Final report

National Workshop – Feed intake and efficiency measures in sheep

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Abstract

This project was a national workshop of key researchers with an interest in the genetics and physiology of feed efficiency and intake in sheep.

Objectives included:

- Discussion of what constitutes efficiency at an individual and system level;
- Identification of gaps in knowledge and understanding of feed intake and efficiency traits;
- Consensus on the appropriate technical measures and equations with recommendations and preliminary plans for collaborative research;
- Drafting a national framework for a collaborative research program to improve the breeding and management of more efficient sheep.

The meeting was conducted via Zoom due to COVID-19 travel restrictions and the Western Australian lockdown.

Key issues were identified as follows:

- Efficiency needs to be defined clearly prior to finalisation of research priorities – different interpretations led to different priorities.
- Limitations in the use of Residual Feed Intake (and other efficiency parameters) to select for more efficient sheep were identified, listed and critiqued. The diversity and variation in sheep production systems mean significantly more information is required on genetic parameters related to RFI across these different systems.
- Lack of technology and methods to estimate grazing feed intake is limiting progress
- Whole farm modelling is required to establish the value of selection for different efficiency traits.

Three sub groups were formed to progress recommendations for targeted research and discussion. The first was a national panel to discuss and define common language for industry around feed intake and efficiency traits. The second group to develop a research program to address methodology of feed intake traits (what to measure and how) and the third group to further develop system modelling of feed intake and efficiency traits to inform selection indexes for breeding programs. Further action and coordination is required to progress these activities.

The workshop provided a starting point for the development of research priorities that will ensure more cost effective use of research funds for physiological and genetic improvement in the sheep industry.

Executive summary

Background

The purpose of this project was to convene a national workshop of approximately thirty industry scientists to review feed intake and efficiency research for sheep. The workshop was used to identify gaps and opportunities for collaborative research to inform and implement a targeted and effective breeding and/or management program for sheep that will ensure the industry remains competitive at a system level for the next 20 years.

Objectives

- Discuss what constitutes efficiency at an individual and system level of sheep production (achieved successfully)
- Identify gaps in knowledge and understanding of feed intake traits for sheep (achieved)
- Seek consensus on the appropriate technical measures and equations for sheep and make recommendations and preliminary plans for collaborative research (achieved partially)
- Draft a national framework for a collaborative research program to improve the breeding and management of more efficient sheep (limited progress)

Methodology

A national workshop of thirty invited scientists was delivered and recorded via zoom. Seven industry scientists from Australia and New Zealand were invited to submit a discussion paper and present on key aspects of feed intake and efficiency.

Results/key findings

The first and primary objective of this proposal was to hold a national discussion to address issues around the measurement of feed intake and efficiency for sheep. This was completed successfully. National experts and industry colleagues who have coordinated research efforts into this area participated in a national discussion on what constitutes "efficiency" at an individual and system level of sheep production. Consensus on the appropriate technical measures and equations for sheep at all levels of the sheep enterprise was a desired outcome of the meeting, however this was only achieved partially with agreement that selection of sheep based on Residual Feed Intake alone is not recommended. The workshop drafted preliminary working groups to develop a framework for immediate research efforts so that a targeted program that improves the efficiency of sheep can be executed nationally and collaboratively between state institutions.

Key issues were identified to be considered prior to drafting a targeted research program for sheep, these included confusion over terms and definitions of efficiency traits for sheep; limitations in the use of Residual Feed Intake to select more efficient sheep; concern that selection for current feed efficiency traits could result in earlier maturing, larger sheep, limitations in measuring grazing feed intake and the integration of efficiency traits within a whole farm system. Within this report, the term feed efficiency is used as a general term referring to production per unit of feed consumed, unless otherwise defined. Three sub groups volunteered to progress recommendations for targeted research and discussion. The first was a national panel to discuss and define common language for industry around feed intake and efficiency traits. The second group to develop a research program to address methodology of feed intake traits (what to measure and how) and the third group to further develop system modelling of feed intake and efficiency traits to inform selection indexes for breeding programs.

Benefits to industry

Breeding for improved feed efficiency is seen by geneticists as an attractive long-term goal due to its permanent cumulative nature. Deriving the genetic parameters required to include feed efficiency in a selection index will be a long term and expensive process, however there are several non-genetic priorities that are likely to have shorter term, higher payoffs. This workshop and the discussions and development that will follow identified limitations in parameter definition. The results will inform priorities to ensure more cost effective use of research funds for genetic improvement in the sheep industry.

Future research and recommendations

A clear outcome was that the diversity of management and environments within the Australian sheep industry presents complications for the application of genetic parameters for feed efficiency. Future research priorities should include developing better tools to measure grazing feed intake, determining the genetic gain in efficiency relative to what is possible by other methods and how feed efficiency and correlations between feed efficiency and other traits varies with different diets and across environments. This should be combined with whole farm modelling to estimate the value of potential improvements.

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1. Background

Feed is the greatest cost in most livestock production systems. Selecting livestock based on their Residual Feed Intake (RFI) has been used as a genetic tool to improve the efficiency of feed utilisation in cattle and pigs. This has enabled reduced production costs leading to more competitive beef and pork industries in Australia. It was argued that using a similar approach for sheep could therefore also increase efficiency of feed utilisation by sheep, thus improving Australia's competitive edge in producing sheep. However preliminary genetic measures suggest that feed efficiency traits could be erratic for sheep. This may be associated with the biological complexities of a dual-purpose animal and the diverse and variable production systems within the sheep industry. Indeed, this has been the topic of much debate and research by multiple national institutions over the last decade. Therefore, the purpose of this workshop was to consider the existing position of our competitive livestock industries in terms of feed efficiency, review where measures for sheep are at, and what the gaps and opportunities are for collaborative research so that we can implement a targeted and effective breeding and/or management program for sheep that will ensure the industry remains competitive at a system level for the next 20 years.

2. Objectives

There were four key objectives for the national workshop:

- Discuss what constitutes efficiency at an individual and system level of sheep production (achieved)
- Identify gaps in knowledge and understanding of feed intake traits for sheep (achieved)
- Seek consensus on the appropriate technical measures and equations for sheep and make recommendations and preliminary plans for collaborative research (achieved partially)
- Draft a national framework for a collaborative research program to improve the breeding and management of more efficient sheep (limited progress)

3. Methodology

The agenda of the workshop included presentations and discussion via Zoom on:

Topic	Presenter
Learnings about feed intake	Hutton Oddy
Feed efficiency – cattle experience	Paul Arthur
Deconstructing feed intake	Wayne Pitchford
Feed efficiency in sheep a NZ perspective	Trish Johnston
Genetics of feed intake	Daniel Brown
Insights from whole farm modelling	John Young
Adult efficiency whole body energy and other components	Sarah Blumer

Participants in the workshop included 45 participants from 19 different institutions.

4. Results

Thirty industry scientists from Australia and New Zealand attended the workshop via Zoom. All attendees were enthusiastic to participate and all seven invited speakers prepared well-referenced discussion papers and accompanying presentations that invited much comment and discussion. The discussion papers are a useful resource for future planning and are appended to this report (Appendix 2). The presentations were excellent. A recurring divergence in priorities was evident between genetic and physiological approaches to the principles of the efficient utilisation of feed.

4.1 What is efficiency?

Many different interpretations and terminologies for intake and efficiency were presented. These included, system efficiency (product per capital invested), energetic efficiency (amount of product per feed consumed), digestive efficiency (Oddy 2021; Young 2021), residual feed intake (RFI – residual after adjusting for feed intake for weight and weight gain) , net feed efficiency (same as RFI but in opposite direction), feed conversion ratio (Arthur 2021; Brown *et al.* 2021; Johnson 2021; Oddy 2021), whole body energy and potential intake (Blumer 2021; Young 2021).

Different interpretations of the terminology resulted in quite different emphasis on options for future research. For example, selection for RFI has demonstrated that significant potential improvement in cattle and sheep is possible within tight feeding and environmental protocols (Arthur 2021; Johnson 2021), however the case for application of such improvements within a commercial grazing system for sheep is unconvincing. Others suggested that greater gains could be achieved by targeting system efficiency through managing or altering the quality and form of the feed available (Oddy 2021; Pitchford 2021).

Clarity in definition and terminology is required to reduce confusion and align objectives across disciplines. The forum was not long enough to achieve consensus around language, but it was agreed that addressing the differences is a priority. Hutton Oddy agreed to lead a national panel to develop guidelines for language that should be used in the further development of breeding and production objectives around feed efficiency.

4.2 Genetic priorities for RFI

The meeting was well supported by genetic expertise, with details of priorities presented in Brown *et al.* (2021). From a genetic perspective, breeding for improved feed efficiency was seen as an attractive long-term goal due to its permanent cumulative nature. Within this discussion, the term feed efficiency was used as a general term for production per unit for feed consumed. RFI is preferred for genetic assessments because it is independent of how much the animal produces. However, RFI needs to account for carcase composition, wool, disease resistance, methane production and reproduction. Relationships between RFI and these traits have not been researched sufficiently.

Feed efficiency of the ewe was considered more important as the ewe eats all year irrespective of feed quality and availability and the lamb spends less time in the production system often on a more consistent pasture supply.

System modelling was proposed to determine the relationship between chosen efficiency traits (however defined) or RFI and system efficiency. The economic value of feed intake and feed efficiency will vary between production systems.

It was suggested that achieving sensible selection emphasis towards feed efficiency in a balanced breeding objective requires the establishment of a research and genomic reference population to explore efficiency traits. This is to allow measurement of genetic correlations of feed intake and methane with other key production traits for both grain and pasture systems of diverse quality and quantity. Equally important would be to investigate indicator traits that are cheaper and more practical to measure on farm than feed intake (such as methane). The economic value of each trait would provide information for combination into a selection index to maximise progress in the breeding objective. Currently the genetic parameters to inform this process are incomplete. Protocols to measure feed intake and efficiency traits need to be consistent, repeatable and reliable.

Within this genetic approach, consistency of protocols would be essential for measurements within a genomic reference population. A stable measurement of growth requires a longer test period than a stable measurement for intake in cattle and similar observations have been published for sheep. Consistency of protocols would also be paramount when measuring gases as diet, time off feed, type of measurement as well as calibration protocols will all influence the measurements. Genetic and phenotypic gas traits are correlated strongly with intake for cattle and sheep and thus may make a good proxy measurement for intake. Research protocols should be standardised nationally for efficiency parameters so that test lengths for feed intake, growth and gases are comparable. If using DXA technology for body composition, non-animal components such as gut fill need to be considered. These results therefore need to be interpreted with caution.

Many gaps in the knowledge required to capture genetic improvement in feed efficiency were identified, including:

- Measures and indicator traits for feed intake (eg methane),
- Energy requirements across the production cycle,
- Genetic correlations of feed efficiency with other key production traits,
- ASBV's for indicator traits that could be measured on farm,
- A reference population to underpin R & D,
- Genomic prediction of traits related to feed efficiency,
- Understanding of genetic x environment interactions,
- Feed efficiency of ewes and lambs fed grass or grain

Priorities were identified as:

- The establishment of a research and genomic reference population,
- Estimates of correlations with key production traits,
- Identification of easy to measure indicator traits.

4.3 Selection for low RFI

Selection of cattle for low RFI has resulted in lower feed intake and FCR and calves with higher weaning weight but less rib fat (Arthur 2021). Selection for low RFI did not cause any changes in pregnancy, calving or weaning rates. In these studies feed efficiency was clearly defined and time required for feed adjustment, intake measurement and body weight change determined (70 days). Similar protocols were implemented in selecting for RFI in sheep in New Zealand. Using a feed intake facility, a set diet (lucerne pellets) and 1000 individual ewe lambs over 3 years, RFI was highly heritable (0.46) (Johnson 2021). In both the sheep and cattle studies, the inability to accurately measure feed intake of grazing animals was a limitation. For sheep, a full set of other genetic parameter estimates were measured. There was evidence of a relationship between methane and feed intake with higher methane yields (CH_4/kg DMI) at lower feed intakes.

Interestingly, in one dataset from New Zealand, low RFI sheep had higher fat reserves, in contrast to low RFI cattle. This may be partly due to the different fat measurement techniques used. The distribution of fat in sheep selected for low and high RFI differs, making fat changes more difficult to detect without sophisticated technology such as DXA and/or CT scanning. The two largest datasets of feed intake for sheep in the world (WA & New Zealand) suggest that fatter lambs are more efficient, which is at odds with other livestock datasets (poultry, pigs, cattle), but similar to mice. Activity was not measured for the sheep datasets though, leaner sheep may just be more active as was observed for mice. Or, if fat is more expensive to deposit but cheaper to maintain at some point on the growth curve feed efficiency may switch from leaner to fatter animals. This could be related to the time of measurement relative to maturity and reproduction. Relationships between fatness and reproduction are understood for cattle and sheep, however relationships between efficiency and reproduction are not understood well and require further investigation as reproduction constitutes the most important part of system efficiency irrespective of whether meat or wool are the higher valued products. A reference flock to measure reproduction like the Sheep CRC Information Nucleus Flocks or the current AWI Merino Lifetime Productivity Trial offer suitable templates for intake and efficiency measures to inform breeding and selection programs.

While RFI is heritable and there is significant variation in the trait, the trait appears unstable. From the limited information available there is low correlation of RFI across ages, feed types (quality, diversity, composition), management systems and seasonal conditions, with a poor understanding of the consequences of selecting within one scenario on performance within another and on correlations with other performance traits across environments. Relevant examples were described of little growth difference between high and low RFI cattle when fed near maintenance with large differences when fed *ad lib.* Similar results were reported when low and high quality feed was provided to Merino and Damara sheep (Pitchford 2021). All of these studies indicate the limitations of RFI as an indicator of efficiency for a farming system where feed quantity and quality is changing throughout the year as the animal matures and reproduces. In summarising the results from multiple projects, Pitchford (2021) concluded that variation in RFI is associated with variation in appetite rather than maintenance efficiency and further suggested that selection for greater appetite is better, as, when feed is plentiful and cheap, animals can utilise this feed to gain condition and set themselves up for times of feed shortage. Feed intake is an important trait in a breeding objective as it is correlated highly with output traits (liveweight, growth, lactation, condition score). Weight and body composition are the drivers of carcase value and thus efficiency of feed utilization into productivity gains. Measuring feed intake therefore plays an important part in selecting for efficiency, but this needs to be done with the output traits. More information on the genetic variation in feed intake and how this correlates to production traits is required to achieve sensible selection emphasis towards feed efficiency in a balanced breeding objective. Pitchford (2021) further suggested it is more efficient to focus on weight and composition at slaughter, along with weight and body condition of breeding ewes.

What was clearly stated was that there is no evidence that selection for RFI, weaning weight, fleece weight or methane yield affects the energetics of the animal – changes in efficiency are not linked to variation in energy metabolism (Oddy 2021).

4.4 Lessons from other species and selection lines

Examples were presented of some of the consequences of selecting for RFI in other species, where mice and chickens with low RFI were shown to be less active (Brown *et al.* 2021; Oddy 2021; Pitchford 2021). Such observations highlight the need for a considered approach in the sheep industry where selection for sheep in a low activity environment such as a pen or shed may be poorly transferable to a grazing environment.

Changes due to selection for a single trait selection were also discussed. Selection for high weaning weight breeds big lambs that suck more milk. Selected lambs from both groups grew at the same rate when infused with equal amounts of milk. Breeding for high clean fleece weight increased wool production but reduces body fatness. Selection for high clean fleece weight results in increased efficiency in the use of digested nutrients for wool. Selecting for low methane producers reduced rumen size but increased digesta flow. Striking the right balance is key and the right balance will be different for different environments and farming systems. Our extensive and very different sheep production systems will therefore require different genetic and management solutions.

4.5 Genetics, physiology and environment

While the genetic perspective was clearly articulated within the workshop, many of the participants pointed out that physiological and environmental changes could contribute to variation in RFI and, that a focus on RFI alone may not provide an appropriate phenotype for the future. Developing a suitable phenotype may take many years with potential interruptions if relationships with other desired production traits are unfavourable. Work with cattle also indicates selection for feed efficiency (low RFI) has had a very slow uptake. Within this genetic research, feed intake and related traits are usually measured under intensive animal house conditions that have not yet been calibrated to or even correlated with grazing under extensive production. Therefore investing in genetic solutions researched under animal house conditions may produce favourable breeds for secondary processors, live sheep export and feedlotters, but these selection lines may not be the most productive for extensive sheep production systems. The most efficient lamb for an intensive feedlot will be different genetics to the most efficient ewe breed for an extensive wool production system in the eastern wheatbelt of Western Australia. For example, because maintaining ewes in condition score 3 throughout the reproductive cycle is far more profitable than allowing ewes to drop to condition score 2, a ewe that has a high intake over lactation and post-weaning when cheap green pasture is available, lays down stores of fat, then uses these stores when feed is limiting is more likely to have a higher lifetime reproductive profitability. The requirement for expensive supplements to increase condition over summer for breeding is minimised.

To achieve this, measurement of potential intake of a wide variety of feeds of different digestibility by sheep in different stages of growth to inform predictive models, feeding strategies and genetic objectives is required. Coupling these feed intake measures with changes in body composition, gas production, digestibility and nitrogen balance will ensure future genetic phenotypes will remain a viable competitor for land use.

The identification of information required to facilitate genetic improvement highlights the need for the development of practical technologies to measure feed intake in grazing animals for comparison with housed measurements. Sensors to measure total grazing and rumination time are looking promising. Developing these types of research tools are essential to identify potential opportunities for improvements in feed efficiency at a system level.

In short, many inputs are required. These types of studies can be overlayed on resource flock studies to give earlier improvements in system efficiencies. The holy grail of animal production science is an accurate measure of feed intake in the paddock. This is where we need to think creatively about investing our research for solutions. Better to find out sooner rather than later whether the genetic traits invested in are relevant to the adult reproducing ewe in the paddock, because without this relevance they will be of much lower value to system efficiencies and whole farm profit.

4.6 System efficiency

While many of the reactions and processes in the body are well understood and allow theoretical predictions on growth and production under set conditions, in reality, a grazing system may be highly variable. The system for sheep for example is nothing like the controlled feeding and environment used to produce pigs, chickens and to a lesser extent dairy or feedlot cattle. The selection process is far simpler under controlled production conditions. Furthermore, sheep production systems also vary across climatic zones. Sheep also have a diversity of products that may simplistically be considered as meat and wool, however, quality must also be considered, as a kg of 35 µ wool is not equivalent to a kg of 19 µ wool and a kg lamb is not equivalent to a kg of mutton.

The presentations from Young (2021) and Blumer (2021) both focussed on whole farm profitability. While they focussed on genetic improvement of efficiency there was an acknowledgment that genetics and management need to be considered together and that it is best to evaluate improved genotypes in the system where they will be used. These presentations introduced the concept of whole body energy (WBE). WBE is an indicator of energy stored or the difference between energy intake and energy required for maintenance (multiplied by the efficiency of storage). WBE is most strongly associated with whole body fat.

The value of WBE was evaluated using the MIDAS whole farm model. Higher WBE was associated with significant increases in profit due to higher stocking rates, less supplementary feeding and increased pasture utilisation. Feed quality was more important than quantity to whole farm system profits. Sheep that eat more when good quality feed is available (eg. spring) are the most profitable, irrespective of whether they have increased appetite or whether they are more energy efficient (the amount of energy stored per unit of energy eaten). When pasture is abundant, storing the excess energy in the sheep as whole body energy (fat and protein) is cheaper than cutting hay, silage or other mechanical preservation techniques for pasture. Therefore bioeconomic modelling suggests that increasing genetically the whole body energy of sheep should lead to increased farm profits. Liveweight change under conditions of restricted intake could be a better indicator of system efficiency and how feed is converted to stores and then used in times of restriction to maintain production indicates system efficiency better than perhaps RFI. However, we must be wary that selecting sheep genetically for increased whole body energy does not mean selection for sheep that may mature more early, or that have a larger mature size. An interesting concept resulting from bioeconomic modelling was that increasing appetite (feed intake under *ad lib* conditions) or increasing feed intake efficiency were equally valuable mechanisms (Young 2021).

Blumer (2021) expanded on the modelled results by presenting WBE estimates from different sire groups and the potential benefits of stored energy for periods of poor nutrition. Oddy (2021) expanded the discussion by providing examples to improve system efficiency other than through the selection of animals. He suggested that the fastest and most cost-effective way to improve system efficiency is through modification of the feed base. Examples included changing the form of the feed ingested consequently changing the energy available to an animal and through changes in the diet selection by the animal. This information could be used for pasture management, on-farm resource allocation and even plant breeding to improve plant morphology, nutrient composition and plant / animal management options.

5. Conclusion

While the presentations and discussion provided some consensus on gaps in knowledge and priorities to target our research questions, the ultimate objective of developing a collaborative program or national framework to improve the feed efficiency of sheep was not met due to limited workshop time and not being able to meet in person. There continues to be debate and disagreement on application of efficiency traits such as RFI in the extensive sheep industry. What is clear is that the physiological consequences of selection for such traits needs to be understood. Variation in feed intake exists between sheep and may be useful in combination with output traits such as growth, methane, wool and reproduction to improve the efficiency of feed conversion into product for sheep production systems. This needs to be complemented with an understanding of the physiological differences caused by selection across sheep breeds, different environments and physiological states. Research that explores the genetic relationships between intake, growth, body composition, wool, reproduction and methane and that explores how these relationships change as sheep age and feed quality varies is warranted. Whole farm, systems modelling is then required to assess the influence of phenotypic change on productivity and profit. Aligned with this is progress through understanding changes due to availability, selection, digestibility and protein utilisation of different feedstuffs.

A national reference flock such as the genetic resource flock and/or the AWI Merino Lifetime Productivity Trial should be considered for added measures of feed intake and efficiency to inform breeding programs and assist with system modelling of efficiency traits. Non-genetic approaches to improving feed efficiency are likely to have much higher and immediate payoffs than genetics, but first we need to prioritise the development of technologies that can measure grazing feed intake accurately.

5.1 Key findings

- Variation in feed intake exists between sheep, and this will lead to variation in many measures of efficiency, but it is unlikely that partial efficiency of protein and fat deposition vary. For these reasons it is important to clearly define what is meant be efficiency at the animal level versus variation in efficiency between sheep, dependent on the definition of efficiency.
- Residual Feed Intake for grazing sheep has a different value to more intensive livestock industries like poultry, pigs and perhaps even cattle. The heritability of RFI appears to (or is suspected to) change in relation to breed, age (repeatability), diet (grain or grazing), physiological status, time of year etc.
- By selecting for Residual Feed Intake there are likely to be physiological changes in the rate of maturity and body composition that must be considered before selection indexes are developed for sheep.
- Non-genetic approaches to improving feed efficiency are likely to have higher and more immediate payoffs to genetics but first we must invest in developing technology that can measure grazing feed intake accurately.

5.2 Benefits to industry

Breeding for improved feed efficiency is seen by geneticists as an attractive long-term goal due to its permanent cumulative nature. Deriving the genetic parameters required to include feed efficiency in a selection index will be a long term and expensive process. However, there are several non-genetic priorities that complement selection that are likely to have short term, higher payoffs. This workshop and the discussions and development that will follow identified limitations in parameter definition especially at the whole farm level. The results will inform priorities to ensure more cost effective use of research funds for genetic improvement in the sheep industry.

6. Future research and recommendations

- Form a national panel to discuss and provide consensus on defining "efficiency" and language recommended for use with industry.
- Use feed standards to calculate breeding values for sheep
- Combine feed intake measures with changes in body composition and measure digestibility and gas production
- Measure feed intake, body composition and gas traits from different quality feeds and physiological states (gestating, lactating, recovering)
- Measure *ad lib* intake of a wide variety of feeds by sheep in different stages of growths to inform predictive models of animal performance
- Measure feed intake and body composition regularly on ewes from weaning to their adult weight see if RFI switches from leaner to fatter animals as they mature
- Develop selection indices for efficiency traits but avoid selection pressure that will cause early maturing animals
- Develop technology that can measure or indicate feed intake of sheep grazing pasture accurately
- Measure feed intake and methane traits on reproducing adult ewes grazing pasture
- Correlate feed intake at pasture during multiple seasons with feed intake under shed/feedlot conditions
- Develop and apply system models to estimate the value of changes in feed intake, feed conversion efficiency and body composition under different, variable environmental conditions. Focus on the reproducing ewe.
- Explore genetic relationships between intake, growth, body composition wool and methane and breed sheep that eat well, grow well, grow lots of wool and produce minimal methane throughout their productive lives
- Combine all of these aspects into a practical advisory service for producers

These recommendations for targeted research were categorised into three key areas for future development by participants at the workshop with suggested leads for each group/theme:

1. Common understanding and language around feed efficiency (led by Hutton Oddy including Wayne Pitchford, Paul Arthur and Holland Dougherty)
2. Methodology, what needs to be measured and how this should be done (led by Gus Rose and including Julius Van Der Werf, Hans Daetwyler, Beth Paganoni, Ralph Behrendt, Daniel Brown, John Young, Tricia Johnson, Stephanie Muir, Johan Greeff, Phil Vercoe and Hayley Norman)
3. System modelling to focus on the value of feed efficiency traits and inform selection indexes (including Daniel Brown, John Young, Julius Van Der Werf, Hutton Oddy, Gus Rose, Sarah Blumer, Andrew Thompson and Ralph Behrendt)

7. References

Arthur, P (2021) Feed efficiency - what we have learnt fronm cattle. In 'National Feed Intake Workshop. pp. Appendix 2, Paper 2, p18.

Blumer, S (2021) Adult efficiency; whole body energy and other components. In 'National Feed Intake Workshop. pp. Appendix 2, Paper 7, p23.

Brown, D, Paganoni, B, van der Werf, J, Rose, G (2021) Breeding for feed efficiency in sheep. In 'National Feed Intake Workshop. pp. Appendix 2, Paper 6, p20.

Johnson, T (2021) Feed efficiency in sheep - a New Zealan perspective. In 'National Feed Intake Workshop. pp. Appendix 2, Paper 5, p22.

Oddy, H (2021) What have selection lines ever done for us? - implications for future research into variation in feed intake and efficiency in sheep. In 'National Feed Intake Workshop. pp. Appendix 2, Paper 1, p17.

Pitchford, W (2021) Deconstructing feed intake. In 'National Feed Intake Workshop. pp. Appendix 2, Paper 4, p19.

Young, J (2021) Feed efficiency - insights from whole farm modelling. In 'National Feed Intake Workshop. pp. Appendix 2, Paper 3., p21

Appendix 1

Department of
Primary Industries and Regional Development

GOVERNMENT OF WESTERN AUSTRALIA

National Feed Intake Workshop

Date: 4 Feb 2021

Virtual attendees: Zoom link - https://us02web.zoom.us/j/87493384295
Meeting ID: 874 9338 4295

NZST	EST	**WST**	Presenter	Theme (brief)
12:15am	10:15am	**7:15am**	David Masters	Welcome and introductions
12:30am	10:30am	**7:30am**	Hutton Oddy	What have selection lines ever done for us?
				What have we learnt from cattle?
01:10pm	11:10am	**8:10am**	Paul Arthur	
		Break (5 min)		
01:50pm	11:50am	**8:50am**	John Young	Insights from whole-farm modelling
			Wayne Pitchford	
02:30pm	12:30pm	**9:30am**		Deconstructing feed intake
		Lunch/brunch (20 min)		
03:30pm	1:30pm	**10:30am**	Trish Johnston	Overview of research from NZ
04:10pm	02:10pm	**11:10am**	Daniel Brown	Breeding for feed efficiency in sheep
				Adult efficiency: whole body energy and other components
05:50pm	02:50pm	**11:50am**	Sarah Blumer	
		Break (10 min)		
05:40pm	03:40pm	**12:40pm**	David Masters	Discussion
06:40pm	04:40pm	**01:40pm**	David Masters	Close

*Times may change slightly

Appendix 2

What have selection lines ever done for us? – implications for future research into variation in feed intake and efficiency in sheep

Hutton Oddy

Livestock Industries Centre, NSW Department of Primary Industries, Trevenna Rd, University of New England, Armidale NSW 2351. hutton.oddy@dpi.nsw.gov.au

Presenter Biography

Hutton's role in NSWDPI is to support ongoing research on topics that improve productivity and sustainability of livestock production. Current activities include work to establish an improved framework for prediction of quantitative relationships between nutrition and body composition in ruminants. Hutton has continuing interest in understanding the basis for variation in RFI and methane production from ruminants.

Cost of feed is arguably the most significant cost in animal production, and a considerable amount of time and money has been directed to reducing feed costs. Ways to reduce feed costs have involved combinations of pasture improvement (grow more, use more), use of feedlots (increase feed quality, remove stock from poor feed supply), increased reproductive performance and other different strategies to manage the interaction between animal and feed base (i.e., maintain plants in vegetative state for as long as possible). Over the past 50 years, there has been increased attention to exploring the possibility that there is individual animal variation in "efficiency of feed use". Given this workshop *"...will address the measurement of feed intake and efficiency for sheep"*, the intent of this paper is to provide a context for subsequent discussion and to document some learnings not embodied in the Residual Feed Intake field alone.

Warning - Definitions are important. Efficiency means different things to different people. As a biochemist I might consider it to be the amount of energy captured in a reaction relative to that of the reactants. Some animal scientists could mean it to be how much feed is eaten relative to gain of product. Some farmers expect efficiency to reflect labour (or money) invested relative to return. It is therefore extremely important that when discussing efficiency those in the conversation agree to discuss the same thing.

Increasing efficiency (defined here as product output per capital invested) of animal production requires a "whole of system" approach. Increased whole of system efficiency comes from growing and using more feed of higher nutrient density (including moving feed resources into the system) and adjusting stocking rate to maximise animal production without causing adverse long-term effects to the land. These actions occur in the face of increased variability in rainfall events and temperature, and in the case of south western Australia, a systematic decline in rainfall since the 1970's, coinciding with increased average temperature, leading to an increasingly dry and variable environment.

In this changing environment, animal improvement has mainly focussed on changing the animal to suit changes in market preference (meat v wool; quantity v quality) and adaptation to the environment (disease / heat resistance, do-ability). Recent activity has addressed increasing the

Feed Efficiency – What have we learnt from cattle

Paul Arthur
NSW Dept of Primary Industries

Introduction : Providing feed to animals is a major input cost in most livestock production systems but feed intake by individual animals is difficult to measure. Feed intake measurement equipment are now available in most livestock species, hence the interest in measures relating to the efficiency of utilization has increased. The objective is to share what we have learnt in cattle to inform new R&D in livestock

Trait definition and measurement protocols : The utilization of the feed consumed by an animal involves complex biological processes and interactions with the environment. In addition, it is complicated by the fact that feed intake is highly correlated with body size and level of production. To overcome these complexities and to relate feed intake to production system efficiency, several measures (or traits) of feed efficiency have been developed over the years.

It is important that the measure(s) of feed efficiency is/are clearly defined and measurement protocols for all the component traits are developed and followed. In growing cattle, for example it was found that after an initial 21 d adjustment period feed intake can be measured accurately in 35 days whereas accurate body weight is achieved in 70 days. Hence the length of test for a feed efficiency trait that utilizes these two component traits (e.g. residual feed intake) should be 70 days (Archer et al., 1997).

Genetics of feed efficiency in cattle : Most feed efficiency traits in cattle are heritable and can be improved by genetic means. They are also phenotypically and genetically correlated with other production traits at the same age (Arthur and Herd, 2005) and at later ages (Arthur et al., 2005; Arthur et al. 2014). This is illustrated by the extracts in Tables 1 and 2 (extracts from Arthur et al., 2005) after 1 to 2.5 generations of divergent selection for RFI, and Table 3 (extract from Arthur et al., 2014).

Conclusion : It is therefore important that for genetic improvement a selection index approach should be one of the considerations.

Table 1. Predicted means (± standard errors) for transformed (T) and untransformed (UT) values for maternal productivity traits of cows divergently selected for residual feed intake (RFI)

		Selection line		
Trait	Data type	Low RFI	High RFI	Signif.
Number of cows exposed to bull		222	247	
Pregnancy rate (%)[A]	T	2.38 ± 0.40	2.35 ± 0.40	n.s.
	UT	90.5	90.2	
Calving rate (%)[A]	T	2.19 ± 0.37	2.09 ± 0.36	n.s.
	UT	89.2	88.3	
Weaning rate (%)[A]	T	1.52 ± 0.29	1.44 ± 0.29	n.s.
	UT	81.5	80.2	

[A]Per cow exposed to bull through natural service or artificial insemination.
n.s., not significant at $P \geq 0.05$.

Table 2. Least squares means (± standard errors) for maternal productivity traits of cows divergently selected for residual feed intake (RFI)

	Selection line		
Trait	Low RFI	High RFI	Signif.
Number of cows exposed to bull[A]	222	247	
Calving day[B]	215 ± 2	210 ± 1	$P = 0.07$
Milk yield[A] (kg/day)	7.5 ± 0.3	7.8 ± 0.3	n.s.
Wt of calf born per cow exposed (kg)	33.6 ± 1.1	31.8 ± 1.0	n.s.
Wt of calf weaned per cow exposed (kg)	191.3 ± 8.4	198.4 ± 7.7	n.s.

[A]Through natural service or artificial insemination. The number measured for milk yield, were 56 and 66 for Low and High RFI cows, respectively.
[B]January 1 = Day 1 each calving year.
n.s., not significant at $P \geq 0.05$.

Deconstructing feed intake

Wayne Pitchford, Director, Davies Livestock Research Centre, University of Adelaide SA 5371

Presenter Biography

Wayne completed Agricultural Science at Adelaide Uni, PhD at UNSW and has been teaching Agricultural, Animal and Veterinary Science students at Adelaide since 1992. He has been involved in the Beef, Sheep and Pork CRCs. In November 2019 he became Director of the Davies Livestock Research Centre. His work has focused on genetics of feed efficiency, maternal productivity and meat quality. He has a farm at Keith which is run in partnership with his son.

I may be a bit slow, but I feel like I have been on a long journey that has gone full circle that with the benefit of hind sight, could have been a much shorter journey and, therefore, more efficient.

In the period 1989-92, I was doing my PhD. I was enrolled through University of New South Wales with John James as my primary supervisor. I was based at CSIRO Division of Animal Production at Prospect in Western Sydney and was given the opportunity to analyse a large sheep crossbreeding project that was well designed by former employee T-S Chang. I started my PhD on 3rd April and my CSIRO supervisor, Ian Franklin, said "You've got 3-4 years, go and see Rod Evans to get access to the data, off you go". So my PhD journey began.

I realised the number of live weight and other measurements was overwhelming and so decided to fit growth curves to the data to summarise growth with the minimal number of parameters as possible. I modified a parameterisation of the Gompertz curve that was fixed through birth weight and then had just two parameters to describe growth, mature (asymptotic) weight (A, kg) and rate of maturity (k, days^{-1}) fitted to each ewe. I found that the effect of heterosis was to increase mature weight by approximately 10% but with minimal impact on rate of maturity (Pitchford 1993).

I thought it would be good to test whether this would also apply in cattle and so asked Roger Barlow and Helen Hearnshaw at NSW DPI Grafton whether they would be willing to let me analyse their *Bos indicus* content evaluation trial data in the same way. This trial comprised purebred Hereford, Brahman cross and both Hereford and Brahman backcross. One of the great things about this trial was that it was designed to evaluate genotype by environment interaction effects. This was done by raising the cattle on Low, Medium or High quality pasture. I fitted the same growth curve to all the cows and then estimated the genetic effects. Indeed, on High quality pasture there was large heterosis for mature weight (21%) and not for rate of maturity (Pitchford *et al.* 1993), the same result as for sheep. However, on Medium quality pasture there was less heterosis (13%) and negligible (1%) on Low quality pasture. I hypothesised that the effect of heterosis must be due to increased appetite rather than improved efficiency *per se*. The implications are that heterosis is expressed only when that greater appetite was satisfied. I returned to the sheep data set and, as expected, heterosis effects were greater in lambs raised as singles than twins (unpublished but QED!).

There weren't many PhD students at CSIRO, but one who was there was Peter Speck. He was working with Peter Wynn, Robert Herd and Hutton Oddy (NSW DPI Glenfield) on the Trangie Weaning Weight lines selected for either High or Low weight with the aim of examining correlated genetic changes and understanding biological mechanisms of growth (Herd *et al.* 1993, Oddy *et al.* 1995). They found very few differences in partial efficiencies of metabolism but came to the grand conclusion that Hutton

Feed Efficiency – Insights from Whole-farm Modelling

John Young, Manager, Farming Systems Analysis Service, Denmark Western Australia

Presenter biography

John works as a livestock farming systems modeler focusing on feed allocation within the flock and the impact on profitability. He is involved in the GEPEP (Genetic Evaluation, Productivity, Efficiency and Profitability) project that is evaluating productivity, intake and energetics of wether teams as an add-on to the Merino Lifetime Productivity project.

Objectives of the presentation

- To quantify the potential of research in efficiency to increase farm profit
- Examine novel concepts that provide focus to maximizing value
    - The difference between maintenance requirement and appetite drives system efficiency
    - The effect is through feed quality and pasture utilization

Summary of presentation

This talk is prepared from insights gained from whole-farm modelling carried out as part of projects that have been examining traits related to feed utilisation (SRLE project: Selecting Sheep for a Resource Limiting Environment ON-00364, GEPEP project: Genetic Evaluation, Productivity, Efficiency and Profitability ON-00521).

The main focus is around the genetic improvement of efficiency rather than improvements through management although as observed by Andrew Kennedy in his PhD it is necessary to evaluate improved genetics in the system that is best for that improved genotype, so both management and genotype must be considered together.

Definitions

In general terms increasing efficiency is "producing more product with less inputs". The type of efficiency being examined determines the 'product' and the 'inputs'. In a sheep enterprise we would simplistically think that the products are wool & meat. However, we also need to think of the quality because a kg of 35µ wool is not equivalent to a kg of 19µ wool , a kg of mutton is not equivalent to a kg of lamb, and a kg of fat is not equivalent to a kg of muscle. This is the National Feed Intake workshop, so the main input is feed.

The consideration of the system boundaries and the awareness of the range of products indicates that there are likely to be a range of different definitions for feed efficiency. For this paper:

- feed efficiency, the quantity of product produced by a specific class of animal per unit of feed consumed, when measured over a short time frame (weeks). With this definition there is an efficiency for each product eg wool or LW (RFI is a metric of LW efficiency).
- energetic efficiency, the amount of energy stored per unit of feed consumed. Energy stored is the difference between energy intake and energy required for maintenance, multiplied by the efficiency of storage. The metric that has been adopted for the amount of energy stored is whole body energy (WBE) and high wholebody energy is associated with high wholebody fat.
- system efficiency for an extensive production system, the value of products produced by the whole flock per unit of feed available for consumption (which could be thought of as per hectare of pasture if production technology is fixed) measured over an entire production cycle (a year or a lifecycle).

Breeding for feed efficiency in sheep

Daniel Brown, Beth Paganoni, Julius van der Werf and Gus Rose

Presenter Biography

Daniel is Principal Scientist at the Animal Genetics and Breeding Unit in Armidale. For the last 20 years, Daniel has been responsible for the routine estimation of Australian Sheep Breeding Values for Sheep Genetics to deliver to ram breeders, as well as the ongoing research and development of the genetic evaluation system. Daniel is also a program leader for the Advanced Livestock Measurement Technologies project, aiming to develop objective measurement technologies to collect lean meat yield and eating quality data from commercial supply chains.

Objectives of the presentation

We assume most of the key aspects of the work on feed intake and feed efficiency has already been covered by the previous presenters.

Thus, this presentation will focus on the R&D required to implement a system to direct more selection emphasis toward feed efficiency in a balanced breeding objective. In doing so we will highlight the research gaps that currently exist.

Introduction

The amount of feed that a sheep consumes to maintain, produce and reproduce constitutes the largest cost in a livestock system. Improving feed efficiency in sheep therefore represents a great opportunity for sheep producers to improve profit. This can be thought about at the individual level or system/enterprise level. Breeding for feed efficiency is an attractive long-term strategy to lower costs cumulatively over time due to its permanent cumulative nature. Intensive animal industries have successfully improved feed efficiency through breeding. For genetic improvement of efficiency to be successful in extensive (in species) industries, feed efficiency traits need to be heritable with genetic variation within the population.

Until now in extensive industries genetic improvement has focused on production with little emphasis on feed efficiency. It could also be thought that they have had little focus on true cost of feed also and it could actually be possible that feed cost is more important than feed efficiency.

This selection for production may have indirectly improved feed efficiency when animals are managed with a similar amount of feed resources available over time. It is thought by most feed efficiency in both the growth and maternal phases has improved due to faster, leaner and more muscled growth, and through improved reproduction rate under basically the same production conditions. Furthermore, the extra feed costs of higher weights of animals resulting from selection have been accounted for in breeding objectives, although the approach used could be reviewed.

Trait definitions

Feed efficiency in sheep - a New Zealand perspective

Tricia Johnson

Animal Genomics, AgResearch Invermay, Puddle Alley, Mosgiel, New Zealand

Presenter Biography

Tricia is senior scientist in the AgResearch Animal Genomics team, focusing on the phenotypes that are used in genetic evaluations for the New Zealand sheep industry. Specializing in phenotypes that fall in to the "hard to measure" category, including meat yield, meat quality, facial eczema and more recently feed efficiency and the use of GPS and accelerometers to capture novel data explaining grazing behavior and movement. Tricia's research career has been undertaken with interactions with industry breeders, commercial farrmers and meat companies which provides a real world context to her research.

Objective

The purpose of this discussion document and associated presentation is to provide an overview of the feed efficiency research that has been undertaken in sheep in New Zealand (NZ) over the last decade; primarily key findings but also the questions that remain.

Background

Feed efficiency was identified as a trait of significant economic importance to the NZ sheep industry in the Beef + Lamb New Zealand Genetics trait priority analysis. Not only does it have a direct cost, but it is also considered to be an important sustainability trait as New Zealand's environmental focus on farming increases. In New Zealand, feed efficiency research with a genetics emphasis was historically limited to dairy cow trials that were undertaken by DairyNZ and Livestock Improvement Corporation (LIC). From 2015, funding has been obtained by Beef + Lamb New Zealand Genetics and the Pastoral Greenhouse Gas Research Consortia with support from AgResearch to undertake research to investigate genetic variability in feed efficiency in New Zealand maternal sheep breeds. While the holy grail for feed efficiency research in pasture grazing animals is to measure intake at pasture, there continue to be no proven methods for estimating intake (discussed later in the document). As an alternative, an indoor feed intake facility was established, and custom-built feeders were manufactured by the AgResearch Engineering team to enable measurement of feed intake. Twenty feeders were commissioned capable of feeding up to a total of 200 animals.

Research undertaken

Recent research aimed to provide data on approximately 1000 individuals from which genetic parameters could be estimated. Data were collected on seven cohorts of ewe lambs approximately 7-9 months old over three years. The ewe lambs used were of New Zealand maternal genetics sourced from one of three genetically linked sources: the Beef + Lamb New Zealand Genetics Central Progeny Test (n=400) described by McLean et al. (2006), the AgResearch Research flock (n=408) and the Greenhouse Gas selection lines (n=192) (Pinares-Patiño et al. 2013).

When the ewe lambs were introduced to the facility they were allowed fourteen days to adjust, with the test period following immediately for a period of 42 days. Daily intake was recorded, and live

Adult efficiency: whole body energy and other components.

Sarah Blumer, Research Officers, Murdoch University, Perth Western Australia

Presenter Biography

Sarah Blumer works as a research officer at Murdoch University based in Perth, Western Australia. Her PhD work examined the mitigation of liveweight loss in adult ewes during summer and autumn in Mediterranean farming climates. Current research work includes: Managing Mums with Multiples, Lifetime Maternals, and the Merino Lifetime Productivity value add project - Genetic Evaluation: Productivity, Efficiency & Profitability (GEPEP). Sarah's main areas of interest are composition, feed efficiency and the value of fat in the adult ewe flock, and translating experimental results to value in the field. Sarah has 10 years experience in production research following completion of a masters in Meat Science from Bristol University.

When animals from different genotypes or sires have been run together they have different body composition or levels of fatness and productivity, which indicates variation between genotypes or sire groups in their ability to utilise the feed resource and/or partition fat and protein. For example, some sire groups from the Merino Lifetime Productivity project at the Pingelly site are 0.5 to 0.7 of a condition score fatter than other sire groups at the end of spring. Adult animals that are fatter can either be fed less supplementary grain in subsequent feed shortages or more animals could have been carried on the same pasture. The "Selection in a Resource Limiting Environment" project (AWI - ON364) Final Report shows that optimum stocking rate and level of grain feeding has a tight relationship with change in whole body energy stores and feed intake. The profit equations developed by AWI-ON364 quantify these differences in optimum stocking rate and level of grain feeding based on feed intake and differences in body energy stores. Therefore, having measurements of feed intake and body composition for sire groups from the Merino Lifetime Productivity project could greatly improve the estimation of their potential profit per hectare, and determine if there is any re-ranking of sires based on production per head and estimated profit per hectare.

Previous work has demonstrated that whole body fatness contributes significantly to models describing feed efficiency so that adult ewes with a higher proportion of body fatness had a lower requirement for feed to maintain liveweight (Blumer et al., 2016). Earlier work by (Knott et al., 2008) showed that while fat was not significant in their work, including it in feed efficiency models meant that additional variation in intake could be explained. These authors suggested that including measurements of composition would more accurately reflect biological efficiency. Lean tissue is largely water and has a lower energy content when compared to a similar weight of fat tissue. By mass, fat tissue is more energy costly to deposit however is also of higher value to the animal when nutrition is limiting. Additionally, fat tissue has a low maintenance cost in relation to lean tissue (protein) which is in a constant state of degradation and replacement (Toyama and Hetzer, 2013). The composition of liveweight gain differs with maturity, level of body stores, and between breeds. Work by Blumer and Thompson (2018, AWI: ON-00439) showed that at the same level of liveweight gain, the energy gained was significantly different between two divergent Merino bloodlines due to one line gaining a higher proportion of fat tissue (measured using computer tomography – CT). However, using RFI to compare these bloodlines would not result in differences of interest as intake and liveweight change were not significantly different for the two lines, although one line deposited significantly more energy at the same level of intake.

Therefore, using liveweight change to compare efficiency particularly in adult animals is likely to discriminate against individuals that deposit more liveweight as fat tissue, as they could be observed to consume more feed energy while gaining less weight. More precise measurement of energy intake and deposition (or use) could provide more accurate understanding of differences in how genotypes