



DAIRY RESEARCH FOUNDATION

CURRENT TOPICS IN DAIRY PRODUCTION

VOLUME 21

2016

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Welcome to the Dairy Research Foundation 2016 Symposium

This year we've taken the Dairy Research Foundation Symposium to the Riverina in southern NSW!

The extremely positive response to the Symposium visiting different dairying regions of NSW has brought about the decision to make this a more regular occurrence.

We are excited to see the NSW dairy industries come together once again to hold their meetings in line with the Symposium. We welcome the collaboration of NSW Farmers, Dairy Connect and Dairy NSW whom are all staging meetings over the duration of the event.

For 2016 we have a brilliant line-up of speakers, headed by Professor Russ Hovey from the University of California, Davis. Russ is an expert in lactation physiology. He will present on Symposium Day and will be doing something a little bit out of the ordinary on Farm Day!

Farm Day will take us to Millwood Farm, Currawarna. Glen and Andrea Jolliffe will host the day and explain their mixed (cropping and dairy) farming operation.

In keeping with tradition, the real focus of the Farm Day will be our Emerging Scientists - the best and brightest of our next generation researchers. Bring your voting hats as they vie for first place in the 2016 DRF Emerging Scientist Award.

We trust that you will join us again in 2016 as we have planned a program that will not only excite you about the future but will also give you some tools to take home and implement on your own operations.

We look forward to welcoming you to Wagga Wagga in June.



Dairy Research Foundation 2016 Symposium

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The Emerging Dairy Scientists' Program

The Dairy Research Foundation is pleased to showcase the talents of Australia's emerging dairy scientists at the 2016 event.

Their presentations are the focus of our Field Day program and all have been paired with a senior consultant or scientist to create a highly interactive series of discussions.

The intent behind this encounter is to offer an opportunity for professional development for these emerging scientists.

Here we introduce them to and assimilate them with our industry. The program is in the form of a competition, where we ask you, the audience, to assess the quality, relevance and interest of each presentation – with the audience scores combined to determine a winner. This is announced at the conclusion of the Field Day.

The program clearly identifies those competing in the Emerging Scientists' Program – and we encourage your full participation which will do much towards encouraging our next generation of dairy scientists.

Dairy Research Foundation 2016 Symposium Sponsors

The Dairy Research Foundation would like to acknowledge and sincerely thank the following organisations and companies for their support.

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Managing and manipulating the mammary glands for more, and modified milk

Russ Hovey

Department of Animal Science, University of California, Davis

A cow's udder is arguably the most valuable asset on a dairy. While it brings in a great deal of revenue, it also takes considerable time and inputs to develop, and can be expensive to maintain. They can be finicky at any time, and breakdowns can be costly. This presentation will review the various factors that influence optimal mammary gland development and function, and the potential for future 'new model' releases.

Windows of sensitivity – A lifetime of consequences

The udders of high-producing dairy cows produce impressive volumes of milk across the planet and help feed the world. Because heifers are not born well-endowed, they must develop this organ to the point it is amassed with specialized epithelial cells prior to calving. Ironically, a lot of what we have come to learn about this organ – the mammary glands in all mammals – aligns with our goal as humans of understanding a woman's risk of developing breast cancer. And what has become clear from that field is that there are phases, or 'windows', during a lifetime, that are more sensitive to changes and adverse exposures that can change the chance of developing breast cancer over a lifetime. The questions that stem from these types of findings include how do these changes affect development of the normal mammary gland and what it does?, how can this type of information be applied to dairy management decisions?, and what potential exists into the future to transform how we harvest, process and market milk?

Windows of change - First, maybe it was all mum's fault

The mammary glands of females are unique among various organs in the body in that they mostly develop after birth. However, they first start to form in the unborn female and male fetus, where cells in the skin become specialized epithelial cells that burrow and grow into the underlying tissues that become the fatty part of the udder after birth. A number of insights suggest that this period may be more critical for how the mammary glands function through the rest of the female's life than first thought. And there may be a diversity of factors that can affect this stage. For example, evidence from studies in biomedical animal models have highlighted that environmental chemicals such as certain pesticides and the widely-used plastics additive bisphenol-A can act to mimic estrogens in the circulation, serving as 'environmental estrogens' to stimulate premature mammary gland development. Meanwhile, it is during this period of life that the developing mammary glands in some species are extremely sensitive to testosterone, either in the case of sexually-dimorphic suppression of mammary growth in males, or through effects of brothers on the mammary glands of sisters in litter-bearing species. While information regarding any impacts of fetal life on udder development in heifers is lacking, studies in sheep have highlighted that even a dam's nutritional status can impact the future lactation potential of her progeny (Paten *et al.*, 2013), suggesting that careful nutritional management of pregnant heifers and cows may also have long-term consequences for the herd's next generation.

Windows of change - Those awkward pre-teen and teen years

Raising dairy heifers to the point of their first lactation comes at a significant cost, even before she yields any milk yield return. Yet more and more it is recognized that the prepubertal window before, during, and after weaning has the potential to influence a female's lactational capacity later in life. As females approach puberty, activation of the reproductive axis increases the synthesis of estrogens from the ovaries, stimulating growth of epithelial cells within the mammary glands at a rate that is faster than growth of the rest of the body, commonly referred to as 'allometric growth'. At the same time, females destined to enter the herd should also be growing at a maximal rate in preparedness for mating. Over the years considerable attention has been given to the importance of ensuring that heifers do not experience growth that is too rapid for fear of them developing 'fatty udders', a phenomenon that may well be a function of past genetics as well as the fact that animals were reaching puberty earlier. In turn, these findings regarding the growth potential of heifers has raised important insights to suggest that heifers should receive a diet that is more energy-dense than would have historically been considered appropriate (Soberon and Van Amburgh, 2013).

The effect of diet on the developing udder may be more complex than generally appreciated. One question we have been investigating is whether different components of the diet can influence how the mammary glands might grow during early life – an approach that, for convenience reasons, starts in mice. The strategy includes removing the ovaries to halt any development of the epithelial tissue that might otherwise occur, then feeding mice different ingredients before studying how the epithelial cells respond. Similar type of questions can be asked in male mice that lack ovarian estrogen and normally don't develop their mammary glands.

Ruminants such as cows and sheep are unique in that they synthesize different forms of fatty acids due to fermentation of dietary unsaturated fats within the rumen that can also go on to modify the yield of milk fat. Isomers of these fatty acids, the 'conjugated linoleic acids' (CLA) are found in milk and meat, and have been investigated for their potential anti-cancer and weight-loss properties. Perhaps not surprisingly, one can also readily find these CLA supplements in health food stores. One question we posed is whether these CLA can affect how the mammary glands grow by feeding these CLA to male mice and female mice lacking their ovaries (Berryhill *et al.*, 2012). Dogma would have it that only estrogen can make the mammary glands grow during this window of life. Fascinatingly, that turned out to not be the case – when either male or ovariectomized female mice were fed the 10,12 form of these CLA their mammary glands started to develop normally, without any requirement for estrogen to direct this response. The question then becomes 'what is driving the mammary glands to grow in the absence of normal estrogen signaling'? To answer this we have used the approach of RNA Sequencing 'transcriptomics' to define all the genetic pathways that are activated in the mammary glands when they are growing in response to estrogen or 10,12 CLA. The outcomes from these analyses suggest that diet might be a more important driver of mammary development during this period of life than first thought.

What has become clear from all different species, whether for normal development or even breast cancer risk, is that this window of life is critical for the long-term health and production potential of the mammary glands. The implications from these findings tie back to much of what we do, and don't, understand about udder growth in heifers. However, given there is an increasing trend toward the mating of heifers at an earlier and earlier age to increase their productive life, their careful and optimal management during the allometric growth phase is of prime importance.

Windows of change - The mother to be

Following mating, epithelial cells within the udder face new and complex challenges. Not only must they continue to grow, but they must also transition from being a growing cell to one that can take a host of essential ingredients and convert it to something as complex as milk, day in and day out. These cells must first arrange themselves into milk-secreting alveoli lined by a single layer of epithelial cells, which lie adjacent to a meshwork of capillaries through which blood flows to deliver water, nutrients and hormones, while removing metabolites. The growth that occurs within the udder during pregnancy is also sensitive to the environment – not just the cues from the outside world, but also the dam's own body and also from the fetus and placenta she carries. Hormones in the body drive much of this development – hormones such as placental lactogen produced by the placenta, prolactin produced by the pituitary gland, and estrogen and progesterone from the ovaries.

The change that epithelial cells must undergo to start making milk is no small feat. First, they must change their configuration to set up a production line of cellular machinery to transcribe their DNA into messenger RNA that then dictates the proteins to be made for either secretion into milk or for all the other processes that will facilitate milk synthesis. At the same time these cells will develop the ability to synthesize milk fats, and will secrete these into milk as droplets, or globules. And to keep things flowing these same cells will take vast amounts of glucose from the circulation, modify half into galactose, and then fuse that with one molecule of glucose to create a molecule of lactose that draws water into these cells. To top it off, these cells have all become precisely organized and positioned to ensure that milk only flows one way – into the gland – and cannot leak back into the female's bloodstream.

The questions that then arise are what is the importance of the different factors regulating these processes leading up to lactation?, and can they be manipulated positively or negatively to impact lactation success? Answers to these questions can be provided from experiments to remove, or other experiments to add back, these different factors. Of these, prolactin has perhaps the most imperative role of all; cows that have their prolactin secretion blocked prior to calving fail to initiate lactation at calving (Akers *et al.*, 1981). A similar situation exists in sows, where the suppression of serum prolactin just prior to farrowing reduces mammary gland development and abolishes milk production during the subsequent lactation (Farmer and Petitclerc, 2003). These findings are also significant in situations where cows and other species may be exposed to alkaloids produced on ergot-infected pastures such as fescue, which can lead to suppressed prolactin and lactation failure on top of suppressed reproduction.

Most recently we posed the converse question – can prolactin be elevated during late pregnancy with the goal of increasing milk production or shifting composition? Some of these experiments were performed in sows, using the drug domperidone to overcome the activation of dopamine receptors on the pituitary, with a goal of increasing serum prolactin levels (Vanklompenberg *et al.*, 2013). Drug treatment was applied during the prolactin-sensitive window during late gestation described above, which led to a transient increase in serum prolactin levels. Subsequently, sows went on to farrow and nurse normally; milk production and piglet growth was monitored weekly. During lactation, treated sows produced approximately 22% more milk without any change in the major components. We also sought to establish how this short treatment during pregnancy led to the sustained, increased milk yield throughout lactation.

One hypothesis was that increased prolactin during gestation increased the number of epithelial cells in the gland, which was assessed by taking serial biopsies of the udder during pregnancy and lactation and measuring cell growth. However, no difference was detected, pointing to the alternative possibility that pathways involved with milk synthesis had been enhanced by prolactin treatment during late pregnancy. Indeed, this turned out to be the case; whereas prolactin treatment ceased a week before

lactation, there were clear and pronounced carryover positive effects on the expression of all the various milk protein genes within the mammary glands throughout the rest of lactation.

The implications from these findings emphasize the importance of the gestation window in preparing the udder for optimal milk production. The example above from pigs serves as an illustration of several other situations where carryover effects from pregnancy can positively or negatively affect milk yield and production. For example, the amount of light, or photoperiod, during the dry period affects subsequent lactation performance, where shorter days increase milk yield, which has been attributed to changes in circulating prolactin (Crawford *et al.*, 2015). In a similar way, heat stress during the dry period has a pronounced negative carryover effect on the next lactation (Wolfenson *et al.*, 1988). Alternatively, ewes that carry twins or triplets produce increasingly more milk proportional to the level of placental lactogen produced by the placenta. Along the same lines, the results from a recent study suggest that dams carrying heifer calves go on to produce more milk than those carrying bulls (Hinde *et al.*, 2014), although this may merely be a function of sex-specific lactation length (Hess *et al.*, 2016).

Windows of change - Is lactation set in cement, or is it plastic?

A general assumption has been that the mammary gland is somehow 'fixed' with regard to the amount and type of milk it is destined to produce. Such a notion aligns with the idea that epithelial cells in the gland become 'terminally differentiated' at parturition as they acquire the ability to actively secrete milk, day in and day out. And certainly for the modern dairy cow milk composition remains relatively constant across her entire lactation. But is it this simple? And if there is plasticity, what examples exist, and what can we learn from, and capitalize on, to manipulate either yield or composition?

Over the years a variety of attempts have been made to identify ways to exogenously manipulate the mammary glands to increase yield. One clear and successful example of this strategy is recombinant bovine growth hormone, or bovine somatotropin (bST) that increases the efficiency by which epithelial cells extract nutrients from the cow's body for making milk. As a rule of thumb, bST elicits a relatively consistent production increase of ~10-15% without any impact on composition (St-Pierre *et al.*, 2014). From an environmental standpoint the effects of bST are desirable given it reduces the carbon footprint of milk production (Capper *et al.*, 2008). At the same time however, consumer acceptance of milk from bST-treated cows continues to decline in the US. Ironically, pST is approved for use in pigs in Australia whereas bST for use in cows is not, while the opposite is true in the United States. Similar, albeit less pronounced, increases in milk production have been achieved by increasing the length of photoperiod to which cows are exposed, which is potentially mediated by increased circulating levels of prolactin. An alternative strategy that has seen widespread adoption, particularly in confinement systems, is increased milking frequency to either 3x or 4x/day. Much of the increased yield response that this practice realizes is assumed to be through less negative feedback on the epithelial cells, thereby encouraging them to remain in a state of maximal secretion throughout the entire day. But does the lactating mammary gland have an inherent ability to locally control its own production or composition, and can this be programmed? Two convincing yet different examples below suggest this may be the case.

First, while 3x or 4x milking increases yield, it only occurs in the quarters milked more frequently, implying that this is a local response and is not occurring at the whole-body level. What is most noteworthy, however, is that if the increased milking frequency is only applied at the beginning of lactation, aspects of the production response persist throughout the entire lactation (Wall *et al.*, 2013). Not only does this represent an opportunity for producers to improve milk yield while restricting management inputs, but suggests a mechanism similar to that outlined above for pregnant sows treated with prolactin during pregnancy.

A second insight into how milk production can be regulated from within the mammary gland comes from non-dairy animals, and the strategy used by some of Australia's most iconic animals (Brennan *et al.*, 2007). Marsupials such as wallabies and kangaroos have the ability to raise two offspring at once – a tiny, hairless, underdeveloped pouch young that is permanently attached to a teat, and an older, developed and growing joey that can leave the pouch and maintain its own body temperature. The evolutionary challenge these animals have addressed is how to meet the dramatically different nutrient requirements of their offspring? These species have developed what is nothing short of a fascinating strategy referred to as 'concurrent asynchronous lactation' – their teats and associated mammary glands can produce two different volumes of milk, each with a dramatically different composition that matches the infant's needs. Taking this type of local regulation to another level, the Cape fur seal has a different, but equally-unique ability, where they are able to pause milk flow for weeks on end while the dam forages offshore before eventually returning to feed her pup on shore.

Combined, these findings point to a host of fascinating processes by which milk production is regulated at the local level of the mammary gland. While in some cases the mechanisms behind these changes remain to be defined, they raise the potential for numerous opportunities to manipulate milk yield, composition, and flow.

Looking out the window, into the future

Where do these types of information lead, and how can they benefit dairy producers? At the farm level there is an increasing appreciation that the seemingly (yet still costly) 'unproductive' phases of a cow's life – as a foetus, as an open or springing heifer, and as a dry cow – are more sensitive to management decisions than is perhaps often recognized, and the future lactating udder certainly becomes part of this equation. From a lactating cow management standpoint, interventions such as increased milking frequency for only the start of lactation have the potential to provide sustained gains from short-term investment. Meanwhile, in only the past decade or so there has been a dramatic uptick in the commercialization of 'designer' milks – whether that be specific harvesting of one specific beta-casein genotype, harvesting particular types of milk as they change with stage of lactation (ie colostrum), breed-specific markets, or environmental factors (ie. night-harvested or grass-fed milk). Then there is the horizon, on which lies a new and exploding potential to use highly-efficient 'gene-editing' technology to create designer animals without any other deleterious changes. For that product, ultimately the consumer will have to decide about a technology that is already here.

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05871 Mar 2016

Water use efficiency and productivity

Andrew Parkes

Customised Farm Management

Background

As mentioned in the introduction, I grew up just east of Wagga in Gundagai on a mixed farm that also irrigated cash crops such as sweet corn and sweet peas for Mountain Maid in Batlow. I received a Bachelor of Applied Science (Entomology) from Hawkesbury Ag College and started work as a trainee agronomist at Warren, west of Dubbo NSW, where I was again working with irrigation where crops such as soybeans corn and cotton dominated. Whilst at Warren, I also started to get involved with the irrigation of pastures on some of the merino sheep studs that proliferated in the area.

After a brief stint in Sydney, I finally arrived in Moree in 1990, where I still live today and where I managed a large irrigation property 'Keytah' (30,000 Ha's with over 10,000 Ha's of irrigation) for 13 years. I currently own a consultancy and farm management business that manages a variety of assets from Goondiwindi to the Western Districts of Victoria, with a relatively large 'hub' in the Riverina region. The current enterprises managed on the properties include irrigate crops under surface furrow irrigation, lateral move and centre pivots, as well as dry land cropping, cattle and sheep enterprises.

Preface

Due to my background being heavily related to irrigated cotton and other broad acre, or 'row' crops such as wheat, barley, corn, sorghum, etc., the question of how this relates to this dairy symposium is a fair and reasonable one! Noting that the topic for the symposium is 'Hunting Efficiency from the Inside Out', some of the work that I have led and introduced, has been driven by the need to become more efficient with our most precious and rare resource – water. Whilst there will be obvious differences between things such as water delivery, crops/pastures irrigated, environment, climate, etc., I believe there are also a number of basics and simple principals that can be adopted and, if adopted, will most definitely increase not only the efficiency of the water used but will also increase productivity.

The Need

The obvious initial question to ask is - 'How did the need to improve Water Use Efficiency (WUE) arise'.

The answer is quite simple, when we became aware that there was very little water available on allocation for the 2002-2003 season in the Gwydir Valley. For the first time (since taking on the management of 'Keytah' in 1997) we were forced to concentrate heavily on becoming more efficient with the water that was available in that year, as it had suddenly become our most limiting resource in terms of how many hectares of cotton could and, consequently, how much, if any profit could be returned.

To put this in real terms, the average area of cotton at 'Keytah' supported by the water entitlement held in the four years leading up to the 2002-3 season was an area of 6,650 hectares per year. In the 4 years including and following 2002-3 season (subsequently recognized as 'the millennium

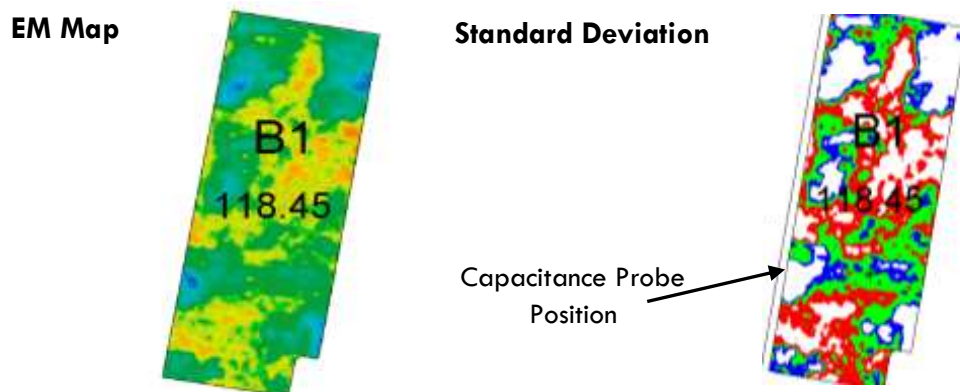
drought'), the average area of production was only 2,750 hectares, or 140% lower production based on area alone. There was only one limiting factor associated with this reduction – water availability!

What was done

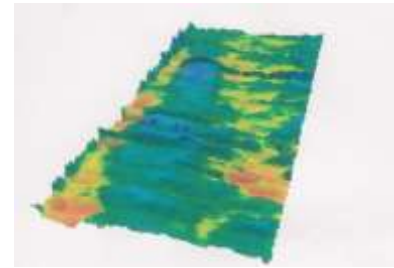
Firstly, budgeting focused more heavily on how many hectares of cotton could be grown with the amount of water available for the season. Using both our own figures and some other industry calculations, we believed that our average past water use was approximately 10 Megalitres of water per hectare to produce 10 Bales of cotton per hectare, or 1Bale/Megalitre. We believed we could improve this by 10 to 15% by improving certain aspects of our irrigation management and, therefore, budgeted for the number of hectares to be grown against a requirement of 8.5 Megalitres per hectare, rather than on 10Mls/Ha.

Management decisions then implemented in order to achieve this reduction in water use included:

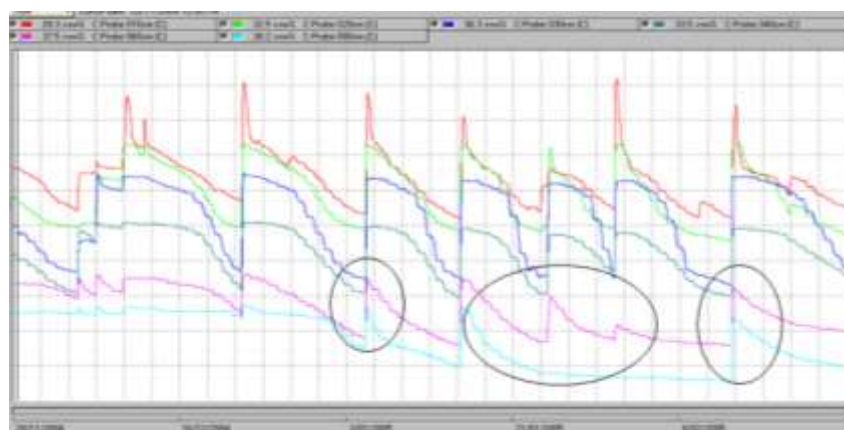
1. Positioning the crop around our most efficient water storage's to reduce both evaporation and transmission losses. In later years each on farm water storage was measured for its efficiency and ranked from best to worst.
2. Only using one water storage on each farm as a buffer rather than an area to store large volumes of water with most irrigation water being ordered as required from Copeten Dam, again to reduce evaporation.
3. Soil moisture measurement equipment (Capacitance Probes) was positioned in fields with much greater technical emphasis. To do this the following process was adopted:
 - a. EM38 maps were commissioned to provide an understanding of the overall moisture holding capacity of the soil types to be irrigated and how this moisture holding capacity varied spatially. (Refer Map below)
 - b. The EM38 maps were then manipulated to show the area of every field that related to 66% of the fields moisture holding capacity (soil type). (Refer Map below)
 - c. The capacitance probes were then positioned according to the 'median' soil moisture holding capacity of the field and, therefore, recorded water use with reference to the majority of the soil type in each field. (Refer Map Below)



4. The capacitance probes were then further referenced to an 'Error from Perfect Plane Map' downloaded from tractor GPS guidance systems. This ensured that probes were not accidentally positioned in a small depression or on a ridge and, therefore, providing false readings relating to the rest of the field, which could have negatively influenced the decision making process around irrigation scheduling. The example map to the right is one put into a three dimensional view to show the hills and depressions more obviously!

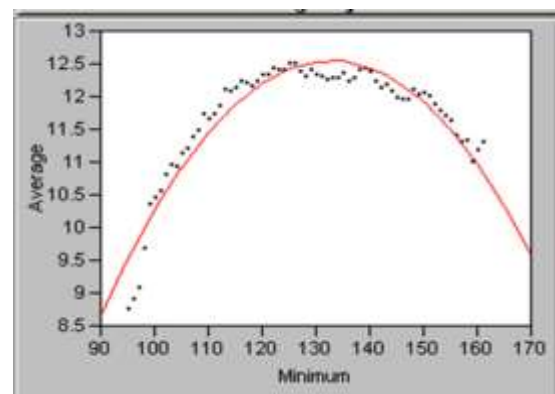
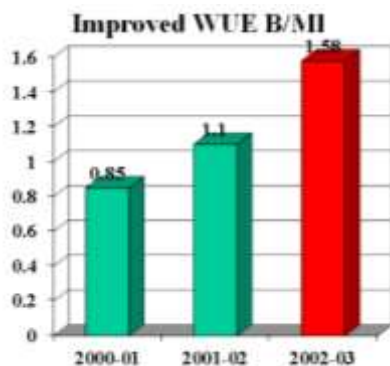


5. A better understanding of the irrigation application system was developed and considered in an attempt to recognize if anything could be done to improve water delivery by manipulating various aspects of the system. In a 'surface furrow irrigation system' it was recognized that water reached the end of the field at varying times. Why this occurred was analyzed and the 'evenness' of consequent irrigations was improved by adjusting the number and size of the irrigation siphons used as the 'water head' over the field varied.
6. By analyzing closely the previous measurements provided by capacitance probes, differences were recognized in how the crop 'reacted' to irrigation applications using one siphon per furrow versus two siphons per furrow. These records and analysis clearly identified the double siphon applications, where the time taken to irrigate was reduced, also reduced the effect on the crop from water logging. Some areas where single siphons were used took up to 7 days to fully recover from an irrigation event and to start using moisture again. The double siphon areas started using some moisture after only two days and reached peak moisture use after 5 days. So a 'water on and water off' approach was adopted with particular emphasis provided to increasing the water flow across the fields and to stop the irrigation as soon as possible.
7. Once the season began, the capacitance probes provided information to a central server based web site every 15 minutes, essentially providing real time data crop water use. (Refer graph below). Due to this information being provided this consistently a decision was made to not use 'fixed deficits or refill points' but to use the information the probes provided to warn when the crop was approaching a potential irrigation. When this point was reached many hours were then spent walking in and out of fields 'ground truthing' the information and trying to delay each irrigation until there were physical signs being provided by the plants themselves that they were showing the effects of a lack of water. This process was reflected on the capacitance probe graphs, showing the crop root systems working deeper into the profile between each irrigation (Refer graph below). It was presumed that the crop didn't only access additional moisture at this level but also accessed nutrition and, importantly, oxygen that it could utilize during the irrigation process itself whilst water was inundating the balance of the profile.



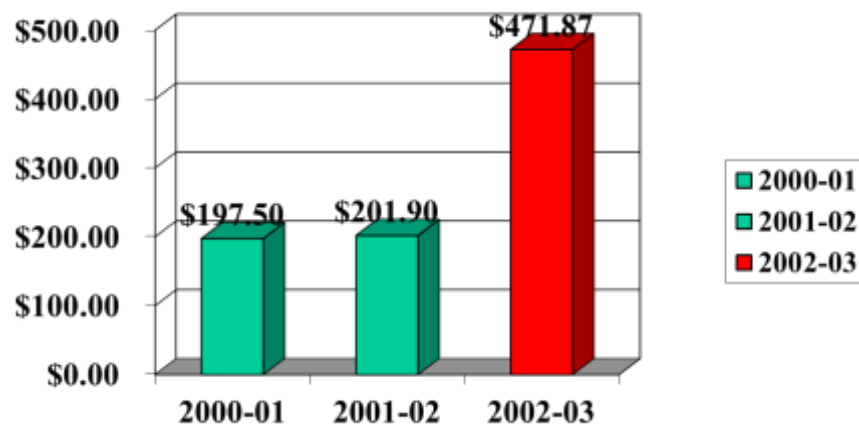
Results that were achieved!

1. The initial aim was to reduce the water required per hectare from 10Mls/Ha to 8.5Mls/Ha and to grow 10Bales of cotton per hectare with that water. The following are the headline achievements:
 - a. The crop was grown with 7.1 megalitres per hectare instead of the usual 10 megalitres per hectare.
 - b. 2.9 megalitres per hectare were saved compared to 'normal' water use (or almost 30%).
 - c. 1.4 megalitres per hectare were saved over and above the initial target saving of 8.5Mls/Ha
 - d. The previous three year average production figure for the property was 10.1 Bales per hectare, yet the 2002-2003 crop average was 12.43 Bales per hectare, an increase of 2.33 Bales per hectare or more than 20% of additional yield. This yield increase and achievement was further underscored and emphasized by the comparison to the entire Gwydir valley in the same year, which was 8.53 Bales per hectare or more than 45% increase over the valley average.
 - e. This all converted into a WUE calculation that went from a previous average of 1 Bale per megalitre to 1.58 Bales per megalitres or an increase of almost 60%. (Refer Graph below)
 - f. In an attempt to verify definitively whether the management changes made were reflected in the outcome in some way, it was decided that a graph or map of yield by EM38 measurement would provide an understanding of how well the crop was irrigated. The graph below shows that there was an exceptional correlation between EM38 readings (X axis) and yield (Y axis). This suggests that the lower moisture holding capacity areas of soil within the field, as measured by EM38, had lower yield and that this could be presumed to have occurred due to these areas not receiving enough water in between irrigations. Conversely, the areas of high moisture holding capacity, also had lower yield which can be assumed to be due to receiving too much irrigation and, therefore, being affected by waterlogging. The graph clearly shows, however, that the median moisture holding capacity soils were the highest yielding areas of the field, presumably due to being irrigated as effectively as possible for the season and crop, as was intended from the start.



2. A bonus that occurred, but which was never expected (and anecdotally only!) was that we grew more cotton per hectare because we used less water. With marketing removed as a variable, the calculation was made that showed the net return per MI of water increased from approximately \$200/MI to over \$470/MI (Refer Graph below), which is a 143% increase.

Initially, this didn't seem to add up, given that WUE only increased by 60%, it seemed difficult to understand how the net return could increase by 143%. As mentioned above, however, anecdotally it was accepted that additional yield was provided in this particular season by not only the season but also because the crop was able to function more effectively throughout its growing period because it was irrigated more closely to its actual requirement. Ultimately, it is hard to know how much the season contributed to this additional yield and how much was due to the better irrigation scheduling and delivery but a conservative estimate suggested that at least 50% of the additional yield seen was due to the new management practices applied.

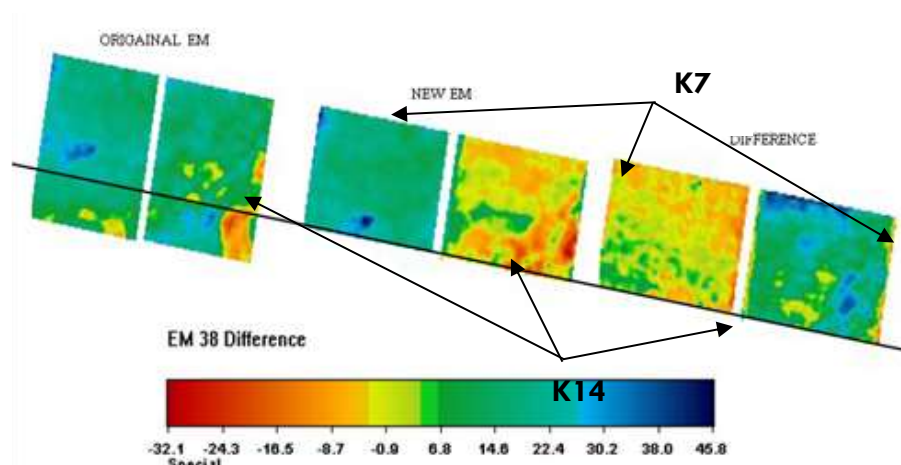


What further improvements are possible?

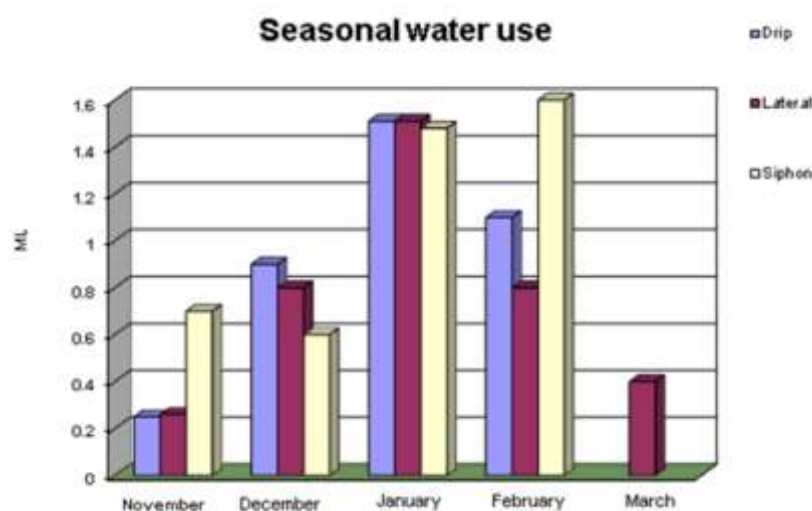
Additional work done with EM38 surveys have allowed us to recognize moisture retention differences that the 'farming system' itself can be responsible for!

The following series of EM38 maps shows the difference in soil moisture captured in two fields geographically identical, with the same soil type and same cropping history. Following a rainfall event that occurred after K7 was tilled but prior to K14 receiving the same treatment, a second EM38 assessment was run to measure the difference in soil moisture and this is shown in the 'difference map and scale' below, which highlights a difference of approximately 30% more moisture being registered in K14 when compared to K7.

This shows the definitive moisture loss that can occur due to tillage practices. Following this understanding, the entire irrigation farming system at 'Keytah' was altered to incorporate a minimum till approach to irrigated agriculture, as had been incorporated into dry land farming systems in the same region decades before.



Another interesting large scale trial was also developed on 'Keytah' which looked at the WUE of different irrigation application systems for cotton production. The trial included large scale comparisons of surface furrow irrigation, bankless channel irrigation, lateral move (overhead) irrigation and drip irrigation systems. This trial was partly funded by the National Water Initiative and still continues today in its 6th year of operating. What was surprising after the results of this trial were established is reflected in the graph of water applied below. Despite much publicity associated with both overhead and drip irrigation systems being more efficient than surface furrow (flood) irrigation, this has not been seen to be the case in the data below or across the entire trial to date. Clearly, a surface furrow irrigation system can be as efficient as either an overhead or drip system if it is 'maximized' for efficiency. If pressurization costs are included for the drip and overhead systems, the net return per hectare from the crops produced is actually less than for the surface furrow.



Rainfall	Syphon	Drip	Lateral
Total in season rain (ML/ha)	3.05	3.05	3.05
Seasonal water use (total) ML/ha	9.5	8.8	8.46
Gross Production Water Use Index (Total) Bales/ ML	1.27	1.3	1.28

SO - How do we practically link this to a use in dairy?

Calculate how much a megalitre of water returns you in profit. For cotton, I know this to be between \$200-\$400/ML. You then know how much each Megalitre saved is worth and can consider the cost of investing into WUE generating equipment, such as EM surveys, capacitance probes, software, etc. Be prepared for a shock – as it is not as expensive as you think. If your profit is \$400/ML, you only need to save 50MLs to pay back a \$20,000 investment in year 1!

Don't wait for the next millennium drought to 'trigger' the need to become more efficient with water. Government regulation has brought us the Murray Darling Basin Plan and, despite the massive volume

of water recovered; do not fall into the trap of thinking that once this claw back of water is completed that more won't follow! Add to the two certainties in life (death and taxes) that consumptive water in Australia will always be an issue!

Consider the probability that crops and pastures are most likely being over watered and that over watering is as detrimental, if not more so, to growth than under watering! We think we are doing the right thing but may be restricting growth by a lot more than we imagine.

No matter how much you think your soil is consistent across a spatial scale – it isn't, even if it all looks the same! The moisture holding capacity will vary so – when you go to irrigate a crop or pasture, where do you best measure the moisture extraction and how do you schedule the impending irrigation in terms of volume and timing, given the spatial scale variability? If you do not already have one, get an EM of one field (cost \$12/Ha) and understand how variable the moisture holding capacity of that field is!

If you can't measure you can't manage! Not measuring how much water you need and use today is like not measuring how much fertilizer you need or are applying! Buy, or lease a capacitance probe, position it according to the moisture holding capacity of your soil and schedule irrigation requirements from it. Try and compare this with how it is done today and measure the difference.

Consider that the management changes made above were all done in the one year, the cost of applying the changes was minimal and that the result was a 60% improvement in WUE! What would half of that mean to your business?

Soil moisture monitoring – When does irrigation technology increase pasture productivity?

David O'Donnell

South East Local Land Services, Bega

Fully irrigated dairy pastures have a relatively high annual water requirement of six to eight megalitres per hectare. These high volumes of water purchased and pumped makes the profitability of dairy irrigation sensitive to the input costs of energy, labour and water pricing. A key to maximizing productivity from irrigation is to utilize some form of management tool to better time irrigation and refine irrigation volumes – a term referred to as 'irrigation scheduling'.

Using soil moisture monitoring as a basis for irrigation scheduling is broadly recognized within the irrigation industry as the single most effective management change linked with improved irrigation efficiency. Soil moisture monitoring is common place in many Australian agricultural industries but not widely adopted in the dairy sector. The South Coast Water Use Efficiency program has supported landholders to install and utilize irrigation management tools and identifies in which situations the tools have been utilized and valued by irrigators and in which situations these tools just do not fit.

Environmental monitoring technology has rapidly evolved in the past decade. Soil moisture monitoring tools are becoming more affordable and simple to interpret.

Management tools are becoming increasingly relevant as more dairy irrigators manage 'modernized' irrigation systems enabling them to apply water evenly in the paddock and adjust irrigation volumes without large amounts of additional labor or farm management complication.

Soil moisture data for each site can be easily accessed on the web, with clear, simple irrigation targets and refill points that are easy to interpret.

Sophistication of soil moisture monitoring tools varies enormously with both ends of the cost spectrum being useful depending on the farmer's needs.

The South Coast Water Use Efficiency program demonstrates the use of two very different commercially available soil moisture monitoring systems; the more costly web based technology and the simplest display in the field. Both levels of technology utilise the same type of in ground sensor.

The program evaluates the relevance and benefit of soil moisture monitoring under the wide range of irrigation system types common to coastal dairy irrigation. The value of tools to better manage the earliest bike shift systems and the latest Centre Pivot and fixed sprinkler systems varies enormously.

Soil moisture content, and determining pasture irrigation requirement, can be measured in many ways. The CSIRO publication Insights into Irrigation is one of the more comprehensive reviews of commercially available soil moisture monitoring tools and the operating principals and limitations of each sensor type. The sensor type used across this program is the commercially available 'watermark sensor'. These are referred to as granular matrix sensors and measure soil moisture tension.

South Coast dairy Water Use Efficiency trial design

Eight relatively sophisticated soil moisture monitoring sites were established in September 2014. These sites continuously uploaded real time soil moisture data to the internet and can be accessed by land managers and farm advisors provided with website and login code. These monitoring systems are manufactured in Australia and a cost effective management option to improve water use efficiency in pasture irrigation. The sites have now been operational for 2 years and the technology has been demonstrated to be reliable, accurate and routinely used by the irrigation managers and farm advisors.

Sixteen sites have been established with a simpler soil moisture monitoring technology, based upon the same in ground sensor, but with a simple field display with no data storage or internet upload. These management tools ('G dots') are of minimal cost and ideal for daily management decisions at these 16 irrigated sites.

Five quite distinct irrigation system types are common to the coastal dairy industry, these being: Bike shift sprinklers, towable pods, travelling guns, fixed sprinklers and center pivot irrigation. Improved Water Use Efficiency management under all system types can be measured although there is much more capacity to refine scheduling under Centre Pivot and fixed sprinkler systems than the older bike shift and travelling gun irrigators.

Irrigation efficiency case studies

Centre pivot sites

Three continuously monitored web based sites were established under Centre Pivot irrigation. It is simple to alter the volume of water applied under center pivot irrigation by system speed adjustment. These irrigation systems can be started with the push of a button. The capacity to easily alter irrigation frequency and volume applied in each irrigation event makes improved soil moisture data extremely relevant to irrigation managers.

Fixed sprinkler irrigation is becoming increasingly common on dairy farms. Again, the fact that sprinklers can be managed in a block, started at the push of a button and irrigation volume easily adjusted makes refined irrigation management and soil moisture monitoring relevant to these irrigation managers.

The pivot and sprinkler irrigation sites are redeveloped irrigation sites at which significant financial investment has been made. These are the sites where landholders have a clear focus on making the most of the irrigation system they have invested heavily in.

There are obstacles to overcome with improving irrigation management under both bike shift and travelling gun systems. Bike shift requires six to nine manual sprinkler moves to water the irrigated area. This makes a management plan to dry the soil to a desired refill point and then rewetting at an ideal date fairly irrelevant as it may take a further 6 to 9 days to complete the irrigation cycle. When summer evaporative conditions begin to increase landholders with these systems basically do the best they can to keep up with pasture water demands.

Both bike shift and travelling gun irrigation inherently applies water with relatively low uniformity across the paddock. Poor field application uniformity makes it difficult to match ideal irrigation volumes with pasture water demands with much level of accuracy.

Conclusion

Irrigation management can be greatly improved by use of even the simplest soil moisture monitoring tools. The more sophisticated, continuous web based soil moisture monitoring systems enables the irrigation management program to be reviewed, planned remotely and easily shared between farm managers and advisors.

The soil moisture monitoring technology has no major limitations. Sensors installed in the soil are inexpensive and reliable and have the accuracy required to manage irrigated pastures under optimal growth conditions.

A fundamental aspect of improved pasture irrigation efficiency is ensuring that irrigation 'spring start up' is timely. One of the single greatest pasture irrigation inefficiencies is to delay starting irrigation when soils dry down in spring. Soil moisture monitoring data is valuable, irrespective of irrigation system type, as it reliably defines when soils have dried to the point where productivity is lost and spring growth set back. The monitoring systems at all project sites provide clear information to manage this spring irrigation start up optimally and maximize water use efficiency.

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Charlesworth P, Soil water monitoring, CSIRO publishing 2005

More from less - water use efficiency and productivity

Leigh Verhey (Skeeta)

Koondrook, Victoria

Brief History from the beginning to now

- Purchased original home farm in July 2005. Purchased 3 additional neighbouring properties in the following years
- Current landholding is 176ha irrigated border check gravity irrigation system within the Goulburn-Murray Irrigation area (Northern Victoria); along with an additional 120ha leased areas
- Open cut channels with Padman outlets – no pipes & risers (no pumping costs)
- 9 mag-flow meters service farm direct from backbone channels
- Full farm internal reuse system
- Irrigation season: 15th August – 15th May
- Water entitlement owned: 329mgs high reliability permanent allocation
- 142 mgs low reliability shares
- Water entitlement leased: 252mgs high reliability permanent allocation
- Total annual water use approximately 850-900 mgs – additional water sourced on the temporary market
- This current season milking 290 cows
- This coming season milking 350 cows
- 60/40 split for Spring & Autumn calving patterns

Growing more feed with less water

- Pasture based system predominately annual pastures (approx. 80% of the farm is annual based (March – October/November) with balance of both winter & summer active fescues (all year round)
- During summer months only irrigate Fescue areas
- Annual pastures receive 2 irrigations at start up (Late March/Mid April)
- Most cost effective feed for our business model is home grown fodder
- Last year (season 14/15) home grown feed= 1.3 tonne dry matter per megalitre of water used
- This year (season 15/16): on target for home grown feed= 1.7 tonne dry matter per megalitre of water used
- Targeted fertilizer use (phosphorous/nitrogen) based on soil samples
- 15/16 season temporary water price in Northern Victoria average \$260-\$280/mg
- On target to grow 1.7 tonne/megalitre:
- Temp water @ \$260/mg
- $\$260/1.7\text{tonne} = \$153/\text{tonne dry matter as grown on farm}$
- Take into account approx. 20% wastage as fed = $\$183 \text{ tonne/dry matter as fed (18\%-20\% protein)}$

- High quality protein sourced hay around (>20% protein) is outsourced to complement homegrown feed
- All decisions re fodder purchased are based around temporary water market – do we grow it or do we buy it in?
- Pasture plant varieties are chosen against climate & water availability
- Northern Victoria = hot, dry summer; mild spring & autumn
- Most efficient use of water (maximum growth/mg water) in our system is during autumn & Spring to grow relatively cheap feed.
- Silage harvested to capture true spring surplus and is fed back to the milking herd over the summer months.



Soil preparation with a multi-disk, a typical view of paddock towards the end of summer (February).



March – the start of the transformation – this will be unrecognizable in a few weeks.



Open cut channels with Padman outlets – having the channel bed 50-75 mm higher than the paddock gives a good fast flow onto the paddock.



Modernisation and new metering took us from the traditional 'death-ridgewheel' to 'mag-flow meters'.



We aim for residuals of 4-6 cm and pre-graze at 2.5-3 leaf stage for our ryegrass



All of our paddocks are generally sown within 2-3 weeks but this can make it a bit tricky to get on and graze all paddocks at the perfect stage – depending on the climatic conditions. This one got away from us a bit.



Who wouldn't be proud of this.....



Our business is a family affair. This oats/rye blend also got away from us a bit last spring. Tested out pretty well though and definatley made great dry cow feed - they still need good quality feed.



If we can't grow it viably we buy it. Unfortunately this ended up getting rained on and went from an estimated 1600 tonne to 400 tonne. It still tested out at 17% protein.

Using Herd Recording Data to Predict the Success of Transition Period in Fresh Calving Dairy Cows.

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Over the last two decades, Dairy Australia (DA) has developed and implemented several dairy cow health programs. These programs were developed through several avenues:

- InCalf (2004) – extensive data collection and analysis from dairy farms across Australia allowed critical determination of benchmark performance indicators to be primarily developed for improving conception and submission rates. Data was also captured to determine best practice in a number of secondary aspects of fertility including heifer management, artificial insemination, bull management, etc.
- Countdown Downunder (1998) – a DA program developed by the Australian Mastitis Advisory Council to improve milk quality (90% of all farms supplying milk with a cell count less than 250,000 cells/mL and 100% of farms less than 400,000 cells/mL). A key conclusion of the program was the importance of control of mastitis in the peri-calving period.
- Transition Cow Management (2010) – a research based review by DeGaris and Lean to develop best practice in the implementation of successful transition pre-calving feeding programs to reduce the of milk fever and other cow health incidence around calving, and to improve milk production and fertility.

In addition to this, many data collection and benchmarking surveys were completed. The most recent of these is the Dairy Farm Monitor Project which DA has rolled out in south-eastern states.

All of the above mentioned programs highlighted and measured the importance of the peri-calving (or transition) period in terms of milk production and cow health and through the Dairy Farm Monitor Project (DFMP), have highlighted the relative inefficiencies that still exist on dairy farms.

Throughout the evolution of DA programs there has been excellent and critical data collection. This data suggests that there are a number indices available to measure farm performance. This paper explores the data that is readily available on farm through periodic herd recording and other available 'on farm' tests and how it might be used to compare the individual farms performance to established benchmarks.

Herd Recording Data

Twelve dairy farms from the Hunter and Tamworth region participated in this pilot study. Farm data was downloaded from the MISDI files from Dairy Express. This data contained 1,252 cow records. A further subset of data was extracted from two dairy farms and contained 260 heifer records. This data was then manipulated so that information from the first test after calving was extracted.

Fat and Protein Yields

DeGaris and Lean (2010) determined that cow with a 'successful' transition produced 1.1kg milk fat and 1.0kg milk protein per day in the first 30 days after calving. The standard deviations for the fat and protein yields were approximately 0.05kg per day respectively.

Using the lower deviations of daily milk fat and protein, the criteria for determination of 'success' was cow producing $\geq 1.0\text{kg}$ fat and $\geq 0.9\text{kg}$ protein per day. Cow producing $< 1.0\text{kg}$ fat and $< 0.9\text{kg}$ protein were deemed 'unsuccessful' in their transition. Cows with either 'successful' fat or protein yields were classified as 'partly successful' in their transitions.

A model to determine this 'success of transition' is defined is the proportion of 'successful' cows plus a 50% loading of those 'partly successful' cows.

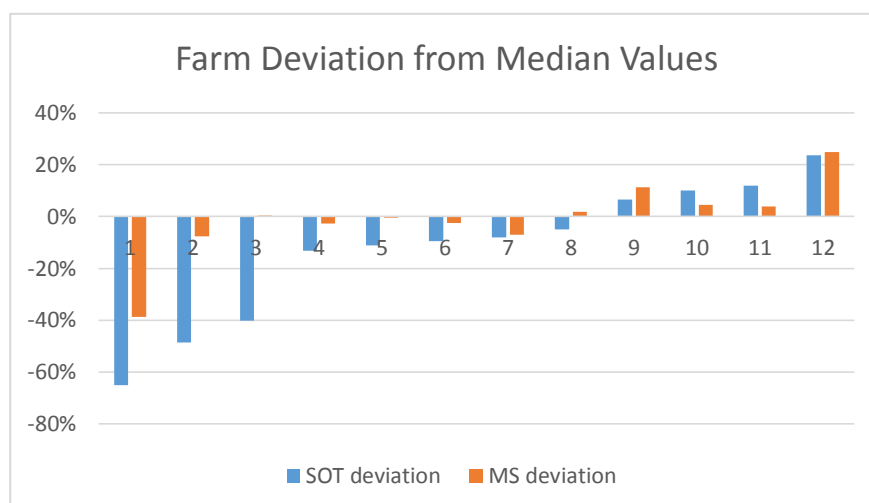
Results

An example of a herd is tabulated:

Number Milk (L) (SCC)	<1.0kg FAT	$\geq 1.0\text{kg}$ FAT	Herd 13 1 st Test Cows = 69
<0.9kg PROTEIN	9 21.9 (755)	17 25.3 (162)	Transition success 71%
$\geq 0.9\text{kg}$ PROTEIN	5 28.3 (171)	38 33.7 (79)	Herd FAT = 271kg Herd PROTEIN = 335kg Total MS = 606kg

Of the 12 herds included, the median herd milk solids (MS) was 580kg, compared to the DFMP average for northern NSW for 2015 of 477kg MS. The average success of transition (SOT) was 65%. The lowest yielding herd MS was 356kg and a SOT of 23%. The highest yielding herd MS was 724kg and a SOT of 80%.

This data was then compared to the herd milk fat plus protein yields (or milk solids) and ranked.



Somatic Cell Counts

Countdown 2020, through their economic modelling, has demonstrated financial benefits from reducing bulk milk cell counts (BMCC). Somatic cell count results from first test cows were also collated from the pilot study farms and tabulated:

(Number) SCC ('000)	<1.0kg FAT	>=1.0kg FAT
<0.9kg PROTEIN	(282) 419	(266) 290
>=0.9kg PROTEIN	(58) 380	(646) 202

Countdown 2020 Farm Guidelines for Mastitis Control (2014) used a step diagram to show the financial benefits for reducing cell counts. The increased income per cow per year is based on the herd reduction of BMCC in 50,000 cells/mL reductions.

Using this model, the reduction from 400,000 cells/mL to 350,000 cells/mL has a benefit of \$111 per cow. Similar reductions from 350,000 to 300,000 cells/mL (\$44 benefit), 300,000 to 250,000 cells/mL (\$63 benefit) and from 250,000 to 200,000 cells/mL (\$56 benefit).

If the SCC in transitioning cows continued through lactation, difference between the 'successful' and 'unsuccessful' transition cows would be 217,000. To extrapolate the financial benefits, this could be in excess of \$275 per cow between the groups.

Discussion

The idea of measuring the SOT has been developed from existing 'best practice' parameters previously developed by DA programs.

This pilot study has demonstrated that a value can be given to the performance of the first test (or 'fresh cows') performance in dairy herds, and that this value correlates to herd 305day MS performance. It is therefore demonstrated that a successful transition into lactation is important to establishing successful milk yields.

Secondary measures were also taken for first test somatic cell counts. It is known that mastitis (both clinical and sub-clinical) has peak prevalence in the first month after calving. Study data demonstrates that 'successful transition' cows have one-half the SCC of 'unsuccessful transition' cows.

Further consequences of 'unsuccessful transition' cows are being studied. These include the effects of poor transition on reproduction and other health parameters.

Influence of intensification on animal welfare: implications for dairy cow welfare

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Introduction

Public concerns and policy debates on livestock production generally centre on conditions that guarantee food security, public health, environmental quality, and animal welfare (Vanhonacker *et al.*, 2012). Public attention on animal welfare appears to arise from concerns about the negative effects of intensification of livestock production on animal welfare. In general, societal concerns dictate the need for animal welfare standards and animal welfare legislation. While all stakeholders along the livestock product chain acknowledge the importance of animal welfare, retailers and particularly supermarkets which control a large share of the livestock product market, often have a large influence on production practices and consumer purchasing behaviour (Vanhonacker and Verbeke, 2014).

Intensification of the Australian dairy industry with an increasing number of large herds appears to be a cause for some community concern for the welfare of dairy cows. The average Australian herd size has risen 37% over the past 10 years, with a significant increase in the proportion of farms with herds milking in excess of 300 cows from 17% in 2004 to 30% in 2013 (see Beggs, 2015). This paper will briefly review the literature on the influence of intensification of production including scale of production on animal welfare with particular reference to the implications for dairy cow welfare.

Ethical duty of care to the animals that we use

It is recognised that most of the animals that society uses can suffer. As argued by Mellor *et al.* (2009), in using these animals for our purposes we exercise varying degrees of control over the quality and duration of their lives, which provides us therefore with the opportunity to manage them humanely. Moreover using them for our own purposes, not theirs requires us to do so. Therefore we have an ethical 'duty of care' towards the animals in our control and this translates into a practical obligation to keep their welfare at acceptable levels.

Animal welfare and its assessment

Animal welfare is a state and it is generally agreed that animal welfare relates to experienced sensations, that is, how the animal feels. These experiences are all subjective, varying in their affective or emotional contents and, based on human experience, are likely to include negative affective experiences such as thirst, hunger, nausea, pain and fear, and positive affective experiences such as satiety, contentment, companionship, curiosity and playfulness (Hemsworth *et al.*, 2015).

Most research during at least the last 40 years concentrated on preventing and ameliorating negative states, as reflected in codes of welfare or practice. However, there is increasing societal interest in providing domesticated animals with the opportunity for positive affective experiences (Tannenbaum 2001) and increasing research focused on positive welfare states in these animals.

There are basically two conceptual frameworks that scientists have used to assess animal welfare, namely, biological functioning and affective state (Hemsworth *et al.*, 2015). The rationale for the biological functioning framework is that difficult or inadequate adaptation will generate welfare problems for animals. This conceptual framework emphasises that animals use a range of behavioural and physiological responses to assist them to cope with challenges, and while biological regulation in response to challenges occurs continuously, successful adaptation is not always possible. Depending on the severity of the challenge, the biological costs include growth, reproductive, health and other impairments, which may reflect and/or result in welfare problems for the animal. Thus animal welfare is at risk in environments to which adaptation is difficult.

The conceptual framework of affective state emphasises that the welfare of an animal derives from its capacity for affective experiences. Thus, the welfare state is likely to be negative when the predominant affects experienced are unpleasant, and vice versa. It is well recognised that affective experiences are generated both by sensory inputs that reflect the animal's internal functional state and by other sensory inputs that reflect the animal's perception of its external circumstances. Thus, preference research, in which the strength of the preference for a chosen environmental option or the motivation to perform a type of behaviour is measured, has been used by some scientists to make inferences about animal welfare particularly in research examining the welfare implications of housing and husbandry practices.

There is a third conceptual framework which is not often well enunciated in the literature. This concept of natural living is predicated on the view that the welfare of animals is improved when they can express their normal behaviour. For some people this also implies that the animal should be raised in a 'natural' environment and allowed to behave in 'natural' ways. However, the concept of natural is usually too poorly defined to provide a sound basis for animal welfare assessment, and thus when applied uncritically it may lead to poorer welfare instead of an improvement. There is a need to define natural behaviours that are desirable or undesirable in terms of animal welfare and to clarify the rationale for their inclusion or exclusion.

The biological functioning and affective state frameworks were initially seen as competing, but biological functioning is recognised to include affective experiences and affective experiences are recognised as products of biological functioning (Hemsworth *et al.*, 2015). The measures used to assess animal welfare with these two conceptual frameworks have included: behavioural variables, such as fear, pain and illness behaviours; physiological variables, such as circulating concentrations of cortisol, neutrophil: lymphocyte ratio and immunoglobulin A; and fitness variables, such as lameness, skin lesions, liveweight change and reproductive performance.

Science and education

Science provides the means to understand the impact of animal use on the animal and thus science has an important role in underpinning societal decisions on animal use and the acceptability or otherwise of attendant conditions and compromises. Science therefore should continue to have a prominent role in underpinning our decisions on animal use and the attendant conditions and compromises. Exclusion of science can result in emotive or self-interested arguments from sectional groups dominating community debate. This is not to say that such arguments should be ruled out; quite the reverse, as they reflect, in part, current community values. However, they should contribute to, not pre-empt, the debate (Hemsworth *et al.* 2015). For example, the publicly engaging concepts of 'free range' and 'capacity to express natural behaviour' among domesticated animals can lead to compromised welfare when implemented in circumstances which, on the face of it, suggest that welfare would be improved. For example, in a study of 1,486 UK flocks, Weeks *et al.* (2012) found that mortality of hens over a 52-week laying period was 9.5% for free-range hens compared to 5.4% for hens in cages.

Obviously, societal interests in animal welfare also include consideration of wider issues such as human health, economic and social implications, as well as environmental impacts. Decisions on acceptable animal use can therefore involve difficult and complex choices and consequently they may remain controversial.

In terms of education, there needs to be transparency to the public in farming techniques and in particular a clear articulation of the implications both for food quality on the one hand and animal welfare on the other. Furthermore, the fostering of a culture shift amongst the livestock industries is desirable to sensitize them to changing cultural values about animal quality of life. Industry responses need to be a balance between listening to community requirements on the one hand and a preparedness to defend a practice if, on balance, it is considered the best in terms of healthy food, economics and welfare. This is essential for a well-informed community able to make rational choices and if industry is to respond appropriately to community expectations.

Intensification of livestock production

Intensification of livestock production in the last half century has consisted of two key elements: new confinement systems that generally kept animals in specialized indoor units that used hardware and automation instead of labour for many routine tasks and production that was concentrated on fewer farms (Fraser, 2005).

Intensive livestock production is not a recent development. For example, dairy cattle for centuries have been intensively housed (tethered) in barns within/beneath farmhouses during the winter, and calves have been intensively housed and fed surplus milk for veal production (Cronin *et al.*, 2014). However, the main impetus for 'modern' intensive livestock production occurred after the Second World War, when Western governments developed policies to increase the availability of cheap and safe food, and especially protein. Through research and industry development, improved housing, management, health and animal genetics have increased productivity, improved the quality of food and lowered the cost of food.

In general, these improvements in animal nutrition, health and reproductive management, environmental control and genetic selection of better performing animals have reduced or eliminated a number of welfare problems, such as predation, thermal stress, some infectious diseases and nutritional stress. However, these changes in livestock production methods have exacerbated or created other welfare problems. The modern indoor intensive production system, particularly for pigs and poultry, is intensive and thus considered today by some sectors of the community to be inherently 'bad' because of lack of space, 'barrenness' of the environment, and the reliance on technology (Barnett *et al.*, 2001). In contrast, outdoor housing is typically extensive and so considered by some to be inherently 'good' because it provides a more 'natural' environment and choice for the animal in performing a number of behaviours over a relatively large area and the lower technological inputs provide for fewer equipment breakdowns that may adversely affect welfare.

Common international concerns for intensively farmed dairy cows include foot and leg disorders, mastitis, metabolic and infectious diseases, poor body condition, heat load (high temperatures and humidity) and pain associated with husbandry procedures such as dehorning, disbudding and tail docking (EFSA, 2009; von Keyserlingk *et al.*, 2009; Cronin *et al.*, 2015).

Pasture-based production in comparison to indoor production provides less restriction on social behaviour, choice of living environment and group mates, environmental stimulation and behavioural activities. There is limited evidence that dairy cows generally prefer to be at pasture, although this preference is complex, affected by a number of factors including weather, food availability and

requirements, body condition score, season, time of day, and distance to pasture (Charlton *et al.*, 2011; Falk *et al.*, 2012; Motupalli *et al.*, 2014). Furthermore, as concluded by von Keyserlingk *et al.* (2009) and Motupalli *et al.* (2014), providing dairy cows with more control over their own environment seems to have welfare, health and production benefits.

While extensive livestock production systems are generally not considered to involve 'housing', extensive systems do impose restrictions on animals, albeit with considerable freedom and there are different welfare risks including frequency of inspections, ease of intervention if animal health or welfare problem are encountered, climatic conditions and natural disasters. Risks associated with frequency of inspections and ease of intervention are of less concern with pasture-based dairy production because of opportunities to inspect and intervene at milking.

As the scale of production increases, there are potential benefits to cows as well as potential risks to animal welfare (Verkerk and Hemsworth, 2010; Beggs *et al.*, 2015). Benefits may relate to economies of scale which facilitate greater use of consultants (nutritional and veterinary), adoption of new technologies, larger and more flexible labour, and more opportunities for formal and informal training. However when farms increase in physical size, this may result in more stock per labour, cows walking greater distances and spending longer time off pasture, reduced pasture availability and more intensive feeding systems.

However, few studies have been conducted on the effects of herd size on animal welfare, particularly in the dairy industry. Botheras (2006) examined the relationship between time spent away from pasture and cow behaviour, welfare and productivity in studies conducted in Victoria. When time off pasture was experimentally manipulated, cows held on concrete yards for 2 h prior to milking to replicate prolonged waiting times had reduced lying times and lower total milk and milk components yields than cows that were milked and returned immediately to pasture. Although there were no discernible differences in lameness as assessed by locomotion scoring, cows that spent a longer time away from pasture had higher traumatic-type hoof lesion scores. There was also a trend for these cows to have higher milk cortisol concentrations, raising the possibility that stress contributed to lower milk production.

The within-herd variation in the time that individual cows spent off pasture was also studied by Botheras (2006) at three commercial farms in south-west Victoria with herd sizes of 350-650 cows. Healthy cows that were consistently early and late in the milking order were compared. Late-order cows spent three hours longer off pasture each day (187 ± 33.5 min; mean \pm SD), more time lying and idling and sometimes also less grazing time than early-order cows. These late-order cows were also found to have reduced liveweight or milk yield, both indicative of lower feed intakes and/or stress.

These two studies in which the cows were fed most of their diet from pasture and other forages in the paddock and grain mixes (concentrates) fed in the dairy during milking provide evidence that increased time spent away from pasture may reduce grazing and lying behaviour and, in turn, reduce animal welfare and productivity. Rest and lying are important behaviours for dairy cows. Dairy cows are highly motivated to lie down, even after relatively short periods of deprivation (Metz, 1984) and lying-deprived dairy cows have increased plasma cortisol concentrations (Fisher *et al.*, 2002). Botheras (2006) also suggested that these findings may also be applicable in other situations in which the feeding and lying behaviour of lactating dairy cows is influenced by management practices and routines.

Recently, Beggs *et al.* (2015) conducted a survey of Australian dairy farmers to assess relationships between herd size and possible risk factors for adverse animal welfare outcomes. Increasing herd size

was associated with several risk factors for adverse animal welfare outcomes including increased stocking density, decreased labour units per cow, increased grain feeding, increased milking time, increased time away from pasture, and increased distance walked. However, increasing herd size was also associated with factors that may reduce the risk of adverse welfare outcomes including a greater capacity for strategies such as better training and education of staff, routine veterinary herd health visits, separate milking of the main herd and the sick cows, transition diets before calving, and written protocols for treatment of disease.

While intensive livestock production provides both animal welfare benefits and costs, community concerns about animal welfare in these systems will continue because of the intensive nature of the farming. Thus with increasing intensification in the dairy industry, such as scale of production and further evolution of supplementary feeding practices, research on the long term effects on cow welfare are warranted.

Management and design of the production system

While there is a focus on housing systems in intensive livestock production systems, research in many livestock industries indicates that the design of the production system is probably more important for animal welfare than is generally recognized (Barnett *et al.*, 2001; Rushen and de Passillé, 1992; Hemsworth *et al.*, 2015). For dairy cows in indoor and outdoor systems, the design of resting, walking and feeding areas should allow for sufficient movement and exercise and the design of feeding space and protection at feeding from bunks should minimize competition and thus aggression (EFSA, 2009; von Keyserlingk *et al.*, 2009; Hetti Arachchige *et al.*, 2014).

The principle that management, including supervising and managing animals, affects farm animal welfare is widely recognized within the livestock industries. However, the manner in which management affects animal welfare, both directly and indirectly is probably not fully appreciated (Hemsworth and Coleman, 2011). At the level of farm management, human resource management practices, including employee selection and training, and animal management practices, such as best practice in housing and husbandry, and implementation of welfare protocols and audits, all impact on farm animal welfare.

At the stockperson level, a range of well-developed husbandry skills and knowledge are required to effectively care for farm animals. Technical skills and knowledge are important attributes of the work performance of stock people and clearly training targeting these attributes is important in improving animal welfare and performance. Furthermore, research on commercial farms has shown consistent relationships between stockperson attitudes (based on beliefs), stockperson behaviour, animal fear and animal welfare and productivity (see Hemsworth and Coleman, 2011).

Indeed, research on dairy and pig stock people has demonstrated that cognitive-behavioural training targeting key stockperson attitudes and behaviours can reduce animal fear and improve productivity. Thus technical and cognitive-behaviour training is a necessity to ensure that stock people have well-developed husbandry skills and knowledge and the motivation to apply these skills and knowledge to effectively care for and manage their animals.

Thus the focus on different production systems ignores many of the important factors that can affect animal welfare such as the design of the system per se and the quality of management.

Conclusions

In a future in which the food supply may be limited as the world's population grows and land availability shrinks, intensive animal production is likely to expand, but at the same time ethical considerations surrounding intensive farming practices may also become more prominent (Cronin *et al.*, 2015).

Irrespective of the production system, the skills, knowledge and motivation of stockpeople to effectively care for and manage their animals and the design of the production system are integral to animal welfare. As Fraser (2005) concludes, the most important determinants of animal welfare are not specific to any one production system. The welfare of cows indoors or on pastures will be improved by stockpeople who are motivated and skilled in detecting and promptly treating disease, while the welfare of farrowing and lactating sows and their piglets will be improved with good maintenance and functioning of equipment as well as stockpeople who are motivated and skilled in caring for these animals. If we think of good animal welfare being influenced by key factors such as staff time and skill, flooring, feed quality and disease prevention measures, then animal welfare problems may be less a function of the production system – confinement, semi-confinement or extensive - but rather how well the system is operated.

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Hunting Efficiency through Technology

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Before investing in any new technology (hardware or software) a strong business case for this investment is required. Measuring and comparing business performance over time is now enabled through DairyBase (www.DairyBase.com.au). If technology can drive profit and/or reduce risk from areas of underperformance, identified as outputs from DairyBase, then this additional investment is warranted - keeping in mind the value of lifestyle. As areas of underperformance or requirement to improve lifestyle differ between farms, the requirement to invest in additional technology will also vary. However, in the authors' humble opinion...some technologies are, or will be, indispensable for a successful hunt.

This manuscript will provide:

1. An overview of technology on Australian dairy farms
2. The potential to 'hunt efficiency' from key technologies as determined by our research at the University of Sydney, and
3. A vision for how these key technologies can, and will, be used in the future

Current technology on Australian farms

An overview of technology on Australian farms is provided as Figure 1 taken from a recent survey (Lyons *et al.*, 2016). Overall, the amount of technology on dairy farms increased with farm size as defined by cow number. There were, however, vast differences in the type of technology taken up on farms. Technologies that collect and collate data and automatically implement actions such as automatic cup removers were much more prevalent than those that generate data with no clear action, outcome or decision support system directly linked such as automatic cow weighing scales (walk over weighing) and pasture measuring devices.

In this regard, of all the literature on sensor systems, including many of those in Figure 1, there is nothing published on integrated decision support (Rutten *et al.*, 2013). These findings together suggest that it is not the technology per se that is limiting adoption by farmers but the lack of decision support systems around them.

Automatic oestrus detection also ranked among those technologies with limited adoption (installed on less than 10% of farms); however, this technology in the same survey (Lyons *et al.*, 2016) was ranked by farmers as the most likely to be adopted in the next 10 years.

This ranking highlights i) the challenges associated with oestrus detection, particularly as farm size increases ii) the associated difficulty to get cows in calf and iii) the provision of decision support associated with this technology as these systems typically provide the optimum time to AI. Electronic

cow ID and computing systems were also prevalent on Australian farms presumably due to the requirement of these systems to enable other technologies to function.

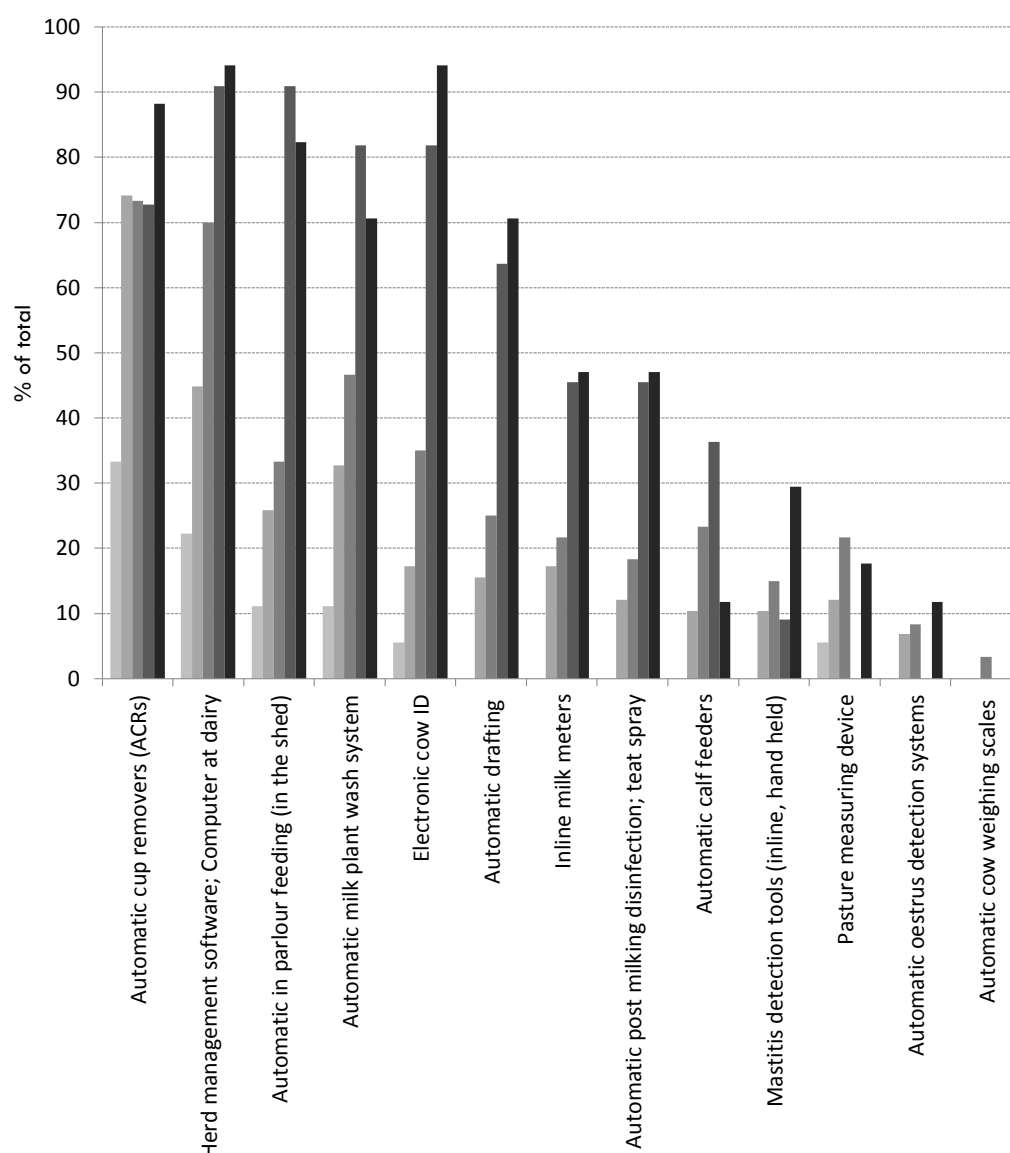


Figure 1. Technologies installed (% total in each farm size category) on small <150 cows (□), medium 151-300 (▤), large 301-500 (▥), x-large 501-700 (▧) and xx-large >701 (■) Australian dairy farms (Lyons *et al.*, unpublished data). Technology ranked by average % across all categories from left to right.

‘Hunting efficiency’ from key technologies

Key technologies to drive efficiency (in Figure 2) from the latest Dairy Science Group research are:

Electronic cow ID

Whilst the value of electronic cow ID is typically derived from linking other data collected by technology on farm with individual cattle (with the exception of pasture measuring devices in Figure 1), recent work highlights the value of this simple form of technology as a stand-alone source of information.

Electronic cow ID when combined with the time of milking gives milking order. In pasture-based systems, dairy cattle in conventional milking systems have a consistent milking order (Dias *et al.*, 2016). After milking, the first cattle typically walk to pasture hours before the last. Pasture varies in its chemical composition from its leaf to stem and cattle prefer to eat the leaf fraction. Our hypothesis was that the first cows accessing pasture would produce a greater milk yield (and milk solids) than those milked last.

We monitored the milking order and milk yield of cows in 6 commercial farms over an 8 month period. After correcting for age and stage of lactation, cows milked first (first 50 cows) produced, on average, 4.5 L /cow/day more than those cows milked last in the order (last 50 cows), equating to 20% more milk volume. Differences in milk production from the first to last cattle between farms ranged from 14 to 29%, presumably due to differences in management practice and associated pasture allowance and pasture nutritive value (Dias *et al.*, 2016).

Vision for electronic ID use in the future

Whilst detailed studies in a controlled environment are required to tease apart many of the variables in the aforementioned study, this work highlights the variability in both milk yield and the pasture state that cows currently access within the same herd. This variability introduces an opportunity to optimise pasture nutrient use for production across a herd to maximize farm profitability without changing feed inputs.

The benefits of either holding the herd back to ensure more even access to pasture leaf and stem, shifting paddocks after a proportion of the herd is milked or alternatively automatically linking milking order and pasture nutritive value data with automatic in parlour feeding systems to achieve the aforementioned aims will form the basis of ongoing research.

These findings will likely provide simple changes to pasture allocation (and/or algorithms to automate and optimise the quantity and type of feed offer to each cow in the herd) to optimise the conversion of feed nutrient into profit.

Pasture measuring devices

Even with fluctuations in milk price, both high and low, we must always remember that the low cost, pasture-based production system is a factor that we can control and is our key international competitive advantage.

In Australian pasture-based dairy farms, feed produced on-farm is typically less expensive than bought-in feed, and as a result the profitability of pasture-based systems is intimately linked to the amount of pasture converted into animal product (Garcia and Fulkerson, 2005). In spite of this, average pasture utilisation on Australian dairy farms and total conversion of pasture into milk both continue to be significantly lower than their potential (DFMP, Victoria).

In a recent review (Garcia *et al.*, 2014); the Dairy Science Group (Camden, NSW) proposed that the gap between what is possible and what farmers typically achieve is due to a series of inefficiencies ('losses') with cumulative effect (Figure 2).

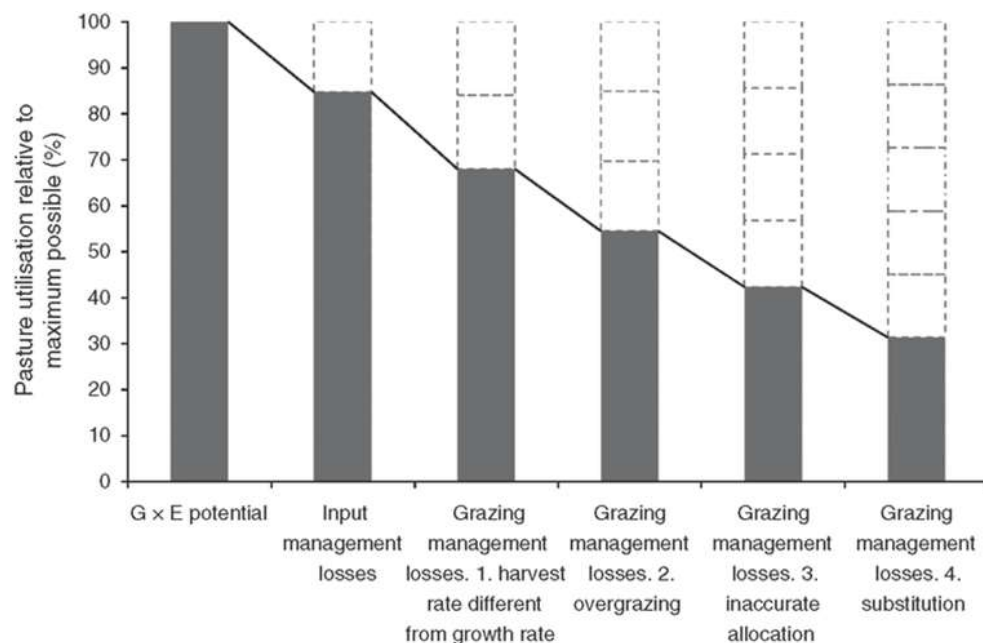


Figure 2. A conceptual model to explain individual and/or cumulative losses in pasture utilisation. For illustrative purposes and due to the lack of data to quantify these losses properly, they are assumed to be all of equal magnitude. Based on FutureDairy's data, losses can exceed 60% of potential pasture utilisation for irrigated systems (Garcia *et al.*, 2014). GxE = Genotype by environment interaction.

Methods to minimise these losses, with the exception of getting to GxE potential, have been and continue to be, provided by industry to farmers based on research such as that of García and Holmes (2005). Summarising the research on this topic; pasture utilisation losses are minimised when a) pasture biomass is systematically monitored and from this pasture growth rate estimated on a weekly basis; b) pasture is grazed in line with plants' optimal growth stage (rotation management); c) pasture allocation and associated residuals are managed to maintain growth rates and pasture quality; and d) supplements are used to cover true pasture deficits. Despite the gains to be made through implementing such strategies (Fulkerson *et al.*, 2005) enabled through the use of pasture measuring devices, the adoption of this technology is amongst the lowest of all those surveyed. In addition, more recent research has shown the inter- (between) paddock variability to be consistently as high as 100% even in controlled situations such as experimental farmlets or whole farm system studies (Clark *et al.*, 2010; Garcia *et al.*, 2013). Furthermore, intra-(within) paddock variability can also be very high in both pasture quantity and quality (Scott *et al.*, 2014).

Vision for pasture monitoring device use in the future

If the value perceived by typically time poor farmers regarding the adoption of automatic cup removers above is correct, then a fully automated, robust pasture monitoring system with data integrated into decision support system will be the way pasture is allocated in the future. Providing valuable actions autonomously through a combination of unmanned vehicles (air or ground) and advanced software, rather than providing copious amounts of pasture biomass data through measuring devices, will form the basis of capitalising on pasture variability.

Such collection and collation of data will also enable the rectification of sub-producing areas through site-specific management (e.g. spatial management of key inputs like N and water) bringing an

additional dimension of incremental productivity to the dairy system by reducing pasture wastage and improving cattle intake. Taking this vision one step further, the creation of pasture monitoring co-operatives to share autonomous pasture monitoring and potential consultancy would spread the associated costs making such technology more appealing.

Animal mounted sensors / Oestrus detection systems

Current on-animal sensor based systems now enable farmers to monitor almost all aspects of behaviour from the time spent eating, lying, walking, standing, ruminating and even sleeping. Our work (Talukder *et al.*, 2015) has shown collar-based sensors to perform just as well at detecting oestrous as humans in a controlled research environment. Additionally, the same sensors have been used to predict the day of calving through rapid changes in rumination levels (Clark *et al.*, 2015) and have distinguished cows with poor health (left-displaced abomasum) much earlier than humans (Talukder *et al.*, 2014).

Vision for animal sensor use in the future

Current research in the field now has a strong focus on combining these and other novel behaviours into predictive models of use to farmers. Further, technology now has the capability to 'learn' from humans to 'observe' discrete behaviours (machine learning). New phenotypes are emerging from these sensor systems to benefit not only to farm management such as the timing of artificial insemination and health treatment but also for genetic selection. Genomic selection is very well suited to traits that are difficult or expensive to measure on a large scale, as genomic predictions can be developed in a reference dataset that comprises animals with phenotypes and genotypes that can then be applied to bulls or cows that are genotyped but do not have phenotype information. Therefore, there is a distinct opportunity to start building phenotype datasets in herds where cows are genotyped focusing in on current areas of reduced health observed in the Australian dairy industry. New valuable traits that cannot be (accurately) measured can then be added to the breeding goals with widespread benefits at both the herd and industry levels. The first step towards this vision would be attaching such sensors to all 10,000 of the Ginfo (genetic information) cows (Australia's national DNA reference population) to start generating an objective new database related to these phenotypes to breed healthier, more profitable cows for the Australian dairy industry.

With some vision, there is low hanging fruit for the Australian dairy industry to grasp to significantly reduce the costs of milk production and provide a step change in efficiency levels on farm. Technology, whilst perceived to be of value by those who create it, without a robust decision support system will either rust in the shed or take up space on computing systems. Fully integrated technological systems (such as those provided above) that collect, collate and act to improve key areas of system underperformance will form the basis of our international competitiveness as an industry into the future.

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Automatic milking: the right thinking process

Garry and Bev Carpenter

Dairy farmers, Tasmania

Introduction

Now in our mid-fifties we have grown our business over the past 28 years. The investment in robots is part of a retirement and lifestyle plan. Needless to say the investment really needed to stack up and wasn't the only option on the table. Working with a consultant, we made absolutely sure that going into robotics was the best option for the operation and our objectives.

Our history

We have been married 37 years and have been self-employed for the majority of that time. We started with a transport and machinery business before buying my parent's 100 acre beef farm in 1988. We built a new 7 swingover dairy and started milking 28 cows. After a few deductions our first milk cheque was \$258. We gradually built up cow numbers, renovated pasture and 2 years later bought the neighbour's 220 acre farm. This was also a beef farm, so as a way of renovating pasture we started growing potatoes. We laid irrigation to where the potatoes were, continuing it on until 80% of the farm was irrigated. There were quite a few dry seasons and without the irrigation we would not have been able to peak at 220 cows milked all year round.

We farmed these two properties for 19 years. Then came a time when it looked like our area would be consumed by tree plantations. Our community took the fight to the tree companies and they backed away. It was at this time our neighbour, fearing being surrounded by trees, put his farm on the market. We purchased this 660 acre farm and joined it to our 220 acre property. The original 100 we sold off. We converted an old barn into a 26 double-up herringbone dairy, which now has cup removers, auto ID and draft and just recently heat detection. 4 years ago we peaked at 600 cows while still growing potatoes and expanding the irrigation. We milk all year round and have done for 28 years.

At that same time our district started getting serious about building an irrigation scheme. The idea had been kicked around for about 15 years. With commitments from both State and Federal governments this scheme has become a reality and now services 48 farms. The down side for us was that the dam site was to be built on 60 hectares of our prime pasture.

Looking into new ventures

So with some money in our pockets we decided it was time to look for our next venture. We found a property in Gunns Plains that was for sale and perfect for dairying. It was previously used for growing hops and had a large shed already on site that could be easily converted into a dairy. It was already set up with irrigation, some solid set and some travellers, and had 2 large pump stations. The Leven River runs the entire length of the property and it had an enormous water license. The property was owned by a trust and was on the market because of the ill health of the principle. We settled on a lease/buy agreement, mainly because we didn't know when the money was going to come through for the sale of the dam site. Our thoughts for this farm were mainly to run young stock and to grow fodder for the main farm, which we thought we would need after losing 60 hectares.

Financially this farm only broke even in results, so Garry and Bev started analysing for different alternatives. We had previously looked at robotics and thought what amazing technology it was, then when we went onto this farm it was almost like they had laid it out with robots in mind. Everything was perfectly designed to suit robots, from the position of the shed to the way the lanes ran away from the shed. We really didn't have to change anything. We also liked the simplicity of the system and how relaxed and animal friendly the whole routine was, where cows could do their things at their own leisure. Additionally, the systems provided a huge amount of information that allows farmers the ability to know what cows are doing, and tweak some things you have control over.

We have 3 children who have established themselves in other areas and have no interest in farming so we saw this farm as our retirement plan. We could semi-retire but continue to do what we love doing. I love growing grass and Bev loves breeding cows. We could continue on with our interests without the pressures of actually milking and eliminate some of the labour issues.

Doing the right homework

We had decided that robots could be an option, but there was still some homework to be done.

One of the first things we did was talk to other AMS farmers to understand how they adapted their farming systems and how AMS changed their work routines and lifestyles. So we re-visited a Tasmanian AMS farm we had seen some time ago, to get a much clearer understanding of farm management aspects, something that absolutely confirmed our initial impression.

We then decided to get in touch with commercial companies that started providing some information and idea of associated costs. As we had no pre conceived ideas about robots we checked out all the brands. Eventually I rang a trusted friend who had installed the first Boumatic plant in Tasmania for us 25 years ago. He said and I quote 'All robots will milk cows, it's what else you want that counts', e.g. Service, pasture base or barn system, ongoing support and future research, trust, availability of good technicians and staff. We spent nearly 2 years researching and planning before making a decision.

Part of that process involved contacting Mr. Alexis Perez, who at that time was a Senior Industry Development and Extension Officer within the Tasmanian Institute of Agriculture. Alexis has been running a discussion group exclusive for AMS farmers over the last 12 months. This group met 4 times a year, each time on a different farm. In those meetings they tried to cover different topics related to their farming systems (such as farm physical performance, cow traffic, training of heifers and feed allocation). They were able to share knowledge and experience, and start providing some benchmarking / key performance indicators that the industry needed. This initiative was key for them, as usually these farmers do not participate in discussion groups for conventional farmers, given that they have particular needs and questions. Having this kind of support networks highly favours successful adoption of automatic milking in Australia.

The next thing we did was to contact Basil Doonan from Macquarie Franklin, a firm that specialises in consultancy for business, agriculture and environment. We had used them before, and really appreciated and respected their theories and ideas. They could help us work through the financials on five options for a dairy enterprise on the property: use as agistment for dry stock, calves and heifer; milk 200 cows either conventionally or with robots, or milk 300 cows either conventionally or with robots. An extensive financial assessment offered a very interesting insight into the different operations, and robots started emerging as a real possibility.

Even being quite conservative in some aspects, the numbers looked very good and it was quite evident the herringbone was not a sustainable way to go. We were not getting younger, and therefore we all

determined that the best option, both economically and that best suited our needs and vision was to invest in a 300 cow automatic milking system.

Overall, the automatic milking system proved to be the best option, given that it would allow us to milk 300 cows with less staff (estimated 1.2 FTE, or 250 cows/FTE). We were conservative in the amount of production per cow (even though some farmers have mentioned a moderate increase in milk production per cow), but did emphasise that we could utilise 10 Tn DM/ha of pasture, and use slightly less concentrates per cow to achieve those results. Although the robots were a high capital investment, the total infrastructure investment was only 10% higher than the cost to install a conventional dairy to milk similar amount of cows (that involved equipment and infrastructure). With robots we could achieve slightly lower operating costs, basically due to savings in labour, but higher repair and maintenance cost. The higher profit seemed to be achieved when production/ha was increased.

Having decided we wanted to put in robots we thought we still had better speak to the property owner, who is based in Singapore. He was quite happy with the idea and only had one stipulation, if we didn't buy the property we had to leave it as we found it. He didn't want to be left with a dairy farm he didn't know how to run. Just before installation started we received a call asking us to relinquish our purchase right and were offered a 15 year lease instead. This suited us even better.

This brings us to 16 months ago

The start of the robotic journey

We started milking in mid-February 2015, about 4 months behind schedule, with 3 A4 Lely boxes. The late start was actually a blessing in disguise as we had beautiful weather for breaking in the cows and plenty of good feed.

We took 60 cows from our home farm after milking Tuesday afternoon and a further 80 cows after milking on Wednesday morning. All cows had been through the boxes and programmed by midnight Wednesday night. During start up our daughter Jayde and I stayed on site along with the Lely techs and staff while Bev stayed at the home farm. We had anticipated a 14-day breaking in period with Lely's support on hand 24/7, but by 2 pm Friday all the support staff had left. When Bev arrived Friday night expecting all sorts of angst she found myself and a neighbour sitting on chairs having a whiskey and watching the cows go through. We were very fortunate I think.

So today we have 180 cows milking and are in the process of installing box number four.

Key elements of success

AMS won't suit every farmer or every farm layout. There can be some very big pitfalls if you go in with your eyes shut. You can't put them in and walk away, they need to be monitored at least twice a day, whether that is on site or by remote link in from wherever you are.

It is important to have someone else learn with you; otherwise you can be trapped into being available 24/7. With at least one other person you can rotate time away.

Robots will milk cows and do an excellent job but you still need to use your eyes, observe your cows. Being a cow person definitely helps. The software and data collection is first class and there is so much of it but if you don't allow the time to analyse it and use it then it is totally useless. Even after 16 months we are still learning.

I think starting an AMS dairy is a step by step process

- You need a good farm layout
- Easy access to the shed
- Careful due diligence when planning

Don't focus on 'How many milkings a day' or 'Higher production per cow', instead work on cows being comfortable and at ease. It takes them a while to get to know the farm layout and new milking regime. Be prepared for an initial production drop while they acclimatize. Our cows moved mid lactation and it didn't happen but it very easily could have. We weren't prepared to make the cows hungry to get them to traffic; we continued to feed them as well as we could. We trained them to traffic by getting up through the night and physically moving them. They aren't used to walking to the shed in the middle of the night. The first calf heifers learned easily and very quickly as they know nothing else.

I think that 4 boxes could milk 300 cows. Units need to be working at around 90% capacity to make a good return on investment. To do this cows are the key:

- Good type is extremely important especially udders and teat placement, this allows for faster cupping up
- Temperament - quiet, calm cows
- Feed conversion is a must. We need cows that are aggressive eaters and want to produce milk
- Milking Speed: Slow cows cannot be tolerated; they take up too much time in the box
- Pre breaking in heifers also is important.

Starting up with a conventional dairy still operating is a real plus. To date we have returned around 5% to the home farm.

We use a 3-way grazing system which we find works really well. It also has the ability to extend to a 4-way system, with the use of a feed pad. We may do this when we reach full capacity.

The milking platform is basically fully irrigated now and we direct drilled all paddocks 12 months before start up. Our aim was to have the same quality grass at every break, which I believe helps with cows trafficking.

The future

We don't really know where the future will take us. When we started this farm we were looking at semi-retirement with the eventual sale of our home farm. Now we have been given the opportunity to develop another AMS farm in the same district with the same trust.

We believe we could develop up to 4 farms or around 20 units in Gunns Plains. This would allow staff to be more flexible and have consistent time off and maybe train one to be a qualified technician. The possibilities are endless and hopefully one day we can foster young farmers to take over these farms.

Conclusion

I believe we are a reasonably good example of how you can succeed if you persevere. From leaving school at 14 to running the family farm after my father had a serious tractor accident, to running a multi-million dollar business. I was lucky to marry a town girl who fell in love with black and white cows and shares my passion; we make a very good team. We have seen the full spectrum of lows, interest rates at 24%, low milk prices and extreme dry summers, but have also seen many good times as well.

Some people ask us 'Why Robots?' For us there was no other possibility, but numbers needed to stack up. Bev wouldn't have anything else, it was robots or nothing.

Can every farmer succeed with robots? I think not, but would strongly encourage anyone that's looking to expand or upgrade to at least investigate and ask the question 'Would AMS suit us?'

If you are wondering where we are actually situated, you can look us up on google earth; 687 South Riana Road, South Riana 7316 for the conventional farm and 1568 Gunns Plains Road, Gunns Plains 7315 for the robot farm.

It's 'People' not 'Cows'

*Chris Hibburt
Dairy Consultant
Timboon SW Vic*



*These resources are compiled from Dairy Australia's
The People in Dairy program and the People Development Council's
Stepping up and Stepping back program*

It's 'People' not 'Cows'

Your future is in your hands – setting goals and being in a team with effective leadership breeds both individual success and business success.

Through his involvement in the Stepping Up and Stepping Back program (an industry initiative that aims to help with the development of clear pathways for people to transition through the dairy industry) Chris Hibburt is more than qualified to take you through the value of setting goals.

If you are an employer he will get you thinking about what you can do for your staff and if you are an employee this presentation will inspire you to start really paving your path in this great industry.

The move from the autonomous family farm to one that requires support from a work team that includes non family members, has exposed our industry to our most important resource.

'Its People'



W I I F M

- We're human beings
- We have needs
- We move on if they are not provided



Let's recruit a new employee



The **employer** version of an advert

Farm hand required:

Our vibrant farm business is looking for a self motivated bright person as a junior herd manager.

They need to be reliable, good communicators, have excellent stockmanship, proficient with IT and preferably have several years experience in dairy farming.

They must be able to fit into a team and be prepared to fit into our weekend roster. Award conditions apply. Phone 0400 0000

Let's recruit a new employee



The **employee** version of an advert

Farm hand required:

A great opportunity exists for someone wishing to upskill in dairying on our modern rotary dairy farm. We have a supportive staff with a flexible roster including 4 days off per fortnight. There is accommodation on farm and we are located 10 minutes from our local town and 20 minutes from the iconic SW Victorian coastline. Forward CV to perfectjob@dairyforlife.com.au

How do we keep them



Two thirds of employees leave their job because they

'Don't like the boss'

Have you looked in the mirror lately??

Four non-negotiables for an employee to have

1. The right role that suits them (not the boss)
2. Opportunities to learn
3. A suitable work life balance
4. Appropriate reward and wealth creation

So where do employers go wrong

- They are not good leaders
- They lack empathy
- They are poor communicators
- They allow lack of accountability
- They are selfish and greedy

What to look out for as an employee or share farmer

- Is the farm and its infrastructure any good?
- What is the track record of the employer?
- What do current staff think of the boss?
- What do previous staff think of the boss?
- Do your homework!!!

Selecting a good senior employee or share farmer

- Have they been able to accumulate wealth
- If they have a partner, are they 'on board'
- Thorough reference checking is essential
- Try to have a courting / probation period

The fork in the track

Share farming

Employment



Wealth creation as an employee

Stock bonus

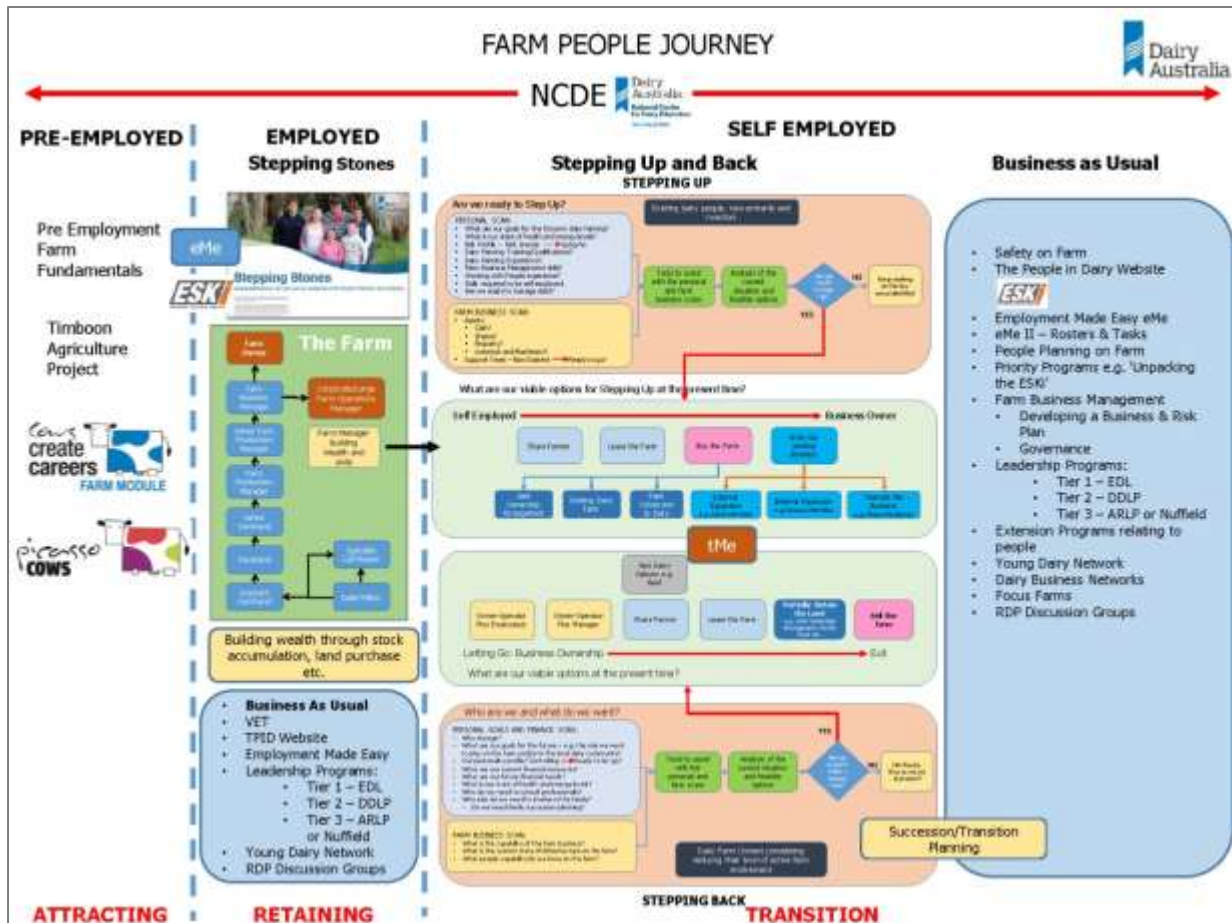
- Reward for longevity
- Tax protected
- Incentive for stockmanship
- Sense of ownership
- Golden handcuffs
- Minimises business risk

Wealth creation via stock accumulation through a longevity bonus										
Stock values										
Age	R 1yr	R 2yr	1st C	2nd C	3rd C	4th C	5th C	6th C	7th C+	
Value	\$800	\$1,600	\$1,800	\$1,800	\$1,600	\$1,400	\$1,300	\$1,100	\$1,000	
Adult herd number	250									
Heifers reared as % of herd	25%									
No. heifers reared	63									
Long term commitment	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Bonus % of heifers	10%	25%	30%	35%	40%	45%	50%	55%	60%	65%
2016	10.0%	10.0%	10.0%	9.0%	8.1%	6.5%	5.2%	3.6%	2.2%	1.3%
Number of heifers	6	6	6	6	5	4	3	2	1	1
2017		25.0%	25.0%	25.0%	22.3%	20.3%	16.2%	13.0%	9.1%	5.4%
Number of heifers		16	16	16	14	13	10	8	6	3
2018			30.0%	30.0%	30.0%	27.0%	24.3%	19.4%	15.6%	10.9%
Number of heifers			19	19	19	17	15	12	10	7
2019				35.0%	35.0%	35.0%	31.5%	28.4%	22.7%	18.1%
Number of heifers				22	22	22	20	18	14	11
2020					40.0%	40.0%	40.0%	36.0%	32.4%	25.9%
Number of heifers					25	25	25	23	20	16
2021						45.0%	45.0%	45.0%	40.5%	36.5%
Number of heifers						28	28	28	25	23
2022							50.0%	50.0%	50.0%	45.0%
Number of heifers							31	31	31	28
2023								55.0%	55.0%	55.0%
Number of heifers								34	34	34
2024									60.0%	60.0%
Number of heifers									38	38
2025										65.0%
Number of heifers										41
Value	\$5,000	\$22,500	\$51,250	\$85,750	\$122,163	\$158,170	\$193,125	\$227,010	\$259,291	\$290,575
Total number	6	22	41	62	85	109	133	156	180	202
Average Value	\$800	\$1,029	\$1,262	\$1,386	\$1,441	\$1,457	\$1,456	\$1,451	\$1,444	\$1,439
Addition	\$5,000	\$17,500	\$28,750	\$34,500	\$36,413	\$36,008	\$34,955	\$33,885	\$32,282	\$31,284



Essentials for optimising our 'people efforts'

- A well resourced farm
- The right people in the right roles
- A farm operations strategy that is designed to suit people
- Great leadership



FARM PEOPLE JOURNEY

STEPPING UP

Existing dairy people, new entrants and investors



Are we ready to Step Up?

PERSONAL SCAN:

- What are our goals for the future in dairy farming?
- What is our state of health and energy levels?
- Risk Profile – Risk Averse → Gung-ho
- Dairy Farming Training/Qualifications?
- Dairy Farming Experience?
- Farm Business Management skills?
- Working with People experience?
- Skills required to be self employed
- Are we ready to manage debt?

FARM BUSINESS SCAN:

- Assets:
 - Cash?
 - Shares?
 - Property?
 - Livestock and Machinery?
- Support Team – Non Existent → Ready to go?

Tools to assist with the personal and farm business scans

Analysis of the current situation and feasible options

Are we ready to Step Up?

NO

Keep working on the key areas identified

YES

What are our viable options for Stepping Up at the present time?

Employee

Self Employed

Business Owner

Employee Building Wealth

Farm Manager Building Wealth and skills

Corporate Farm Operations Manager

Share Farmer

Lease the Farm

Buy the Farm

Grow our existing Business

Joint Ownership Arrangement

Existing Dairy Farm

Farm Conversion to Dairy

External Expansion e.g. Lease next door

Internal Expansion e.g. Increase Herd Size

Diversify the Business e.g. Cheese Production

STEPPING BACK

Dairy Farm Owners considering reducing their level of active farm involvement



Who are we and what do we want?

PERSONAL GOALS AND FINANCE SCAN:

- Why change?
- What are our goals for the future – e.g. the role we want to play on the farm and/or in the local dairy community?
- Our personality profile? Controlling → Ready to let go?
- What are our current financial resources?
- What are our future financial needs?
- What is our state of health and energy levels?
- Who do we need to consult professionally?
- Who else do we need to involve in the family?
- Do we need family succession planning?

FARM BUSINESS SCAN:

- What is the capability of the farm business?
- What is the current state of infrastructure on the farm?
- What people capability do we have on the farm?

Tools to assist with the personal and farm scans

Analysis of the current situation and feasible options

Are we ready to make a change now?

NO

Not Ready. Stay as we are at present?

YES

What are our viable options at the present time?

Letting Go: Business Ownership

Exit

Owner-Operator Plus Employee/s

Owner-Operator Plus Manager

Share Farmer

Lease the Farm

Partially Retain the Land e.g. Equity Partnership, Family Trust etc.

Sell the farm

Non Dairy Options e.g. Beef

2016 EMERGING SCIENTISTS PROGRAM

THIS HIGHLY ACCLAIMED PROGRAM IS THE PERFECT SHOWCASE FOR AUSTRALIA'S UP AND COMING DAIRY SCIENTISTS



Juan Molfino

Juan Molfino was raised spending every opportunity he could get on his grandfather's dairy farm back in Argentina. Later on he started working on his family beef and crop farm whilst completing his Bachelor degree in Agriculture. After finishing his degree he moved to New Zealand where he worked on a commercial Dairy farm, before making the move across the ditch to Australia. Juan joined FutureDairy in 2012 to work on Camden Automatic Milking System research farm and later he conducted the Labour & Lifestyle audits on commercial farms operating with AMS with the objective of evaluate the impact of this technology in Australian farms. In 2014 Juan commenced a PhD in Veterinary Science focusing on how to increase efficiencies in pasture-based Automatic Milking Systems. Juan's primary interest is in how to make pasture-based dairy systems more sustainable, profitable, and competitive; and how to best integrate robotic milking systems into Australian dairy. He is passionate about sports and food, and he loves to travel to discover new places and different cultures.



Marefa Jahan

Marefa studied 'Doctor of Veterinary Medicine (DVM)' from Faculty of Veterinary Science, Bangladesh Agricultural University, Mymensingh, Bangladesh and completed M. S. in Physiology from the same University in 2006. She was awarded 'The University Gold Medal' on 08 March 2011 for securing A+ (CGPA 4.00) in MS in Physiology Examination and started stated her PhD in August 2013 under the supervision of Professor Bing Wang and Professor Peter Wynn achieving Charles Sturt University Postgraduate Research Scholarship. Research interest is in Sialic acid and my areas of expertise includes molecular & cell biology, biochemistry and analytical biochemistry (UHPLC). Marefa's future plan is to do some significant research in Nutritional Neurobiology and Glycobiology to make major contribution in animal production, as well as, human and animal health.



Alexandra Green

Alexandra Green is a passionate emerging dairy scientist who recently completed a bachelor of Animal and Veterinary BioScience (First Class Honours) at the University of Sydney. Having had no previous background in farming, Alexandra's interest was sparked when she worked at a dairy in northern New South Wales during her university placements. Here she learnt the importance of care at the individual cow level and developed an understanding of behaviour and welfare. This led to her undertaking an honours project in 2015, where she trained dairy heifers to respond to a sound stimulus in a T-maze. This research demonstrated that cattle have the decision making ability to follow a sound signal and proposes that individuals or groups of cattle can be called in for milking; an alternative to fetching. It received positive feedback from NSW Farmers Association, and media coverage including the Sydney Morning Herald and The Australian Dairyfarmer. Alexandra has recently extended this knowledge of sound by beginning a PhD with the dairy science group at Camden. She aims to become the leading expert in dairy cattle vocalisations with the intention of analysing their acoustic features to determine individual cow welfare states.



Alex John

I am a third year PhD student from the University of Sydney. My background is in Agricultural Science, in which I completed a Bachelor degree at the University of Tasmania in 2013. I have a natural interest in new technology and was drawn to the idea of robot milking during my undergrad studies, completing an honours project looking at pasture management in automatic milking systems. Robotic milking is an exciting emerging technology for the dairy industry and has been proven to work very well in Australian conditions. For my PhD I have looked to further continue on in this area, focusing on the feeding behaviour of cows and how this can affect the interaction between cow and robot. My aim is to build up a better understanding of how cows react to different feeding strategies in order to create new feeding systems to test in pasture-based automatic milking systems. In future I hope to continue working in the rapidly evolving space of precision technologies and help advance its use within agricultural production systems.



Lucy Watt

Lucy completed a BAniSc (Hons) at Charles Sturt University (CSU) in Wagga Wagga, before undertaking a PhD in livestock production and ruminant nutrition at CSU. Lucy completed her Honours research year in 2014 at the W.K. Kellogg Biological Station Pasture Dairy Research Centre, Michigan State University in the USA. Outcomes from this research were published in the Journal of Dairy Science in 2015, being her first publication as principal author. Although Lucy's PhD project is focused on sheep production, she has a great passion for dairy science. Lucy is scheduled to complete her PhD at the start of 2018. She hopes to build her career in agricultural research and development working for a research company that has strong ties with industry members. She also hopes to one day venture into the university stream and become a lecturer to encourage others to pursue a career in agricultural research. Lucy's other interests include working with her parents on their prime lamb property in Cumnock, NSW; volunteering for various community groups at university and in her hometown; and cooking.



Rachael Rodney

Rachael Rodney is a PhD candidate at the University of Sydney and Scibus. Her studies focus on relationships between nutrition and fertility in the dairy cow, particularly around transition. Rachael completed a Bachelor of Animal and Veterinary Bioscience with honours through the University of Sydney in 2010. She spent time working as a Sustainable Agriculture Policy Officer at the federal Department of Agriculture before undertaking her PhD and is Chair of the Royal Agricultural Society of NSW Youth Group.



Joanna Newton

Jo Newton currently works as a Research Scientist in Dairy Genetics for the Department of Economic Development, Jobs, Transport and Resources (DEDJTR) in Victoria. Prior to this Jo spent 8 years based in Armidale, NSW. In 2015 Jo completed a PhD in Animal Genetics and Breeding at the University Of New England (UNE). Her thesis explored the genetic and environmental factors influencing sexual maturity and reproduction in young ewes and the implications this has in designing breeding programs.

Prior to this she completed a Bachelor of Rural Science (Hons) at the University of New England (UNE) graduating in 2012 with first class honours and a University Medal. Whilst studying, Jo worked part-time on several farms in NSW. In 2011 Jo led the design and implementation of a breeding program that included the use of breeding values for Stanley Vale Merinos, a superfine wool Merino stud in Uralla, NSW. One of Jo's main interests is the translation of genetics research into new genetic technologies and tools for the agricultural industry. During her time working in the sheep industry as well as presenting her work at several scientific conferences Jo was an invited speaker at several key sheep industry events including; LambEx 2014 and the Sheep Genetics Leading Breeder forum. Now, Jo is enjoying the applied nature of her work on the Improving Herds Project, an Australian dairy initiative whose goal is to make it easier for farmers to make quick, data-driven decisions to increase herd profitability.



Stephanie Bullen

Dr Stephanie Bullen graduated from Charles Sturt University, Wagga Wagga, in 2011 with a double degree in veterinary biology and veterinary science. Her undergraduate honours research investigated the paternal heritability of worm egg counts in Angus cattle and formed the foundation for the development of EBV (Estimated Breeding Value) for parasite resistance in beef cattle. This work also awarded her a George Osborne Memorial Speakers Award at the 2012 Australian Cattle Veterinarians Conference. Upon graduation, she worked as an associate veterinarian at the renowned Maffra Veterinary Centre under dairy cattle medicine specialist Dr Jakob Malmo for two years. She then completed a three-year residency in dairy cattle medicine and surgery, also at Maffra (through the University of Melbourne) in 2016. This involved advanced training in dairy cattle medicine and surgery, tutoring and mentoring of final year veterinary students and undertaking a double Master's Degree.

Upon discussing potential research topics for her Masters she was told by one of her supervisors that 'parasites weren't very sexy' when compared with issues such as mastitis, reproduction, lameness and nutrition. However, through her work as a veterinarian in the Macalister Irrigation District she had recognized that current parasite control practices on local dairy farms were not sustainable and as an industry we were lagging a long way behind the small ruminants in terms of research. Therefore, she set out to determine the current status of drench resistance on local dairy farms with a view to raising awareness amongst farmers about the importance of using drenches sustainably and creating a platform for further dairy industry-specific research into this 'not so sexy' field in the future. Her research has now been presented at a number of Australian and international scientific conferences but her greatest passion is working with individual dairy farmers to create tailored parasite control programs according to their needs and facilitating parasite control Q & A sessions at farmer discussion groups.

She currently lives with her fiancé Brenton on their 400-cow predominantly Holstein-Friesian dairy farm in Denison, Victoria.



Ashleigh Wildridge

Growing up in the Camden area, I never really had much farm exposure, but I always had an interest in large animals. When I hit high school and elected to do the agricultural based electives I became particularly interested in farming and livestock. I then spent four years at Charles Sturt University in Wagga Wagga studying a bachelor of Animal Science where in my final year I completed an honours project studying social behaviour of beef cattle. This led me to a symposium where I met the dairy research group at Camden (yep back home) and the following year began a PhD with them. I am now in the middle of my PhD looking at the manipulation of management and infrastructure on pasture based automatic milking systems (AMS) to observe the impacts on cow behaviour and welfare with a particular focus on heat stress in these systems.



Joshua Aleri

Josh Aleri is a veterinarian and cattle researcher who has just completed a PhD in dairy cattle health and welfare at the University of Melbourne. His research program focused on assessing the relationships between animal immune responses with health and production performance.

Josh has a strong interest in cattle medicine, herd health programs and disease control and eradication programs. He hopes to improve dairy farming sustainability through his research.

**MAKES
OTHER
COFFEE
LOOK LIKE TEA**



BRING IT ON

Efficient and Inefficient cows in Pasture-based Automatic Milking Systems

Juan Molfino., S.García and K. Kerrisk

Faculty of Veterinary Science, School of Life and Environmental Sciences, The University of Sydney Camden, New South Wales, Australia
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Abstract

In pasture-based automatic milking systems (AMS) operating with voluntary traffic it is evident that there are cows which are more efficient (produce more milk from relatively less milkings) and some which are less efficient. The aim of this study was to develop a methodology to identify Efficient and Inefficient cows through the analyses of milk production and the frequency of milkings across the whole lactations. Two large datasets from two commercial farms were collected from a 4 year period. Linear mixed models were used to determine the effect of stage of lactation and parity and to obtain predicted means and residuals for daily milk yield (DMY) and daily milking frequency (DMF). Relative residuals (RR (%)) = residual/predicted mean) were calculated and used to estimate the DMY and DMF of each cow in relation to her predicted mean. Average DMY, DMF and RR were calculated for the whole lactation of each cow. Cows presenting a positive RRDMY and a negative RRDMF were categorized as Efficient and cows presenting a negative RRDMY and a positive RRDMF as Inefficient. Efficient cows were identified in both farms producing on average 9% more milk with 5% less milkings per day and Inefficient cows producing 10% less milk with a 6% higher milking frequency in relation to their predicted means. These findings demonstrate the success of the methodology designed in this study to identify Efficient and Inefficient cows. Developing an understanding of the causes of the differences will be an important next step which may help to determine the potential to lift inefficient cows into the efficient category.

Introduction

The adoption of Automatic Milking Systems (AMS) in Australia continues to increase. In early 2016 there were 38 farms operating and another 5 in an installation phase. Most of these farms (85%, N. Lyons pers. comm.) are pasture-based and operate with voluntary cow traffic. When voluntary cow traffic is evenly distributed (over 24 h) the utilisation of the milking robots is optimized and the amount of time cows spend queuing for a given milking session is minimized thereby improving the general efficiency of the system. The regularity and timing of voluntary cow traffic is affected by many factors including (but not limited to) cow (e.g. genetics, breed, age, stage of lactation, production level), management (e.g.

timing, placement and distribution of feed) and environmental factors (e.g. climatic conditions, laneways).

It is known that in AMS there is a strong positive relationship between milking frequency (determined predominantly by voluntary cow traffic) and milk production levels. In conventional milking systems milking frequency is controlled by the farm operators and is typically held at twice a day. In contrast, AMS farms operating with voluntary traffic create opportunity for cows to access the robots and get milked more often and therefore the possibility to achieve greater milk yields.

However, anecdotal evidence suggests that some cows are more efficient (produce more

milk from relatively less milkings) than other cows in the same herd. If the 'inefficient' cows (those who produce less milk from relatively more milkings) were identified, they could be managed separately to increase the whole farm system performance.

A higher proportion of 'efficient' cows in a herd will allow an increase in the number of cows milked per robot and resultant increased volumes of milk harvested per AMS thereby positively influencing the profitability of the operation (Jago *et al.*, 2010). 'Efficient' cows could also be more suitable for farms milking large herds under pasture-based conditions, as every milking session is attributed with walking (from paddock to the dairy) in which cows spend a considerable amount of time and energy (both limited resources). Increased walking distances will divert energy from milk production, reduce available grazing time and has the potential to negatively impact dairy cow welfare.

Automatic milking systems capture large volumes of data about the individual cows, most of which are not readily utilised by the farmer. Some of this data could be used to identify cows with different levels of 'efficiency' and see if the variability between Efficient and Inefficient cows is large enough to allow different management practices to be implemented on each type/group of cows. Thus, whole lactation data from two commercial AMS farms were used to firstly develop a methodology to identify Efficient and Inefficient cows; and secondly, assess the magnitude of the associated variability.

Materials and Methods

Data were collected from the AMS software on 2 commercial farms (NSW and VIC). Farm 1 had 4 single box milking units and Farm 2 had 2 single box milking units (both Lely A4). Both farms operated as pasture-based systems with voluntary cow traffic and were managed with a 3-way grazing system (Lyons *et al.*, 2013a). Cows in both herds had access to concentrate feed (allocated based on their production level), during milking in the AM unit and after

milking in automated feed stations. Farm 1 managed a seasonal (Spring) calving pattern with a Holstein-Friesian herd and Farm 2 operated with a year-round calving pattern with a mixed-breed herd of Holstein-Friesian (90%) and Brown Swiss (10%). Historical data covering the period from January 2012 to January 2015 were collected from both farms. Data collected included cow number, parity, days in milk, daily milk yield (kg milk/cow/day) and daily milking frequency (number of milkings/cow/day). The dataset was organised, filtered and aberrant values were deleted. The final dataset contained records from 206 cows from Farm 1 and from 179 cows from Farm 2. Farm datasets were analysed separately throughout the study.

The data capture period extended across several years which resulted in some cows contributing to the dataset across more than one lactation. Due to the variability (between days) of daily production and milking events typically observed in AMS, seven-day averages were used to calculate daily milk yield (DMY) and daily milking frequency (DMF). The following variables were categorized: Parity (5 categories, lactation number 1=1, lactation number 2=2, lactation number 3=3, lactation number 4=4, lactation number $\geq 5 = 5$) and days in milk as Stage of lactation (SOL as 31 categories using a span of 10 days per category).

Statistical Analysis

A linear mixed model (REML) was used to determine the effect of stage of lactation and parity on the two outcome variables DMY and DMF, and to obtain predicted means and calculate residuals values. In both models Stage of Lactation, Parity and their interactions were included as fixed effects and Cow ID was fitted as a random term. All analyses were conducted using Genstat 16th Edition (VSN International Ltd). Residual analysis was performed to check for normality. The model for both analyses was as follow:

$$y = \text{constant} + \text{Parity} + \text{SOL} + (\text{Parity} * \text{SOL}) + \text{CowID} + \varepsilon$$

Where, y is daily milk yield (DMY; kg/cow/day) or daily milking frequency (DMF; number of milkings/day); Parity = effect of parity (LacNo 1... 5); SOL = effect of stage of lactation (SOLNo 1, ..., 31); Cow ID = effect of Cow and ε = random error.

For both outcome variables DMY and DMF, predicted means and residual values resulting from the model were used to calculate the relative residual (RR): Relative residual (%) = residual value / predicted mean.

The relative residual was calculated in order to estimate how much a cow produced (for DMY), or how many times she was milked per 24 h (for DMF) in relation to her fitted or expected value after removing the effects of stage of lactation and parity number. For example, a cow presenting a RR of DMY of 10% and a RR of DMF of -20% indicates that the cow produced 10% more milk above her expected production value with a milking frequency 20% below her expected frequency value.

Categorization and Lactation data analysis

In order to categorize cows, lactation curves were constructed utilizing DMY, DMF and RR for both variables for each cow, excluding lactations <290 and >310 days and/or lactations with less than 90% of the lactation records available.

Thus, only 113 lactations from 85 cows were included in the categorisation from Farm 1 (30% of the total recorded lactations) and 179 lactations from 110 cows from Farm 2 (44% of the total recorded lactations). There were 28 cows in Farm 1 and 62 cows in Farm 2 that were included more than once (up to 3 lactations).

For each cow lactation, averages of relative residual for DMY (RRDY) and DMF (RRMF)

were calculated for the whole lactation and utilised to categorize the performance of cows. Cows presenting a positive RRDY and a negative RRMF were categorized as Efficient (EFF); cows presenting a negative RRDY and a positive RRMF as Inefficient (INEF). For each category, averages of DMY and DMF were calculated for three periods: whole lactation, early lactation (30-60 days in milk) and late lactation (180-210 days in milk). A simply ANOVA was used to determine if the differences between the averages of the 2 categories for each variable were significant (P values lower than $P < 0.05$ were considered significant).

Results

Lactation data characteristics for both farms are shown in Table 1. Values for DMY and DMF were within the range of typical values for a pasture-based AMS and were greater in Farm 1 (high input system) in comparison to Farm 2.

Categorization

On Farm 1, 9 cows (11 lactations; 10% of total lactations) were categorized as EFF and 18 cows (19 lactations; 17% of total lactations) were categorized as INEF. On Farm 2, 25 cows (29 lactations; 11% of total lactations) were categorized as EFF and 12 cows (13 lactations; 7% of total lactations) were categorized as INEF. Lactation characteristics for each category are shown in Table 1.

In Farm 1, average DMY for the whole lactation was 30% higher in the EFF than in the INEF group with a 9% lower DMF. In Farm 2 the difference between EFF and INEF groups for DMY and DMF were of 40% and 6% respectively. Although the differences in milking frequency observed between the groups are relatively modest in both farms (Table 1) they were significant. Efficient cows presented significantly higher average DMY and lower DMF than Inefficient cows in early, late and whole-lactation in both farms ($P < 0.001$).

Table 1. Averages of lactation characteristics for each group for Farm 1 and Farm 2.

	Farm 1				Farm 2			
	All	SE	Efficient	Inefficient	All	SE	Efficient	Inefficient
Lactations (n)	113		11	19	179		29	13
Cows (n)	85		9	18	110		25	12
Relative Residual DMY (%)	-1	0.02	8 ^a	-9 ^b	4	0.01	10 ^a	-11 ^b
Relative Residual DMF (%)	1	0.01	-7 ^b	7 ^a	0	0.01	-6 ^b	5 ^a
Lactation DMY (kg/d)	25.2	0.48	29.7 ^a	22.8 ^b	19.2	0.4	21.09 ^a	15.01 ^b
Early lactation DMY (kg/d)	36	0.74	44 ^a	33.15 ^b	23.2	0.55	25.54 ^a	16.93 ^b
Late lactation DMY (kg/d)	19.7	0.45	22.8 ^a	18.15 ^b	18.3	0.39	19.74 ^a	15.12 ^b
Lactation DMF (events/d)	2.25	0.03	2.13 ^b	2.33 ^a	2.02	0.02	1.95 ^a	2.08 ^b
Early lactation DMF (events/d)	2.65	0.05	2.52 ^b	2.86 ^a	2.08	0.03	2.01 ^a	2.12 ^b
Late lactation DMF (events/d)	2.15	0.04	1.96 ^b	2.24 ^a	2.01	0.02	1.93 ^b	2.05 ^a

SE: Standard Error; Different letters (within row) indicate significant differences ($P < 0.05$) between groups.

Table 2 shows an estimation of what could be achievable in Farm 1 and Farm2 if the milking herd was composed in their totality by cows of the same category, assuming the robot performs around 160 milkings per day (occupation rate of 80%, fixed duration of a milking of 7 minutes, typical values observed on commercial AMS farms under grazing conditions in Australia; K. Kerrisk, pers. comm.)

When comparing milking an 'efficient' herd against 'inefficient' herd, production per AMS unit increases 42% for Farm1 and 49% for Farm 2, with a relative increase of only 6 and 5 cows per AM unit respectively.

Table 2. Estimation of number of cows and extra milking production for Farm 1 (F1) and Farm 2 (F2).

	Efficient		Inefficient	
	F1	F2	F1	F2
DMF (events/d)	2.13	1.95	2.33	2.08
DMY (kg/d)	29.7	21.0	22.8	15.0
Cows milked/AMS (n)	75	82	69	77
Milk harvested (kg/AM unit)	222	172	156	115
	7	9	6	6

The objective of this estimation and comparison is to show the potential increases in milk harvested per AMS however, it is important to recognize that a more realistic approach on a commercial farm will likely be to firstly attempt to reduce the proportion of INEF cows present in herd and at the same time increase the proportion of EFF cows. Another way of generating a significant impact would be by managing the different groups of cows in different ways, and not necessarily eliminating those individuals that are not efficient.

Repeatability

In Farm 1, of the 28 cows that presented two lactations analysed, only 2 were categorized as EFF in both lactations and one cow was categorized as INEF in both lactations. There were no cows categorized EFF and INEF (in different lactations). In Farm 2, 4 cows were categorized as EFF in both lactations and one cow was categorized as INEF in both lactations. There were 2 cows that were categorized as INEF in the first lactation and EFF in the second lactation analysed.

Category & Parity

In Farm 1, the majority of cows in the EFF group (81%) were in their 4th or 5th lactation and most of the INEF cows (42%) were primiparous or cows in their second lactation (32%) despite correcting for parity in the models. Conversely in Farm 2 almost half of the EFF lactations were 1st & 2th lactation cows (48%).

Discussion

The objective of this study was to develop a methodology to identify EFF and INEF cows through the analysis of whole lactation datasets from two commercial farms. This was achieved by comparing data from complete lactations of individual cows with the predicted means for each category of parity. Our results showed that on both farms, about 13% (range 10-16%) of the lactations analysed were identified as EFF and about 12% (range 7-17%) as INEF.

In this study Efficiency was defined as a relationship between daily milk yield and daily milking frequency; DMY is the main output of the system and; DMF represents a 'cost' for not only the cow (time and energy, both limited resources) but also the system (power, water consumption, etc.) The most efficient operation of an AMS will be an optimisation of milkings/cow/day to maximise the number of cows that can be milked whilst minimising any drop in production per cow associated with lower milking frequency.

The variability in cow performance (DMF and DMY) observed among cows in both datasets was key and enabled the categorisation of the cows based on their performance. These differences may be explained by multiple factors including Cow factors (genetics, animal behaviour, milking characteristics, feeding efficiency, and previous experience) and System factors (feed management, herd dynamics, waiting times, walking distances).

Differences in DMY and DMF between groups in early lactation were also evident in late

lactation, indicating that a cow could remain EFF/ INEF for the whole lactation. This may allow us to use early lactation data to predict which cows are EFF or INEF, in order to apply different management strategies for the different groups to improve the performance of the system. However, results also indicate that a cow is unlikely to be 'efficient' for its lifetime as only a low proportion (8%) of cows which had two or three lactations analysed were categorized as efficient or inefficient across more than one lactation. This suggests that the factors creating 'efficiency' (high producing cows with less than average milkings per day, as defined in this study) could be driven mostly by management/environmental factors rather than genetics or a combination of them, but further investigation is required to confirm this.

Individual milking characteristics like milking speed and time spent in the robot per milking, were not analysed in this study, but are both recognised as significant factors affecting milk harvesting efficiency in commercial AMS herds.

Future research

A more complete understanding of the different levels of Efficiency is needed as many questions about these individual cows still remain. Developing an understanding of the causes of the differences will be an important next step which may help to determine the potential to lift INEF cows into the EFF category. Data from this study suggests that the efficiency is not repeatable – giving a strong indication that is not due to genetic and/or that management/environment is playing an important role. Once an understanding of the key factors impacting on efficiency is developed the research should focus on how to implement distinct management practices on commercial farms and their impact on productivity.

Conclusion

These findings demonstrate the success of the methodology designed in this study to identify Efficient and Inefficient cows. The potential

exists to increase productivity by managing cows with different levels of efficiency in different ways but further research is needed it to improve the understanding.

Acknowledgement

The authors gratefully acknowledge the Dairy Research Foundation for its support of the Dairy Science Group and the investors of the FutureDairy project (Dairy Australia, The University of Sydney, and DeLaval). The authors acknowledge Evelyn Hall and Peter Thompson for their statistical input.

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Concentration and Distribution of Sialic Acid in Sow Milk during Lactation

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Abstract

Sialic acids (Sia), a family of 9-carbon acidic sugar molecules, are key monosaccharide units of brain gangliosides and glycoproteins and a major component of sialylated glycotope in human milk. Human milk Sia has been proposed as a bioactive compound promoting immune function, gut maturation and neurodevelopment of the newborn. Porcine milk however, has received little attention. The aims of the present study were to quantify and compare the levels of N-acetylneuraminic acid (Neu5Ac), N-glycolylneuraminic acid (Neu5Gc) and ketodeoxynonulosonic acid (KDN) in oligosaccharide, glycoprotein and glycolipid in sow milk during course of lactation. Milk samples from 22 sows were collected by manual expression on 3 occasions, day 1 (colostrum), day 3 (transition milk) and day 15-21 (mature milk) respectively. The concentration of Neu5Ac, Neu5Gc and KDN were analyzed using UHPLC. The results showed that sow milk contained significant amounts of Sia with the highest concentration found in colostrum (1238.50 mg/L) followed by transition milk (778.32 mg/L) and then mature milk (347.21 mg/L). Most of the Sia in sow milk was conjugated to glycoproteins (41-46%), free oligosaccharides (31-42%) and then glycolipid (12-28%) throughout the course of lactation. Neu5Ac was the major form of Sia (93-96%) and then Neu5Gc (3-6%), KDN however contained as little as 1-2%. This distribution was common to each milk fraction and to each time point in lactation. In conclusion porcine milk contains a rich source of sialylated glycan in the forms of glycoproteins, free oligosaccharides and glycolipids. The high concentrations of Sia in porcine milk suggest that Sia is an important nutrient that may contribute to the optimization of immune function, neurodevelopment and growth and development of piglets.

Introduction

Sialic acids (Sia), a family of 9-carbon acidic sugar molecules, are key monosaccharide units of brain gangliosides and glycoproteins and a major component of sialylated glycotope in human milk. Human milk Sia has been proposed as a bioactive compound promoting immune function, gut maturation and neurodevelopment of the newborn (Wang, 2009). Porcine milk however, has received little attention. The aim of the present study was to quantify and compare the levels of three important Sia, N-acetylneuraminic acid (Neu5Ac), N-glycolylneuraminic acid (Neu5Gc) and Ketodeoxynonulosonic acid (KDN) in

oligosaccharide, glycoprotein and glycolipid component of sow milk during the course of lactation. Outcomes will significantly benefit pig production as the data will be helpful to pig milk replacer development to optimise growth and development of piglets.

Methodology

Milk samples from 22 of sows (Sus scrofa, Belgian Landrace, Large White and Duroc breed) were collected by manual expression on 3 occasions, day 1 (colostrum), day 3 (transition milk) and day 15 (mature milk) respectively. All samples were obtained from the commercial farrowing shed at the Pig

Improvement Company (PIC) facility at Grong Grong, N.S.W, Australia. Each milk sample was prepared according to figure 1 (Wessel & Flügge, 1984).

The concentration of Neu5Ac, Neu5Gc and KDN were analysed using UHPLC- fluorescence using DMB as the derivatizing reagent (Hara *et al.*, 1989).

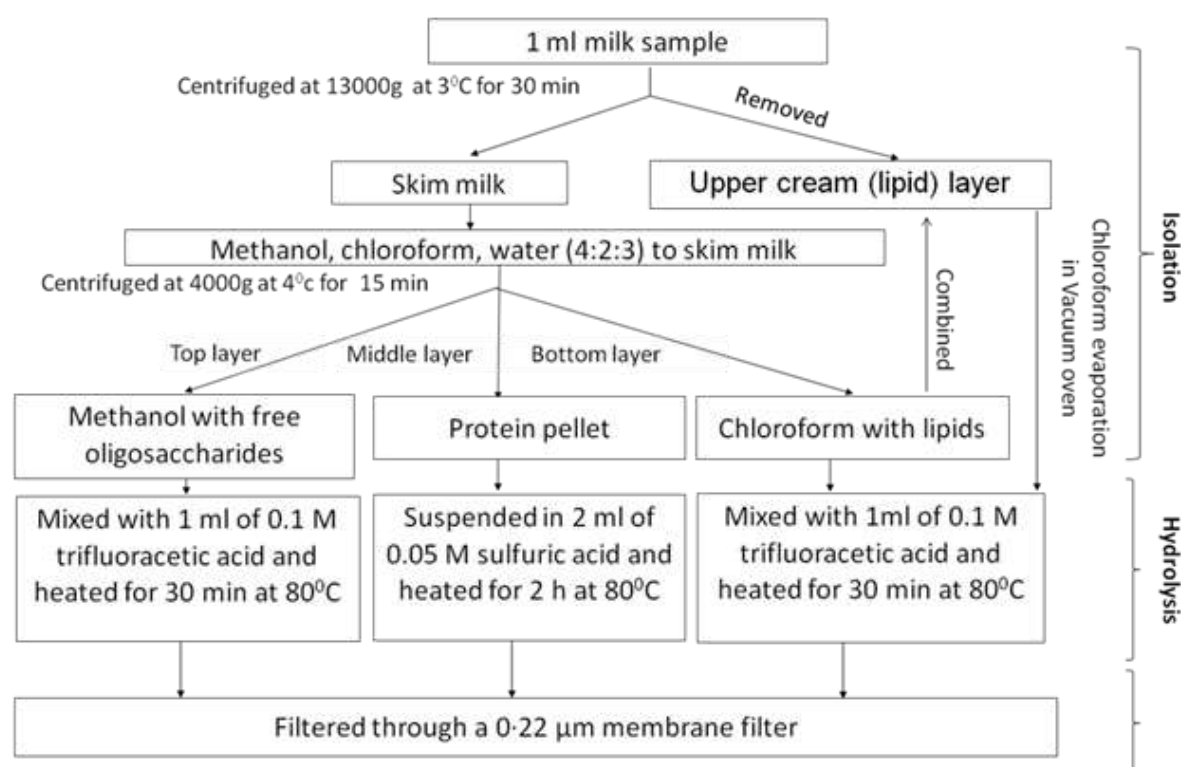


Figure 1: Schematic presentation of preparation of milk sample

Results

In sows the highest concentration of Sia was found in colostrum (1238.50 mg/L) followed by transition milk (778.32 mg/L) and then mature milk (347.21 mg/L). Neu5Ac was the major form of Sia (93-96%), then Neu5Gc (3-6%), and finally KDN (1-2%). Most of the Sia was conjugated to glycoproteins (41-46%), free oligosaccharides (31-42%) and then glycolipid (12-28%).

Discussion

Porcine milk showed significant declines in Sia concentrations over the course of lactation with total Sia in colostrum being about 1.5 times higher than in transition milk and about 4 times

higher than in mature milk. The possible reason of this decline might be caused by reducing Sia synthesis and/or increasing dilution of Sia due to increased synthesis of milk the course of lactation in lactating pigs. Špinková, Illmann, Algers, and Štetková (1997) reported that the milk output per teat increased from 18.0 ± 1.1 g/h on day 1 to 21.5 ± 1.0 g/h on day 2, and to 24.5 ± 1.3 g/h on day 3. Similar results were also reported in human milk (Wang, Brand-Miller, McVeagh, and Petocz (2001); bovine milk (Nakamura *et al.* (2003) and both human and bovine milk (Martín-Sosa, Martín, García-Pardo, and Hueso (2003).

According to Verstegen, Moughan, and Schrama (1998) transition from colostrum to 'mature milk' is generally associated with a

substantial decline in total solids from 25 % to 18 % and proteins from 15 % to 5 %. At the same time an increase in concentration of lactose from 3.4 % to 5.3 % and fat from 6 % to 8 % is usually found. Csapo, Martin, Csapo-Kiss, and Hazas (1996) reported that porcine colostrum contained 16.65% protein, which then decreased to 5.83% in mature milk. Therefore the overall decrease in total solid content of porcine milk, in particular the protein content, might help explain the decline in Sia concentration in both sow and gilt milk. Useh, Olaniyan, and Nok (2008) also suggested that the higher level of Sia in the colostrum compared to mature milk could possibly be related to more complex interactions between the glyco-conjugates associated with mucosal immunity and enteric pathogens.

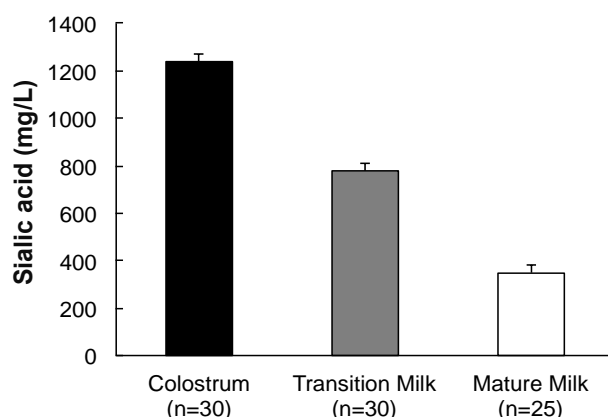


Figure 2: Total Sia concentration in colostrum, transition milk and mature porcine milk * Significant difference with colostrum ($P < 0.001$) † Significant difference with transition milk ($P < 0.001$)

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Testing decision making in dairy heifers using a sound stimulus

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Abstract

Dairy cattle use sound to not only communicate, but also interpret their environment. The ability to use sound signals on dairy farms to benefit cattle productivity and welfare remains largely unexplored. This experiment trained dairy heifers to follow a 500 Hz, 70 dBA sound stimulus positively reinforced by pelleted grain-based concentrate (GBC). Six heifers were habituated then conditioned with classical and operant techniques to associate the sound with GBC in a symmetrical T-maze over 21 days. Side preference and feed motivation was also tested. Heifers correctly chose the side of the T-maze where sound was emitted 54% of the time on day one of testing which increased markedly to 92% by the final day. Side preference had no impact on the ability to be trained despite five out of six heifers having distinct laterality to the T-maze, four of which preferring the right hand side. There was no impact of feed motivation on the ability for each heifer to learn the sound stimulus and there was no inter-trial or inter-heifer variation detected for choice tests. We conclude that heifers have the cognitive ability to rapidly learn tasks associated with sound stimuli justifying further investigation into the use of sound on farm to improve dairy cattle productivity and welfare.

Introduction

In conventional and automatic milking systems (AMS), dairy farmers are subject to the repetitive task of fetching cattle for milking which is problematic to both farm efficiency and cow welfare. Since dairy cattle have an auditory detection extending from 23 to 37,000 Hz (Heffner & Heffner, 1992), which is utilised to acquire information about their environment and subsequently modify their behaviour (Kaplan, 2014), the application of sound signals could be adopted as a novel method to encourage voluntary cow traffic. Through classical and operant conditioning training, the association between sound signals and a feed reward could be formed, to entice herds or individuals to the milking unit thereby alleviating farm workload, and reducing

injuries of cows moved by 'pushing up' as they could instead walk at their own optimal pace.

There is a paucity of data on the use of sound stimuli in dairy cattle with existing research mainly focusing on training at the herd level (Albright *et al.*, 1966; Kiley-Worthington & Savage, 1978). Individual differences in decision making remain largely unexplored and of the studies that have attempted to address this, there have been methodological problems. Most recent studies have highlighted the difficulty of training individual cows in one context, where context involves the location of the sound source and physical environment, to respond to sound stimuli at other locations on farm (E Wredle, Rushen, de Passillé, & Munksgaard, 2004; Ewa Wredle, Munksgaard, & Spörndly, 2006). The study of Wredle, Munksgaard & Spörndly (2006)

involved training heifers to a sound stimulus indoors in a 3 m wide pen, resulting in only 28% success when applied outdoors. The inability of these heifers to transfer their learning highlights the necessity to broaden the training context, such as the setting in which training takes place, in order to achieve responses high enough for commercial application.

The aim of this study was to determine the ability of dairy heifers to be trained to follow a 500 Hz, 70 DbA sound stimulus in a T-maze, where responses were reinforced by pelleted grain-based concentrate (GBC). By applying the sound stimulus at different locations in the T-maze, the dependence of learned behaviour on a specific context is mitigated, individual ability in decision making is assessed and any confounding factors such as side preference to the T-maze is determined. It was hypothesised that (1) heifers would successfully be trained using classical and operant conditioning, with responses to the sound stimulus improving with increased days of training; (2) heifers will have specific left side preference to the T-maze setup as suggested by Hopster, Van der Werf & Blokhuis (1998) and this would influence their ability to learn the operant task; and (3) there would be differences between the cognitive abilities of each animal, with the more feed-motivated heifers showing a greater number of correct responses.

Methods

Animals and Management

The trial was conducted at The University of Sydney Camden Campus 'May Farm' over a 21 day period between 22 June 2015 and 12 July 2015. Six heifers were selected from a herd of 50 Holstein-Friesian, Angler and Australian Red cattle, to have similar (mean \pm S.D.) age (28.3 months \pm 0.11), live-weight (436.8 kg \pm 49) and predicted date of calving (4 November 2015 \pm 35 days). Having had no pre-training or exposure to the T-maze, these heifers were naïve to cognitive testing.

Testing procedure and T-maze layout

The testing procedure was conducted in a symmetrical T-maze (width = 48m, length = 7m) between 0800 and 1200 h, with remaining heifers kept in individual pens (width = 80 m, length = 60 m) for a maximum of 4 h. The T-maze contained feed bins on both the left and right sides along with speakers for the sound stimulus. To prevent bias in the learning procedure, black tarpaulin covered the T-maze edge adjacent to the individual pens and pink background noise was played at an amplitude of 80 dB to mask the sound of the signal.

Heifers were habituated to the T-maze with the assistance of 250 g pelleted GBC at each feed bin, firstly in pairs during days 1 to 4 and then individually from days 5 to 7. On days 8 to 15 individual side preference of each heifer to the T-maze was tested. Heifers were again enticed by the 250 g pelleted GBC at each feed bin and whichever side they visited first was recorded for the 17 trials.

From days 11 to 15 the heifers were 'classically' conditioned, to associate the 500 Hz intermittent tone with the reward of eating at the feed bins. The heifers had free access to both the left and right hand side of the T-maze, and each time the heifer placed her head in a feed bin the sound stimulus was activated remotely to play on the speaker located at that feed station.

On days 16 to 21 'operant' conditioning took place with heifers tested 4 times per day. Operant conditioning involves the feed reward being dependent on the heifers' response to 'coming when called'. Therefore, the reward was only provided on the side of the T-maze where the tone was emitted, with the tone beginning to play as the heifer entered the gate of the T-maze. Correct responses were classified as the heifer making her way to the side of the T-maze where the sound stimulus was playing and incorrect responses were classified as the heifer approaching the side of the T-maze where the sound stimulus was absent. To prevent any olfactory bias, GBC was located on both sides of the T-maze but

inaccessible by the heifer on the incorrect side. On days 16 and 17 preliminary data was collected with the sound stimulus paired to each heifer's preferred then non-preferred sides respectively. On days 18 to 21 (16 trials) the sound stimulus and feed reward were applied to a randomly selected side of the T-maze. Time to access the feed bin and duration spent eating was recorded for each heifer.

Finally a feed motivation task was conducted amongst the six heifers over five rounds in a similar maze setup. In the first round, all six heifers had access to a feed bin with pelleted GBC. After each round, a feed bin was removed and the heifer which spent the least time with her head in the feed bin during that round was eliminated. Animals were then ranked according to the last round they accessed feed, with a greater number of rounds being associated with a greater feed motivation.

Statistical analysis

The frequency of visits for each heifer to the left and right sides of the T-maze was calculated using 'GenStat', 17th edition. Where side preference was not 100%, paired t-tests were conducted to determine whether a particular side was significant.

The percentage of daily correct responses for the herd was calculated for days 18 to 21. The proportion of these correct responses was compared using a logistic binomial regression model and a logit link in R: 'R Studio', version 3.2.0. The dataset of 96 observations included the variables of heifer ID (1 to 6) and trial number (1 to 16) which were random effects, and day (1 to 4) and ranking (1 to 6) which were fixed effects. Deviance difference tests were conducted with the level of significance set at $P < 0.05$.

Results

Heifer 2, 4, and 5 were classified as having preference to the right hand side of the T-maze (Table 1). Heifer 6 showed distinct preference to the left hand side of the T-maze

(Table 1). Heifer 1 expressed 76% of her T-maze choices on the left hand side, and her left hand side preference was still significant ($P = 0.02$). In contrast, Heifer 3 expressed 70% of her T-maze choices on the right hand side, but this result was not significant ($P = 0.09$) (Table 1).

The proportion of correct responses to the sound stimulus for the herd increased over time ($P = 0.006$). Every additional day of the experiment increased the log odds of a correct response by 0.64 units (equation 1). This is an increase in the odds of a correct response by a factor of $e^{0.64}$, or 1.90. The formula for calculating this is as follows:

$$\log_e \left(\frac{\hat{\pi}_i}{1-\hat{\pi}_i} \right) = -0.42 + 0.64day_i$$

(equation 1) where π_i is the estimated probability of a correct response to the sound stimulus at day_i . The random effects of trial and heifer were not significant in this model (0, 1.03 at 95% CI), and (0, 1.35 at 95% CI) respectively.

On day 18 the percentage of correct responses for the 6 heifers was 54%. On days 19 and 20 the percentage of correct responses rose to 75% and by day 21 correct responses were achieved on 92% of trial runs. In particular, Heifer 2 achieved 100% correct responses from the third trial onwards. Heifer 4 demonstrated a significant decrease in time to access the feed bin as correct decisions improved ($P = 0.004$). Minimum times to access feed, minimum eating times and heifer ranking in the feed-motivation task are provided in Table 1.

Discussion

The results demonstrate that sound signals have the potential to be applied on farm as a means of 'calling' cattle. This research showed that heifers have the decision making ability to modify their choice behaviour in a T-maze over the course of testing, so as to follow a sound stimulus to receive positive reinforcement. The random allocation of the sound signal throughout the trials and larger outdoor testing

facilities allowed us to mitigate the issue of context specificity, minimising the potential interference of sound signal location on decisions made. As conditioning progressed, heifers showed a significant increase in correct responses, indicating an improvement in learning performance with extra days of training. Similar successful outcomes of conditioning have been reported where cattle have been trained to approach a feeder where sound stimuli are applied indirectly on the animal (Albright *et al.*, 1966) or directly at the food source (Kiley-Worthington & Savage, 1978).

The behaviour expressed in the side preference testing is consistent with the finding that individual cattle side preference exists (Paranhos da Costa & Broom, 2001). Contrary to our hypothesis, while 5 of 6 heifers had distinct laterality to the T-maze, the majority of them preferred the right side over the left. This is despite both sides of the T-maze containing pelleted GBC and may be attributed to the tendency of heifers to repeatedly select the side where feed was previously placed (Hopster, Van Der Werf & Blokhuis, 1998). Regardless of any side preference the heifers were neither discomforted nor stressed when trained to follow the sound stimulus on their non-preferred side. This agrees with Paranhos da Costa and Broom (2001) who found that while 72% of cattle were consistent in their side choice at the milk parlour, there was no significant evidence that they were uncomfortable when milked on their non-

habitual side ($P > 0.05$).

The behaviours expressed in the feed-motivation task depict how cattle organise themselves into hierarchies based on their willingness to obtain a certain resource (Phillips, Oevermans, Syrett, Jespersen, & Pearce, 2015). Heifer 2 was the most willing to compete for the pelleted GBC evident by her minimum recorded time of 16 seconds to access the pelleted GBC, and minimum eating duration over the 16 trials (Table 1). It suggests she was the highest feed-motivated heifer and may explain why she was able to achieve the most correct responses. Despite Heifers' 3 and 1 being the least willing to obtain the reward in the feed motivation task, they exhibited high appetitive behaviour when conditioned individually achieving 81.3% and 62.5% correct responses respectively (Table 1). Evidently heifer ranking did not encumber learning the sound command since individual animals had equal opportunity to access the reward, suggesting that in the group setting they were more influenced by avoidance of agonistic interactions than feed (Rioja-Lang, Roberts, Healy, Lawrence, & Haskell, 2009). This explains why there was no detectable inter-heifer variation in the response to the sound stimulus, as seen by the non-significant random effect of heifer.

Conclusion

This training procedure highlights the opportunity to use sound signals to call in cattle

Table 1. Individual responses to feed-motivation ranking, side preference testing and sound stimulus conditioning

Heifer	1	2	3	4	5	6
Feed-motivation ranking (1st-6th)	6	1	5	2	4	3
LHS preference (%)	76	0	30	0	0	100
RHS preference (%)	24	100	70	100	100	0
Overall correct responses (%)	62.5	87.5	81.3	56.3	87.5	68.8
Min time to access feed (s)	32	16	35	35	29	29
Min time to eat (s)	105	72	90	90	101	101

for milking but should be subject to further research including testing whether expanding the training context to the T-maze allows heifers to apply their knowledge of the sound signal at the milking unit. Extension of this study should also involve a greater number of animals and a longer testing period to determine if supplementary training would lead to further improvement in learning performance and to test if learning remains over time.

Acknowledgement

This experiment was supported by a grant from the University of Sydney, Faculty of Veterinary Science. Special thanks to Jan Van Ekris, Kim McKean, Kamila Dias, Leesa Dinham and Juan Molfino for their assistance in developing and conducting the trial.

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Diurnal feeding patterns of dairy cattle and implications for automatic milking systems

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Abstract

The robot utilisation and diurnal feeding patterns of cows in automatic milking systems (AMS) are closely related. Therefore, understanding the factors influencing grazing behaviour is fundamental to unlocking the full potential of AMS. This study determined the diurnal feeding behaviour of non-lactating dairy cattle when the nutritive value of feed remains constant and when the time of feed on offer is restricted. Lucerne hay cubes were offered ad-libitum in three treatments: 24 h feed access (24 h), day feed access (day) (0600-1800 h) and night feed access (night) (1800-0600 h). Here we discovered 24 h treatment cows consumed 69% of total daily intake during the day (0600-1800 h), with only 12% of intake occurring between 2400-0600 h. Day treatment cows split their intake relatively evenly between the two feeding periods (56% 0600-1200 h and 44% 1200-1800 h). In comparison, night treatment cows consumed 74% of their feed during the first six-hour period (1800-2400 h). Total daily eating time and intake was greater ($P < 0.001$) in the 24 h treatment (220min, 23.0 kgDM/cow/day) compared to the day (180min, 20.4 kgDM/cow/day) and night (164min, 19.0 kgDM/cow/day) treatments, which did not differ. Diurnal lying patterns varied between all treatments ($P < 0.001$). However, no difference in total daily cow lying time was observed. The low intake levels between 2400-0600 h correspond with the period of lowest robot utilisation typically observed in pasture-based AMS, suggesting a link between diurnal intake patterns and robot utilisation is likely. Future work from our group will test feeding strategies to increase activity at night by varying the amount and type of feed offered throughout 24 h.

Introduction

In pasture-based automatic milking systems (AMS), cows have the freedom to choose when to graze. This creates a unique challenge for farmers utilising AMS in pasture-based systems, as a number of factors can influence feeding and trafficking behaviour of cows (John *et al.*, 2016). These influences come from animal factors such as cow health, stage of lactation, system experience and environmental

conditions, and from management factors such as the type, location, timing and quantity of feed offered. Though, feed availability is the major motivation for cows to return to the dairy for milking (Prescott *et al.*, 1998). For this reason, fresh feed availability is the main incentive used to encourage voluntary cow traffic in pasture-based AMS (Kerrisk, 2009), though how to optimise feed allocation throughout 24 h is still unknown. Robot utilisation has also been linked to diurnal feeding patterns, as influenced by feeding

strategies used on farm (John *et al.*, 2016). Managing 24 h feed allocation to compliment the natural feeding behaviour of dairy cows could improve production in pasture-based AMS by changing the feeding and lying behaviour to suit the system.

Cows follow a diurnal pattern of grazing, with the most intense grazing periods occurring at dawn and dusk, and least intense at night (Gibb *et al.*, 1998). The dusk grazing event comprises approximately 40% of total daily feeding time, whilst grazing at night accounts for as little as 16% of total daily feeding time (Stobbs, 1970). There are a number of reasons for this behaviour, such as diurnal fluctuations in feed quality, photoperiod, predatory instincts and satiety hormones (Gregorini 2012). Gibb *et al.* (1998) found dry matter intake rates of dairy cows increased (17.1 to 23.0 g/min) from 0700 to 1900h and coincided with pasture DM content. Likewise, pasture quality improves throughout the day. Therefore, dusk is the most efficient and nutrient rich time of day to graze. However, diurnal variation in pasture quality adds a confounding factor to studies involving grazed pasture. The impact of time of day on feeding behaviour, in absence of diurnal variation in feed quality is unknown.

The aim of this experiment was to determine the diurnal feeding behaviour and intake patterns of dairy cows in isolation of the diurnal variation in feed quality. A secondary objective of the experiment was to determine if amounts and timing of feeding and or lying behaviour changed when feeding was restricted to only day or night periods.

Material and methods

Animals and treatments

Use of animals was approved by the University of Sydney's Animal Ethics Committee (2014/753). The study was conducted between May 25 and June 14 2015 at one of The University of Sydney's research farms, 'Mayfarm'. Mean (\pm SD) daily minimum and maximum temperatures were 4.1 (\pm 3.0) and 18.1 (\pm 2.2) °C throughout the trial. Cows were

subject to approximately 10/14 light-dark cycle.

Nine non-lactating, multiparous, non-pregnant, Holstein-Friesian cows (626 ± 53 kg live weight, 96 ± 33 months old) were used. Cows were acclimatised in a paddock adjacent to the experimental site 10 days before the experimental period. Lucerne cubes (DM = 88.7%, NDF = 46.4%, ADF = 39.5%, CP = 18%, ME = 8.0 MJ/Kg.DM) were introduced to the diet and offered alongside ad-libitum Lucerne hay (DM = 70.1%, NDF = 51.3%, ADF = 37.3%, CP = 20%, ME = 8.4 MJ/Kg.DM) and built up gradually until consisting of 100% of the diet. Four days before the experimental period, cows were weighed and randomly allocated to 3 treatments ($n = 3$ cows per treatment) and moved to individual pens. Pens measured 30x10 m in dimension, separated by a double wire electric fence. Water was available ad-libitum in each pen.

The experiment duration was 21 d, divided into 3 periods of 7 d in a 3x3 Latin square design. Cows were weighed using a Thunderbird SS1000 system (Thunderbird, Australia) on the first day of each period. Each day was divided into 4 feeding times (1 = 0600-1200 h, 2 = 1200-1800 h, 3 = 1800-2400 h, 4 = 2400-0600 h). Depending on the assigned treatment, cows were offered Lucerne cubes ad-libitum in all 4 feeding times (24 h treatment), in feeding times 1 and 2 (day treatment) or feeding times 3 and 4 (night treatment). To maintain an ad-libitum feed state, cows were offered 13.5 kg DM at the start of each feeding time, with the exception of feeding times 1 and 3 for the day and night treatments respectively, where 18 kg DM was offered.

Data collection

Feed samples were collected daily for analysis of dry matter (DM) content. Pre- and post-feeding feed weight was recorded for every feed period and corrected for DM. Gross intake was determined from the difference between pre- and post-feeding weight. Feed samples were dried at 70°C for 48 h and

ground to <1mm sample size. Dry matter content was calculated using the following equation:

$$\text{Dry matter percentage} = \frac{\text{dry weight}}{\text{wet weight}} \times 100$$

Cows were recorded 24 h/d for the duration of the trial via CCTV (Mobotix M15D, Mobotix Ag, Germany), with an infrared camera used for night recording. Feeding (1 = feeding, 0 = not feeding) and lying (1 = lying, 0 = standing) behaviours were recorded at 5 min intervals for each cow.

Statistical analysis

The last 4 days of each experimental period were used for data analysis. To determine the effect of each feeding treatment on cow feeding and lying behaviour (Figure 1 and 2), binomial data was fitted with general linear mixed models (GLMM) procedure of Genstat version 17 for Windows (VSN International Ltd, Hemel Hempstead, Hertfordshire, UK). Treatment and time were included in the models as fixed effects and cow, nested within day, nested within period, was included as a random effect. Lying behaviour for each feeding period was directly compared between treatments. For feeding behaviour data, the active feeding times for day (feeding time 1 and 2) and night (feeding time 3 and 4) were directly compared. The proportion of daily intake occurring between feeding times were compared between day and night treatments and within the 24 h treatment using REML variance components analysis with treatment and feeding time as fixed effects, and period and cow as random effects. Total daily intake was compared between all three treatments using REML variance components analysis with treatment as the fixed effect and cow as the random effect.

Results

Total daily intake was greater ($P<0.001$) for the 24 h treatment (23.0 kg.DM) compared to the day (20.4 kg.DM) and night (19.0 kg.DM) treatments, which did not differ from one

another. Total daily feeding time decreased ($P<0.001$) from 220 min for the 24 h treatment to 180 min and 164 min for the day and night treatments respectively. Total daily lying was similar between treatments, with 834 min, 804 min and 818 min of the day spent lying for 24 h, day and night treatments respectively.

An effect ($P<0.01$) of feeding time on feed intake (% / feed period) for the 24h treatment was observed. 69% of intake occurred during the day feeding time (0600 to 1800), with the lowest proportion of intake (12%) occurring during the 2400 to 0600 feeding time (Table 1). An interaction ($P<0.01$) between feeding time and treatment (day vs. night) on feed intake (% / feed period) was also observed (Table 1).

Table 1. Percent intake per feeding period

Period	1	2	3	4
24 h	30	39	19	12
Day	56	44	-	-
Night	-	-	74	26

Feeding probability behaviour for each treatment is presented in Figure 1. There was an interaction between treatments (day and night) and time ($P<0.01$) on feeding behaviour. The lying probability behaviour for all treatments during 24 h is presented in Figure 2. There was an interaction between treatment (24h, day and night) and time of day ($P<0.01$) on lying behaviour.

Discussion

The main objective of this study was to determine diurnal feeding behaviour and intake patterns of dairy cattle in isolation of diurnal variation in feed quality. A distinct diurnal feeding pattern was observed. Our results for feeding behaviour (Figure 1) and intake (Table 1) highlight a large variation in feeding activity throughout 24 h between the three treatments. Cows on the 24 h treatment consumed the majority (69%) of their feed during day light. Feeding activity peaked at

dawn (0600 – 0730 h) and dusk (1500 – 1730 h), as observed by Gibb *et al.* (1998). Conversely, the smallest proportion of intake (12%) and associated feeding behaviour occurred between 2400 – 0600 h which is consistent with similar studies (Stobbs 1970). The large variation in feed intake and feeding activity occurring throughout 24 h suggests a value in ‘tailoring’ feed allocation through time to suit diurnal feeding behaviour of cows.

Studies from indoor AMS have linked robot utilisation and feed bunk activity (John *et al.*, 2016). Therefore, a similar link is likely in pasture-based AMS. The use of variable feed allocation on a commercial three-way grazing system has shown that high robot utilisation can be achieved when matching pasture allocation to cows diurnal feeding patterns (John *et al.*,

2013). It is likely that the smaller allocation (20%) offered between 1730 – 0200 h resulted in feed being depleted more rapidly, encouraging cows to voluntarily traffic in search of fresh pasture during the early morning hours. From the evidence of diurnal feeding patterns presented within this paper, varying the amount of feed offered throughout 24 h in pasture-based is likely to provide benefits for voluntary cow traffic and robot utilisation.

A secondary objective of the study was to determine if the occurrence of feeding or lying behaviour changed when feeding time was restricted. Cows on both the day and night treatments showed an initial spike in feeding activity during the first 60 minutes of access to

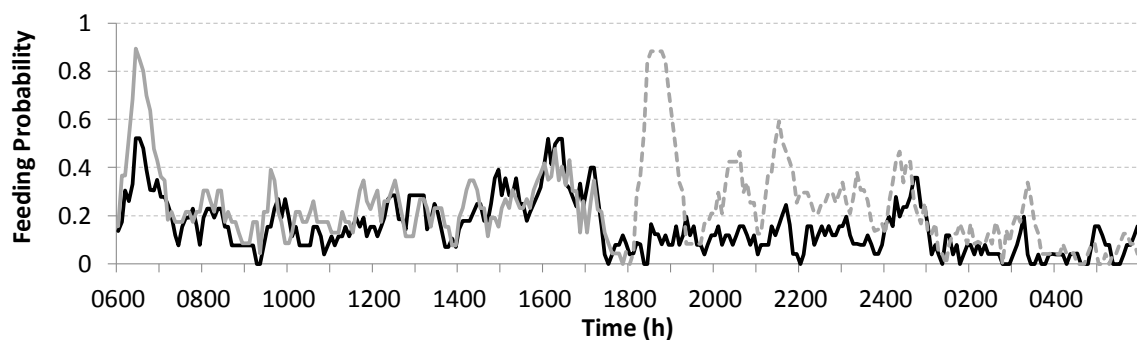


Figure 1. Feeding behaviour probability plots for 24 h (—), day (—) and night (---) treatments.

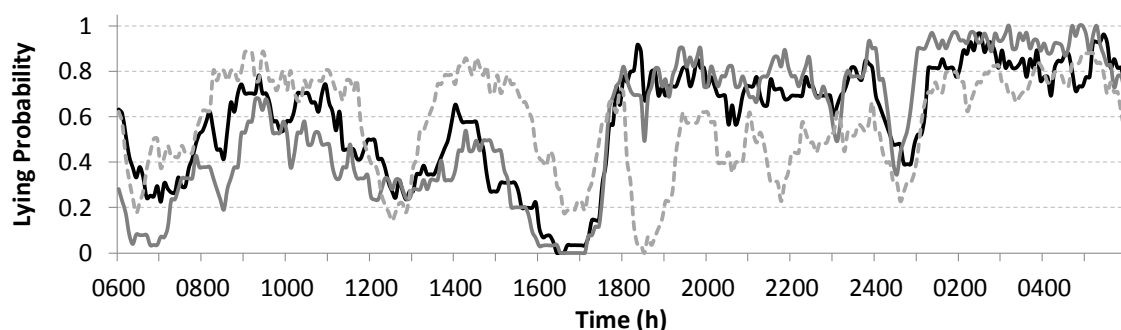


Figure 2. Lying behaviour probability plots for 24 h (—), day (—) and night (---) treatments.

feed, a behaviour also seen by Gregorini *et al.* (2009). Two distinct patterns of feeding behaviour were observed for the day and night treatments. Feeding activity for the day treatment was more consistent across 12 h

periods, with intense feeding activity occurring in the final 3 h of the feeding period (dusk). In contrast, the night treatment exhibited greater feeding activity in the first 7 h and a large decrease thereafter. This pattern was also

observed with the feed intakes data for these treatments (Table 1). These results confirm the strong diurnal feeding patterns discussed above, with night treatment cows prioritising intake in the first 6 h, presumably to minimise the impact on lying time in the early morning. Further, all treatments had unique lying patterns, yet total lying time remained the same. Total daily lying time (42-44%) was comparable to studies conducted on indoor AMS (Deming *et al.*, 2013). Changes in the distribution of lying behaviour (Figure 2) were also similar to that observed by DeVries *et al.* (2005), where cows adjusted their lying behaviour to suit daily feeding frequency. This is an important consideration for pasture-based AMS, as lying patterns are likely to differ from conventional dairies. Thus, dairy cattle can adapt to different feeding strategies without negatively impacting lying time.

Conclusion

A thorough understanding of dairy cattle natural grazing behaviour is imperative in order to formulate sound feed management strategies for pasture-based AMS. We showed dairy cattle to have distinct diurnal feeding patterns, concentrating the majority of their feeding during the day. Minimal feeding occurred at night, especially after midnight. Further, cows were able to adapt their behaviour to suit different feeding regimes. When cattle were required to feed during the night, against their natural behaviour, there was no impact on total daily lying time. Likewise, feeding for 12 hours during the day compared to 12 hours during the night did not compromise total daily intake. The findings presented in this study enable formulation of variable feed allocation strategies for future testing as potential methods to improve levels of robot utilisation in automatic milking systems.

Acknowledgements

The authors would like to acknowledge the support of FutureDairy and its investors:

DeLaval, The University of Sydney and Dairy Australia.

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Impact of concentrate feeding and rumination on the methane production of cows in a pasture-based automatic milking system

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Abstract

The impact of ruminant greenhouse gas emissions on the environment is an issue of global concern. The differential effect of grain-based concentrate (GBC) feeding and rumination level on the enteric methane output of cows was tested in a pasture-based, automatic milking system (AMS). Two close groups of cows ($n=30/\text{group}$) representing either consistently high (HR; $619.85 \pm 8.89 \text{ min/d}$) or low (LR; $472.50 \pm 10.22 \text{ min/d}$) rumination animals were selected and assigned to three GBC treatments offering same pasture and 7, 8.5, or 10 kg/d of GBC obtained by the offering of 7 kg/d of grain-based pellet plus 0, 1.5 and 3 kg/d of ground shelled corn ($n=10 \text{ cows/GBC level}$). Rumination time, mass flux of methane (QCH₄) and carbon dioxide (QCO₂), milk production, and dry matter intake (DMI) derived from QCO₂ measurements, was recorded and analysed with mixed models for a completely randomised design and structural equation models. Regardless of the level of rumination, there was only a marginal effect of GBC feeding on QCH₄. However, evidence for differential effects of DMI on milk production and QCH₄ support promising opportunities to reduce yield of QCH₄/milk in grazing dairy cows.

Introduction

The warming effect of ruminant greenhouse gases is an issue of increasing global concern. Carbon gases in the form of enteric CH₄ often represent 50% or more of the greenhouse gas emission profile in a dairy system (Opio *et al.* 2013). Hence, global research into decreasing enteric CH₄ sources through different dietary manipulations, including feeding of GBC (Hristov *et al.*, 2013) has increased.

Evidence from indoor trials indicate that while both milk yield and CH₄ emissions may increase with increasing GBC feeding, the resulting yield of CH₄/milk generally decreases (Yan *et al.*, 2010). However, more variable and even conflicting results are reported for grazing dairy cows offered increasing GBC. Munoz *et al.* (2015) reported

both increases in milk yield and CH₄ production from grazing cows offered 1.0 vs. 5.0 kg/d of GBC, with no effect on the yield of CH₄ per unit of milk. Young and Ferris (2011) observed that both daily CH₄ production and CH₄ yield per unit of milk were unaffected by the offering of 2.0, 4.5 or 7 kg

of GBC. Conversely, Jiao *et al.* (2014) found same daily CH₄ production but a decreasing yield of CH₄ per unit of milk when grazing dairy cows were offered 2, 4, 6 or 8 kg of a GBC. Thus, according to published literature, CH₄ production and yield appear to be far more variable and complex to predict in pasture-based diets where a number of animal, pasture, and management factors, including type and amount of GBC, can readily interact and trigger distinct responses to increasing GBC feeding. An improved

understanding of the ingestion, digestion, and metabolic processes, including both direct and indirect effects of GBC feeding, may potentiate novel opportunities to effectively achieve reductions of enteric CH₄ in pasture-based diets.

The objectives of the present study were twofold. The first was to investigate the impact of differential GBC feeding and rumination on the enteric CH₄ production of grazing dairy cows. The second objective was to explore mechanistic linkages between feed intake, rumination level, milk yield and production of CH₄, and their likely direct and indirect effects on the yield of CH₄/milk using structural equation modeling.

Materials and Methods

The study was undertaken from July 12th till August 1st 2014, at the Michigan State University's Pasture based-AMS Farm, operated by the W.K. Kellogg Biological Station, Hickory Corners, Michigan, USA.

The rumination time and performance of the 60 top lactating cows (milk = 35 ± 2 kg; DIM = 140 ± 34 ; parity = 2.6 ± 0.3) from the existing herd of 146 cows (73 cows/AMS) was monitored for 9 d. During this phase, cows were offered temperate pasture and were conditioned to a baseline level of 7 kg/d of GBC pellet (DM basis). At the end of this phase, cows representing consistently high (HR; 619.85 ± 8.89) and low (LR; 472.50 ± 10.22) rumination time (min/d) were identified, grouped (30 cows/group), and assigned to three GBC feeding levels, following a 2 x 3 arrangement of treatments for a completely randomised design. The three GBC treatments included low (LGBC; 7kg/d), medium (MGBC; 8.5 kg/d) or high (HGBC; 10 kg/d) concentrate obtained by offering the 7 kg/d of GBC pellet plus 0, 1.5, and 3 kg DM/d of ground shelled corn, respectively. Cows remained within the assigned GBC treatment until study completion, which lasted 12 d.

Grazing and AMS management was conducted as described by Watt *et al.*, (2015). Briefly,

cows were granted milking permission when their expected yield reached 9.1 kg or 6 hours had passed since their previous milking. Cows also had 24 h voluntary access to binary pasture including perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*). A daily allowance of 30 kg of DM/cow/d was split and offered in two breaks of fresh pasture (15 kg of DM/cow), which were accessible from 1000 h to 2200 h and from 2200 h to 1000 h, respectively. Herbage allowance was adjusted according to measurements of herbage mass (Y; measured to ground level) determined by a plate meter ($Y = 125x$; $R^2 = 0.96$), using 30 readings of sward height (x) alongside allocations.

On a daily basis, individualised information of GBC intake, weight, milk production, and milkings were measured and recorded according to electronic collars ported by cows (QWES-HR Tag, SCR Engineers Ltd., Netanya, Israel). The collars also included enclosed loggers to monitor rumination and locomotion activity of cows. A gas capture and quantification system (Greenfeed; C-Lock Inc., Rapid City, SD) fitted in the AMS was used for measurement of mass flux of enteric methane (QCH₄; g/d) and expired carbon dioxide (QCO₂; g/d) as described previously in Huhtanen *et al.* (2015). Indirect measurement of DMI was conducted according to the model of Casper and Mertens (2010), using known QCO₂ fluxes adjusted for milk yield (Watt *et al.*, 2015). Pasture DMI was the difference between total DMI and the known GBC intake.

All response variables were pooled by cow and analysed by least squares ANOVA for a completely randomised design, using maximum likelihood for mixed models. Repeatability of rumination, QCH₄, and QCO₂ was analysed as described in Huhtanen *et al.* (2015); $\text{Repeatability} = \sigma^2_{\text{cow}} / (\sigma^2_{\text{cow}} + \sigma^2_{\text{residual}})$, where σ^2 is variance. The relationships between DMI, milk production, rumination, QCH₄, and output yield of QCH₄/milk were examined by structural equation modeling.

Results

Repeatability of rumination, QCH4 and QCO2 was 0.36, 0.65, and 0.81, respectively. Response variables are shown in Table 1. No effect of rumination or GBC levels was observed on milk yield and milkings/d. Rumination time differed between HR and LR cows, but with no interaction between rumination level and amounts of GBC fed. There was a numerical trend for QCH4 to increase in MGBC cows, which was consistent

with greater QCO2 and DMI detected for MGBC cows. Pasture DMI was lower for HGBC cows. As shown in Figure 1, several common relationships between intake, rumination, milk yield and QCH4 were detected. Intake had a positive direct effect on milk yield and QCH4, but not on rumination. Rumination had no direct effects on milk yield, QCH4 or the resulting QCH4/milk. Milk production had a direct negative effect on QCH4/milk, whilst QCH4 had a direct positive effect on QCH4/milk in both HR and LR cows.

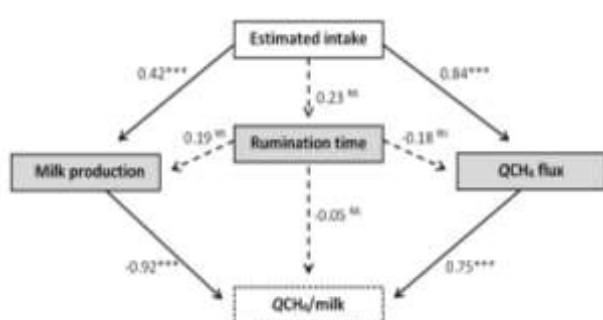


Figure 1: Structural equation model depicting the relationships (direct and indirect) between estimated intake, rumination time, QCH4, milk production, and yield of QCH4/milk of HR and LR cows. Significant; ***= $P < 0.0001$ (solid arrows); non-significant; NS= $P > 0.05$ (dashed arrows). Independent (solid white rectangles), dependent (grey rectangles), and observed (dashed white rectangle) variables are shown together with their corresponding standardised regression coefficient.

Discussion

No evidence for the hypothesis of interactions between rumination level and GBC on QCH4 of grazing dairy cows was found. Regardless of which GBC level was fed, a consistent divergence in rumination time between HR and LR was confirmed. However, no effect of divergent rumination on QCH4 was detected, and this result could be associated to the low repeatability of measurement of rumination (0.36) by the present technique. Conversely, both QCH4 (0.65) and QCO2 (0.81) were measured with a high repeatability, which is consistent with previous studies that used the same gas technique with non-grazing (Huhtanen *et al.*, 2015) and grazing cattle (Watt *et al.* 2015). In addition, only a non-significant difference in QCH4 between GBC treatments was detected which was consistent

with greater QCO2 and total DMI for MGBC cows compared to their LGBC and HGBC counterparts. Both ruminant QCH4 and QCO2 are highly correlated carbon gases (Madsen *et al.*, 2010) affected by digestive (i.e. digestibility) and metabolic (i.e. oxidation) processes. As such, both can be highly impacted by the level of DMI with minor effects arising by differences in diet composition or quality (Dijkstra *et al.* 2013), as suggested by the present study. No difference in QCH4/QCO2 ratio was observed despite marked differences of GBC in diets (range was 40 to 60% of GBC).

Moreover, the increase of GBC from 7 to 8.5 kg/d appeared to have an additive effect on total DMI with no evident effect on pasture DMI, whereas an increase of GBC from 8.5 to 10 kg/d appeared to have a depressor effect on DMI, both pasture and total.

Table 1: Effect of individualised allocation of three levels grain-based concentrate (GBC) (LGBC, MGBC and HGBC) on performance traits and carbon gas emissions of high (HR) and low (LR) rumination cows in a pasture-based automatic milking system.

	HR			LR			SEM	P-value		
	LGBC	MGBC	HGBC	LGBC	MGBC	HGBC		R	C	RxC
Milk (kg)	34.9	36.7	32.9	32.9	33.2	33.0	2.2	0.304	0.652	0.708
Milkings/d	2.4	2.3	2.3	2.2	2.3	2.4	0.1	0.705	0.856	0.567
Concentrate DMI (kg)	7.1	8.6	10.2	7.0	8.6	10.1	0.1	0.085	<0.0001	0.298
Pasture DMI (kg)	13.4	12.9	8.0	11.8	12.0	7.3	1.1	0.312	<0.0001	0.961
Total DMI (kg)	20.5	21.4	18.2	18.9	20.6	17.4	1.2	0.234	0.019	0.923
Rumination (min/d)	580	611	569	448	482	477	17	<0.0001	0.141	0.401
QCH4 (g/d)	410	442	377	370	409	387	27	0.283	0.138	0.511
QCO2 (g/d)	12306	12736	11275	11577	12365	10895	527	0.238	0.019	0.923
QCH4/QCO2 (g/g)	0.033	0.035	0.033	0.030	0.033	0.035	0.001	0.367	0.113	0.076
QCH4/Milk (g/kg)	12.1	12.4	11.6	12.0	12.5	12.0	1.0	0.865	0.702	0.965
QCO2/Milk (g/kg)	376.7	379.4	336.7	361.8	357.1	347.0	22.5	0.613	0.357	0.727
QCH4/DMI (g/kg)	18.5	19.9	22.3	20.2	20.8	20.6	0.8	0.644	0.020	0.059
QCO2/DMI (g/kg)	606.2	599.6	622.9	620.9	608.2	632.9	9.3	0.134	0.031	0.939

HR=high rumination; LR=low rumination; LGBC=low grain-based concentrate (7 kg); MGBC=medium grain-based concentrate (8.5 kg); HGBC=high grain-based concentrate (10 kg).

P-value= ANOVA for R=rumination group, C=concentrate level, and interaction R x C.

QCH4=mass flux of methane; QCO2=mass flux of CO2; DMI=dry matter intake.

Consequently, greater DMI with the offering of 8.5 kg/d of GBC triggered greater QCO2 and a numerical quadratic trend for increased QCH4, which is in agreement with modeling work conducted by Hristov *et al.*, (2013).

Conversely however, a depression of DMI (both pasture and total), noted by the offering of 10 kg/d of GBC increased the yield of

QCH4/DMI. This unexpected result could be related to an extended metabolic satiety created by an hepatic oxidation of increasing GBC-derived fuels (Allen, 2014) which in concert with a delayed resumption of grazing caused cows to consume more low quality pasture high in NDF (closer to the base of the sward)(Hills *et al.*, 2015). Thus, this likely undesirable effect could override any benefit of GBC feeding on reducing QCH4/DMI (Hristov *et al.*, 2013).

Structural equation modeling indicated similar interactions and mechanisms in HR and LR cows. Intake had a direct positive effect on increasing milk yield and QCH₄, but no effect of rumination on these two variables was seen. Consequently, either increasing milk yield or reducing QCH₄ were identified as either independent or joint mechanism that can markedly cause a decrease on the yield of QCH₄/milk, as previously reported (Watt *et al.* 2015).

All other aspects of management equal, no increase in milk to increasing GBC was observed within ranges of 7 to 10 kg/d of GBC. Passing this limit of GBC is also not advisable because it could depress rumen health and production (Bargo *et al.*, 2003). However, the cows in the present study did not compromise milk yield or rumination, suggesting that the rumen buffering capacity of cows was unaffected within the range of GBC offered.

Conclusion

Manipulating pasture-based diets to reduce carbon gas emissions is difficult. The results suggest potential opportunity to reduce carbon gas emissions through allocation of concentrates but likely indirect effects on pasture intake, of fibre in particular, can override potential benefits. All other aspects equal, increasing intake and milk yield or decreasing enteric QCH₄ are supported as main pathways to reduce the carbon gas footprint of milk production in pasture-based dairy systems.

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Metabolic and production responses to calcidiol treatment in mid-lactation dairy cows

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Abstract

The study of vitamin D in cattle has often focused on its role in calcium and mineral metabolism. However, there is evidence of a wider role for vitamin D in integrated metabolism, in particular, with bone and energy metabolism. This study explored changes in blood minerals and metabolite concentrations, and production responses to increasing calcidiol supplementation in mid-lactation dairy cows. Twenty-five cows were fed one of five supplementary calcidiol doses (0, 0.5, 1, 2 or 4 mg calcidiol/day) for 30 d, with blood sampled every 10 days. Increasing calcidiol dose quadratically increased blood calcidiol, 24,25-Dihydroxycholecalciferol (24,25-(OH)₂-D₃), and phosphate, increased and then decreased 25-Hydroxyvitamin D₂ (25-OH-D₂) and linearly increased 3-epi-25-Hydroxyvitamin D₃ (3-epi 25-OH-D₃) and milk calcidiol concentrations. Calcidiol supplementation did not affect milk yield or composition, body weight or condition score. Overall, this work provides support for a positive effect of calcidiol treatment on dairy cow metabolism.

Introduction

The study of vitamin D in cattle has traditionally focused on its role in calcium (Ca) and mineral metabolism in response to hypocalcaemia and parturient paresis. Oral supplementation with calcidiol can increase both blood calcidiol and calcitriol concentrations in cattle (Wilkens *et al.*, 2012). When calcidiol was fed at 3 mg calcidiol/d in combination with a negative dietary cation-anion difference (DCAD) diet before calving, plasma concentrations of ionized Ca increased (Wilkens *et al.*, 2012). Hence, strategic feeding of calcidiol may increase responses to low blood calcium and enhance hormonally controlled increases in calcium absorption, allowing the body to respond to metabolic stressors more rapidly. There is also increasing

evidence of a wider role of vitamin D in integrated metabolism, in particular, links with bone and energy metabolism (Lean *et al.*, 2014; Lee *et al.*, 2007). Despite evidence for the positive metabolic effects of supplementary calcidiol, the optimum dose required to improve dairy cattle performance and health is unknown. Excessive doses of calcidiol may have negative effects on mineral homeostasis including phosphorus metabolism.

This study examined the responses of mid-lactation cattle to increasing calcidiol dose, with the aim of identifying the dose that increased calcidiol concentration in the blood to approximately double the concentration in the control cows, and identify any effects of calcidiol feeding on milk production and composition, BW and BCS.

Materials and methods

Cows, treatments and environment

This study was conducted between August and September (Australian winter-autumn) in Camden, New South Wales Australia. Over this period, the average maximum daily temperature was $25^{\circ}\text{C} \pm 5$, average minimum temperature was $9^{\circ}\text{C} \pm 3$, total precipitation was 46.4mm and daily sunshine hours were 7-8 h/day. All practices were approved and reviewed by SBScibus Animal Care and Ethics Committee (SBScibus 1213-1214). Twenty five mid-lactation Holstein dairy cows (206 ± 53 days in milk) of mixed ages were blocked by age (63 ± 17 mo), and milk production (20 ± 9 L) and randomly allocated to receive one of five doses of supplementary calcidiol (0, 0.5, 1, 2, or 4 mg of active calcidiol/day) ($n = 5$ cows/treatment). Treatments were pre-mixed with wheat mill run and individually top dressed on wheat mill run in the milking parlour once daily for 30 d. Feed bins were fitted with liners that were cleaned between each cow. Cows were milked twice daily.

Diet

Cows were maintained on a diet representative of an extensive grazing dairy system in Australia. The diet consisted of an alfalfa (*Medicago sativa*) based pasture grazing allocation each morning, supplemented with wheat mill run in the parlour during milking, and greenchop (alfalfa or oats (*Avena sativa*)) following the afternoon milking. From daily observations, the size of grazing allocations fluctuated. Samples of each feed were taken weekly and composited by feed type into early (weeks 1-2 of trial) or late (weeks 3-4) diets for analysis. Cows were allowed to graze on kikuyu (*Pennisetum clandestinum*) based pasture between evening and morning milkings.

Feed Analysis

Samples were dried in an oven (45°C) for at least 48 hours prior to analysis. The predicted

chemical composition of the diet was calculated using the CPM Dairy Ration Analyzer (version 3.1 ; Cornell-Penn-Miner, Cornell University, Ithaca, NY) from ration components analyzed by wet chemistry (Dairy One Cooperative Inc., Forage Testing Laboratory, Ithaca, NY).

Sample Collection

Milk volume was measured and samples were taken every two weeks, starting in the week prior to commencement of treatment, and tested for milk protein yield and percentage, fat yield and percentage, and somatic cell count (SCC) by Dairy Express (Armidale, New South Wales Australia), and calcidiol concentrations (DSM Nutritional Products Basel, Switzerland). Blood serum and plasma (preserved with lithium heparin) samples were taken from the coccygeal vein every 10 days, commencing the day before the start of treatment ($n=4$ /cow). Plasma samples were placed on ice immediately after collection; while, serum samples were maintained at room temperature. Samples were centrifuged at $1,512 \times g$ for 20 mins at 4°C to separate plasma or serum. Plasma or serum was pipetted into 1.5mL aliquots and frozen at -20°C for future analysis. Body weight and Body Condition Score (BCS) (1-5 scale) were recorded after the morning milking every 2 weeks.

Sample Processing and Analysis

Blood concentrations of Ca, Mg, P, NEFA, BHBA, cholesterol, and glucose were determined for each of the four samples taken from each cow by the University of Sydney (Camden, Australia) (kit numbers available). Calcidiol, cholecalciferol, 24,25-Dihydroxycholecalciferol (24,25-(OH) $_2$ -D3), 3-epi-25-Hydroxyvitamin D3 (3-epi 25-OH-D3), and 25-Hydroxyvitamin D2 (25-OH-D2) for each of the four samples were measured by DSM Nutritional Products (Basel, Switzerland).

Statistical Analysis

All analysis was performed using Stata (Intercooled Stata v.13, USA). Autoregressive mixed models (STMIXED, Intercooled Stata v.13, USA) were used to compare treatment and control groups over time for each blood metabolite. Somatic cell count concentrations were log transformed (loge) before analysis. Pre-treatment metabolite measures taken at day 0 were included in each model as a covariate. One cow from the group receiving 1 mg calcidiol/day was removed from Vitamin D analyses as an outlier as this cow had abnormally low calcidiol concentrations throughout the treatment period.

Results

Vitamin D

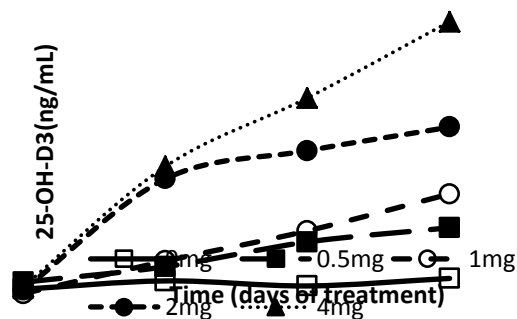


Figure 1 Blood calcidiol concentration over time by calcidiol dose (Experiment one).

Calcidiol quadratically increased both blood calcidiol and 24, 25-(OH)₂-D₃ ($P < 0.001$; Figure 1) with increased dose. Blood calcidiol doubled in the group receiving 0.5 mg calcidiol/day after the 30 d of feeding when compared with the control group (67 vs. 32 ng/mL for 0.5mg and control treatment groups respectively). There was no response in blood cholecalciferol in response to feeding calcidiol ($P = 0.262$). Increasing calcidiol, linearly increased 3-epi 25-OH-D₃ in the blood ($P < 0.001$). Calcidiol treatment also increased and then decreased blood 25-OH-D₂ with a quadratic response, as cows receiving 4 mg/day had numerically lower blood

concentration than other groups ($P = 0.004$). Blood concentrations of all Vitamin D metabolites changed over time, ($P < 0.001$) and a treatment by time interaction was evident for all metabolites ($P < 0.04$). There appears to be a cumulative effect of calcidiol supplementation over time.

Blood Metabolites and Minerals

The only effect of calcidiol treatment on metabolites or minerals was on blood P which had a quadratic response to calcidiol treatment ($P = 0.003$). Cows that received 4 mg calcidiol/day had higher concentrations of P than other groups, apart from the group receiving 0.5 mg/day. Glucose, BHBA, and cholesterol all varied over time and there was no treatment by time interaction for any blood metabolite or mineral.

Milk Yield and Composition

Milk yield, protein yield, protein percentage, fat percentage, and SCC were unaffected by treatment ($P > 0.08$); however, milk yield, protein yield, and fat percentage varied over time. No treatment by time interaction was present for any milk yield or composition variable ($P > 0.6$). Milk calcidiol increased linearly with increasing calcidiol dose ($P < 0.001$). There was a significant influence of time on milk calcidiol concentration ($P < 0.001$); although no time by treatment interaction was observed.

Body weight and Body Condition Score

Neither BW nor BCS were affected by treatment ($P > 0.6$); while, both varied significantly over time ($P < 0.005$).

Discussion

In this experiment, mid-lactation dairy cows receiving no supplementary calcidiol had circulating calcidiol concentrations within the normal range of 20-50 ng/mL, reported by Horst, Goff, and Reinhardt (1994). Calcidiol concentrations increased above this range in all the dose response treatments; in the group

receiving 0.5 mg calcidiol/day this increased to 67 ng/mL after the 30 d of treatment. As such, supplementary calcidiol feeding in these experiments increased blood calcidiol above normal ranges, rather than being used as a therapeutic agent to correct a vitamin deficiency. Other studies have shown supplementary feeding increases blood calcidiol (Rivera *et al.*, 2005; Taylor, Knowlton, McGilliard, Seymour, & Herbein, 2008; Weiss, Azem, Steinberg, & Reinhardt, 2015); however the increases have differed from those seen in this study, possibly due to the variety of methods used to deliver the calcidiol (dietary, bolus, or buccal administration) and other dietary factors. For example, negative DCAD diets are known to affect PTH sensitivity and amplify the effects of calcidiol on Ca metabolism (Lean *et al.*, 2014; Wilkens *et al.*, 2012). These studies all had baseline calcidiol concentrations higher than those observed in the current study, but examined cows during the period around calving when the increased demand for nutrients, especially Ca, may have influenced Vitamin D metabolism. It should be noted that the cows in our experiments were fed pasture and consequently there would be daily fluctuations in availability of nutrients.

Calcidiol supplementation increased blood concentrations of vitamin D metabolites for which it is a precursor. The quadratic increase of 24,25-(OH)₂-D₃ in response to increased calcidiol dose suggests that a feedback mechanism exists between the two metabolites. The role of 24,25-(OH)₂-D₃ is not clear, but may be part of the normal mechanism for removing calcidiol from cells. The biological significance of 3-epi 25-OH-D₃ is poorly understood, although the linear increase with increasing calcidiol dose shows a clear relationship between the epimers. In this experiment, 25-OH-D₂ quadratically increased and then decreased with increasing calcidiol dose and cows receiving 4 mg of calcidiol had numerically lower blood concentrations than other groups. This decrease at higher calcidiol concentrations may indicate a negative feedback mechanism between the metabolites as they have a similar biological

role and some mammals may discriminate against D₂ (Horst *et al.*, 1994).

Feeding supplementary calcidiol during times of high Ca demand may limit the deficit, or lag time observed between decreased blood Ca or other signals and stimulation of calcidiol and calcitriol synthesis, allowing the body to respond to metabolic stressors more quickly. Increased blood calcidiol has increased Ca absorption, and hence plasma Ca concentrations (McGrath, Savage, Nolan, & Elliott, 2012). Despite this, there was no effect of calcidiol treatment on blood Ca identified in this experiment, a relationship similar to that described by Taylor *et al.* (2008). Calcium in plasma is maintained under tight homeostatic control. Studies that have demonstrated increases in total plasma Ca in response to calcidiol have used non lactating cattle (McGrath *et al.*, 2012; Wilkens *et al.*, 2012), suggesting that in lactation calcium absorption, accretion, or excretion may differ from non-lactating cattle. Rivera *et al.* (2005) found that supplementary calcidiol increased plasma Ca, within 24 h of supplementation in non-lactating beef heifers, but these were single buccal dosages much higher than those used in our experiments (100 and 1000 mg calcidiol). Magnesium and P are important for tissue sensitivity to calcitrophic hormones and PTH, and production of active vitamin D metabolites. The observed quadratic increase in P in response to increasing supplementary calcidiol may have been expected, as active vitamin D increases both Ca and P retention (McGrath *et al.*, 2012).

We found no increase in milk production, or composition. Other studies found a similar lack of milk yield response when transition cows were fed calcidiol, compared with those fed cholecalciferol, when both vitamin D treatments were combined with negative DCAD diets (Weiss *et al.*, 2015). In contrast, when cows were fed 3mg/d calcidiol 3.5% fat- and energy-corrected early lactation milk yield increased by 3.7 ± 1.2 kg/d when compared with cows fed cholecalciferol (Martinez *et al.*, 2015). Milk calcidiol concentration also

increased linearly with increasing calcidiol dose.

Conclusions

Feeding supplementary calcidiol quadratically increased concentrations of blood calcidiol in mid-lactation cows. Blood calcidiol concentration in the group receiving 0.5mg calcidiol/day was increased from 32 ng/mL to 52 ng/mL. This study provided an understanding of the response of dairy cattle to increasing calcidiol dose during mid-lactation. These relationships should be explored in cattle during periods of higher metabolic stress, such as transition, where positive effects of treatment could be highly beneficial, particularly in relation to calcium and energy metabolism.

Acknowledgements

This research was supported by funding from DSM Nutritional Products (Basel, Switzerland) and Scibus (Camden, New South Wales Australia).

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Factors influencing the profitability of genomic testing in commercial dairy heifers

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Abstract

The commercialisation of genomic testing offers the opportunity to obtain Australian Breeding Values (ABVs) with high reliability (>60%) to select heifers as herd replacements. At a cost of ~\$50 per genomic test, it is not clear whether the investment can be justified. Therefore, the objective of this work was to evaluate the cost-benefit of genomic testing commercial heifers. The ultimate aim of this work is to develop a tool for farmers to predict the likely return on investment (ROI) of genomic testing on their farm. The cost-benefit of genotyping heifers for a wide range of scenarios was modelled deterministically in R version 3.2.3 and validated with industry data. Factors varied included: 1) reproductive performance, 2) replacement rate and 3) the availability of information on heifer selection candidates. The reliability of genomic testing was 0.66. Selection of replacements was based on truncation selection of the Balanced Performance Index (BPI). The benefit of genotyping was calculated as the superiority (in \$) of selected heifers for each lactation that they remained in the herd. Low replacement rates and high reproductive performance lead to the highest ROI. The benefits of genomic testing were more marginal when farmers already had access to parent average ABVs for heifers compared to a strategy that was not data based (i.e. farmers select heifers using visual assessment). As the national average replacement rate is ~22%, at least half of Australian dairy farmers can justify the investment in genotyping regardless of their current strategy for selecting replacement heifers.

Introduction

The commercialization of genomic testing has revolutionized bull breeding programs around the world (Pryce & Daetwyler, 2012). Although genomic tested bulls are widely used in Australia very few commercial dairy heifers are genomic tested. Less than 5000 commercial cows were genomic tested in the 2014/15 financial year (ADHIS Pty Ltd, 2015).

Heifers that are genomic tested receive genomic-based ABVs (ABV(g)) with the possibility of also confirming parentage and identifying carriers for genetic defects (Pryce & Hayes, 2012). It is now feasible to obtain

ABV(g)s with reliabilities greater than 60% in heifers meaning the ABV(g)s are as accurate as a cow's ABVs are with 7 years of lactation records. One of the benefits of having highly accurate ABVs on heifers at young ages is that it offers the opportunity to make more informed decisions about which heifers to keep as herd replacements (Pryce & Hayes, 2012).

Most dairy genomics research has focused on the benefits of genomic testing in bull breeding schemes (as in Pryce and Daetwyler (2012)) with less information available on the return on investment (ROI) from genomic testing commercial heifers. With the cost of genotyping heifers now \$50 per test, we

hypothesis that genomic testing of commercial heifers is now profitable for more dairy farmers.

The aim of this study is to see if the cost of genomic testing heifers can be justified under the wide range of farming conditions experienced by the Australian dairy industry. The results of this study will be used to develop a ROI calculator, enabling dairy farmers to predict whether genomic testing of their heifers is profitable in their farming system.

Method

The ROI of genotyping heifers was modelled deterministically using the computer program R version 3.2.3. The factors that were varied in the model were 1) reproductive performance, 2) replacement rate and 3) the availability of information on heifer selection candidates. Herd size was arbitrarily set at 100 cows for ease of interpretation. It was assumed that all heifer calves born were genotyped at 3 weeks of age at a cost of \$50/test and having genomic test results did not influence the cost of heifer rearing or the age at which surplus stock was sold.

Herd reproduction

Heifers were assumed to undergo one round of artificial insemination (AI) at 15 months of age while cows had 6 weeks of AI mating annually. Both age groups were then joined to herd bulls for 6 weeks. Three herd fertility levels; low (L), medium (M) and high (H), were modelled with reproductive performance separated by age group (heifers and cows) and mating type (AI or natural) (Table 1). This was to capture fertility differences and account for differences in merit of calves sired by AI bulls versus backup bulls. Calf mortality rate to weaning was 10%, whilst heifer mortality rate to first parturition was 5%.

Table 1. Overview of the different reproduction parameters used in the simulation for the three levels simulated low (L), medium (M), high (H).

Reproduction Parameter	Fertility Level A		
	L	M	H
Heifer conception rate from AI	0.51	0.56	0.70
Total heifer pregnancy rate	0.76	0.89	0.94
Cow conception rate from AI	0.41	0.50	0.59
Total cow pregnancy rate	0.72	0.80	0.87

A Heifer AI conception rates from Noonan *et al.* (2016). Remaining parameters from InCalf Report (Morton, 2011).

Replacement rate

Replacement rate ranged from 10% to 40%. This represents the percentage of the herd culled each year and is related to the number of heifers needed to be kept to maintain herd size. Productive life (PL), the average number of lactations per cow is the inverse of replacement rate and was used to calculate the net merit of genomic testing.

Selection decisions

Heifers born from AI and natural matings were eligible for selection as replacements. Selection of heifer replacements was based on truncation selection of the Balanced Performance Index (BPI). On average the BPI of natural born calves was \$62.70 lower than the BPI of AI born calves (Byrne *et al.*, 2016). However, the 'best' natural born calves are superior to the 'worst' AI born calves. An optimisation equation was used to ensure that the best calves from both groups were kept as replacements (Hopkins & James, 1978). Two different scenarios were considered, Scenario A where selection decisions had previously been non-data based (no ABVs were available) and Scenario B, selection was previously based on parent-average ABVs.

Calculating Return on Investment

One of the benefits of genomic selection is the ability to make more accurate decisions about which heifers to keep. The superiority of selected heifers, S , can be calculated from the formula:

$$S (\$) = \sigma_{BPI} * i * (\sqrt{r_g} - \sqrt{r_c})$$

Here, $\sigma_{BPI} = \$90$, represents the standard deviation of BPI, i the selection intensity, which is a function of the proportion of heifers selected, $r_g = 0.66$, the reliability of genomic information, and r_c the reliability of the current selection strategy. For Scenario A, $r_c = 0$. For Scenario B, r_c ranges from 0.04 to 0.10 as it is influenced by selection intensity, reproductive performance and accounts for a pedigree error of 10% using the method of Visscher *et al.* (2002). Net present value of the lifetime contribution of a selected heifer was calculated, assuming a discount rate of 8%, by multiplying heifer superiority, S , by the average number of lactations heifers remained in the herd. Net ROI is this figure multiplied by the number of heifer replacements minus the initial genotyping costs.

Ground Truthing

As a final step this model was validated against results from dairy farms who had genotyped their entire heifer cohort. Input parameters in the model were altered to reflect those of actual dairy farms. The predicted benefit of genomic testing was then compared to the on-farm results.

Results

Regardless of fertility level, or the current selection strategy, when herd replacement rates were 23% or lower, genomic testing of heifers resulted in a positive ROI of up to \$3093 (Figure 1). Changes to herd replacement rate had the biggest impact on ROI, with ROI varying by up to \$5071 with replacement rate. As replacement rate increased the difference in ROI between

scenarios was smaller. In the case of low fertility, the ROI from the two scenarios reached parity at replacement rates of 35% and above as there were not enough heifers to meet replacement requirements.

Selection strategy had the next most influence on ROI with genomic testing more likely to yield a positive ROI if the current selection strategy did not use ABVs. Herd fertility level had a smaller but still significant impact on ROI. In low fertility herds the breakeven point occurred at replacement rates of 23% and 27% in the two scenarios, whilst breakeven point occurred at replacement rates of 26% and 30% in high fertility herds.

The benefit of genomic testing in the model was either equal to, or underestimated, compared to the actual benefit reported by dairy farmers currently using ABV(g)s to select heifer replacements on-farm (Table 2).

Table 2. Difference in merit of heifers kept and sold on-farm and predicted difference from model

	On-farm	Model	% differenceA
Farm A	37.28	36.91	+1%
Farm B	58.53	27.33	+54%

A Difference = actual merit on-farm - predicted merit from model

Discussion

The national average herd replacement rate is ~22% (Byrne *et al.*, 2016) so it is estimated that at least half of Australian dairy farmers can justify the investment in genomic testing of commercial heifers to guide the selection of heifer replacements. This is reflected by the observation that all replacement rates of 22% or lower had a positive ROI, regardless of fertility or previous selection strategy.

As expected, the ROI from genomic testing was more marginal when farmers already had access to parental-based ABVs to make selection decisions. However, the estimates from

this study are more favourable than those of an early study by Pryce and Hayes (2012). Using a genomic test cost of \$50 and assuming parent-average ABVs were available, Pryce and Hayes (2012) did not predict a positive ROI from genomic testing regardless of herd replacement rate or the number of heifer selection candidates. This present study differs significantly from these earlier findings. This is likely due to the new method adopted to calculate the accuracy of using parent-average ABVs to select heifer replacements (Bijma, 2012). Furthermore, this study used the relationship between replacement rate and productive life to account for a longer productive life and thus greater contribution of cows in herds with low replacement rates, compared with Pryce and Hayes (2012). Conversely, the results in this study are more conservative than those of Calus *et al.* (2015) who concluded that as long as there are at least 2 heifers surplus to replacement

requirements there is a benefit to using genomic testing to guide heifer decisions. A key difference between these results and Calus *et al.* (2015) is that they did not account for discounting over time.

The benefits of genomic selection are not realised at the time of genomic testing, instead are realised gradually at each lactation. If a heifer's superiority is estimated to be \$10 and she stays in the herd for 4 lactations, without discounting her net merit is estimated at \$40. When discounting over time is factored in her net merit is \$28.40, nearly 30% lower. If the cost of genomic testing reduces further in the future, it is likely that genomic testing will be a viable investment for even more Australian dairy farmers.

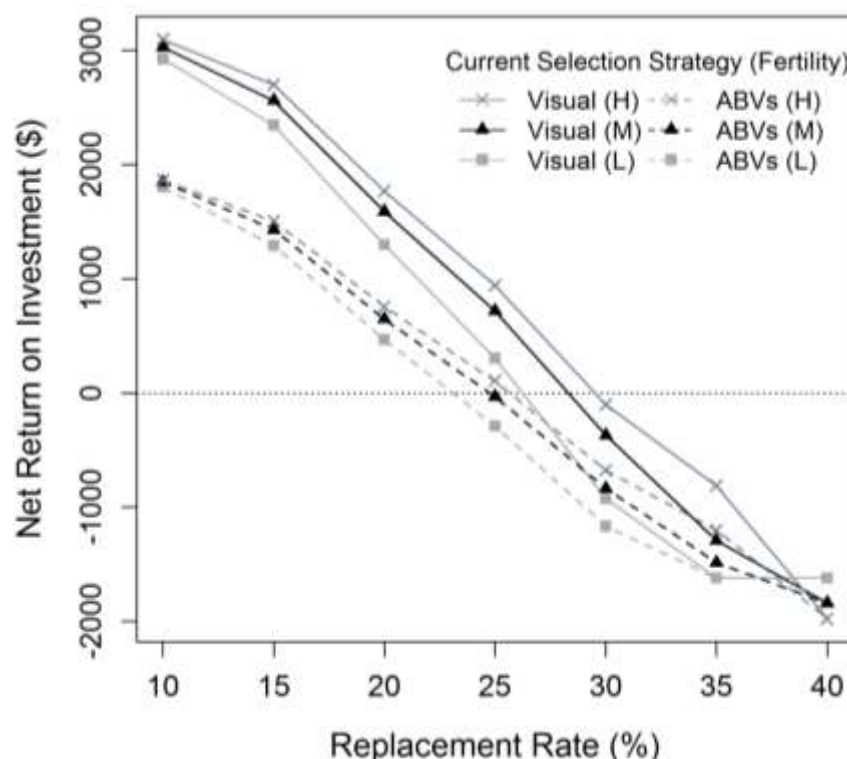


Figure 1. Net return on investment (\$) from genotyping commercial heifers in herds with differing reproductive performance (low (L), medium (M) & high (H) fertility) and replacement rates. Solid and dotted lines indicate the additional benefit of genotyping heifers given the current strategy for selecting heifer replacements is through visual assessment (Visual), and parent average ABVs (ABVs), respectively

The largest benefits from genomic testing were seen in high fertility herds, with lots of heifer selection candidates. The use of sexed semen to lift the number of selection candidates may offer the opportunity to further benefit from genomic selection (Calus *et al.*, 2015). Historically, using sexed semen has resulted in lower conception rates (Butler *et al.*, 2014). Recent field trials conducted by the Warrnambool Vet Clinic are promising with conception rates from fresh and frozen sexed semen nearly equalling those of frozen conventional semen (Dr J. Kelly, Warrnambool Vet Clinic, pers comm.). However, adoption of sexed semen requires further consideration as there are additional costs and risks to account for.

Conclusion

The results from this preliminary study show that many Australian dairy farmers should see a positive ROI from introducing genomic testing of commercial heifers. However, this current model only considers the benefit of genomic testing to guide heifer selection decisions. In reality, other opportunities exist such as; saving rearing costs by selling surplus stock earlier, receiving a premium price for surplus stock with ABV(g)s and/or using ABV(g)s in designing mating programs. When these additional benefits are included it is likely a larger proportion of dairy farmers stand to profit from genomic testing of heifers. Further exploration of other possible uses of ABV(g)s will lead to the development of a robust model for use in an ROI calculator.

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The feasibility of targeted selective anthelmintic treatment of dairy replacement heifers – a pilot study

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Abstract

Targeted selective anthelmintic treatment, where some animals in a group are left untreated, has been effective in slowing the development of anthelmintic resistance in small ruminants without adversely affecting growth rate performance. The aim of this pilot study was to evaluate the feasibility of a targeted selective treatment regime in terms of anthelmintic usage and live weight gain in dairy replacement heifers using a non-inferiority design. One-hundred and eighty-nine weaned heifers from three commercial dairy farms in the Macalister Irrigation district were allocated to either a conventional treatment or targeted selective treatment regime according to odd or even ear tag number. Live weights and faecal egg counts were monitored three times over 12 weeks. Heifers in the conventionally treated group were treated on each occasion with moxidectin injection. Heifers in the targeted selective treatment group were treated with moxidectin only if they failed to achieve a predetermined live weight target. An arbitrary non-inferiority margin of 10%, the largest commercially acceptable difference, was defined a priori and average daily gain (g/day) was compared statistically. Based on this margin, targeted selective treatment was not inferior to conventional treatment ($p=0.65$) and anthelmintic usage was reduced by 48%. In conclusion, this study supports the case for further study into targeted selective treatment on commercial dairy farms. Targeted selective treatment is expected to reduce selection pressure for anthelmintic resistance.

Introduction

Anthelmintic resistance in gastrointestinal nematode parasites is emerging as a major threat to the productivity of grazing livestock worldwide. The first substantial investigation of anthelmintic resistance on Australian dairy farms identified resistance in *Ostertagia ostertagi*, the most economically important parasite species, on 86% of farms (Bullen *et al.*, 2016). One approach for slowing the development of anthelmintic resistance is to only treat those animals within a group that are most likely to respond (targeted selective treatment). Live weight gain-based targeted selective treatment has been highly effective in reducing overall anthelmintic use, slowing the development of anthelmintic resistance on sheep farms and is likely to be feasible on

commercial dairy farms. However, the uptake of this strategy is dependent upon the ability to maintain adequate levels of animal performance. The aim of this pilot study was to determine the feasibility of targeted selective treatment by comparing the number of anthelmintic treatments and live weight gain performance of dairy replacement heifers subjected to conventional, whole-group anthelmintic treatment at 6-weekly intervals with a live-weight gain-based targeted selective treatment program.

Materials and Methods

Experimental animals and herds

One-hundred and eighty-nine weaned dairy replacement heifers (mean live weight 181kg)

from three commercial herds (A, B & C) located in the Macalister Irrigation District of Victoria were enrolled in the study. Heifers were grazed on perennial ryegrass dominant pastures naturally infected with gastrointestinal nematode parasites and managed according to routine farm practices.

Treatments

On each farm, heifers with even numbered ear tags (conventionally treated group) were treated with 0.2mg/kg moxidectin subcutaneously (Cydectin Injection for Cattle®, Virbac Animal Health, Australia) at six weekly intervals. Heifers with odd numbered ear tags were also treated with moxidectin, but only if they failed to reach individually predetermined live weight targets (targeted selective treatment group) calculated according to the Dairy Australia Heifer Weight Chart Tool (www.dairyaustralia.com.au/HeiferDietCalculator/index.htm). Faecal samples were collected directly from the rectum of the 20 heifers in each group on each visit. Samples were submitted for parasitological examination in order to estimate pasture contamination and composition of the parasite population in the two groups.

Parasitology

All parasitological procedures were conducted according to Australian and New Zealand Standard Diagnostic Procedures (Hutchinson, 2009). Individual faecal egg counts were performed using a modified McMaster method where one egg counted represented 25 eggs/g. Faecal samples were pooled within each treatment group for larval culture and morphological identification.

Statistical analysis

A non-inferiority trial design was used. An arbitrary non-inferiority margin for the difference in mean average daily gain (g/day) between conventionally treated and targeted selective treatment groups was defined as 10%. The generalized linear model

procedure of SPSS (IBM Corporation, Australia) was used to compare average daily gain (g/day) after 12-weeks. Age, breed composition and herd were fitted as fixed effects. Model effects were considered statistically significant when the Type I error rate was <5%. All biologically plausible interaction terms were examined but omitted from the final model if they were not statistically significant ($p > 0.05$). Non-inferiority was considered to be present if the upper 95% confidence interval for the difference between the two means was less than 10% of the average daily gain (g/day) of the conventionally treated group.

Results

Parasitology

Faecal egg counts ranged from 0-250 eggs/g (mean 39 eggs/g) in the conventionally treated group and 0-200 eggs/g (mean 40 eggs/g) in the targeted selective treatment group at the commencement of the trial. Faecal egg counts conducted at the conclusion of the trial ranged from 0-175 eggs/g (15 eggs/g) in the conventionally treated group and 0-175 eggs/g (28 eggs/g) in the targeted selective treatment group. The percentage of *Ostertagia ostertagi* cultured at the end of the trial was 19% in the conventionally treated group and 20% in the targeted selective treatment group, and at the conclusion of the trial was 12% and 21%, respectively.

Anthelmintic treatments

The proportion of heifers in the targeted selective treatment group requiring treatment in Herds A, B and C was 35/42 (83%), 19/32 (59%), 5/22 (23%), respectively, at the commencement of the trial and 42/42 (100%), 7/32 (22%) and 6/22 (27%), respectively, at week 6. The mean reduction in anthelmintic treatments was 48%.

Animal performance

The average daily gain during the trial period for the targeted selective treatment group was 505 ± 23 g/day compared to 514 ± 19 g/day ($p = 0.65$) in the conventionally treated group. Non-inferiority was established as the upper limit of the 95% confidence interval of

the difference between the two groups (48 g/day) was less than the non-inferiority margin of 10% of the mean average daily gain of the conventionally treated group (51 g/day). The results of the Analysis of variance in average daily gain, including 2-sided 95% confidence intervals are shown in Table 1.

Table 1: Analysis of variance in average daily gain (g/day), including 2-sided 95% confidence intervals.

Variable	Coefficient	SE	95% CI		P-value
			Upper	Lower	
Intercept	504.9	23.1	459.3	550.5	<0.001
Herd A	-226.4	25.6	-276.8	-175.8	<0.001
Herd B	-52.5	26.9	-105.6	0.71	0.053
Herd C	Reference				
Conventional	9.0	19.8	-30.1	48.1	0.651
TST	Reference				

TST, targeted selective treatment; CI, confidence interval.

Discussion

The results of this pilot study suggest that targeted selective treatment is feasible on commercial dairy farms and is likely to reduce the number of anthelmintic treatments whilst maintaining acceptable levels of animal performance. The mean and maximum differences in average daily gain of 9g/day and 48g/day (upper 95% confidence interval) are considered commercially acceptable and were not statistically significant. Further exploration of targeted selective treatment with a larger sample size and longer study period is supported by these results. This study was conducted in the immediate post weaning period when susceptibility to gastrointestinal parasites is often at its highest; however,

faecal egg counts throughout the study period were relatively low. It is hypothesized that the differences observed early in the post weaning are unlikely to persist because of the development of immunity to nematode parasites with age and exposure. A reduction in anthelmintic treatments of 48% is less than previously reported for similar studies in cattle; however, the non-treatment threshold in the present study was more conservative in an attempt to minimize any potential production loss (Greer, McAnulty, & Gibbs, 2010; Höglund, Dahlström, Sollenberg, & Hessel, 2013). The major advantage of using live weight gain as a selection criterion for targeted selective anthelmintic treatment is that it is cheap and easy to measure, allows treatment decisions to be made crush-side and the data can be used

for purposes other than parasite control. There is some argument that parasitological indicators, such as individual faecal egg counts, are more appropriate for targeted selective treatment as they better account for increased pasture contamination; however, labour intensity for sample collection, relatively high laboratory expenses and time-lag before treatment decisions can be made are likely to preclude adoption in a commercial situation.

Conclusion

This study demonstrates that targeted selective treatment can reduce the number of anthelmintic treatments without significantly impairing productivity of dairy replacement heifers. It is expected that implementation of targeted selective treatment on commercial Australian dairy farms would reduce selection pressure for anthelmintic resistance.

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The impact of a partially shaded laneway on voluntary cow movement to an automatic milking system

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Abstract

Dairy cattle typically respond to hot weather by reducing feed intake and locomotion, increasing water consumption and seeking shade. This often leads to reductions in milk production (at least partially due to reduced dietary intakes) which may be further amplified in a system with voluntary cow traffic (due to a reduction in milking frequency). In this study it was hypothesised that access to small intermittent shade sources along a laneway between a feed source and a milking facility would result in improved voluntary cow movement (compared to no shade provision) during summer (December 2015). Four groups of six cows were introduced to a laneway of approximately 930m in length where they were exposed to either a SHADE or NO SHADE treatment. SHADE consisted of five 3m x 3m x 2.4m (L x W x H) shade structures were evenly spaced along the laneway between a feeding area and the milking facility; these structures were removed for the NO SHADE treatment. Each group of cows was exposed to each treatment twice. Behaviour and location of cows was recorded between 10:00 and 17:00 each day. SHADE cows were more likely to leave the feeding area and move further towards the milking facility than NO SHADE cows ($P < 0.001$). NO SHADE cows had higher average body temperatures and respiration rates ($P < 0.001$) and spent less time ruminating and more time grazing ($P < 0.001$ and $P = 0.017$ respectively) than SHADE cows. The results of this preliminary investigation suggest that the provision of intermittent shade along a laneway might enhance voluntary cow movement and cow comfort during hot conditions.

Introduction

When the environmental temperature humidity index (THI) is high, dairy cattle behave and perform differently to reduce the heat load on their bodies. Feed intake and locomotion normally decrease to reduce the amount of body heat produced (West 2003), and shade and water-seeking behaviour increase to further reduce heat load (Blackshaw and Blackshaw 1994). As a result, cow performance

and milk production often decline during hot weather (Ominski *et al.* 2002).

In an automatic milking system (AMS) operating with voluntary cow traffic, further reductions in production may be seen due to a reduction in milking frequency (MF) caused by decreased activity (Speroni *et al.* 2006). In this system type, feed is typically used to encourage cows to volunteer to be milked and travel within the farm (Prescott *et al.* 1998), however, as feed

intake declines during hot weather, alternative methods of encouraging cow movement may need to be enforced. Water consumption (Meyer *et al.* 2004) and the use of shade (Kendall *et al.* 2006) both increase in desirability to the cows as THI rises and it is possible that the manipulation of these resources may create opportunity to encourage voluntary cow movement. As access to water should not be restricted at any time, particularly during hot weather due to the welfare implications associated with this, investigations into the manipulation of shade as an incentive to encourage voluntary cow movement during hot weather is preferred. Shade is an affective aid for cooling cattle and is often utilised for long periods of time by cattle when ample space is provided (Schütz *et al.* 2010). Because of this, it was predicted that the use of small shade sources would encourage cows to use the shade with competition from other cows preventing excessive amounts of time spent under them. It was hypothesized that the provision of small intermittent shade sources along a laneway would result in improved voluntary cow traffic between a feed source and an automatic milking facility.

Method

Animals and Management

In December 2015, 24 pregnant lactating Holstein Friesian dairy cows were selected to participate in the study. The cows were located at the University of Sydney's Corstorphine dairy farm at Camden (NSW, Australia) and milked in an automatic milking rotary (DeLaval AMRTM, Tumba, Sweden).

The cows were selected from the main milking herd and divided into four groups of six which were matched closely for average milk yield (MY, 19.84 ± 0.66 kg milk/cow/day), days in milk (DIM, $2.31.17 \pm 8.5$), age (63.61 ± 1.525 months), and MF (1.72 ± 0.04 milking/cow/day).

The cows all had previous experience in a three way grazing system where they

voluntarily travelled between pasture and the AMR. Throughout the duration of the experimental period, the cows were housed in a separate paddock with a small batch milked herd where they were fetched to the AMR twice daily to be milked.

Treatment and design

The experiment consisted of two treatments, SHADE and NO SHADE, and took place over 16 days. One group was tested per day and all groups were systematically exposed to both treatments twice. This was to ensure that all groups had the same number of days rest between test runs, and that no group was exposed to the same treatment twice in a row. The test area was a laneway leading to the AMR from a starting location where the cows had access to 8 kg/cow of Lucerne cubes out of a communal feed trough and a loafing area. The laneway was approximately 930 m in length and had 5 movable shade structures (3 x 3 x 2.4 m, w x l x h) which were positioned 150 m apart for the SHADE treatment, and removed for the NO SHADE treatment. The shade structures consisted of shade cloth blocking out 90% of UV light across the top of the structure. The location of the shade structures separated the laneway into six separate 'zones'. Zone 1 was the area from the starting point to the first shade structure (inclusive), zone 2 was the area after the first shade to the second shade structure (inclusive) etc. All groups of cows were habituated by exposing them once to each treatment.

On the first testing day for each group, the cows were automatically drafted into a holding yard after the morning milking where they were encouraged into a restraint crate and fitted with a temperature logger. The temperature logger (DS1922L Thermochron iButton, Thermodata, VIC, Australia) was mounted to a blank (no hormone) controlled internal drug release (CIDR®, Zoetis, NSW, Australia) and inserted vaginally into each cow. This was removed on the final testing day of each group.

Each day after the morning milking the designated trial group was walked from the holding yard at the AMS to the starting point, granted immediate access to the feed allocation and locked into the feeding area. At 10:00 the feeding area was opened allowing the cows to walk to the dairy voluntarily. Observations started from the time the feeding area was opened where stance (standing, lying, walking or other), behaviour (ruminating, idle, grazing or other) and location (feeding area, water trough, shade (structure 1-5) or out in the open (zone 1-6)) were recorded every 10 minutes. Respiration rate of each cow was recorded (at 20 minute intervals) by observing the expansion and contraction of the mid-section of the cows from a short distance over 15 seconds. Respiration rates could only be recorded when the cows were stationary and not grazing. Observations ceased once the cows entered the milking facility, or at 17:00 (whichever occurred first). Environmental temperature was logged every 10 minutes (USB datalogger 98582, OnSolution, NSW, Australia) and solar radiation was measured every 20 minutes during observations using a handheld pyranometer (Ciderhouse tech, VIC, Australia).

Data analysis

All data were collated in Microsoft Excel (Microsoft Office Corporation 2010) and analyses were performed using GenStat® 16th Edition (VSN International, UK) and ASReml (VSN International, UK). Linear mixed models (LMM) were used to identify if treatment was associated with internal body temperature and respiration rate, and generalized linear mixed models (GLMM) were generated to determine if treatment was associated with cow behaviour.

Zone was converted into approximate distance from the starting point, based on the midpoint distance of each zone, where the start/feeding area was defined as 0 m. An ordinal logistic regression with random effects was conducted to determine if treatment had any effect on the distance from the starting point the cows had travelled at each observation. Here distance,

or zone, was categorised into three groups, 0 m, < 375 m (zone 1-3) and > 375 m (zone 4-6) along the laneway towards the milking facility.

Results

The environmental temperature on SHADE treatment days was 28.9 ± 8.4 °C with an average of 26.6 °C and on NO SHADE treatment days it was 28.1 ± 10.5 °C with an average of 29.1 °C. Solar radiation ranged from 668 ± 621 W/m² on SHADE days and 744 ± 621 W/m² on NO SHADE days. As environmental temperature and solar radiation were on average higher on NO SHADE treatment days than on SHADE days, these factors were added to the LMM and GLMM models to allow for correction of these conditions.

On the first testing day of each group, all cows voluntarily walked to the milking facility from the feeding area prior to 17:00. On all other testing days no cows voluntarily entered the milking facility within the observation period, however, on eight of these days at least one cow had walked further than zone 1.

During the SHADE treatment, 23.5% of all observations were recorded with the cows standing under one of the five shade structures. Six out of eight SHADE test days included voluntary shade use by at least one cow.

A significant effect of treatment on distance travelled was identified ($P < 0.001$), where cows were 1.37 times more likely to walk further when shade was provided (Figure 1).

Cows in the SHADE treatment had significantly lower body temperature and respiration rates than cows in the NO SHADE treatment (Table 1).

Significant treatment differences were detected in the probability of grazing and ruminating behaviour (Table 2).

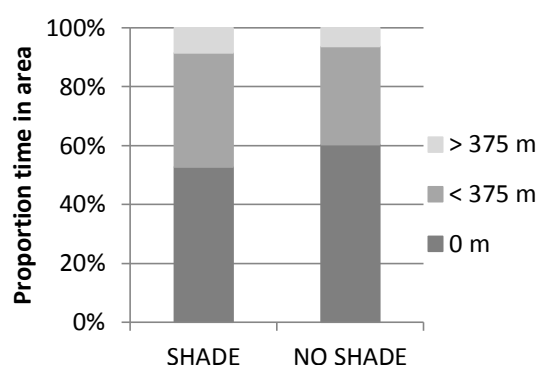


Figure 1: Proportion of observations for each treatment where the cows were at 0 m, < 375 m or > 375 m from the starting point.

Table 1: Effect of treatment on internal cow body temperature (OC) and respiration rate

Predicted means			
Response	Shade	No Shade	P-value
Body temp	38.84	39.04	< 0.001
Respiration (bpm)	79.64	81.44	< 0.001

Table 2: Effect of treatment on cow behaviour.

Probability of behaviour			
Response	Shade	No Shade	P values
Grazing	0.19	0.25	0.017
Ruminating	0.16	0.10	< 0.001
Idle	0.64	0.64	0.778
Lying	0.30	0.27	0.107
Standing	0.65	0.69	0.156
Walking	0.03	0.03	0.690

Discussion

The main objective of the current study was to determine if the provision of intermittent shade sources along a laneway would encourage voluntary cow movement during hot weather. Analysis of the approximate distance travelled by each cow at each observation identified that when shade was available, the cows were more likely to travel further towards the

milking facility than when shade was not offered indicating that the small shade sources did not result in long periods of shade use. This shows promise for the use of shade as an incentive to encourage voluntary cow movement and warrants further investigation.

Cows in the SHADE treatment had a lower respiration rate and body temperature compared to cows in the NO SHADE treatment. This result was expected as shade protects the cows from direct solar exposure (Kendall *et al.* 2006) and is known to reduce respiration rate (Schütz *et al.* 2014) and body temperature (Tucker *et al.* 2008).

Cows under the SHADE treatment spent 6.0% more time ruminating and 5.6% less time grazing than NO SHADE cows. Greater levels of rumination would be expected as when relief from hot weather is not provided rumination time is often reduced (Soriani *et al.* 2013). The greater grazing time for NO SHADE cows was not expected due the impact of hot weather on appetite (Kadzere *et al.* 2002), however, greater time spent in the feeding area and no access to shade would have provided greater opportunity for NO SHADE cows to graze. All efforts were made to restrict the availability of grass in the test area; however, the cows would still spend time 'grazing' after the feed allocation was depleted. Because of this, total feed consumption is unlikely to be significantly different between the treatments.

Conclusion

Voluntary cow traffic on a pasture based AMS reduces the requirement of farmers to fetch cows and positively effects cow behaviour and welfare. When feed incentives are no longer effective to encourage sufficient voluntary cow movement during hot weather, intermittent shade sources may be useful for improving cow flow. In the current study cows were seen to be less affected by environmental conditions when shade was available, as seen by reduced respiration rates and body temperatures, and were more likely to travel further towards the milking facility.

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Association between immune response, stress responsiveness and resistance to internal parasites

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Abstract

Breeding of animals based on their inherent ability to resist diseases is a holistic health approach that not only improves animal health but also welfare and production. This study was designed with the objective of determining the association between immune responses and health parameters. A commercial vaccine was used to induce antibody and cell-mediated immune responses. Short-term handling and yarding was used to assess stress responsiveness and worm egg counts were recorded to assess resistance to internal parasites. A total of 403 pre-joining heifers from two herds in a seasonally calving, pasture-based production system were used in the study. A negative association was recorded between antibody-mediated immune responses and stress responsiveness. Furthermore, higher cortisol plasma concentrations were recorded in animals with the lowest ranks for antibody and cell-mediated immune responses. Similarly, a significant negative correlation was recorded between worm egg counts and antibody responses. These findings provide initial evidence on the relationship between immune responses and health parameters in a pasture-based production system.

Introduction

Immune competence testing refers to assessing an animal's immune response and thereafter assessing their relationships with health parameters. This has the potential to identify superior livestock with an enhanced ability to resist both infectious and metabolic disorders. In addition, allows selection emphasis to be placed on immune competence traits in conjunction with other desirable production and longevity traits (Thompson-Crispi *et al.*, 2012). Studies in Canadian intensive dairy production systems have demonstrated that cows ranked as superior for general immune competence had a lower incidence of periparturient health problems when compared with their inferior immune competence phenotype counterparts (Mallard *et al.*, 2015). Data on associations between immune competence phenotypes,

health and coping traits in extensive pasture-based production systems is limited. Therefore the objectives of this study were to assess the associations between immune competence phenotype, stress responsiveness and resistance to internal parasites in first lactation Holstein-Friesian heifers reared in a pasture-based production system.

Materials and Methods

403 heifers from two dairy farms located in Colac, Victoria, Australia were immune competence phenotyped. Immune competence phenotype testing involved assessing both antibody-mediated immune responses (AMIR), cell-mediated immune responses (CMIR) and combined immune response (CIR) using a protocol developed for the Australian dairy farming set-ups (Aleri *et al.*, 2015). These

animals were assessed for serum cortisol stress responsiveness and resistance to internal parasites using short term-handling and faecal egg counts, respectively. Faecal samples were collected from the rectum and analysed for worm egg counts using the McMaster technique (Kassai, 2002).

Linear regression models were used to determine associations between immune responsiveness (AMIR, CMIR and CIR), stress responsiveness and resistance to internal parasites. Immune competence measures, AMIR, CMIR or CIR, were fitted as the independent variable whereas stress responsiveness and resistance to internal parasites traits were set as the dependent variables. In the regression models, backward stepwise elimination procedures were applied to generate the final analysis models (threshold, $P < 0.05$).

Results

A significant negative correlation between cortisol response and AMIR ($P < 0.0001$, $r = -1.67$) (Figure 1) was observed. There was no association ($P > 0.05$) between cortisol response and CMIR and CIR. Animals with both low AMIR and CMIR had greater stress responses when compared to their counterparts which were average or high for AMIR, CMIR or both traits ($P = 0.039$).

A significant negative correlation between AMIR and worm egg count was observed ($P = 0.019$, $r = -0.118$) (Figure 2). A non-significant negative correlation between AMIR and CIR were also recorded at ($P = 0.866$, $r = -0.009$) and ($P = 0.078$, $r = -0.072$) respectively. Differences in worm egg counts between animals categorised as the fecal high, average and low immune responders for AMIR, CMIR or CIR were not significant with odd ratio of 1.81(0.81 - 4.03), 1.14(0.54 - 2.40) and 0.85(0.44 - 1.66) respectively).

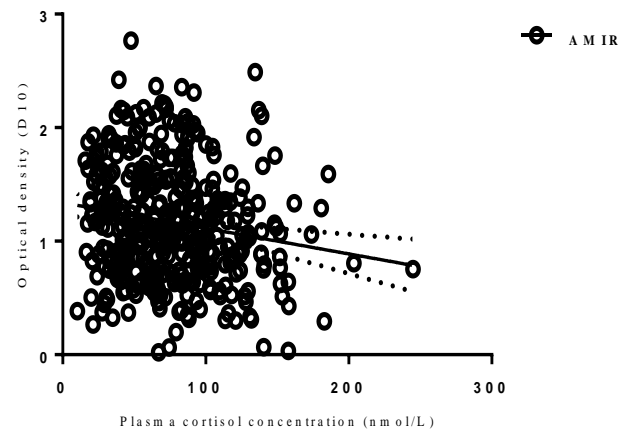


Figure 1. Graph showing the correlation between antibody-mediated immune response (AMIR) ($P < 0.0001$), ($r = -1.67$)

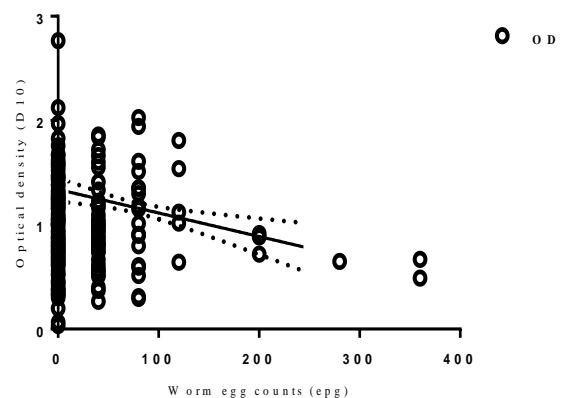


Figure 2: Graph showing the correlation between antibody-mediated immune response (AMIR) ($P < 0.019$), ($r = -0.118$)

Discussion

The objective of this study was to determine the association between immune responses and health parameters (stress responsiveness and resistance to internal parasites) in first lactation heifers reared under a pasture-based production system.

The favourable correlation observed between stress responsiveness and magnitude of AMIR supports our hypothesis that increased stress responsiveness is associated with reduced immune capacity. Reduced stress responsiveness is a desirable trait in production systems due to the favourable correlations between stress responsiveness and other

desirable production traits such growth rate, feed conversion efficiency and social dominance and behaviour (Jenkins *et al.*, 2013). The findings of this study also revealed that animals with both low AMIR and CMIR had significantly greater cortisol plasma concentrations compared to their counterparts. Immune competence and stress responsiveness are interlinked via the immunological, physiological and behavioural mechanisms as supported by our findings. Such cohorts of animals are deemed to have higher resources being directed towards such coping mechanisms rather than production (Colditz, 2002). From these findings we can conclude that, not only is there a benefit from broad-base disease resistance when selecting for generalized immune responsiveness in dairy cows but also other important production traits such as stress coping mechanisms.

The associations between worm egg counts and generalized immune responsiveness showed a negative correlation between AMIR whereas non-significant associations with CMIR and CIR. These findings have not been reported under a pasture-based production system. The assessment of resistance to internal parasites as used in this study was to provide an understanding on general disease resistance to several pathogens other than towards a specific disease. It is important to note that despite AMIR and CMIR working together to protect the host against a wide range of pathogens they are inversely associated as observed in the Canadian intensive dairy production systems (Thompson-Crispi *et al.*, 2012) and therefore a selection based on generalized immune responsiveness provides a more stable and robust approach to improve animal health.

In summary, these findings provide initial evidence on the relationship between immune responses and health parameters in a pasture-based production system.

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