset, to identify which changes may have big payoffs and which ones look less attractive. We present the results of some pre-experimental modelling to inform on the most suitable targets for research efforts in the Victorian lamb industry. Increased stocking rate through improved weaning percentage generated the highest average annual profit after interest and tax of all the scenarios investigated, increasing average annual net profit from the base farm system by 40%. Potentially attractive innovations that allow earlier mating, increased growth rates, increased lamb feed efficiency, faster lamb turnoff, reduced animal health costs and increased ewe fleece weight did not rank as highly in terms of profit and risk as the traditional, well known innovations.

Research Questions

- RFI of Maternal Composite Ewes
  - How much variation is there in the population?
  - Is RFI correlated with Reproduction and Methane Emissions

- Repeatability/ consistency across animals lifetime
  - Simpler and cheaper to measure feed efficiency in younger growing animals but the ramifications/ potential gains in mature breeding ewes are larger.
  - Energy is used for different purposes in mature and lactating animals compared with growing
  - In sheep, wool production and differences in tissue deposition and tissue maintenance at different growth stages and ages may decrease correlation between ages
  - Need to maintain divergence/ variation in trait
  - Significant re-ranking may reduce utility of the trait

- Is feeding behaviour associated with feed efficiency?
  - Binge Eaters V. Nibblers
  - Could changing feed delivery impact efficiency?

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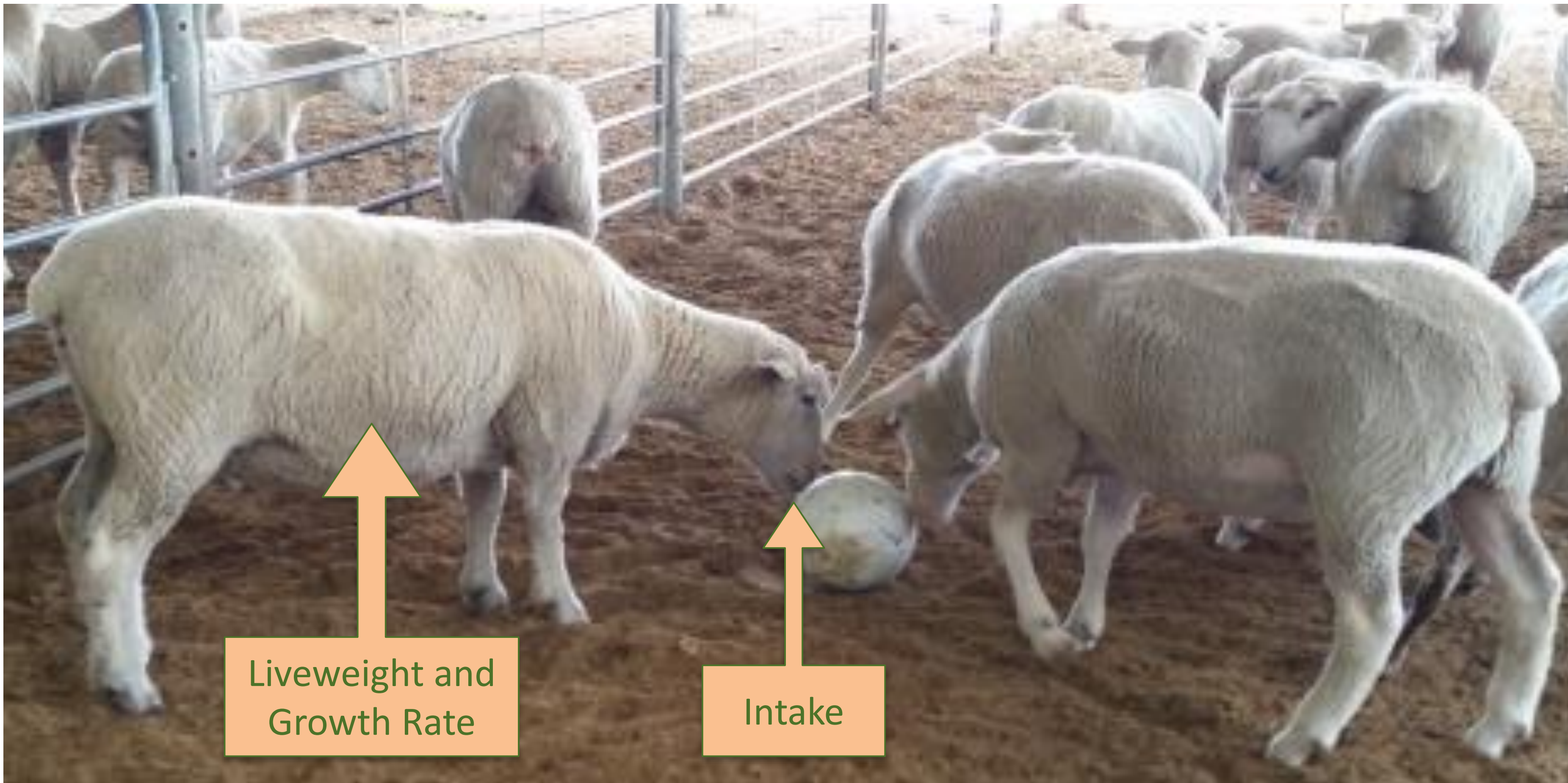
How do we characterise RFI in sheep?

Compare the pair…



Traditional Measures of Feed Intake

- Feed intake is time consuming and expensive to measure

- Intake measurements
  - Individual v. group environment

- Changes to behaviour in individually housed sheep
  - Sheep are highly gregarious and require social interaction
  - Can exhibit conflict between motivation for feeding and social interactions

- Genetics/ Genomics is a ‘numbers game’

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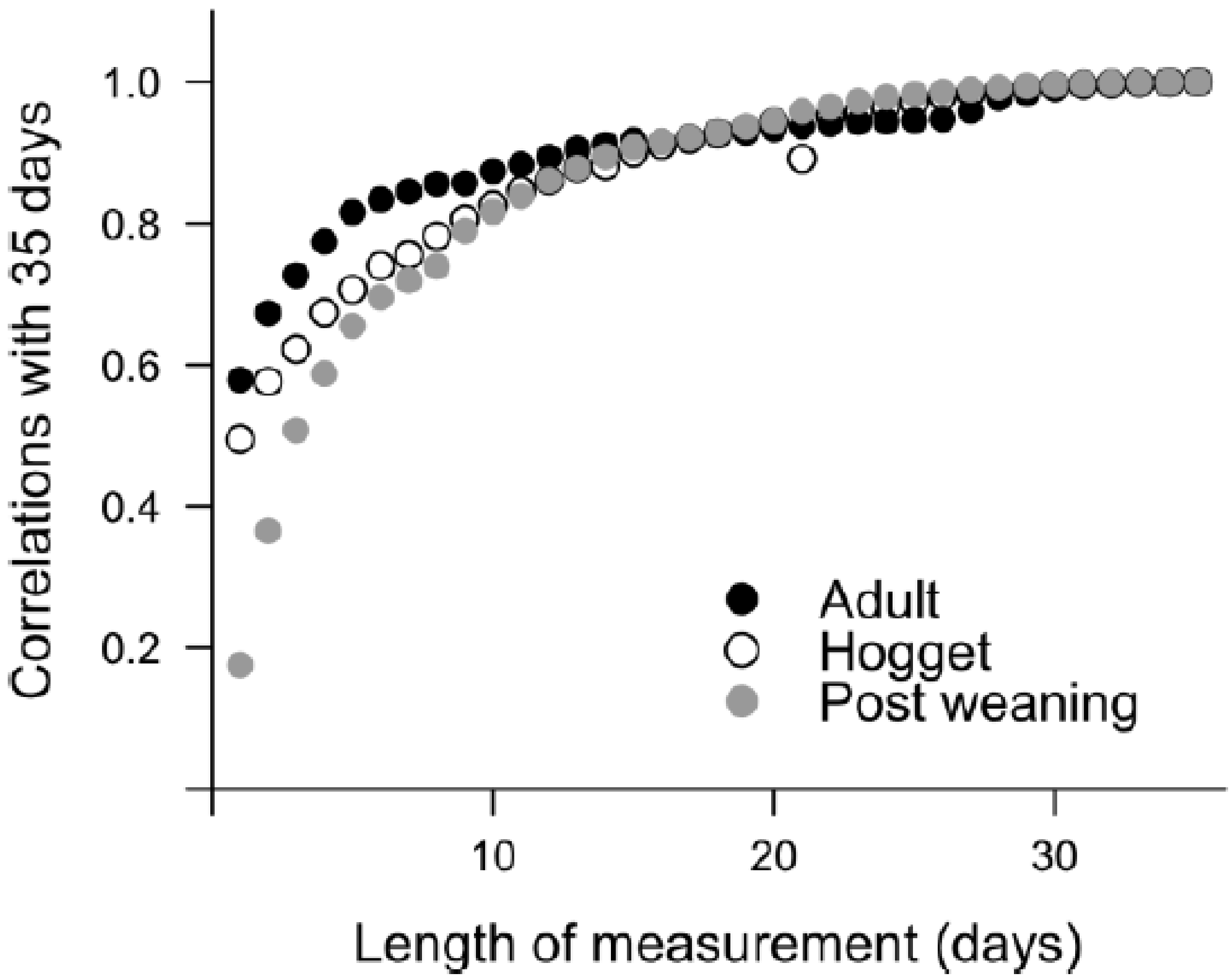
Measurement of RFI Phenotype

- Intake- minimum of 21 days intake measurement
- Live weight- depends on frequency of measurement



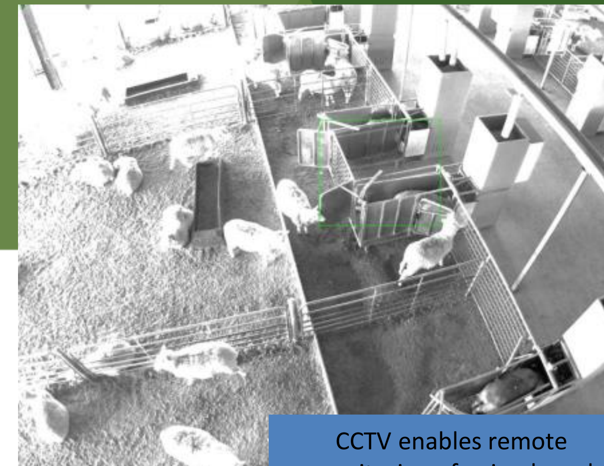
Macleay et al. 2016, Australian Society of Animal Production Conference Proceedings

Automated Intake Measurements of Group Housed Sheep

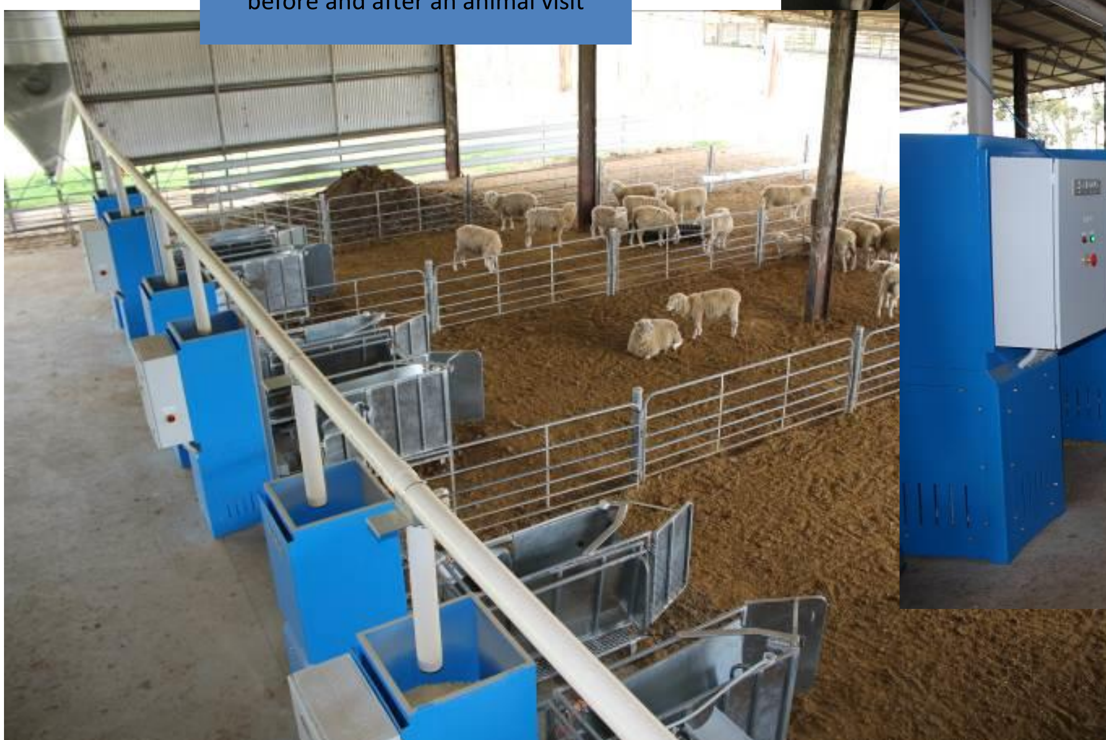
- Utilises EID technology to record when animals visit a feeder
- In-built weigh bars measure feed pre and post an animal visit
- Fresh feed delivered when a sheep exits the feeder
- Locking entry gates minimise disturbance to animal feeding
- Capacity of ~240 animals

The “sheep activated” feed flap enables the sheep to be feed ad lib or restricted amounts

Access to each feeder is restricted to one animal at a time



CCTV enables remote monitoring of animals and behavioural observations



In-built weigh bars measure feed before and after an animal visit

The facility is equipped with 20 feeders located within 10 pens. A capacity of ~240 animals.

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Methane Emissions Testing

- Portable Accumulation Chambers (PACs)
- Sheep is enclosed in a sealed PAC for 40 to 60 minutes
- Methane concentration in PAC measured using a laser methane detector (Gazomat Inspectra Laser)
- Carbon dioxide and oxygen measured using infra-red detector (GFM406 Landfill Gas analyser)
- Methane production is calculated based on accumulation over time, box and sheep volume and temperature to determine total daily emissions.
- 2 x during feed intake test (~ days 30 and 40)





Feed Efficiency Test- Methodology

- Characterise RFI using a ‘feed efficiency’ test
  - 35-42 days plus adaptation to feed and feeders
  - Intake automatically recorded daily, allowed *ad lib* intake daily
    - Allowed 1 kg/ meal, unlimited number of meals daily
  - Standard pelleted ration, high NDF maintenance pellet
  - Live weights measured 3 x weekly (manual)
  - Live weight gain modelled (linear) over intake period
- Predict Intake: DMI= MMWT + ADG (Knott et al. 2008)
  - Where MMWT is the metabolic mid-point weight (weight at the mid-point of the feeding period ^0.75) and ADG is the average daily gain.
- Calculate RFI as difference between measured and predicted intake

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Experiments to Date

- Ewes
  - Correlations between RFI/ FCE, reproduction and methane emissions
  - ~ 500 ewes measured (~1000 records)
  - Post weaning, hogget and adult
  - Two cohorts (2013 born, 2014 born)
  - Pregnancy scanning, number of lambs born and weaned, weight of lambs born and weaned
  - 2 x short term methane tests in each test period

Results: Maternal Composite Feed Efficiency

Results- Ewes

Residual feed intake (RFI), dry matter intake (DMI), growth rate (g/day) and methane emissions (g CH_4/day) for 2013 born Maternal Composite ewes measured at hogget and adult ages and 2014 born Maternal Composite ewes measured at post weaning and hogget ages

Birth Year	2013								2014							
Status	Hogget				Adult				Post Weaning				Hogget			
Trait	Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD
RFI (kg DM)	0.005	-0.69	0.80	0.211	0.002	-1.09	1.04	0.38	0.000	-0.62	0.58	0.201	0.000	-0.72	1.02	0.280
DMI (kg DM/day)	2.06	1.4	3.0	0.29	2.68	1.7	3.9	0.42	1.38	0.5	2.2	0.26	2.15	0.7	3.3	0.37
Growth Rate (g/day)	119	18	264	49	239	57	469	72	167	30	327	54	155	-24	359	55
Methane (g CH_4/day)	33.8	9.2	52.6	8.28	47.3	20.0	71.5	8.62	21.4	5.5	48.2	7.05	39.9	15.8	63.3	7.93

2013 Born Ewes: The most efficient ewes consumed 1.49 kg less DM than the least efficient ewes as hoggets. While adult ewes had a 2.1 kg DM difference in RFI between the most and least efficient ewes.
2014 Born Ewes: the most efficient ewe consumed 1.2 kg less DM than the least efficient ewe post-weaning. There was a 1.74 kg DM difference between the most and least efficient hogget ewes born in 2014.

Methane emissions increased as animals aged, in association with increased liveweight and feed intake.

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Results- Ewes

- Is there enough variation in the population?
  - Standard deviation of phenotypic RFI greater than 0.43 kg of DM/day or standard deviation of RFI equivalent to 5% of average DMI (Williams *et al*. 2011)

  - Standard deviation of RFI ranged from 0.12 to 0.37 kg DM/day or 9 to 14% of average daily DMI.

  - Sufficient variation in the population to enable selection for low RFI to be effective

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Phenotypic correlations between dry matter intake (DMI), residual feed intake (RFI), methane (CH_4) emissions in 2013 and 2014 born Maternal composite ewes measured as post weaners, hoggets and adults.

Ewe Classification	Birth Year		DMI	CH_4	RFI
Hogget	2013	DMI	-		
		CH_4	0.1715*	-	
		RFI	0.7415***	-0.087 NS	-
		Growth Rate	0.4235***	0.2668***	0.1172 NS
Adult	2013	DMI	-		
		CH_4	0.3178***	-	
		RFI	0.896***	0.1701 NS	-
		Growth Rate	0.3749***	0.3341***	0.0065 NS
Post Weaning	2014	DMI	-		
		CH_4	0.4066***	-	
		RFI	0.7649***	0.2703***	-
		Growth Rate	0.35***	0.2248**	-0.0476NS
Hogget	2014	DMI	-		
		CH_4	0.2007**	-	
		RFI	0.8477***	0.0446 NS	-
		Growth Rate	0.1718*	0.3134 ***	-0.0209NS

NS Not significant, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

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Results- Summary

- Residual feed intake was strongly correlated with DMI for all birth year and age group combinations.
- Variation in RFI decreased as animals aged.
- Within age groups, there were significant correlations between measured traits (DMI, growth rate, RFI and CH_4 emissions). BUT not consistent.
- Apart from one age by birth year combination, the relationship between CH_4 emissions and RFI was not significant.
  - Percentage of variation in CH_4 emissions accounted for is very low (7.6%)

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Phenotypic correlations in Dry matter intake (DMI), residual feed intake (RFI), growth rate and methane emissions between age groups (post-weaning, hogget and adult) for ewes born in 2013 and 2014.

	2013	**2014**
Trait	Hogget and Adult ages	Post weaning and Hogget ages
No. Sheep	183	195
DMI	0.4392***	0.4028***
CH_4	0.2403**	0.1954**
RFI	0.1693*	0.1945**
Growth rate	0.3978***	0.1373^{NS}

^{NS} Not significant, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

The strongest correlation between ewes of different ages was for DMI (r~0.4). This suggests that individual animals who eat more as lambs, continue to eat more as adult animals.

While some animals continue to be more or less efficient as they grow, there is likely to be some re-ranking of low and high RFI animals occurring as animals mature.

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Key Messages

This data suggests;

1. There is enough variation in the Maternal Composite population for selection based on RFI to improve feed efficiency

2. "Trade offs" between traits (e.g. methane) inconclusive (not consistent)

3. Repeatability at different ages may be lower than observed for cattle
    1. BUT small numbers (< 200 per measurement group) AND composite breed

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But what about Merinos?

More feed efficient sheep produce less methane and carbon dioxide when eating high-quality pellets

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ABSTRACT: The Australian sheep industry aims to increase the efficiency of sheep production by decreasing the amount of feed eaten by sheep. Also, feed intake is related to methane production, and more efficient (low residual feed intake) animals eat less than expected. So we tested the hypothesis that more efficient sheep produce less methane by investigating the genetic correlations between feed intake, residual feed intake, methane, carbon dioxide, and oxygen. Feed intake, methane, oxygen, and carbon dioxide were measured on Merino ewes at postweaning (1,866 at 223 d old), hogget (1,010 sheep at 607 d old), and adult ages (444 sheep at 1,080 d old). Sheep were fed a high-energy grower pellet ad libitum for 35 d. Individual feed intake will decrease methane (genetic correlation [r_g] range 0.76 to 0.90) and carbon dioxide (r_g range 0.65 to 0.96). Selecting to decrease intake (r_g range 0.64 to 0.78) and methane (r_g range 0.81 to 0.86) in sheep at postweaning age would also decrease intake and methane in hoggets and adults. Furthermore, selecting for lower residual feed intake (r_g = 0.75) and carbon dioxide (r_g = 0.90) in hoggets would also decrease these traits in adults. Similarly, selecting for higher oxygen (r_g = 0.69) in hoggets would also increase this trait in adults. Given these results, the hypothesis that making sheep more feed efficient will decrease their methane production can be accepted. In addition, carbon dioxide is a good indicator trait for feed intake because it

Downloaded from https://academic.oup.com/jas/article-abstract/95/9/3839/47024

Intake more heritable than RFI,
Good genetic correlation between methane and intake

Post weaning	Intake	RFI	Methane
Intake	**0.31 (0.09)**	0.83 (0.00)	0.46 (0.02)
RFI	0.87 (0.05)	**0.17 (0.07)**	0.16 (0.02)
Methane	0.43 (0.19)	0.20 (0.26)	**0.11 (0.03)**

Hogget	Intake	RFI	Methane
Intake	**0.49 (0.09)**	0.64 (0.01)	0.54 (0.02)
RFI	0.82 (0.06)	**0.29 (0.08)**	0.18 (0.03)
Methane	0.77 (0.14)	0.84 (0.19)	**0.14 (0.05)**

Adult	Intake	RFI	Methane
Intake	**0.42 (0.14)**	0.65 (0.02)	0.57 (0.03)
RFI	0.33 (0.89)	**0.07 (0.08)**	0.25 (0.04)
Methane	0.72 (0.22)	0.23 (0.77)	**0.10 (0.06)**

diagonal = h^2, upper = phenotypic, lower = genetic

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Methane and intake similar trait across ages

Genetic	Post weaning/ hogget	Post weaning /adult	Hogget / adult
Intake	0.74 (0.09)	0.64 (0.17)	0.78 (0.12)
RFI	0.36 (0.22)	0.00 (0.53)	0.75 (0.74)
Methane	0.81 (0.14)	0.86 (0.15)	0.62 (0.26)

Phenotypic	Post weaning/hogget	Post weaning /adult	Hogget / adult
Intake	0.48 (0.03)	0.25 (0.05)	0.58 (0.03)
RFI	0.15 (0.03)	0.04 (0.05)	0.33 (0.04)
Methane	0.40 (0.03)	0.38 (0.04)	0.32 (0.04)

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- Intake and methane repeatable across ages (not RFI)
- Reduce intake and you will reduce CH_4 emissions
- Fastest way to decrease emissions is to increase production

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Nibblers v. Binge Eaters

CSIRO PUBLISHING

Animal Production Science, 2018, **58**, 1459–1464
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Sheep residual feed intake and feeding behaviour: are 'nibblers' or 'binge eaters' more efficient?

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Abstract. Efficient liveweight gain is an important component of profitable livestock systems. In cattle, studies of residual feed intake (RFI) suggest that there are behavioural differences between efficient and inefficient animals; more efficient animals have less frequent, larger feed events. There is limited understanding of the association between feeding behaviour and feed conversion efficiency (measured as RFI) in sheep. We hypothesised that more efficient sheep would have lower daily number of meals but larger meal size than would less efficient sheep and that feeding behaviour would be repeatable between measurements conducted using the same sheep at different ages. Feeding behaviour was monitored at post-weaning (average 311 days) and hogget (average 533 days) age in a single cohort of maternal composite 2014-born ewes undergoing feed-efficiency testing. Feed intake (kg/day) and daily feeding behaviour (meal number, meal size and eating rate) were recorded by using automated feeders. Feed intake was recorded daily for a minimum of 40 days (mean 41 days), following a 14-day adaptation period. Animals were fed a pelleted hay-based diet, with liveweight measured three times per week. At both ages of measurement, a positive ($P < 0.01$) linear relationship was established between average daily number of meals and RFI. In these cohorts, as daily number of meals increased, RFI became more positive (less efficient). Meal size (kg DM) was also related to RFI ($P < 0.05$) when measured at the hogget age, with meal size decreasing with an increasing RFI (less efficient animals had smaller meals). These analyses suggest that sheep feeding behaviour, and in particular daily meal number, is associated with feed efficiency.

Hypothesis

- Anecdotal reports (from our facility) of differences in feeding behaviour (number of feeder visits, meal size, meal duration) between ewes.
- Behavioural differences observed between efficient and inefficient animals (cattle, sheep, pigs and poultry)
- Literature reports of correlation between number of meals and RFI in beef cattle and growing sheep
  - Less frequent, larger feed events = efficient (typically)
- Hypothesis: Sheep who are binge eaters (consume a small amount of larger meals) are more efficient (lower RFI) than sheep who are nibblers (large number of small meals)

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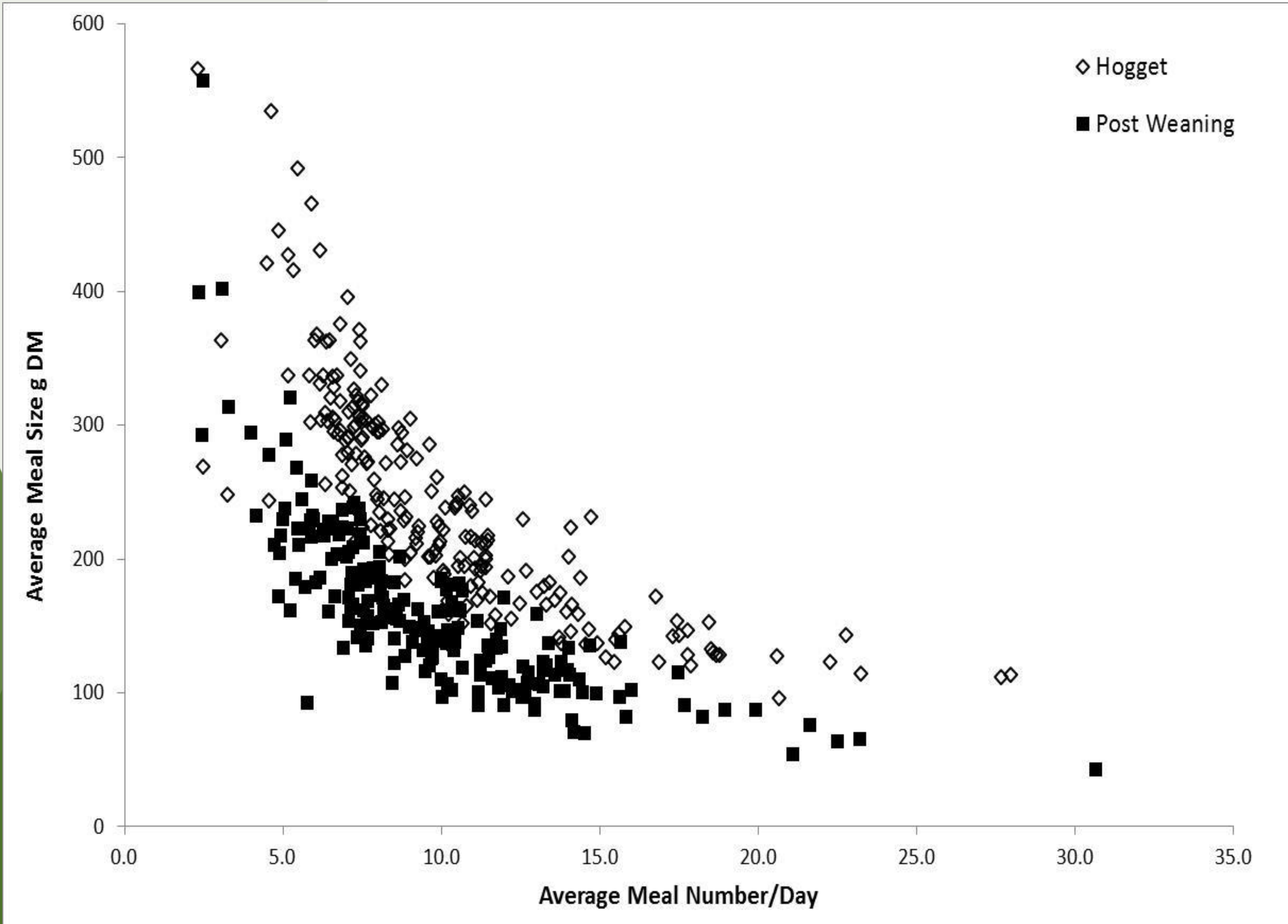
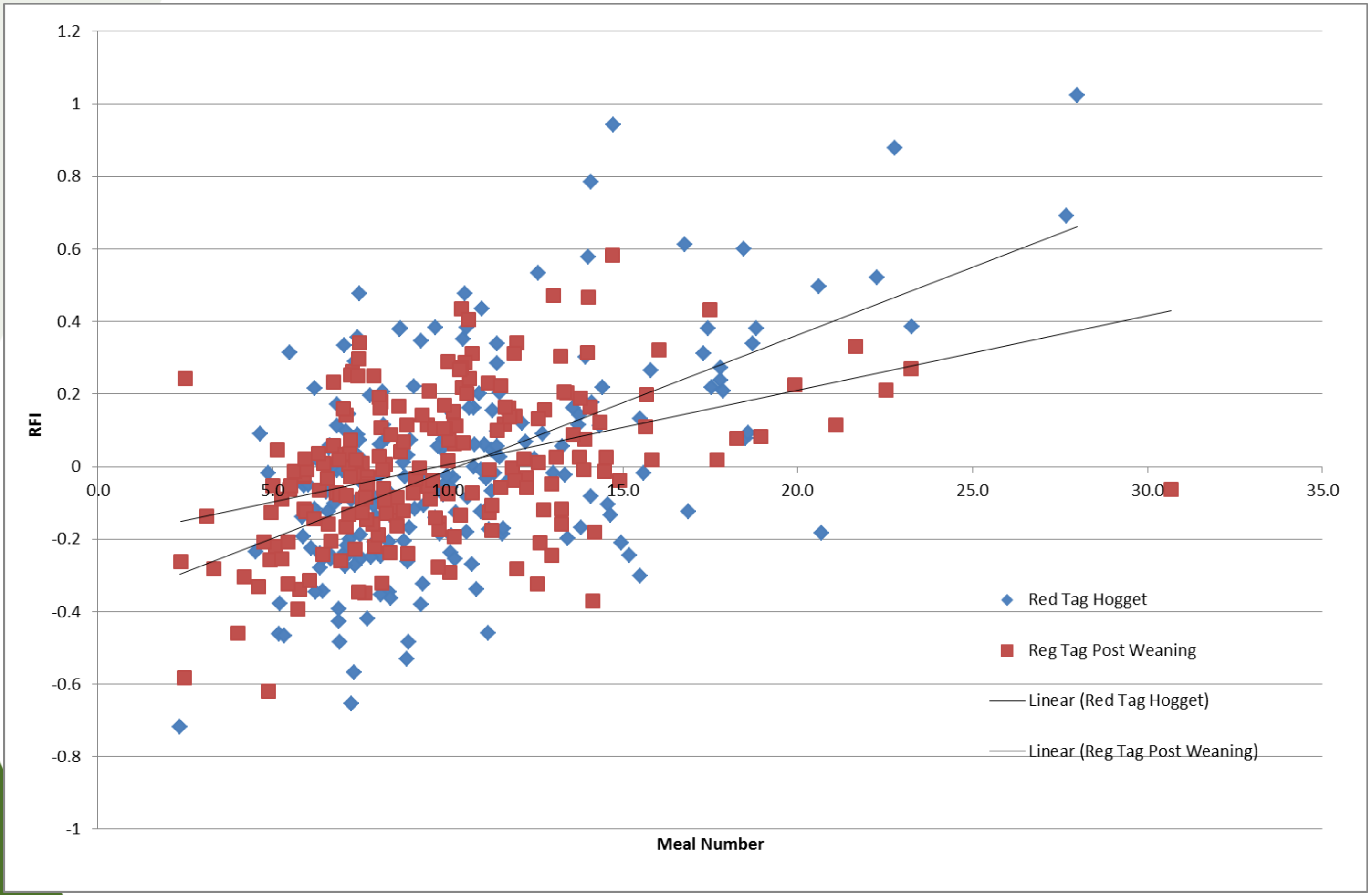


Hogget
Post Weaning
Average Meal Size g DM
Average Meal Number/Day
600
500
400
300
200
100
0
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0

	Post Weaning (average 311 days of age)				Hogget (average 533 days of age)			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Age at Start	311	5.25	295	320	533	5.28	518	542
Start LWT (kg)	39.4	4.01	28.3	51.2	56.3	6.61	41.0	75.0
Mid Point Weight (kg)	42.9	4.17	31.9	56.8	59.6	6.60	43.4	49.9
Growth Rate (g/day)	167	54.1	29.6	327	155	55.2	-2.0	359
Intake (kg DM/day)	1.38	0.26	0.53	2.16	2.15	0.37	0.67	3.34
RFI (kg DM/day)	-1.63×10^{-4}	0.201	-0.619	0.582	-4.76×10^{-7}	0.280	-0.717	1.023
Meal Number	9.74	3.98	2.4	30.7	10.17	4.216	2.35	28.0
Meal Size (g/meal)	161.5	63.5	42.1	557.5	243.1	82.5	95.8	566.0
Eating Rate (g/min)	16.29	5.35	2.12	34.5	27.9	7.87	8.26	70.34

Meal Number and RFI



Nibblers v. Binge Eaters- Results

- Increased feed conversion efficiency (low RFI) was associated with a smaller number of meals and to a lesser extent with larger meal size

- RFI increased by 0.04 kg DM/day for every additional meal a sheep consumed- RFI could vary by over 1 kg DM/day across the range of meal sizes consumed

- Energy use?
  - Accessing feed and overall activity
  - Activity reduced in a feedlot situation- most difference due to feeding behaviour (Robinson and Oddy 2004)
  - Reduced lying and idle periods in high RFI steers (De Costa Gomes *et al*. 2013)
  - Heart rate and heat production increase during eating (Webster 1978)

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What now?

A Genomic Test for Feed Efficiency?

The Future?

- Currently no way to easily select for feed efficiency on farm
- Genomic tests are useful for “hard to measure” traits such as feed intake/ RFI
- Need more measures to create a reference population with reliable accuracy

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But also…

- Results for both Maternal Composites and Merinos show strong relationships between intake and efficiency.
  - Intake is also more consistent between ages and more heritable.

- RFI- like an index
  - RFI is made up of a number of component traits- but is this the best set of traits?

- Can we create a better index for efficiency?
  - Sheep also growing wool, contrast to other meat animals

- Intake is key- measurement in grazing animals?

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Take Home Messages

- Improvements in feed efficiency can improve profitability
- Enough variation in population to influence efficiency using selection
- But we can't easily measure on farm… yet…
  - Genomic test will take time and many more measurements

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"Please sir… can I have some more?"