Genetics of feed efficiency in ruminants and non-ruminants

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(Feed) efficiency – growing animals

- Feed conversion ratio

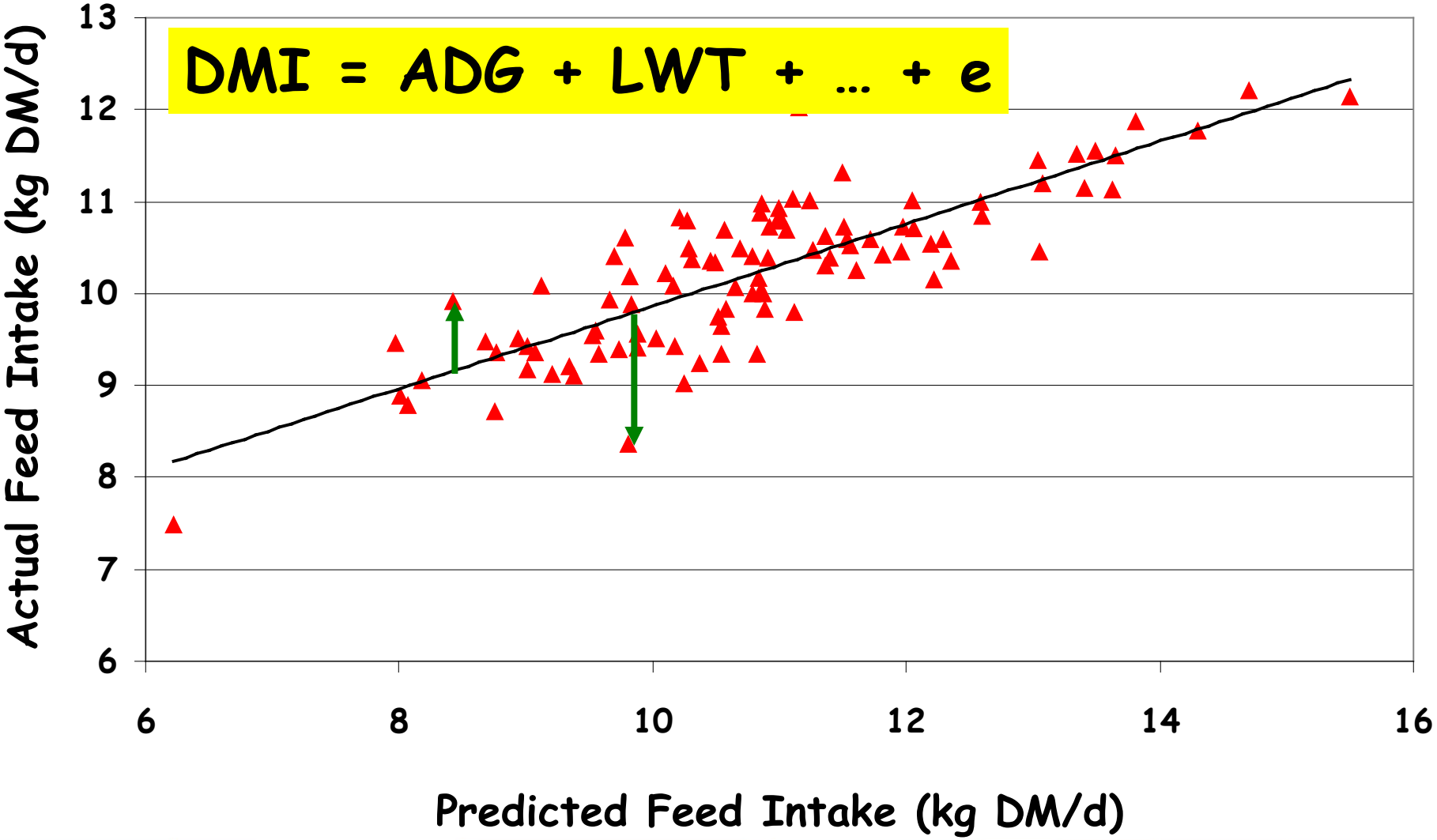
FCR - traditional measure because:

- Easy to calculate
- Correlated with growth
  - Poor animals will unlikely have good FCR

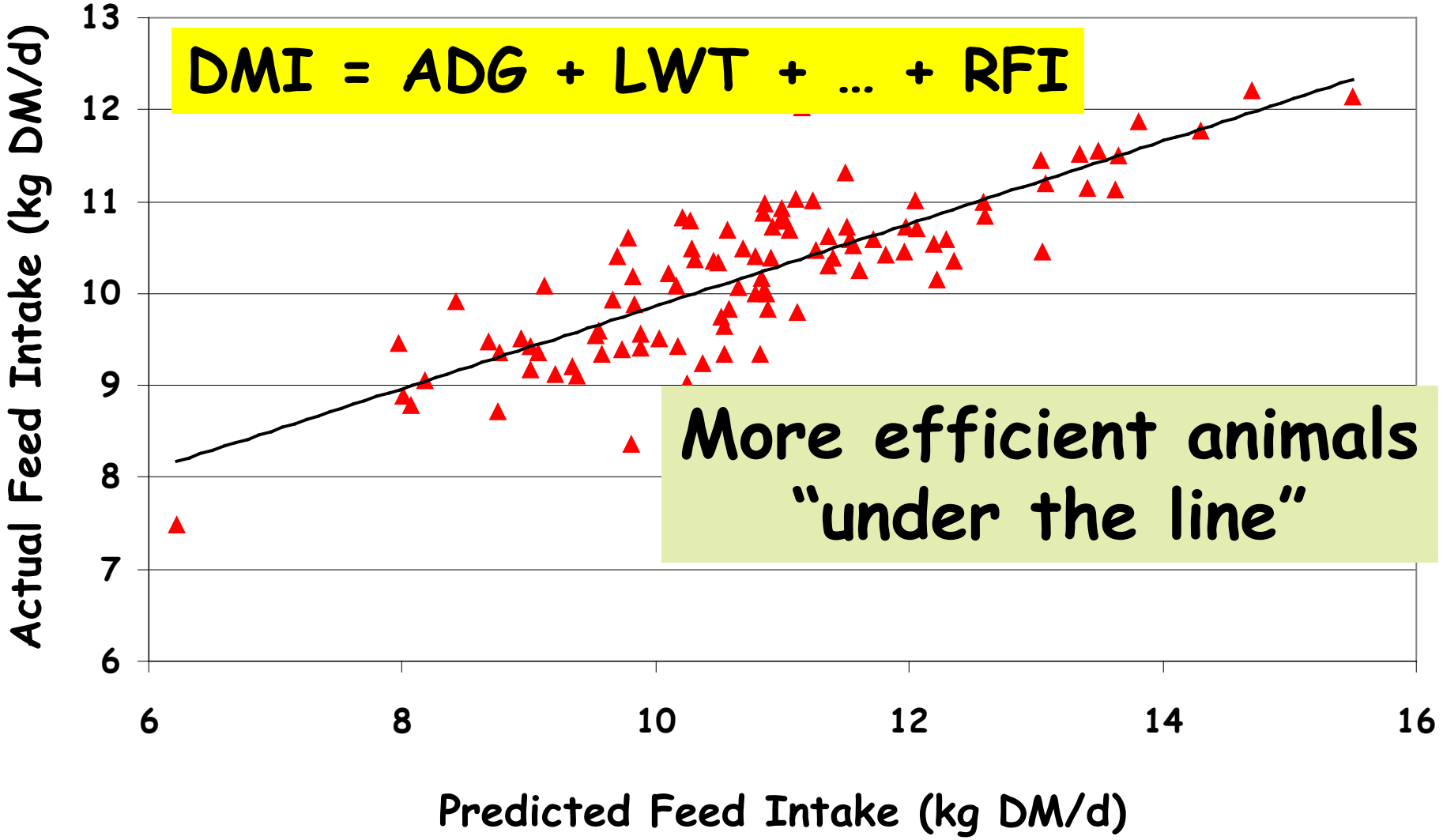
(Feed) efficiency – growing animals

- Feed conversion ratio
- Kleiber ratio
- Relative growth rate
- Residual feed intake (RFI)
- Residual average daily gain (RG)
- Residual intake and gain (RIG)

Residual Feed Intake (RFI)



Residual Feed Intake (RFI)



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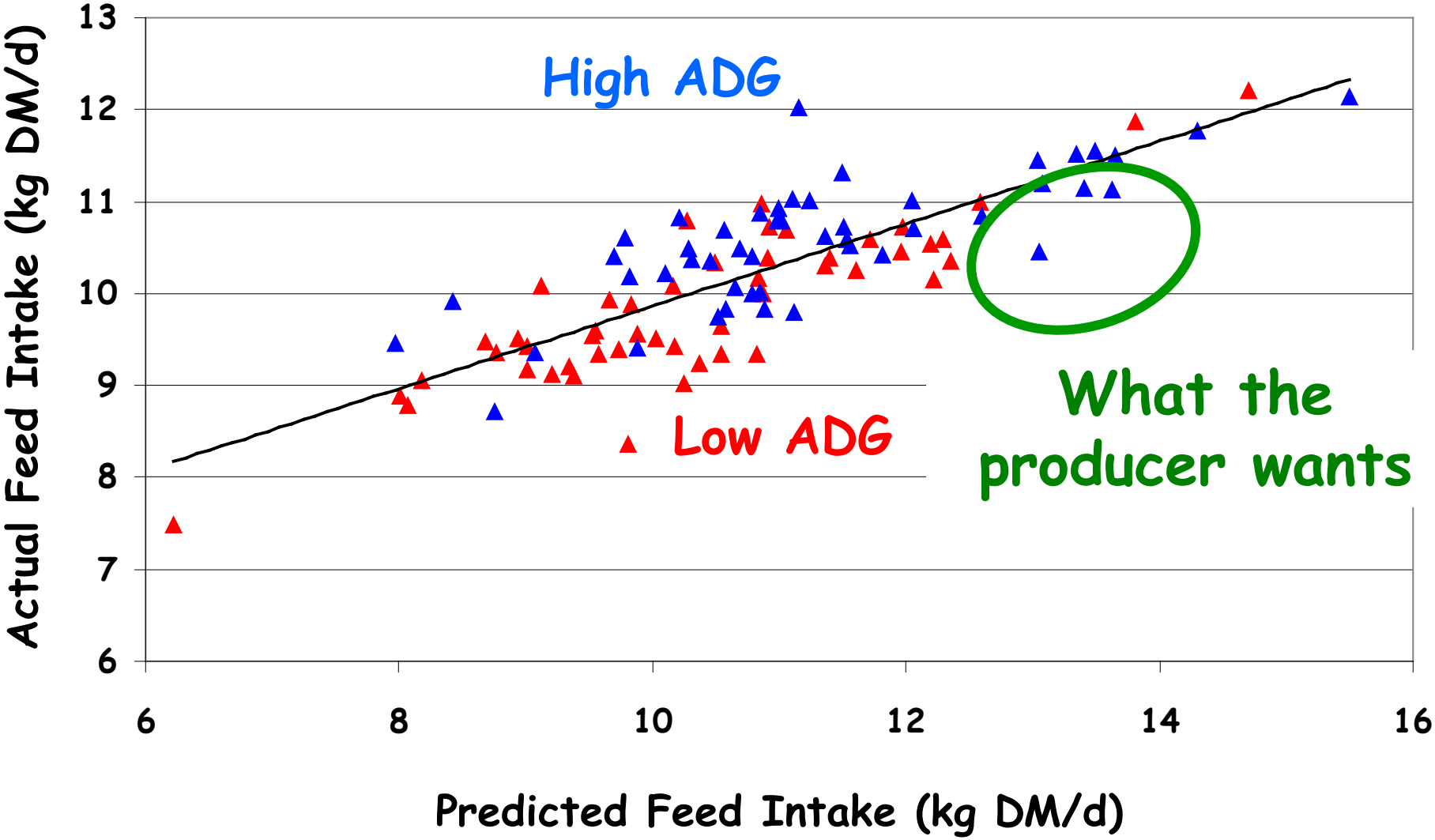
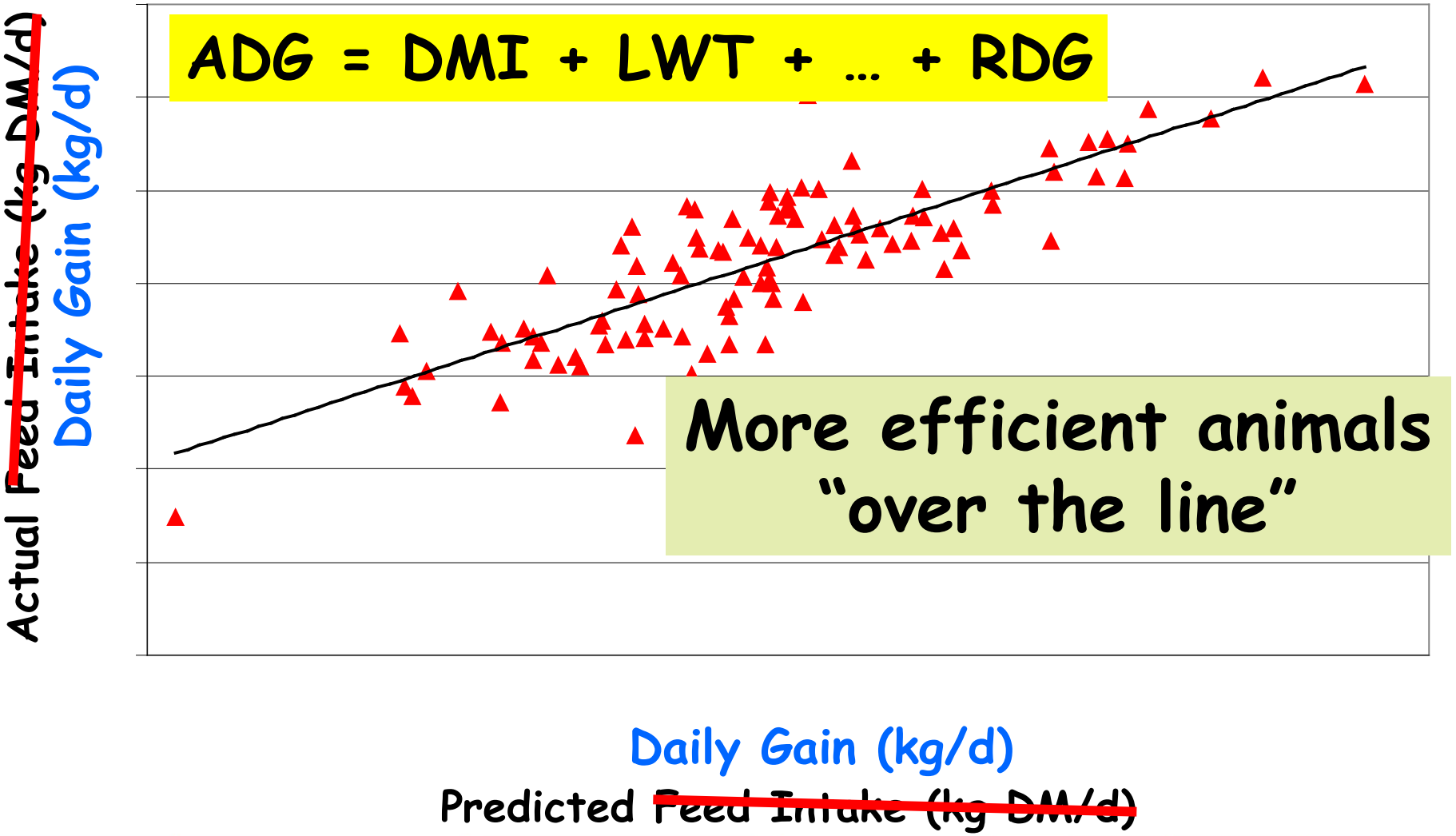


Residual Daily Gain (RDG)



So…..

- RFI is independent of live-weight & growth
- RG is independent of live-weight & feed intake

- -1*RFI + RG must still be independent of live-weight
  - But negative correlation with feed intake and a positive correlation with gain

Options to improve feed efficiency

300 kg weight to gain

	DMI	ADG
RFI	9.2	1.71
RG	10.7	2.18
RIG	9.9	2.06

	Age to slaughter	Total DMI
RFI	176	1619
RG	137	1474
RIG	146	1446

Berry & Crowley (2012)

(Feed) efficiency –lactating animals

- Milk solids per kg live-weight
- Milk solids per kg intake (FCE)
- Intake per kg live-weight

Ratios
Simple

- Residual feed intake
- Residual solids production

Principle from beef
Not common

Is RFI/RSP really useful in mature animals?

$$RFI_t = DMI_t - ([Milk]_t + BW_t^{0.75} + \Delta BW_t + BCS_t)$$

$$RSP_t = MS_t - (DMI_t + BW_t^{0.75} + \Delta BW_t + BCS_t)$$

DMI: 15.6 kg/d
LWT: 452 kg
Milk Yld: 24.83 kg/d
Similar elsewhere

RFI: -1.386 kg/d
RSP: 0.174 kg

DMI: 20.6 kg/d
LWT: 602 kg
Milk Yld: 24.89 kg/d
Similar elsewhere

RFI: -1.386 kg/d
RSP: 0.194 kg

Summary

- Many alternative measures of (feed) efficiency
- All have their own advantages and dis-advantages

Genetics of feed efficiency

Review for cattle

CELL BIOLOGY SYMPOSIUM:
Genetics of feed efficiency in dairy and beef cattle[1]

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ABSTRACT: Increasing food production for the growing human population off a constraining land base will require greater efficiency of production. Genetic improvement of feed efficiency in cattle, which is cumulative and permanent, is one likely vehicle to achieving efficiency gains. The objective of this review is to summarize genetic parameters for feed efficiency traits in dairy and beef cattle and also to address some of the misconceptions associated with feed efficiency in these sectors, as well as discuss the potential use of feed efficiency in breeding programs. A meta-analysis of up to 39 scientific publications in growing cattle clearly showed that genetic variation in feed efficiency exists with a pooled heritability for residual feed intake (RFI) and feed conversion efficiency of 0.33 ± 0.01 (range of 0.07 to 0.62) and 0.23 ± 0.01 (range of 0.06 to 0.46), respectively. Heritability estimates for feed efficiency in cows were lower; a meta-analysis of up to 11 estimates revealed heritability estimates for gross feed efficiency and RFI of 0.06 ± 0.010 and 0.04 ± 0.008, respectively. Meta-analysis of genetic correlations between feed intake, feed efficiency and other performance traits are presented, and selection index theory is used to calculate the proportion of genetic variation in feed intake that can be explained by easy to measure, and often already collected, data. A large proportion of the genetic variation in feed intake could be explained in both growing animals and lactating animals using up to 5 predictor traits, including BW, growth rate, milk yield, body composition, and linear type traits reflecting body size and muscularity. Knowledge of genetic merit for feed intake can be used, along with estimates of genetic merit for energy sinks, to calculate genetic merit for feed efficiency. Therefore, the marginal benefit of collecting actual feed intake data, using the genetic parameters used in this study, appears to be low. There is now sufficient information available to develop a road map on how best to direct research to ensure long-term food security for a growing human population. Gaps in knowledge are identified here, and possibilities to address these gaps are discussed.

Key words: beef, cattle, dairy, efficiency, genetics

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Review for pigs

8. Pig breeding for improved feed efficiency

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Abstract

The feed efficiency of growing pigs has been a matter of serious commercial and scientific interest since at least 1970, but early recording technology made it difficult to produce accurate feed intake data at the individual level. Since electronic feeders were introduced, the pig breeding industry has been making good genetic improvement in feed conversion ratio (FCR) but this has been mainly due to genetic improvement of growth and body composition traits. More than one third of the variation in feed intake is due to processes that are independent of growth and body composition, mainly body maintenance processes such as basal metabolism, protein turnover, thermoregulation, physical activity, immune and other coping functions, nutrient digestion and absorption efficiency. We give an example of how genetic variation in basal metabolism may be generated by electron leakage through the mitochondrial membrane. This considerable (and up to now insufficiently exploited) variation can be accessed through the trait residual feed intake (RFI: feed intake, statistically adjusted for growth and body composition). In routine breeding value estimation systems, this is catered for by including feed intake (rather than FCR) in the breeding goal and in the multi-trait BLUP evaluation. We give examples of how selection for growth and body composition traits and RFI leads to genetic change in feed intake and from there in FCR, in four real-life breeding populations, and show that genetic improvement of FCR is a function of genetic improvement of those underlying traits. Improving the efficiency of any system often leads to a higher sensitivity to extraneous challenges; this also holds for the growing pig. An important element of a breeding program that focuses on genetic improvement of feed efficiency is therefore the proper monitoring and control of side effects in other traits, most notably robustness and quality traits. And because many of the body maintenance processes are strongly influenced by the production environment, the data used for breeding value estimation of RFI should be recorded in commercial conditions.

Review for poultry

Aspects of selection for feed efficiency in meat producing poultry

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Over the last five years, the costs of poultry feed ingredients have increased substantially. This has been due to an increased use of corn for ethanol production and a greater overall global feed grain demand. Across the poultry industry this has led to higher production costs and reaffirmed the importance of feed efficiency on profitability. The effect that an increase in feed costs has on profitability is a clear driver for the selection for birds with better feed efficiency. Feed efficiency selection can be achieved using a number of different analytical methods. Selection for feed conversion ratio (FCR) has been used to improve feed efficiency with success but using a 'ratio' trait has mathematical limitations because selection pressure tends to be placed on the component traits of FCR in a non-linear manner. Another measure, residual feed intake (RFI) shows moderate to high heritability and does not have the mathematical limitations associated with FCR. RFI has little to no correlation with production traits and this indicates that genetic improvement of RFI within a selection index can be done without the confounding issues inherent with FCR. Improvements in RFI or FCR have a favourable effect on environmental emissions and decreases the environmental impact of poultry production. The current global production of ammonia, CH_4, and N_2O by the poultry industry is significant, at levels of 2.1, 29.44 and 279 million tonnes CO_2eq, respectively. Reductions in emissions can be achieved via improvements in feed efficiency by lowering amounts of manure excreted and decreasing emitted by-products such as ammonia and greenhouse gases (N_2O, CO_2 and CH_4). Consequently, improvements in feed efficiency can not only increase profitability of the poultry industries by lowering production costs but also decrease environmental impact by reducing environmental emissions.

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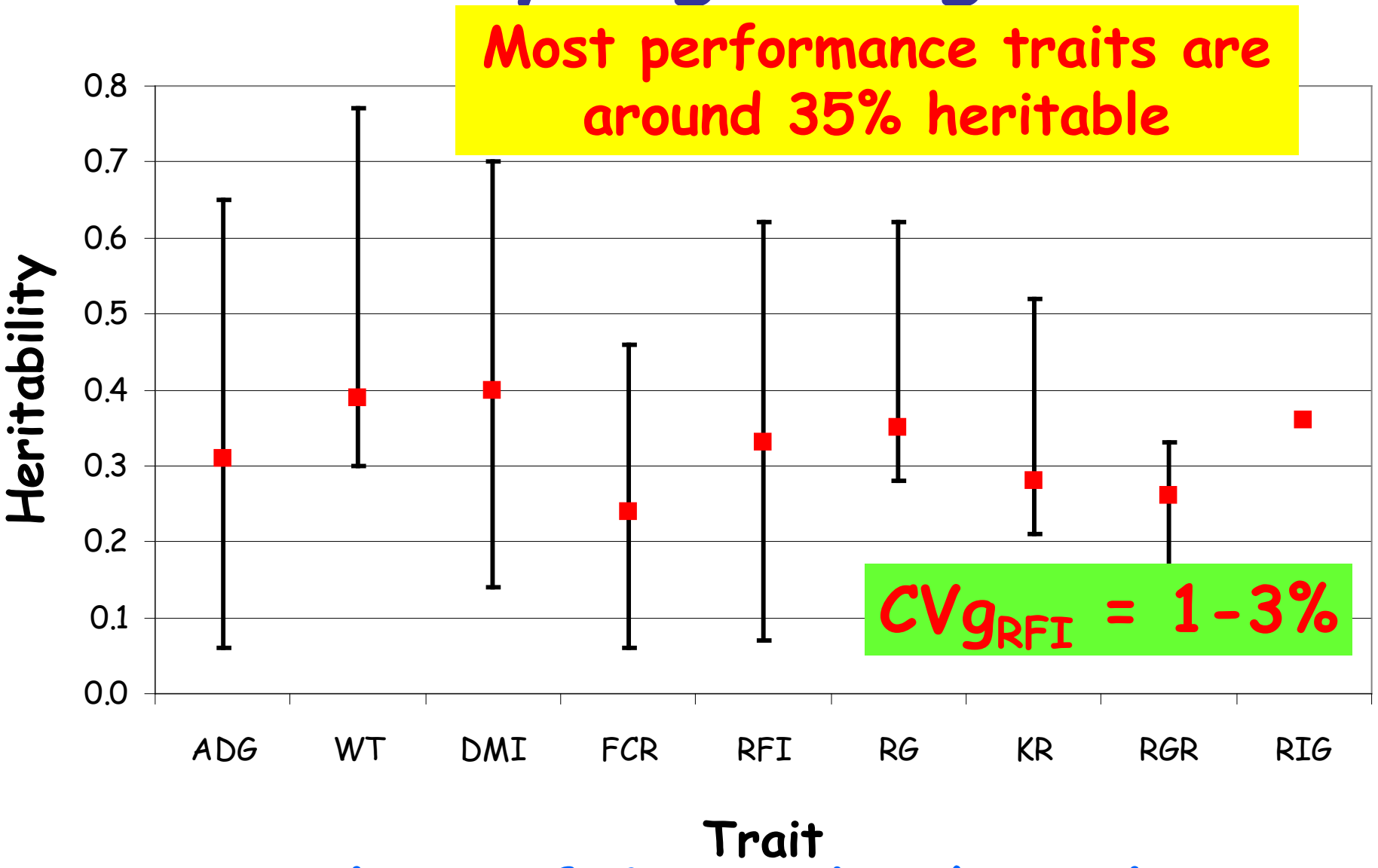
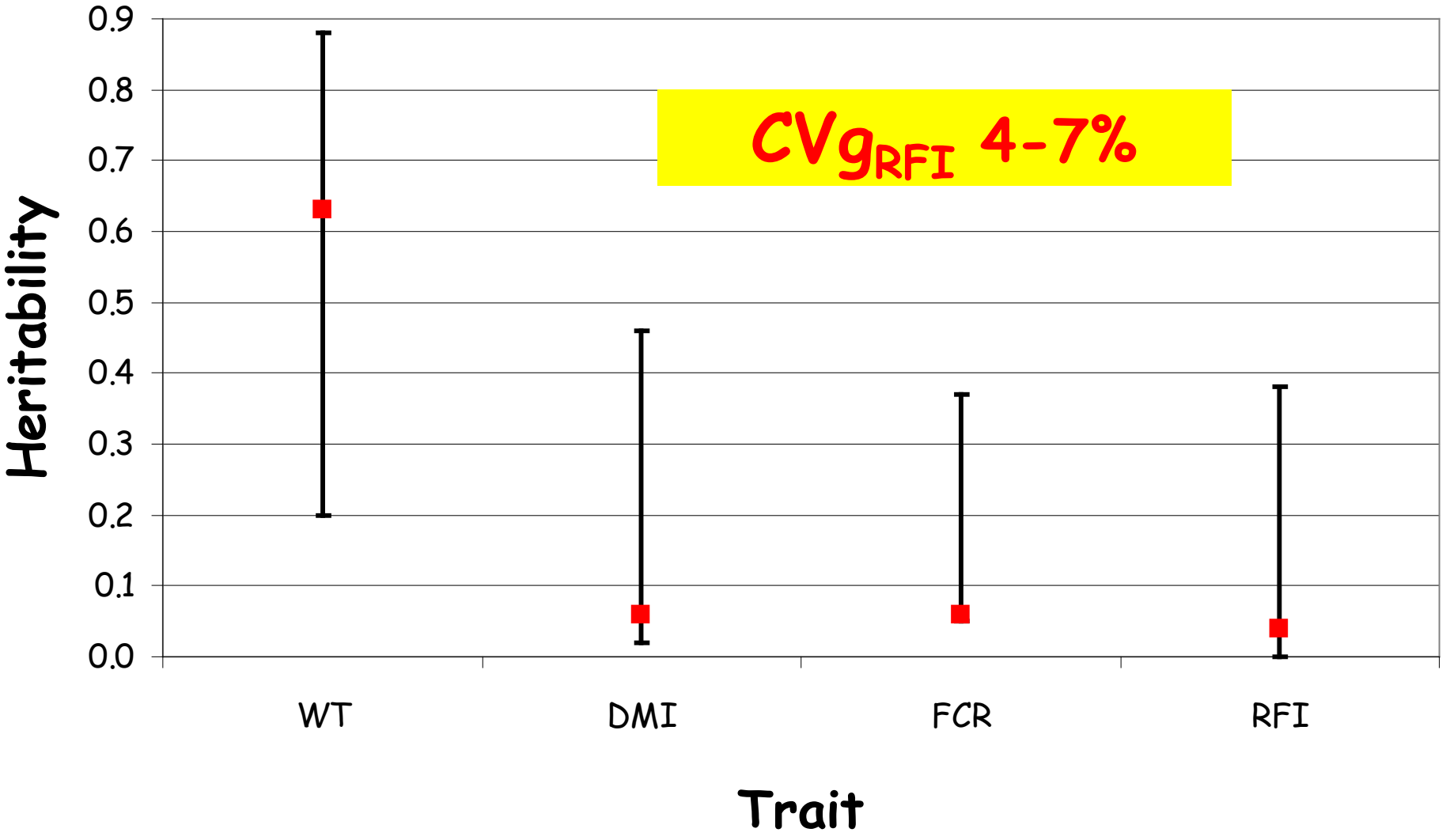
Heritability – growing cattle



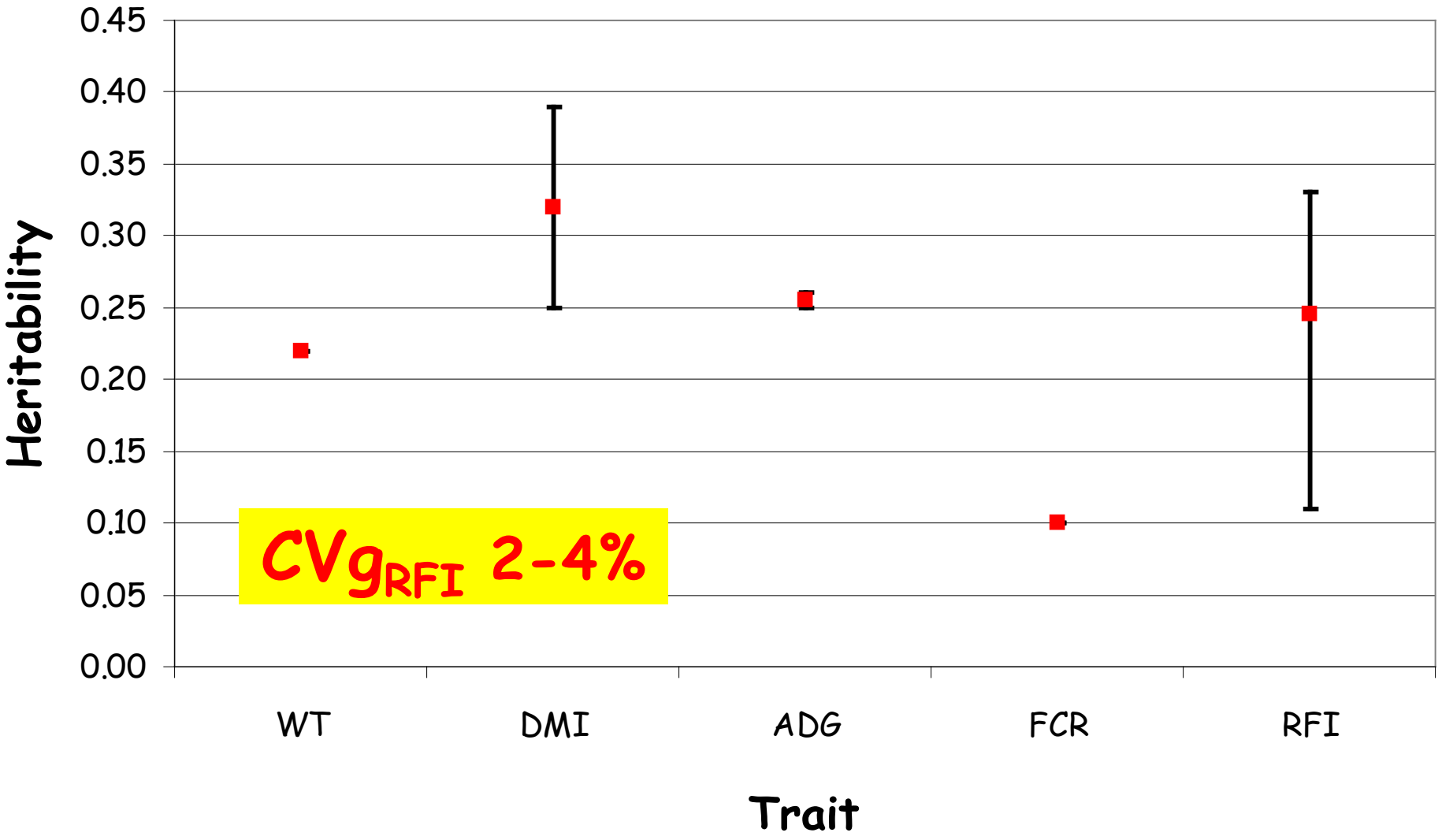
Meta-analysis of 45 studies/ populations

Heritability - lactating cows



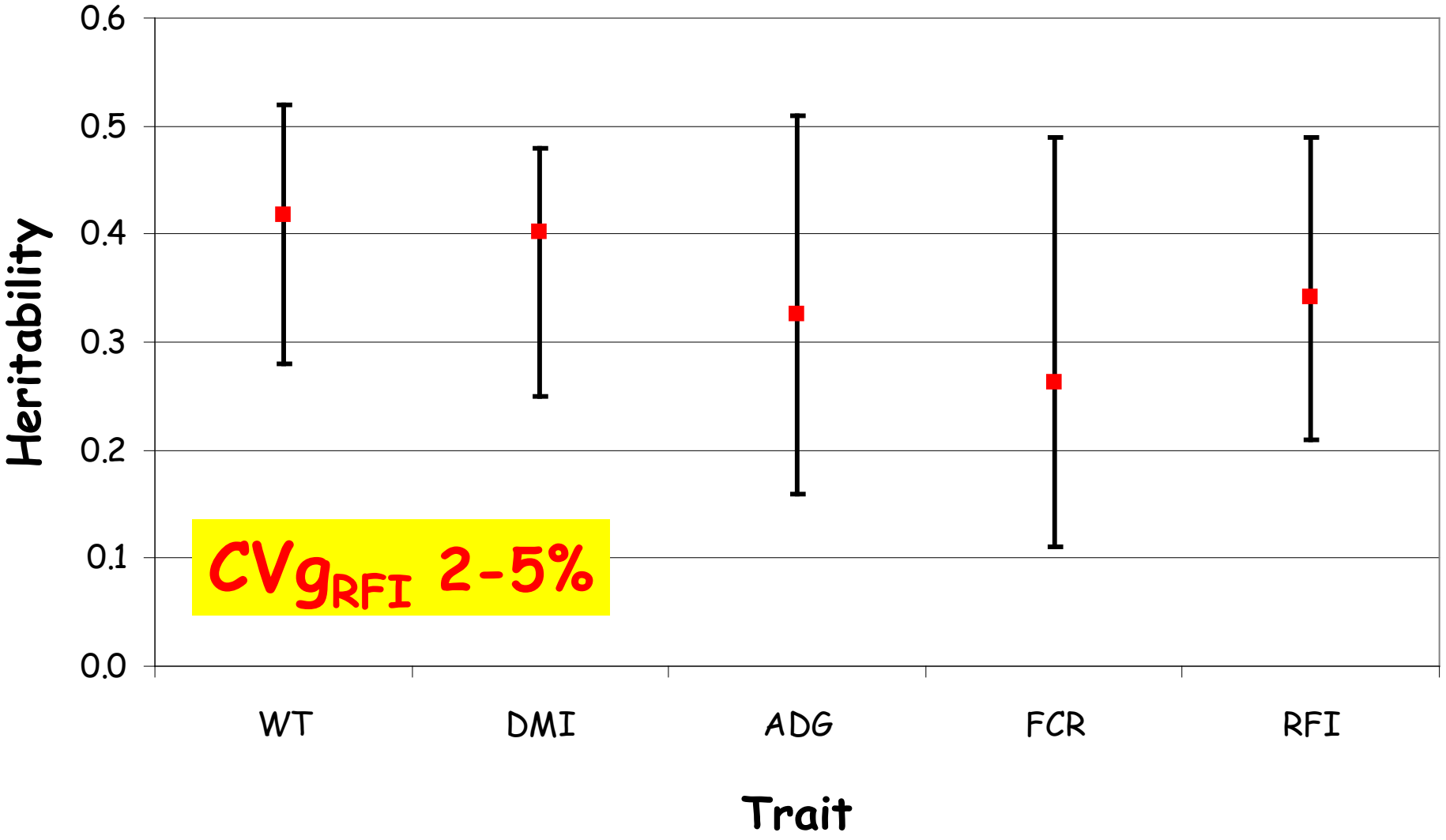
Meta-analysis of 11 studies/ populations

Heritability - sheep



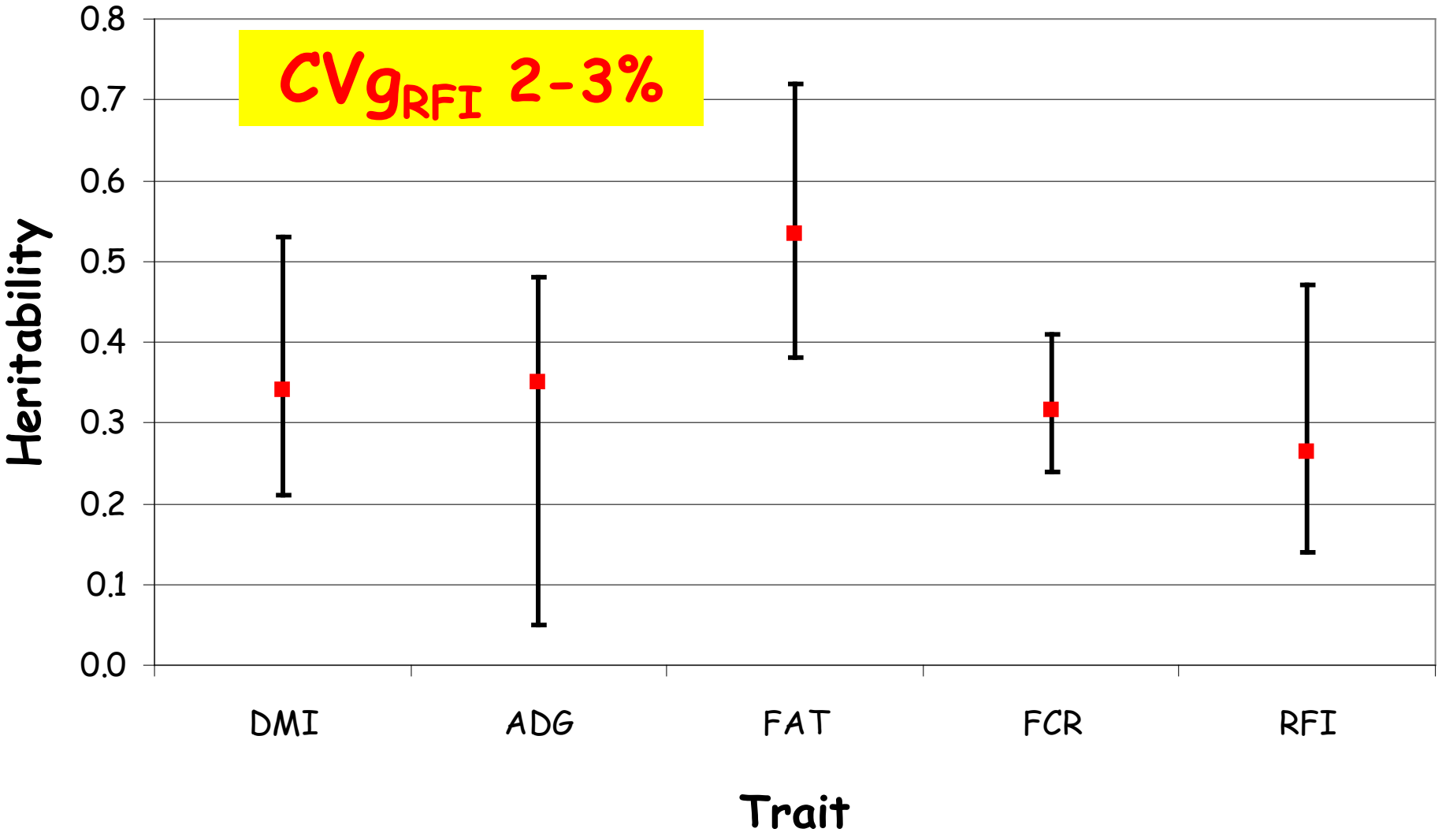
Meta-analysis of 4 studies/ populations

Heritability – poultry



Meta-analysis of 10 studies/ populations

Heritability – pigs



Meta-analysis of 19 studies/ populations

Summary

- Heritability of feed efficiency is similar to other production traits
  - Or is it??
- Genetic variation present is less than many other performance traits
  - As expected because of its mathematical properties

Critique
(points for consideration)

Modelling of metabolic live-weight

$$\overline{FI} = \mu + b_1 ADG + b_2 WT^{0.75} + e$$

$$\overline{FI} = \mu + b_1 \frac{\sum_{d=0}^{length} (WT_{d+1} - WT_d)}{length} + b_2 \frac{\sum_{d=0}^{length} (WT_d)^{0.75}}{length} + e$$

$$\text{Mid test} - \text{weight}^{0.75} \neq \frac{\sum_{d=0}^{length} (WT_d)^{0.75}}{length}$$

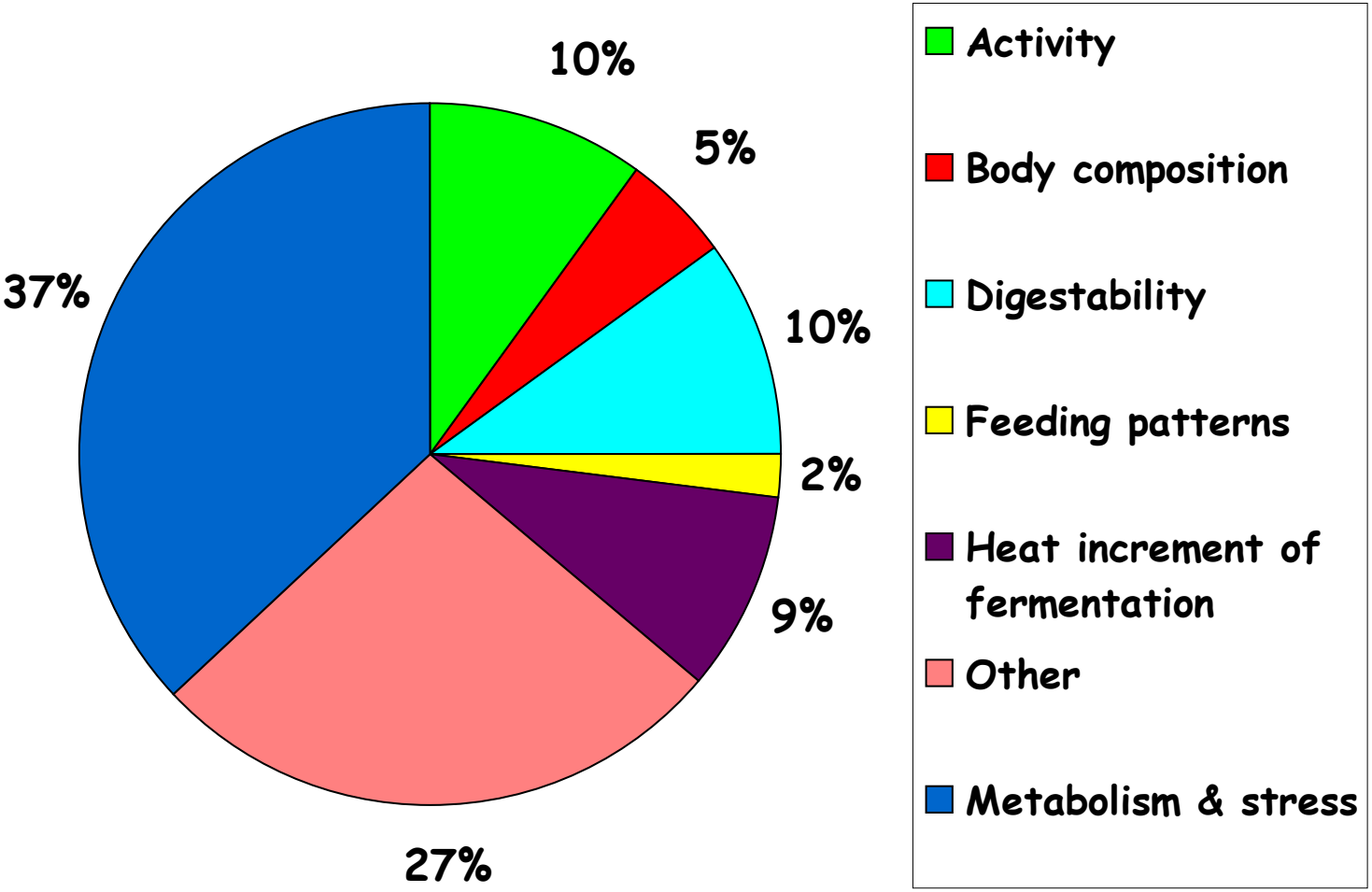
Koch's model (non-linearity)

$$\overline{FI} = \mu + b_1 ADG + b_2 MWT^{0.75} + e$$

$$\overline{FI} = \mu + \sum_{i=1}^{n} ADG^{i} + \sum_{j=1}^{n} (MWT^{0.75})^{j} + e$$

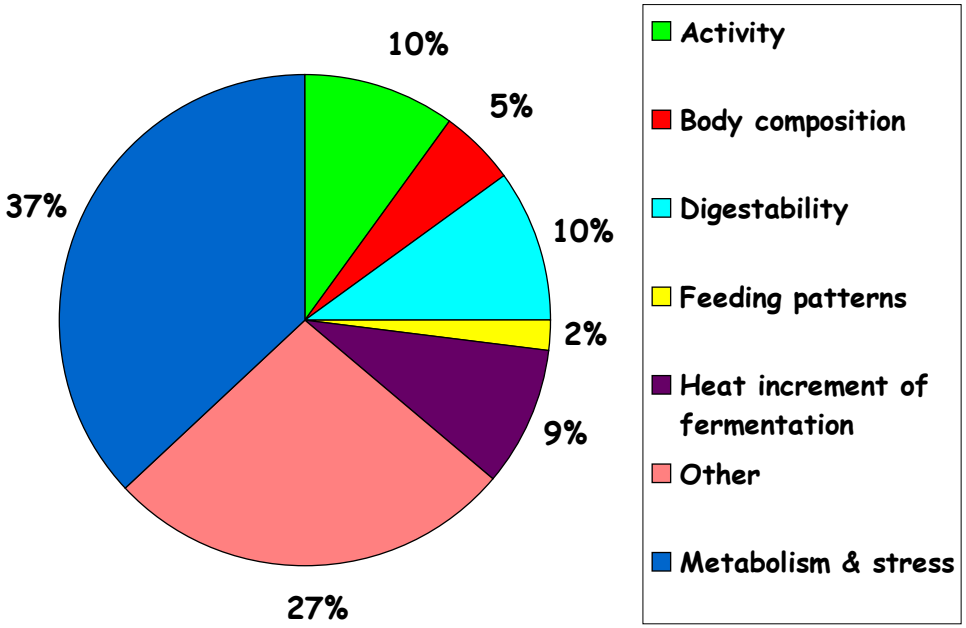
Factors influencing RFI

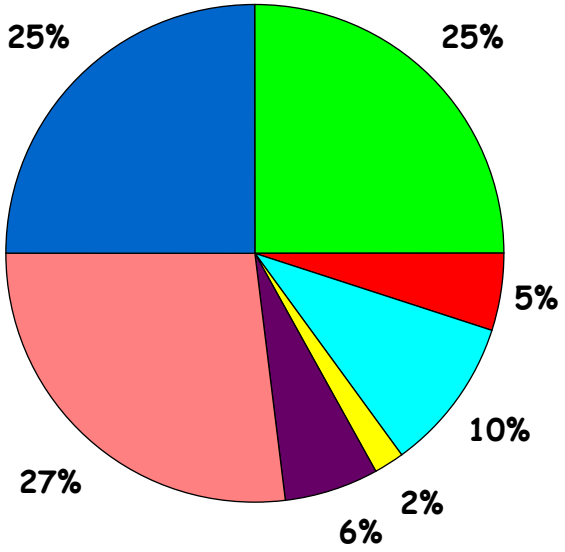
$$FI = ADG + MWT^{0.75} + e$$



Richardson & Herd (2004)

Factors influencing RFI

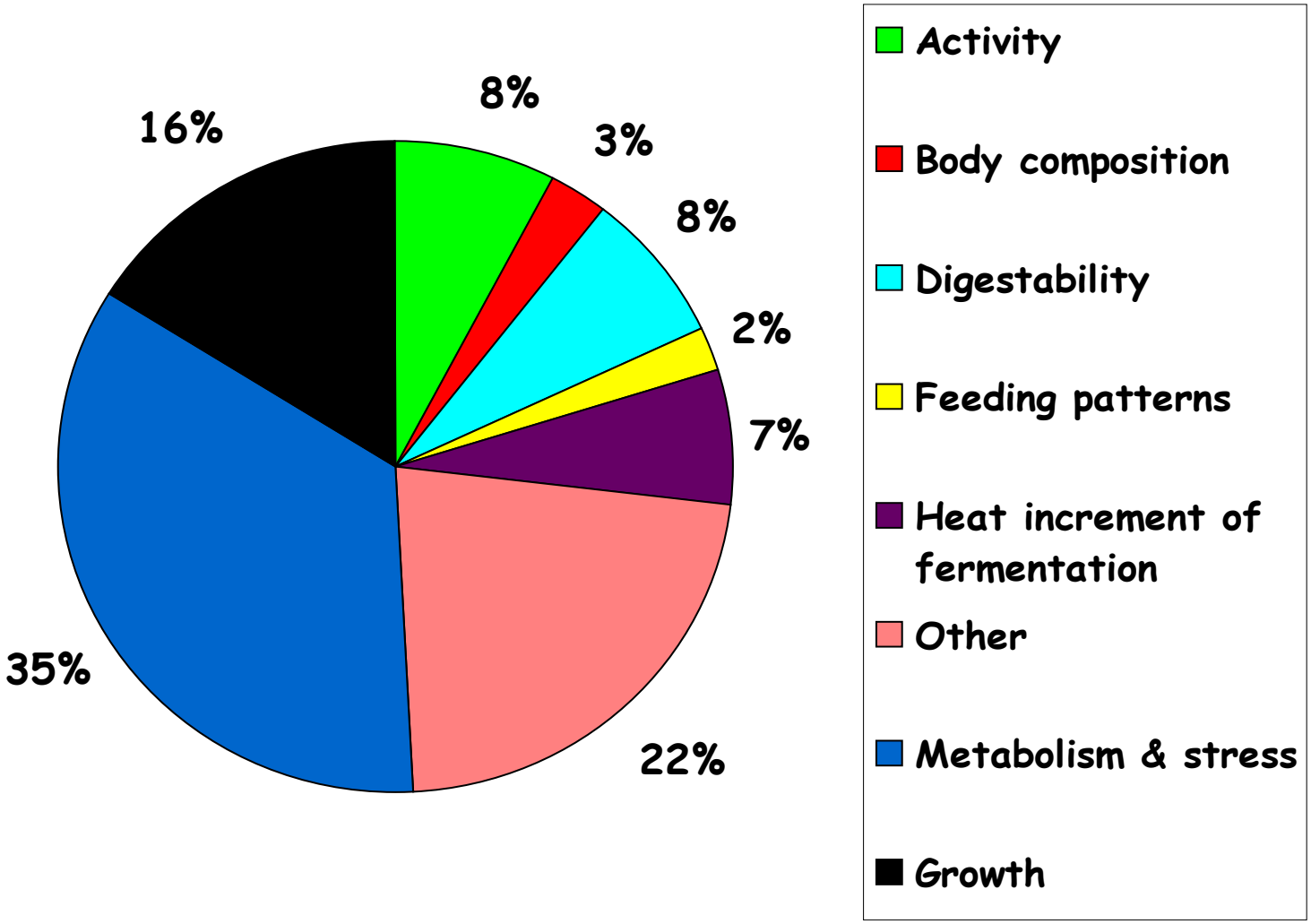




Richardson & Herd (2004)

Factors influencing RFI

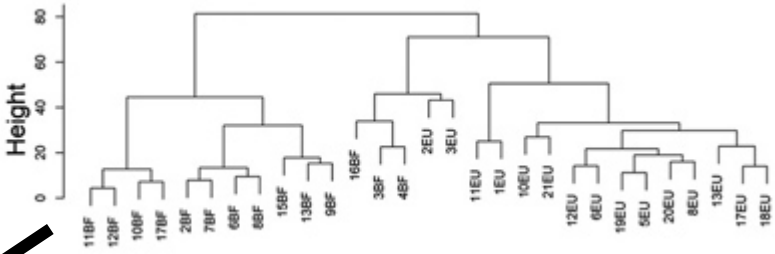
$$FI = MWT^{0.75} + e$$

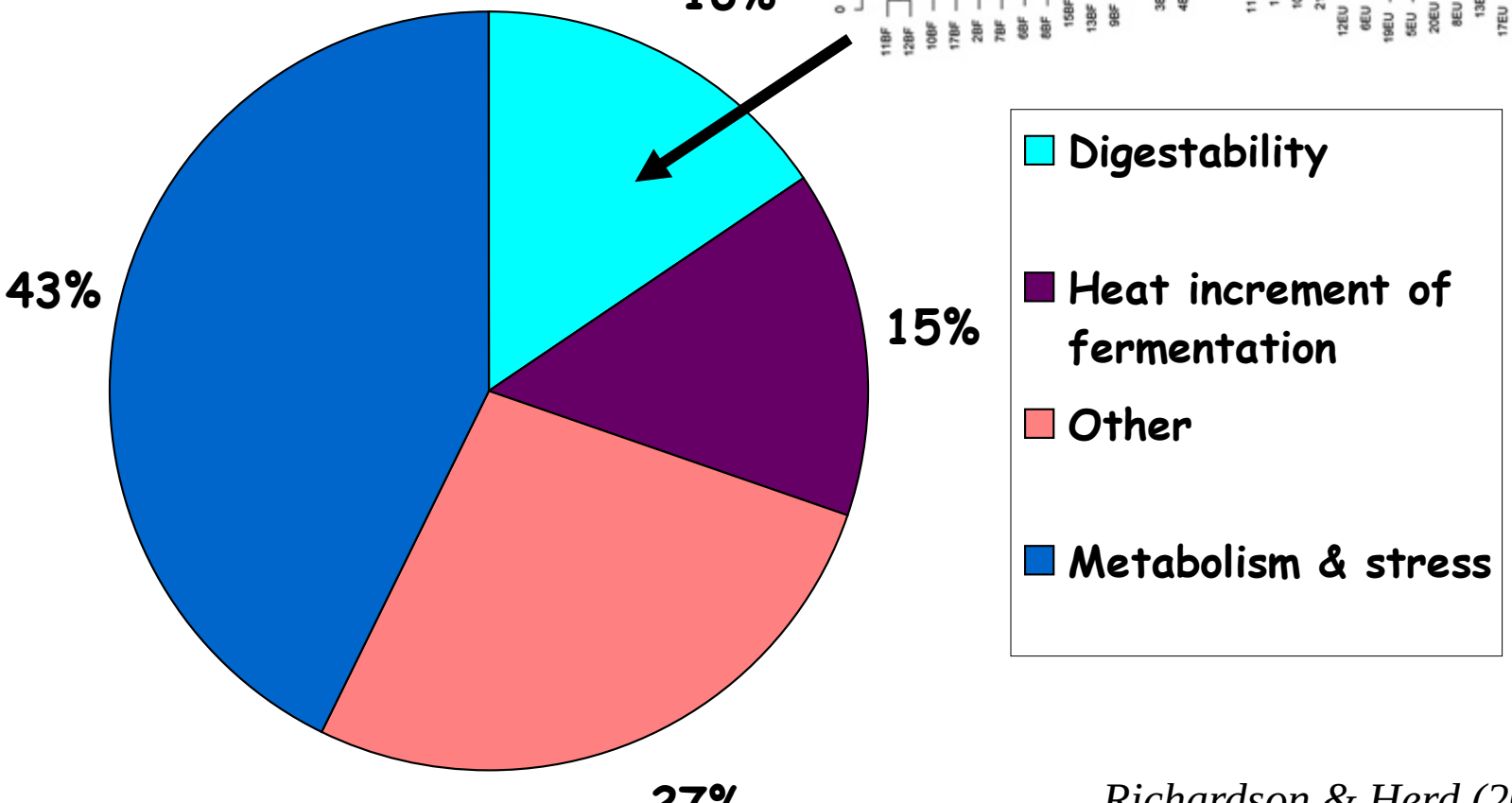


Richardson & Herd (2004)

Factors influencing RFI

$$FI = ADG + MWT^{0.75} + \int Activity + \int FAT + e$$





Richardson & Herd (2004)

Who's got more kilograms fat??

$$FI = ADG + MWT^{0.75} + FAT + (ADGxFAT) + (MWT^{0.75}xFAT) + e$$

Energy cost per step

$$FI = ADG \mid FAT + MWT^{0.75} \mid FAT + MWT^{0.75} \mid Activity + e$$

Is RFI heritability really "heritability of RFI"?

- Simulated DMI [N(10.73,1.52)] and correlation structure with ADG & WT as (Crowley et al., 2010)
- Calculated (phenotypic) RFI
- Heritability of RFI 0.06
  - Picking up genetic correlations with WT and ADG

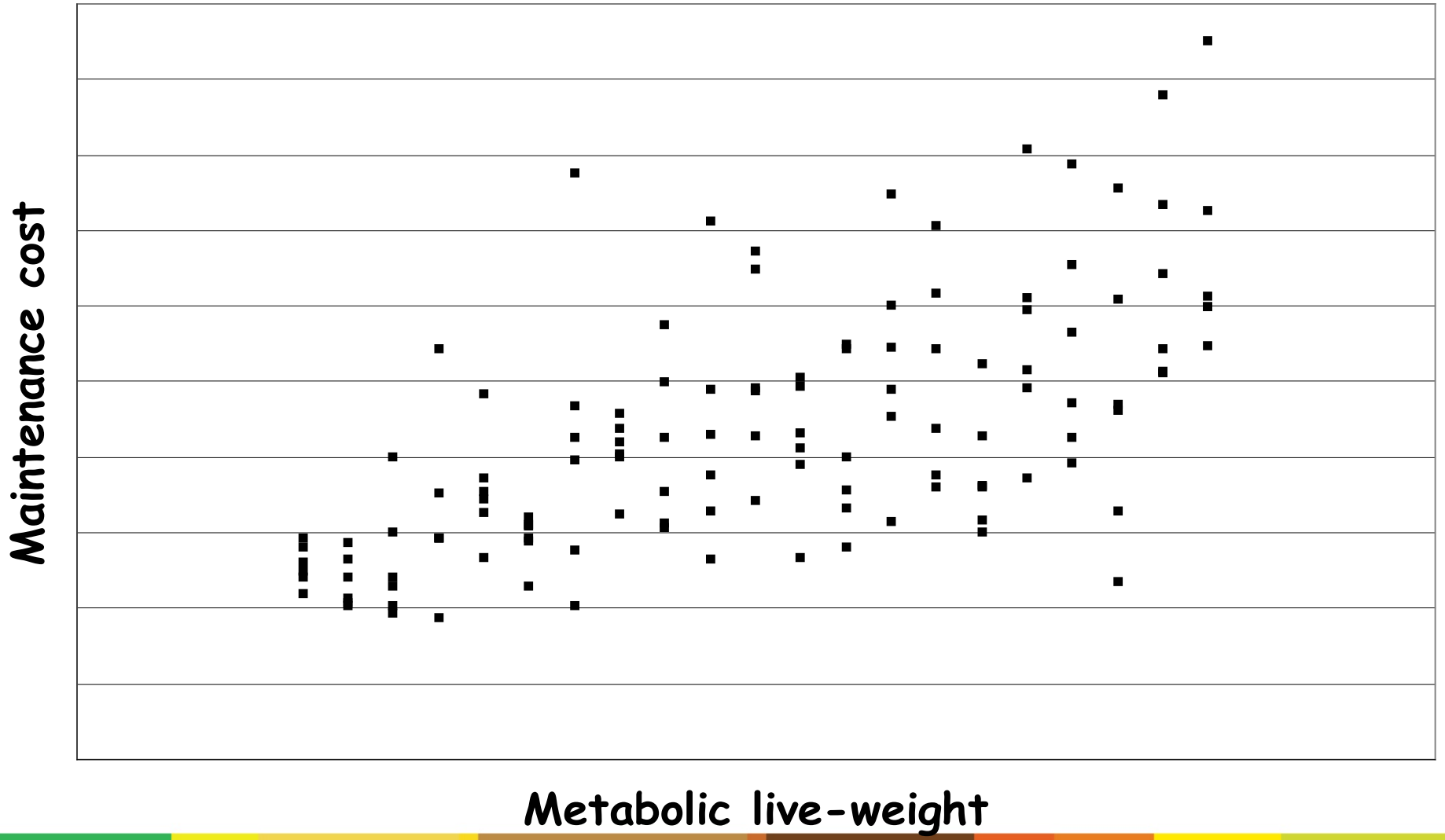
An alternative approach

$$\begin{bmatrix} XX' & X'Z \\ Z'X & ZZ'+\alpha A^{-1} \end{bmatrix} \begin{bmatrix} \hat{b} \\ \hat{u} \end{bmatrix} = \begin{bmatrix} X'Y \\ Z'Y \end{bmatrix}$$

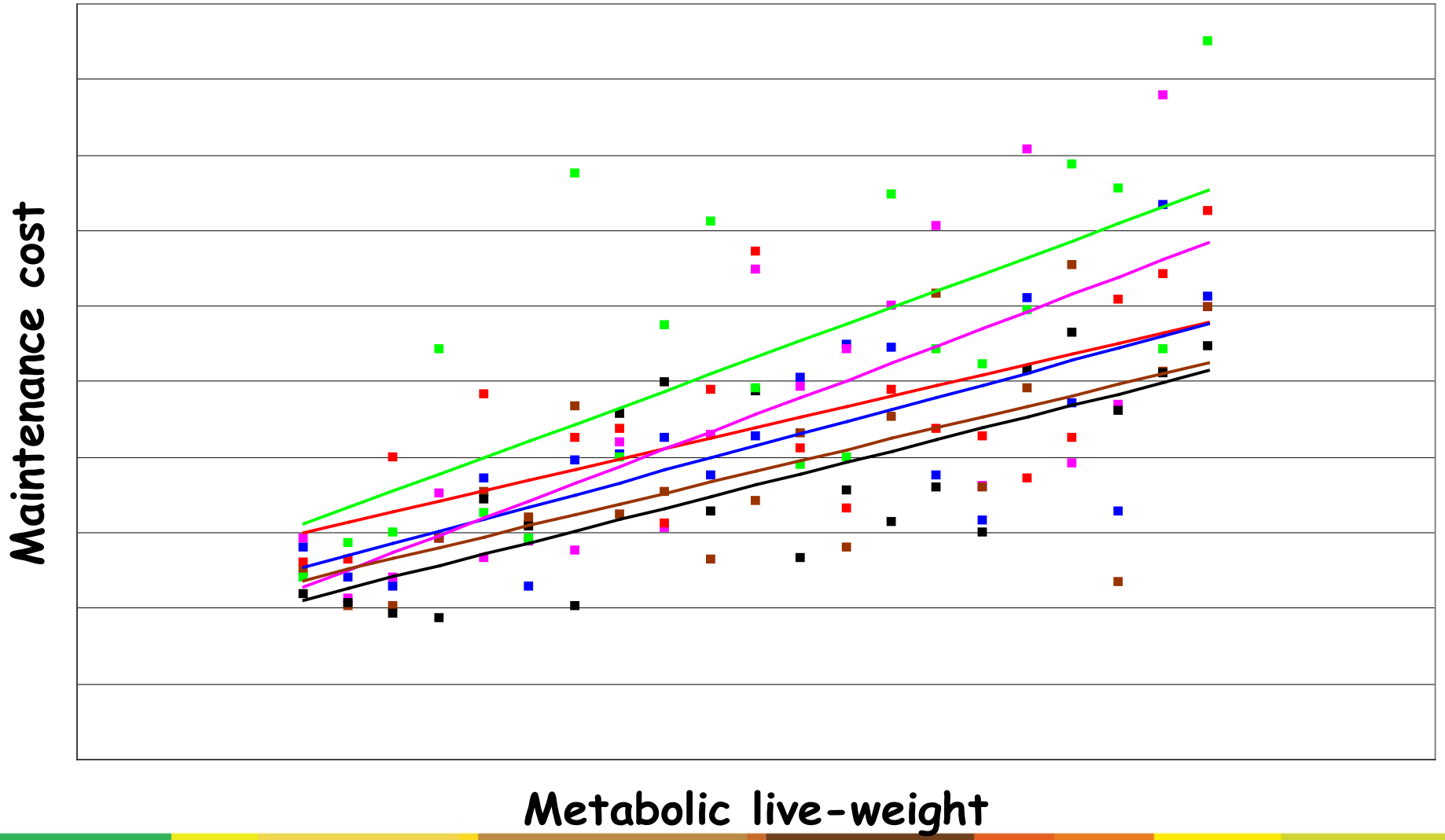
Mixed models (PROC MIXED)

- Models that include
  - fixed effects
    - all classes of interest (treatment)
    - represent population mean
  - Random effects
    - levels drawn from a probability distribution
    - Deviations from population mean (random regression models)

Maintenance efficiency

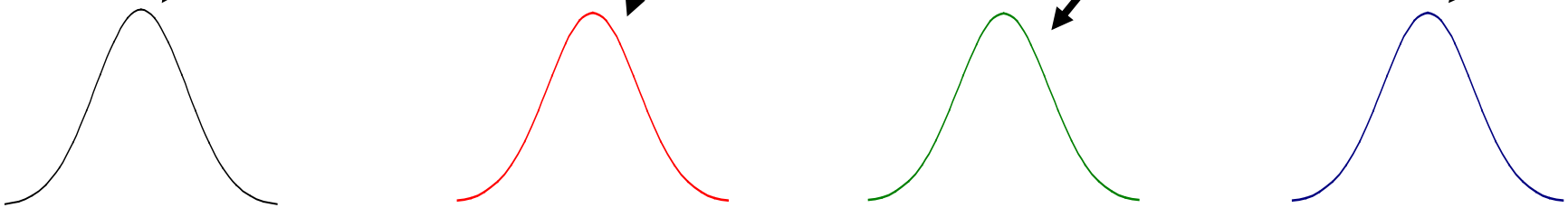


Maintenance efficiency



Mathematical representation

$$FI = (b_{0_p} + b_{0_a})\mu + (b_{1_p} + b_{1_a})ADG + (b_{2_p} + b_{2_a})WT^{0.75} + e$$



Analysis

- 1963 growing bulls on performance test in Ireland
- Genetic variation in random intercept term and random regression on metabolic live-weight
- Novel phenotype for further research
- Is it really differences in energetic efficiency?

Conclusions

- Heritable genetic variation in RFI exists
  - Less then the genetic variation in feed intake
- Feed efficiency (especially in lactating/mature animals) needs further thought
- Residual feed intake must contain minimum "true residual"

10th World Congress on Genetics Applied to Livestock Production

Vancouver, BC, Canada
August 17-22, 2014

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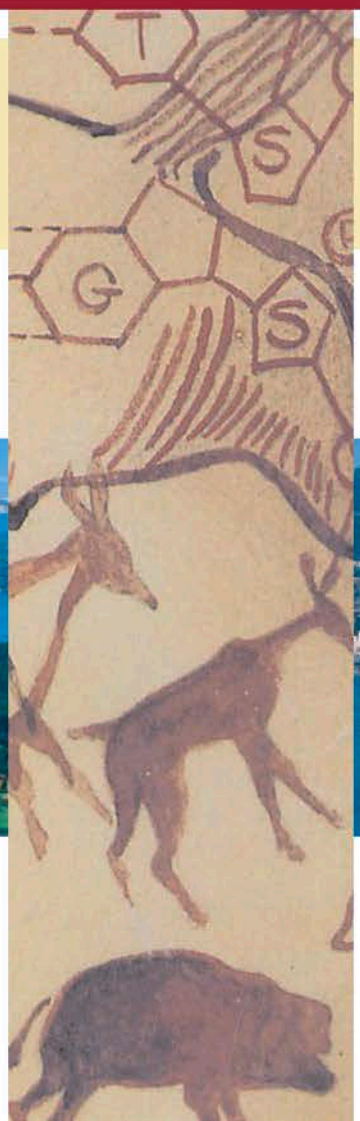

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