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XLIII CONGRESO ANUAL DE LA SOCIEDAD CHILENA DE PRODUCCIÓN ANIMAL

SOCIEDAD CHILENA DE PRODUCCIÓN ANIMAL SOCHIPA A.G.
DEDICADA AL PROGRESO DE LA CIENCIA PECUARIA

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La serie SIMPOSIOS Y COMPENDIOS se ha diseñado con el propósito de suministrar a científicos, docentes, profesionales, técnicos y productores, información de naturaleza más amplia y sistematizada, en diferentes disciplinas de interés en la producción animal. Esta serie incorpora información de las reuniones técnicas que SOCHIPA A.G. realiza y patrocina desde 1975 en diferentes lugares del país, en conjunto o independientemente de la reunión anual de la sociedad, con la participación de destacados investigadores nacionales y extranjeros.

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Simposio:

"Desafíos de los sistemas lecheros basados en praderas"
"Challenges of pasture-based dairy systems"

PRÓLOGO

Al analizar los datos proporcionados por FAO en términos de producción de leche a nivel mundial se observa un estancamiento de la oferta. Similar situación se observa a nivel local, donde la recepción en planta bordea los 2100 millones de litros, con una variación de ±1,5% anual, según datos informados por ODEPA (2019). Esto contrasta con la creciente demanda solo considerando el aumento de población que, según proyecciones de la ONU, el 2050 llegaría a los 9700 millones de personas.

Esta creciente demanda sin lugar a dudas presenta grandes desafíos. Por un lado, los recursos son limitados: la tierra y el agua necesarios para su producción presentan una fuerte presión para ser utilizados en rubros con mejor rentabilidad. La amenaza del cambio climático crea una incertidumbre hacia el futuro, al que debemos prepararnos si se quiere seguir siendo productivos. Los constantes vaivenes de los mercados internacionales, acrecentados por guerras económicas de grandes potencias, como China y Estados Unidos, pueden poner en jaque la producción local de países como Chile u otros. Estas y otras amenazas no presentan grandes desafíos para el futuro.

En este simposio se presentan tres temas en las cuales se está trabajando fuertemente y que debieran seguir siendo priorizadas. El primero, de los autores Yani Garcia y Santiago Fariña, nos presenta una mirada de como los productores de leche australianos están centrando su atención en la producción y utilización de forrajes producidos en el predio, como una forma de disminuir los costos de producción. Son 10 años de estudios don se analizan los límites productivos de las praderas tradicionales (praderas mixtas) y como la producción de materias seca por hectárea puede incrementarse con la incorporación estratégica de cultivos suplementarios.

La siguiente presentación la hace la Dra. Karin Schütz, quien nos entrega información reciente sobre los efectos del calor extremo en verano y frio invernal, sobre las respuesta animal en producción y que estrategias de mitigación debieran ser incluidas de manera tal de disminuir los efectos negativos sobre el animal. El uso de sombreaderos y aspersión de agua en verano, protección contra el viento y humedad (barro) invernal, y los efectos en producción, son temas abordados por la Dra. Schütz.

Finalmente, los Dres. David Pacheco y Juan Pablo Keim, hacen un análisis de como la nutrición y alimentación juegan un rol clave en la productividad de los sistemas lecheros pero que presenta un desafío en aspectos medio-ambientales. Puntos clave tocados en esta presentación son el eficiente uso del Nitrógeno y la disminución de la producción de gases de efectos invernadero, en sistemas de producción de leche basados en praderas.

Los tres temas presentados en este simposio son de importancia actual y que será aun más relevante en el corta plazo: aumento de la productividad de los sistemas de lecheros, bienestar animal y responsabilidad con el medio ambiente, son áreas en que se debe seguir trabajando fuertemente, y nuestros tres invitados aquí los confirman.

Dr. Christian Alvarado G.
Presidente SOCHIPA A.G.

EN MEMORIA DE SOCIOS FALLECIDOS

Dr. NÉSTOR TADICH BABAIC

Oriundo de Punta Arenas, el Dr. Tadich llegó a Valdivia a estudiar Medicina Veterinaria en la UACh, titulándose en 1977. Un año después ingresó a la carrera académica en Categoría V. Cursó sus estudios de postgrado en la Universidad de Liverpool entre los años 1982 y 1986, obteniendo el grado de Ph.D. Posteriormente realizó estadías de postdoctorado en las universidades de Liverpool, Bristol y Warwick en el Reino Unido.

Desde el ingreso a la Universidad Austral de Chile trabajó en el Instituto de Ciencias Clínicas Veterinarias, del cual fue Director desde el año 1996 al 2005. Dentro de su actividad en administración académica se puede mencionar que fue Secretario Académico de su Facultad, Prodecano y Decano de la misma por dos períodos consecutivos (2006-2012). Además, formó parte de la Comisión que creó el Doctorado en Ciencias Veterinarias y hasta el año 2014 fue miembro de la Comisión de Promociones y Ascensos, siendo nombrado Vicerrector Académico de la Universidad Austral de Chile, a partir del 1 de julio de ese año.

Fue Coordinador del Programa de Magíster en Ciencias, Mención Salud Animal (desde julio de 2012 a julio de 2014) y fue parte del grupo ad hoc de la OIE “Group on Animal Welfare and Dairy Cattle Production Systems” desde octubre de 2012. Desarrolló además una extensa actividad académica, destacando el patrocinio de memorias de título de pregrado de estudiantes nacionales y extranjeros y la conducción de seis tesis de magíster. En relación a su actividad de investigación participó en proyectos, de los cuales fue Director de cuatro DID, un IFS, numerosos FONDECYT y un

MECESUP “Innovación y Modernización de la Docencia en Salud Animal en la Universidad Austral de Chile”, que dio origen al actual Hospital Veterinario UACh.

Su participación en proyectos dio origen a 50 publicaciones ISI en revistas de su especialidad y numerosas presentaciones en congresos científicos nacionales y extranjeros. En el ámbito de la extensión publicó más de 30 artículos especialmente en aspectos relacionados con el bienestar animal.

También participó en actividades gremiales de las cuales se pueden destacar el haber sido Secretario del Colegio Médico Veterinario A.G. Valdivia (1987–1990), Presidente del Consejo Regional Valdivia del Colegio Médico Veterinario de Chile (1992-1994), Tesorero de la Asociación Gremial de Académicos de la Universidad Austral de Chile (1999-2001) y Director de la Sociedad Chilena de Producción Animal SOCHIPA A.G. (2000–2002).

Simposio:

“Desafíos de los sistemas lecheros basados en praderas”

A DECADE OF RESEARCH ON THE COMBINATION OF GRAZED PASTURE AND COMPLEMENTARY FORAGES TO INCREASE MILK PRODUCTION FROM HOME-GROWN FEED

Una decada de investigación en el uso combinado de praderas y forrajes suplementarios para incrementar la produción de leche con recursos de producción intrapredial

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Keywords: Complementary forage rotation; pasture; home-grown feed; dairy

Introduction

Land and water availability and cost, lifestyle and labour management, climate change and the effects of agriculture on the environment, continue to be key pressures for dairy farmers in many regions (Garcia and Fulkerson, 2005). In addition, climate change, climate variability and external factors (protectionism, markets) have put upward pressure on price of grain-based concentrates. Dairy farmers in many regions will have to increase not only on-farm productivity, but also the efficiency of use of key expensive resources such as land, water and supplementary feed. A long-term Australian RD&E program called FutureDairy focused on increasing the amount of forage produced and utilized on farm (home-grown feed) as a driver of productivity gain on farm. This paper describes the logic behind the science and the key investigations carried out by FutureDairy in this area.

Limits of pasture utilization

The Forage module of FutureDairy was conceived with the challenge of increasing productivity from home-grown feed. However, despite some anecdotal evidence, there was little scientific-based knowledge about the real limitations of the pasture-based system. Thus the first step was to review the existing literature to i) identify the real limitations and future pressures in relation to forage production and utilization and b) have a better indication of potential and limitations of the current pasture-based system (Garcia and Fulkerson, 2005; Garcia et al., 2007c). Key points from these reviews are summarized below.

In typical pasture-based systems (where pasture comprises >50% of the cow's diet; (Garcia and Fulkerson, 2005), the amount of pasture utilised/ha defines the ceiling to milk production from home-grown forage. On commercial dairy farms in both New Zealand and Australia, the maximum amount of pasture that can be utilised on-farm is about 20 t DM/ha (Clark et al., 2001; Farina et al., 2008). In Australia under dryland conditions, pasture consumption from 7.9 (Grainger, 1992) to 12.8 (G. Rogers, unpub. data) t DM/ha has been reported for Gippsland; from 9.0 (McKenzie et al., 2003) to 14.3 t DM/ha/year (Jacobs et al., 1999) for south west Victoria; and from 10.0 to 12.0 t DM/ha/year in the more favourable climate of Tasmania (Bowman, 1999; Blair, 2002). More recently, about 18 t DM/ha/year of measured utilised pasture have been reported under irrigation in a paddock scale comparison in NSW (Garcia et al., 2006) and on commercial farms in SE South Australia (Spain, 2005). In New Zealand, van Bysterveldt (2007) reported about 16 t DM/ha of utilised pasture under irrigation in Canterbury, whilst a maximum of about 20 t DM/ha had been obtained without irrigation in the Waikato by Penno *et al.* (1999). It is evident from the above information that the pasture utilisation ceiling on-farm is about 20 t DM/ha/year, despite considerable investment in RD&E to improve pasture cultivars, production and utilisation. Therefore the challenge for FutureDairy was to devise alternative systems that could provide a ‘quantum leap’ in productivity potential.

The CFR concept to boost total feed production per ha

The question of producing beyond the current ceiling of pasture potential was extremely challenging. The increase in potential production also needed to be accompanied by a demonstration of its feasibility, i.e. it should be both economic and sustainable. In order to achieve the higher yields, it was obvious that we needed to explore other forages with greater capacity to convert solar radiation into biomass than the typical temperate pasture species being used currently. It was evident also that we would need to use more than one forage crop to exploit the maximum potential of each growing season. However, the combination of crops in a sequence (or rotation) should ensure that neither the soil, nor the animals or the whole system would be adversely affected. In other words, the rotation of forage should be ‘complementary’. This was the origin of FutureDairy’s term Complementary Forage Rotations (CFR). The term CFR refers to those specific combinations of forage crops grown in a rotational sequence and designed to sustainably increase forage production/ha and improve the efficiency of use of limiting resources (e.g. N and water). To achieve these, the forage crops must provide some complementarity at the soil-plant level - e.g. improve, or at least not adversely affect, soil status; at the plant-animal level - e.g. improve the nutritional balance of different forages/feeds; and most importantly, at the whole system level - ‘complement’ rather than ‘replace’ pasture. In practice, CFR can be a series of forages grown rotationally on either the same site over time or as part of a crop-pasture rotation.

We started this challenge by setting up a 3-year field experiment at Elizabeth Macarthur Agricultural Institute, Industry & Investment NSW. The study aimed to compare forage production and quality, nutrient and water use efficiency of a CFR vs. a pasture system. This program of work included extension and social research components (Garcia et al., 2007b).

Details of the experiment and treatments were given in previous papers (Garcia et al., 2006) and results of the 3-year study were published elsewhere (Garcia et al., 2008). The two treatments were Pasture (control) and CFR. The Pasture treatment represented a typical pasture system with a C_4 grass (kikuyu; *Penisetum clandestinum*) in summer, oversown with a C_3 grass (short-rotation ryegrass; *Lolium multiflorum L.*) in early autumn. The rotation comprised 3 crops per year with brassica (forage rape, *Brassica napus* L.), sown in late February-early March as a break crop; an annual legume (either Persian clover (*Trifolium repesinatum* L.) broadcast after the first grazing of the brassicas, or maple peas (*Pisum sativum* L.), sown in early August); and maize (*Zea mays* L.; a bulk crop), sown in early October and harvested for silage in February.

Mean total forage yields for each crop and pasture in each experimental year are shown in Table 1. On average, over 42 t DM/ha/year were utilised (brassicas and legumes) or harvested (maize) for the CFR treatment. This was 2.5 times higher (P<0.001) than total pasture utilised in the control Pasture treatment (17.3 t DM/ha/year, Table 1). Overall, autumn-winter forage yield was 2.6 times higher (P<0.001) for CFR than Pasture.

Table 1 Mean seasonal (autumn-winter and spring-summer), and total year, forage yield (t DM/ha) of complementary forage rotation (CFR) and Pasture treatments over the 3 experimental years. Values for legumes in Year 2 are average of maple pea and Persian clover paddocks.

	Treatment									
	CFR				**Pasture**					
Year	**1**	**2**	**3**	**Mean**	**1**	**2**	**3**	**Mean**	**SED**	**P<**
Forage	t DM/ha									
Brassica	12.0	10.7	11.6	**11.4**						
Legume	3.5	4.6	3.9	**4.0**						
Pasture					5.6	6.1	6.0	**5.9**		
Total autumn-winter	15.5	14.7	15.5	**15.2**	5.6	6.1	6.0	**5.9**	0.2	<0.001
Maize	26.7	26.2	28.9	**27.3**						
Pasture					11.7	11.9	10.6	**11.4**		
Total spring-summer	26.7	26.2	28.9	**27.3**	11.7	11.9	10.6	**11.4**	0.4	<0.001
Total year	**42.2**	**40.8**	**44.0**	**42.3**	**17.3**	**18.0**	**16.7**	**17.3**	**0.5**	**<0.001**

On average, ~600 kg N/ha/year were applied ($P=0.99$) to both CFR and Pasture treatment. In the CFR treatment, 0.55 of total N input (mean 337 kg/ha) was applied to maize, whilst brassicas accounted for another 0.4 (mean 239 kg/ha). The average rainfall was 622 mm. Total irrigation varied ($P=0.01$) from 650 to 830 mm (6.5 to 8.3 ML/ha) among years, but a similar ($P=0.4$) amount of water was applied to both treatments (mean 7.5 ML/ha). Overall, maize used 7.7 ML/ha/year of total water (rainfall + irrigation), brassicas 3.9 ML/ha/year and legumes (average of maple peas and persian clover) 2 ML/ha/year. Due to the differences in forage yield, total N use efficiency (NUE) was 2.35 times higher ($P<0.001$) for CFR than Pasture (mean 70 and 30 kg DM/kg N, respectively. Similarly, water use efficiency (expressed as t DM ML^{-1} of irrigation plus rainfall) was 2.5 higher for CFR than for Pasture. On average, 5.6 and 3.1 t DM were produced per ML of irrigation and total water, respectively, for the CFR, while comparative figures for Pasture were 2.3 and 1.2 t DM ML^{-1}, respectively. These results clearly demonstrated the feasibility of achieving >40 t DM/ha/year through a CFR with a more than double efficiency in the use of key limiting inputs: N and water.

The “40 t experiment” at Camden created great interest in the farmers community. The project was designed to co-learn with farmers about the advantages and disadvantages of CFR and several trials were started on commercial farms in Victoria and South Australia. Although describing these experiences in detail is beyond the objective of this paper, it is worth noting that the “co-learning” methodology, a multidisciplinary approach managed by a full-time extension person and a social researcher (both staff of the project) was successful (Garcia et al., 2007a). Farmers felt more confident due to the close participation of researchers and extensionists and we researchers, received top-class feedback directly from the users of the research outputs.

Evaluating CFR options

Most farmers are practical persons and favour simplicity above anything else. The first question they asked was: *‘Can we achieve the same forage yield with two crops per year instead of three?’* In addition, some farmers perceived forage rape as a difficult crop to manage and were hesitant about incorporating complex triple-crop rotations. They also wanted to know whether CFR could be a fully ‘grazeable’ option instead of a combination of grazing and harvesting as in our original triple-crop CFR. Therefore two small-scale (plot) studies were conducted to address these questions.

In the first study we found that double crop CFR (with either Brassica or clover as autumn-winter crops followed by maize as a summer crop) can achieve nearly 40 t DM/ha/year (average 39.3 t DM/ha/year). Autumn-winter forages achieved between 13.5 (clovers) to 14.4 (brassica) t DM/ha during the period March to early October. In the second study we found that annual clovers sown in a triple mix (Persian, balansa and berseem clovers) in late February yielded over 12 t DM/ha/year and therefore can be an alternative to Brassicas (albeit of lower yield) as an autumn-winter forage for double crop CFRs. Canola can yield over 9-10 t DM/ha in a single cut but forage quality drops significantly and the ability of this crop to be ensiled is doubtful. Maple peas, although a proven interesting option as a high-yielding forage when sown in winter, are not suitable for early sowing, with an average total forage yield of 5-7 t DM/ha in one cut for silage after 6-7 months of growth. Overall, these results indicated that annual clovers could be used instead of brassicas with minimum penalty in forage yield.

Assessing CFR complementarity: 1. Soil level

The other key feedback from farmers was their concern about the environment. We were concentrating on all the technical aspects to

ensure the high forage yield would be achieved. The farmers on the other hand, were equally concerned about the potential impact of the high input CFR on the soil and environment. A big lesson for us!
It was clear from this feedback that, unless we could demonstrate little or no adverse impact on the environment, the CFR concept was condemned to fail. However, assessing complementarity at the soil-plant level is difficult due to its long-term and multi-factorial nature. At a minimum, it requires monitoring soil physical, chemical and biological properties as well as quantifying nutrient movements within the soil profile.

In FutureDairy 1, we conducted a series of studies involving two MSc projects to assess the impact of CFR on environmental sustainability. The first study (Shrestha et al., 2006; Shrestha, 2007) evaluated the impact of growing wholly grazable or wholly harvestable double- and triple crop CFRs on soil fertility, health (microbial activity) and pathogens build-up in the soil. Although this was done over only two years of continuous crop rotation and in small plots, the study found no evidence on any adverse effect of CFR on soil characteristics and soil health. The lack of effect of treatment on soil-born pathogen (nematodes) levels could be due to either a low biofumigation effect or low initial pathogens levels (not tested). Clearly more research is needed to elucidate this.

The second and larger study (Kaboré et al., 2006; Kaboré, 2008) involved the monitoring of key indicators of soil health status and nutrient flows within the system over four seasons. The study was particularly interesting because it involved two different soil types (brown, clay-loam and heavy-clay (black)) and two contrasting years with ~400 and 1000 mm of rainfall. Results showed no significant changes in soil physical characteristics such as bulk density and permanent wilting point. The organic matter content of a soil is an indicator of its potential fertility and it can be dramatically reduced after a few years of continuous cropping. However, there were no significant changes in soil organic matter content between the CFR and Pasture systems.

Overall, the 2 studies outlined here show that, for the soils and conditions used in these studies, the increased intensification in home grown feed through CFR system can be achieved without adversely affecting soil physical and chemical properties and with a significantly higher efficiency of use of nitrogen and water.

Assessing CFR complementary: 2. Animal level

Another question arising from farmers' feedback – documented through social research activities of FutureDairy1- was in relation to the potential impact of these 'newer' forages, particularly brassicas, on rumen function and animal performance. Farmers were confident with the higher yield of forage rape but less comfortable with management of these crops and their utilization as grazable forage by the animals, particularly in relation to impact on rumen function. This latter question initiated a new project aimed at increasing our understanding of rumen function when several different forages crops, pastures, conserved forages and concentrates are offered to ruminants in different proportions. Key questions explored in this project were: is grain level more or less important to affect rumen function when these combinations of conserved and fresh forages are fed? Is the proportion of brassicas in the diet important? Is the time and sequence of feeding the different feeds important in relation to rumen function? Are brassicas better than clovers from a nutritional viewpoint?

A series of experiments were designed using fistulated sheep as a model. This was due to limitations to access fistulated cows at the time and the fact that the objective was to evaluate aspects of rumen fermentation rather than animal performance. However, it is worth noting that the extrapolation of data from indoor feeding trials with male sheep to high-producing grazing cows should be made with caution. Several authors have reported little or no difference in digestion of forages by cattle and sheep (Nandra et al., 2000; Burns et al., 2005), whilst others have criticised the use of sheep as a model for dairy cows due to differences in level of intake (Arman and Hopcraft, 1975) and quality of forage (Poppi et al., 1981).

The first experiment of this project evaluated the effects of feeding different levels of forages and concentrate on the efficiency of feed utilisation and rumen function using rumen-fistulated sheep (Kaur et al., 2008). Treatments were diets comprising 15% (C15), 25% (C25), 35% (C35) and 45% (C45) concentrate (energy-dense dairy pellets) with the rest of the diet being a combination of conserved (lucerne hay and maize silage) forages and (fresh) short rotation ryegrass. The hypothesis of this study was that the decrease in fibre digestibility with increased level of concentrates in the diet (when fed in discontinuous feeding pattern) is due to the replacement of highly digestible fibre by concentrate rather than the associative effects of concentrate on fibre digestion. Main results from this study showed that the apparent in vivo DM digestibility was 4% higher ($P = 0.04$) for C15 than for C35 and C45 diets, which may be attributed to the high quality of the forage (ryegrass) used. Fibre (NDF and ADF) digestibility decreased as proportion of concentrate in the diet increased, but neither pH (6.1 ± 0.23) nor ammonia concentration (24.4 ± 6 mg/100 mL) differed ($P > 0.05$) among diets. This suggested that the decreased NDF digestibility was unrelated to changes in the rumen fermentation pattern but rather related to the different rate and extent of fibre digestion in the rumen for ryegrass than for other feeds. We then speculated that potential gains in animal nutrition and performance could be achieved by increasing the amount of high digestible fibre in the animals' diet by, for instance, incorporating forages of high nutritive value like forage rape, which was shown –in another experiment of this series- to be higher than perennial ryegrass (Kaur et al., 2009; Kaur, 2010). Therefore the expected benefit of incorporating forage rape in complex diets would be also higher. However, management (grazing) of forage rape is less straight forward than ryegrass. This is due to plant architecture and high biomass accumulation, which means that a very high instantaneous stocking rate (~8-10 m2/cow or 800-1,000 cows/ha) is needed to graze the crop effectively. In practice this means that small areas will be grazed each day, resulting in relatively longer rotation lengths.

The obvious question being: *Will the above-mentioned high nutritive value of forage rape be sustained over a relatively long grazing period (typically about 7-8 weeks)?* To address this question, another FutureDairy study (Kaur et al., 2009) was conducted to evaluate the degradability of whole plant and plant fraction of forage rape over the typical grazing window (from week 7 to 13 after sowing). As shown in Figure 1, the leaf fraction of forage rape, which constitutes the largest proportion of the material harvested by the cows, maintained a total potential DM degradability in the rumen >80-90% in 24 h. However, as expected, degradation rate decreased as crop maturity increased. The decrease in total DM (and fibre) degradability was logically greater for petiole and stem fractions. However, this decrease in rumen digestibility of forage rape was smaller in comparison with typical changes in grasses, particularly during the reproductive stages. In practice and from the CFR concept perspective, these results indicate that forage rape has a high potential to be incorporated in the diet of cows.

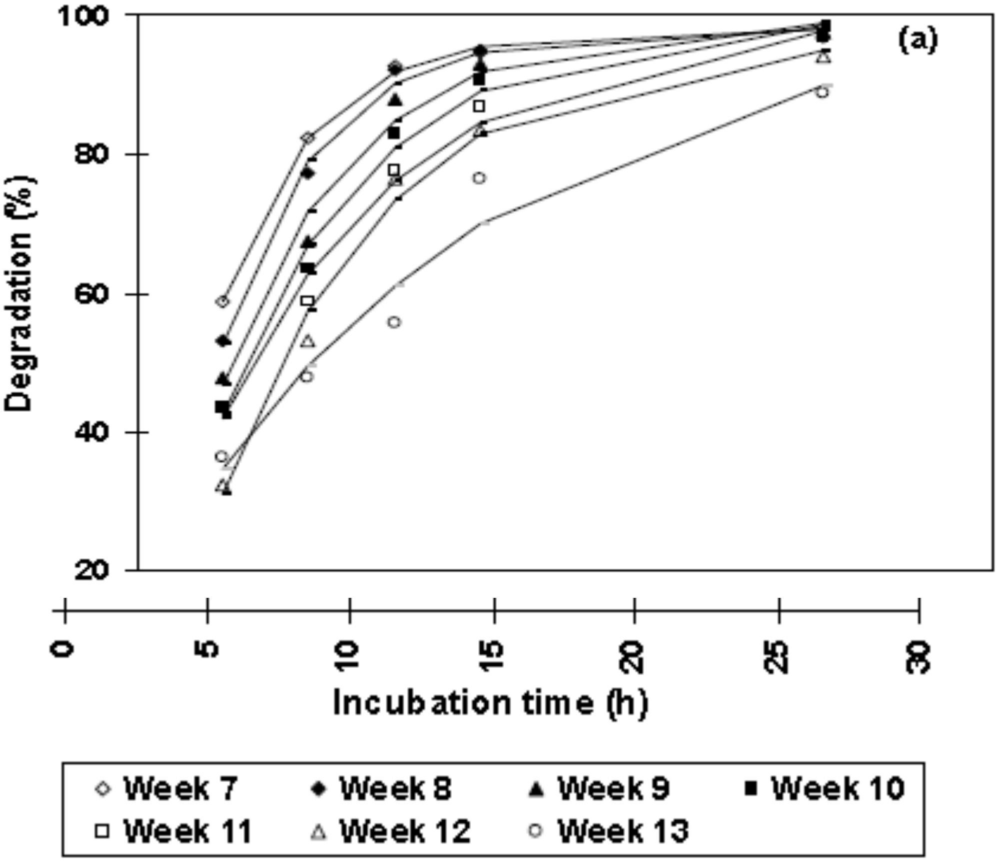

Figure 1. In sacco DM degradation of forage rape leaves at different weeks of maturity (Kaur, 2010).

The potential of manipulating the composition of the diet with the use of high quality forage like forage rape was evident. The next step was to gain better understanding about the use of forage rape in the diet of ruminants. We evaluated first the impact of feeding forage rape in different sequences in relation to other feedstuffs. We found no differences in rumen characteristics, in vivo digestibility and nutrient efficiency when a diet comprising 25% forage rape, 25% maize silage, 10% concentrate and 40% short rotation ryegrass was fed in three different combinations (treatments): forage rape fed after maize silage in the morning (Mz→Fram), forage rape fed before maize silage in morning (Fr→Mzam), and forage rape fed after maize silage in afternoon (Mz→Frpm). The potential of forage rape as part of the CFR concept from an animal nutrition viewpoint was becoming evident. However, as noted previously, some farmers would rather use double-crop forage rotations with maize and an annual clover instead of forage rape. Thus we then compared forage rape with Persian clover (based on the results of the 2-crop CFR outlined above) and found higher voluntary intake of clover by sheep (Kaur, 2010) but higher milk protein in milk with cattle (McIntosh et al., 2009). These studies indicated the potential of high yielding forage crops like forage rape and Persian clover to manipulate milk composition in pasture-based dairy systems.

From Complementary Forage Rotations to Complementary Forage Systems

The question of the integration of the CFR into a pasture-based dairy farm system was still to be investigated. This step was decisive in order to assess the potential productivity and both the economic and environmental sustainability of implementing CFR principles at the whole farm level. To achieve this, a whole farm study was needed, in order to capture the multiple interactions that play within the system, and not just each component separately. This led to the introduction of the concept of Complementary Forage System (**CFS**): the integration of pasture and CFR at the whole farm level to maximize production of milk from home-grown forage. The relative proportions of CFR and pasture on a CFS farm determine the potential production of home-grown forage. From a desktop modelling study (Garcia et al., 2007c) it was estimated that a ratio of 35 % and 65 % for CFR and pasture, respectively, could optimise the impact of CFR on the whole system without compromising practicality (e.g. avoiding too high stocking rate on the pasture area during summer, when maize is grown in the CFR area). The hypothesis was that a 35% CFR:65% Pasture CFS could achieve over

25 t DM/ha.year of utilised forage over the whole farm area, leading to the production of >30,000 L milk/ha.year from home-grown forage. To test this hypothesis, a farmlet study was conducted at the University of Sydney's Costorphine Dairy Farm, Camden, NSW, between April 2007 and April 2009. The CFS farmlet study comprised a total area of 21.5 ha, subdivided into Pasture and CFR sections according to the above described proportions. The Pasture section comprised 12 paddocks of kikuyu grass over-sown in early Autumn with short-rotation ryegrass, and the CFR section comprised 2 different blocks of similar area each: one with a Triple Crop CFR [maize, followed by forage rape, followed by a legume (Persian clover or field peas)] and another one with a Double Crop CFR (maize, followed by Persian clover).

A herd of 100 lactating cows (at peak milking), which calved half in spring and half in autumn, was run on the CFS farm, The dry cows and replacement heifers were managed on a separate area. Management of grazing and supplementary feeding was aimed at maximising utilisation of all forages whilst maintaining a milk production of approximately 25 L milk/cow.day throughout the year. For this purpose, up to 1 t DM concentrate/cow.lactation was fed to each cow as the only bought-in feed used in the system. The grazeable forages (pasture, clover and forage rape) were combined with the maize or legume silage available to provide approximately 230 MJ/cow.day. The target of 25 t DM/ha.year utilised forage as average of two years of study on the whole CFS area was successfully achieved (Table 2).

Table 2 Mean yield (t DM/ha) for each forage section of the farmlet and total for the whole farmlet for years 1 and 2.

	Kikuyu/ Ryegrass	Forage rape	Legume		Maize		Total	
			Double crop	Triple crop	Double crop	Triple crop	Double crop	Triple crop
Year 1	23.9	6.6	6.4	4	19.9	21.9	26.3	32.5
Year 2	20.8	7.5	9.6	5.2	21.6	28.6	31.2	41.3
Average	22.4	7.1	8.0	4.6	20.8	25.3	28.8	36.9

NOTE: the values in Table 2 are the arithmetic mean of the yield of individual paddocks (experimental units), and not the weighed average in relation to the size of each paddock. Hence, total amount of feed produced in the farmlet cannot be calculated from these figures.

The mean (± sd) daily DMI over the two years of study was 20.4 (2.6) kg/cow, which comprised 42.6 % pasture, 9.8 % CFR grazeable crops, 30 % silage and 17.6 % concentrates. The grazeable CFR crops (Persian clover and forage rape) played a critical role during autumn-winter to maintain individual milk production. These crops provided high CP%, low NDF% and high digestibility feed to the diet, to balance-up the low CP%, high NDF% and moderate digestibility of the maize silage fed out at that time of the year when pasture production is low.

Milk production per cow was 7,653 L/lactation whilst total production of milk from home grown-feed was 27,831 L/ha, or 20 % below target (Fariña et al 2011). This was due to the typical decline in daily milk production observed during the summer months, which was in turn explained by the low nutritive value of the kikuyu grass, the main component of the diet during that period.

The present study has shown that a CFR can be successfully integrated into a pasture-based farm, being am alternative to the use of increasing bought-in feed to increase productivity. A full economic analysis involving the use of several biophysical (DairyMod, APSIM, Farmax) and economic models (MilkBiz, RedSky, FFS, @Risk) have been used in conjunction with all the component and field research. The description and details of these modelling exercises are beyond the scope of the present work. However, key results from these analyses (SR Fariña, unpub. data) indicate that well managed CFS systems could be substantially more profitable in comparison to other ways of intensification of pasture-based systems (e.g. not using crops and purchasing additional supplements from outside the farm). As expected, the differences in profitability and risk in favour of CFS systems became even more evident with increased cost of concentrate feed.

From Complementary Forage Systems to change on-farm

The potential of CFR and its integration into CFS became clear in the whole system study outlined above. However, despite all the potential advantages of this technology, it is also clear that most farmers would not "adopt" CFS as a whole concept. Instead, the impact of our feedbase work is likely to be divided into many different principles, processes and components around the issue of growing and utilising forage crops and pastures. In other words the efforts should be concentrated on the "adaptation" of key principles and practices rather than adoption of the whole knowledge 'package'.

The next question, therefore, was simple: *How to achieve this without having extension resources within the project?* A new project involving farmers, researchers from FutureDairy and extension officers from Industry and Investment NSW (formerly NSW Department of Primary Industries) was started in 2009. Six farmers willing to increase productivity from home grown feed were selected by the extension team. The interesting thing is that all farmers would be achieving this goal using this principle but with totally different ways of applying the principle. For instance, one farmer who farms in a small leased block of 50 ha cannot access any more land to lease and therefore the only way he can grow the business is by increasing the total amount of feed produced in the 50 ha with the consequent increase in milk production from it. This farmer applied the triple crop CFR and the CFS concept explained above in full. On the other hand, another farmer who has access to a block of land with irrigation but which is too far away from the dairy (and therefore cannot be used for grazing the lactating cows) was keen to implement a 'wholly harvestable' CFR in that block to increase the amount of quality forage produced from it. These are just 2 distinct examples of how the same principles are being applied differently by individual farmers. The 6 farms are monitored by a technical officer fortnightly and followed up by regular meetings and field days with the researcher and extension team. The project commenced in 2009 and is ongoing. However preliminary results of the first 6 months indicated that all the 6 farms have grown and utilized more forage on farm than for the same period in the previous year. Based on these preliminary results, an increase (average over the 6 farms) of about 20-30% in the total annual home-grown feed is expected. A similar project has been initiated in Northern Victoria in 2010.

Final remarks and conclusions

In this paper we showed the evolution of the thinking and research actions behind a major RD&E project in Australia. In addition to the successful achievement of the project goals, the paper demonstrates the power of simple questions derived from farmers goals as key drivers of whole RD&E programs. We commenced this project with a simple question about the feasibility of producing 40 t DM/ha. Once this was demonstrated, other questions were raised that in turn conducted to even more questions. Overall, the research program has been extremely successful in achieving its goals and demonstrating a much higher ceiling for pasture (or forage) -based milk production than previously thought. As a concept the investigation into complementary forage rotations and systems was completed. However, the number of new questions and the subsequent research programs to address them, are endless.

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EFFECTS OF SUMMER AND WINTER CONDITIONS ON DAIRY CATTLE WELFARE IN A PASTURE BASED SYSTEM

Efectos de las condiciones climaticas de verano e invierno en el bienestar de vacas lecheras en sistemas pastoriles

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Summary

Dairy cattle in New Zealand are predominantly managed outdoors all year round in pastures with or without shade and shelter. Whereas the temperate climate in New Zealand in general allows cattle to be managed outdoors, there are periods where inclement weather, both in winter and in summer, impose challenges to the welfare and productivity of animals. This article describes the effects of warm and cold/wet weather on cattle responses and discusses when mitigation strategies should be implemented to reduce negative effects of inclement weather.

In warm weather, cows will try to cool down using a variety of strategies, which can be used as animal-based indicators of heat stress. These include increased shade seeking, respiration rate, and crowding around a water trough. If these strategies fail, body temperature may rise to above normal levels and there will be a suppression of feed intake and milk production and can, in extreme cases, lead to death. Recent evidence suggests that lactating dairy cattle should have cooling opportunities at air temperature >20°C, depending on humidity levels, to protect welfare and maintain production. Shade is an important resource to cows in summer. Shaded cows are cooler and produce more milk. For shade to be

beneficial, all cows should be able to use it simultaneously and it needs to efficiently block solar radiation. Cooling with water is a more efficient way to reduce heat load than shade alone and is typically applied before milking, however, more research is needed regarding cooling with water in this situation taking into account animal preferences, efficiency and water conservation.

Cattle can generally tolerate low air temperatures in winter if they are healthy, in good condition and well fed, however, shelter is important to the animals in wet and windy conditions. Wet and muddy conditions may result in negative effects on the health and welfare of animals, including reduced lying times which may lead to chronic stress and immunosuppression, increased risk of infection and lameness, increased energy requirements, and decreased production. Recent research suggests that changes in affective state likely underlie behavioural responses to wet and muddy conditions. For example, cattle show rebound responses after being kept short-term on wet and muddy surfaces (i.e., they will try and compensate for low lying times by increased lying when given the opportunity) thus indicating that the motivation to rest is not fulfilled on such surfaces. Also, when given a choice, cattle clearly avoid wet and muddy surfaces to the extent that they will choose to lie down on concrete (a surface they also find aversive) rather than in mud. The changes in behaviour seem to be largely driven by the moisture content of the surface. Providing cattle with shelter that has a dry, soft bedding area for all cows to use simultaneously can enable good welfare and health and mitigate the negative effects of inclement weather and wet and muddy underfoot conditions.

Concerns about effects of climate on farm animal welfare are constantly growing. Indeed, global warming is predicted to increase the frequency of heat waves and extreme weather events as well as global mean temperatures, indicating, for example, that the negative effects of heat stress may increase in future. Whereas new knowledge about animal responses to the environment continues to be developed, managing cattle to reduce the impact of climate remains a challenge.

Heat load and heat stress

Warm summer conditions, such as high air temperature, relative humidity, and solar radiation, cause cattle to gain heat. Cows dissipate heat mainly through evaporation by increasing respiration rate, panting, and to a limited extent, sweating (Gebremedhin *et al.* 2008). Cattle will try to maintain a normal body temperature (38 to 39.3°C) by changing their behaviour and by breathing faster, however, when this is insufficient, body temperature may rise and negatively affect milk yield (Wheelock *et al.* 2010), reproduction (De Rensis and Scaramuzzi 2003) and, in extreme cases, can result in death (Stull *et al.* 2008).

Even though New Zealand has a temperate climate, where the number of consecutive hot days may be fewer, solar radiation levels are higher in New Zealand than in many countries (McKenzie *et al.* 2001). In addition, New Zealand cows often walk long distances to be milked (up to 2 km per trip, Tucker *et al.* 2005) during the warmest part of the day and a peak in body temperature can be seen at this time (Kendall *et al.* 2008).

Heat load has been estimated using a range of environmental measures, including ambient air temperature, and black globe temperature which takes into account solar radiation. Two common indices used to determine heat load in cattle include the Temperature Humidity Index (THI), which combines the effects of air temperature and relative humidity (Thom 1959), and the Heat Load

Index (HLI, Gaughan *et al.* 2008) which incorporates the effects of air temperature, relative humidity, wind speed and solar radiation. Cattle can tolerate higher temperatures at lower relative humidity as their natural capability to dissipate heat load by sweating and panting is compromised in hot and humid conditions (Yousef 1985).

Animal responses to increased heat load

Warm weather will cause cattle to gain heat. Cows will try to avoid a rise in body temperature by using a variety of strategies that can be used as indicators to detect animals that are trying to avoid negative effects of warm weather. These strategies include shade seeking (Tucker *et al.* 2008, Schütz *et al.* 2010a, 2014), increased water intake and time around water, especially if there is no shade (Muller et al 1994a, Schütz *et al.* 2010a), increased sweating and respiration rate (Blackshaw and Blackshaw 1994, Ominski *et al.* 2002), and reduced lying (Tucker *et al.* 2008, Schütz *et al.* 2010a). There is also anecdotal evidence that cattle will huddle together in a group or stand in a line with heads shaded by another cow, which suggests that unshaded cows will try and create a cooler microclimate by shading their heads (Ansell 1981). Perhaps the best recognised effect of heat load is decreased feed intake (Silanikove 2000), which will lead to a reduction in milk production (Ominski *et al.* 2002).

When is cooling needed?

The literature regarding heat stress thresholds is mixed, likely because thresholds differ between individuals. Historically, a THI of 72 (equating to 25°C and 50% relative humidity) has been used to define the point at which heat stress occurs, based on a reduction in milk production (Igono *et al.* 1992). However, more recent research suggests that lactating dairy cattle are more sensitive to environmental conditions than previously thought, possibly partly due to the genetic progress of milk production, which has led to a cow with increased metabolic heat production and therefore is more susceptible to heat stress (Kadzere *et al.* 2002). For example, Hammami *et al.* (2013) suggested a THI value of 62 as a new threshold for Western European Holstein cows, below which milk yield declines with 0.16kg/day/cow. In another study, negative effects on milk production traits and somatic cell counts were found when the monthly THI was greater than 60 (Lambertz *et al.* 2014). In New Zealand, a reduction in milk yield started to occur at THI of 64 (equivalent to 20°C and 40% humidity) whereas milk solids started to decline at a 3-day average THI of 68 (equivalent to 21°C and 75% humidity) in Holstein-Friesian cattle (Bryant *et al.* 2007). Even though New Zealand dairy cattle produce less milk, the production thresholds seem to be similar to that of high producing Holsteins. This could possibly be due to higher levels of solar radiation in New Zealand, and the internal heat load build up due to the distances New Zealand cows often walk to and from milking (Bryant *et al.* 2007).

Respiration rate is a useful animal based indicator of thermal challenge as it increases in cattle in response to increasing ambient temperature (Hahn 1999). Panting and panting characteristics have also been used to measure heat stress in cattle (Gaughan *et al.* 2010, Tresoldi *et al.* 2016) and are useful to identify cows that are heat stressed (e.g., when the mouth is open, and drool and protruding tongue may be visible). In New Zealand, dairy cattle benefited from cooling (reduced respiration rate and body temperature) with shade and sprinklers at THI ≥69 (equivalent to 22°C and 55% humidity, Kendall *et al.* 2007). Access to shade on pasture lowered respiration rates at HLI of 65 (air temperature was 20 to 21°C, Schütz *et al.* 2010a). Cows started to compete to gain access to limited shade when HLI was approximately 75 (air temperature was 19 to 25°C), whereas cows without shade started spending more time around a water trough. These findings indicate that dairy cattle benefit from cooling at heat thresholds lower than previously thought.

Shade cooling

Access to shade in summer improves the production and welfare of dairy cattle. Shaded cows have lower respiration rate and body temperature than unshaded animals (Kendall *et al.* 2006, Schütz *et al.* 2010a). Access to shade also increase feed intake (Muller *et al.* 1994bc) and consequently, milk production (Kendall *et al.* 2006, Fisher *et al.* 2008). Shade is an important resource for cows in summer that they are willing to compete to gain access to. For example, shade use increases with heat load (Tucker *et al.* 2008, Schütz *et al.* 2009, 2010) and cows are willing to trade-off resting after a period of lying deprivation to access shade in warm weather (Schütz *et al.* 2008).

In order for shade to cool cows efficiently it needs to have certain features. First, it needs to protect cattle from solar radiation. Cows prefer and spend more time in shade if it provides greater blockage from solar radiation (Tucker *et al.* 2008, Schütz *et al.* 2009, Figure 1). In both these studies, shade use was directly related to solar radiation levels and peaked when solar radiation levels were highest. These studies show that cows can distinguish between different types of shade and prefer shade that blocks more solar radiation. Second, the shade needs to be large enough for all cows to use simultaneously. Cows with access to 3.6 m^2 shade/cow had lower body temperature and produced more milk than unshaded animals (Kendall *et al.* 2006, Fisher *et al.* 2008). However, while the cows could physically fit under a shade with 3.6 m^2/cow, they did not use the shade simultaneously, likely due to social factors. Cooling benefits are greater if there is enough shade for all cows to use simultaneously (Schütz *et al.* 2010a). For example, cows that had access to 9.6 m^2 shade/cow spent more than twice as much time in the shade compared to cows that had access to 2.4 m^2 shade/cow. Cows with the larger shade area also had lower respiration rates (Figure 2) and fewer aggressive interactions than cows with 2.4 m^2 shade/cow (Schütz *et al.* 2010a). Cows with 9.6 m^2 shade/cow could use the shade simultaneously and could also rest under the shade, whereas cows that had access to 2.4 m^2 shade were never seen using the shade at the same time. Providing cows with more shade is likely beneficial in terms of reducing competition for the resource as well as enabling more space between animals, thereby increasing the air flow around individuals and efficient cooling.

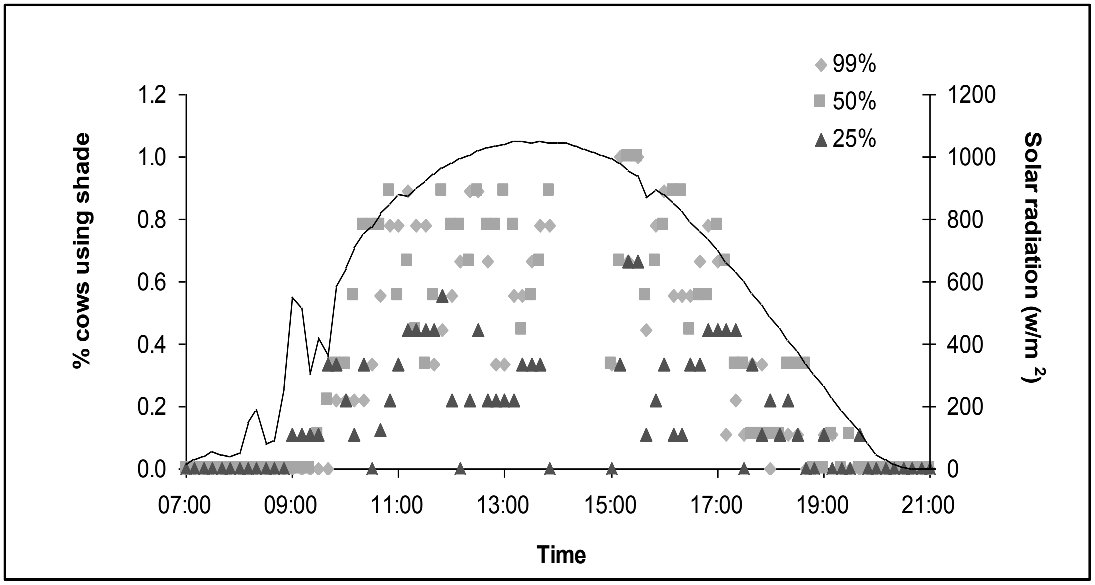

Figure 1. Shade use of dairy cows with varying levels of solar radiaion. The cows had access to shade blocking different amounts of solar radiation (25%, 50%, or 99% protection). Each point shows the proportion of cows in shade throughout a day (3 cows per treatment group, n=3 groups/treatment, Tucker *et al.* 2008).

If shade cannot be provided at pasture, a shade cloth at the milking parlour may be a practical way to provide cooling in the afternoon; access to shade for 90 min before afternoon milking in New Zealand reduced respiration rate by 30% and lowered body temperature by 0.3°C compared to cows without shade (Kendall *et al.* 2007). The cooling benefits of shade persisted after milking; body temperature remained lower for 2 to 4 h after milking (Kendall *et al.* 2007).

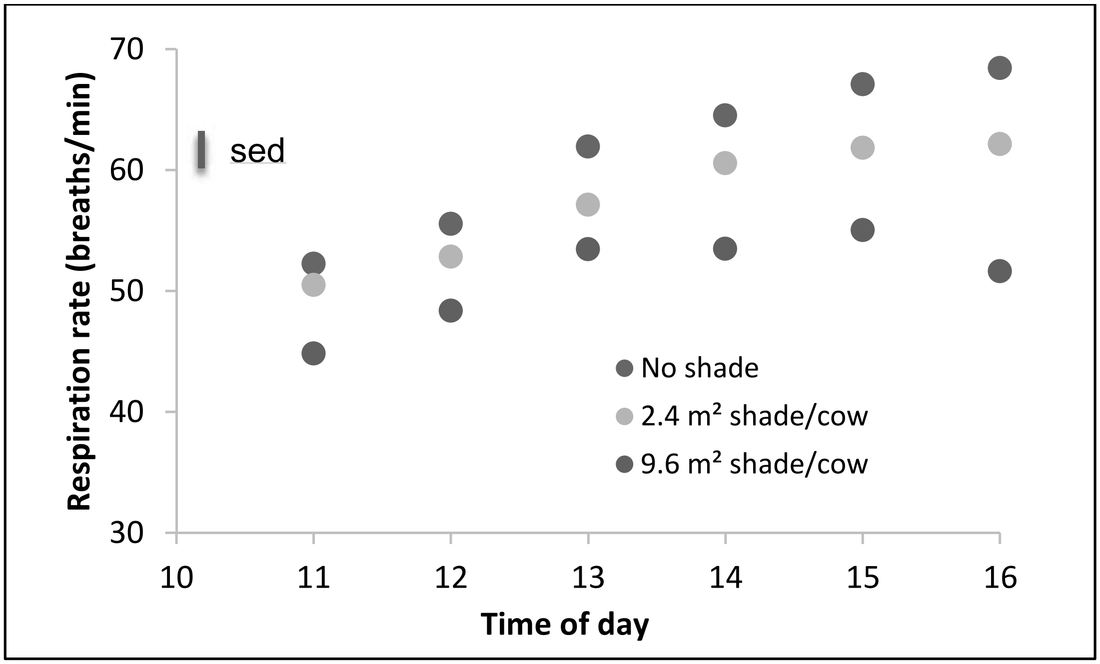

Figure 2. Respiration rate of dairy cows with access to different amounts of shade (2.4m^2 or 9.6m^2/cow), or no shade (n=4 groups/treatment, 10 cows/group, Schütz *et al.* 2010).

Water cooling at the milking shed

Compared to shade alone, cooling with water spray reduces body temperature, respiration rate, and air temperature more efficiently (Kendall et al., 2007; Chen et al., 2013). In New Zealand, cooling with sprinklers for 90 min before afternoon milking reduced respiration rate by 60% compared to non-cooled cows (Kendall *et al.* 2007). Compared to shade alone, sprinklers reduced body temperature more markedly especially at THI ≥69, and the body temperature remained lower for more than 4 h after milking (Kendall *et al.* 2007). A reduction in respiration rate and body temperature was also found when cows were under sprinklers for only 10 min after walking 0.3 or

2 km to milking (Schütz *et al.* 2011). Cooling cows before afternoon milking could be a practical and efficient way to reduce the peak body temperature and respiration rate of cows in pastoral dairy systems. However, cows that were under sprinklers for 90 min had *higher* body temperatures when THI was lower than 69 (air temperature was 23°C), suggesting that the cows were getting hypothermia (Kendall *et al.* 2007) and care needs to be taken not to use sprinklers for too long on cooler days. Sprinklers also provide other welfare benefits, such as reducing insect load (Kendall *et al.* 2007, Schütz *et al.* 2011).

There is some evidence, however, that cows may find sprinklers aversive, possibly because they do not like parts of their heads getting wet (Kendall *et al.* 2007, Schütz *et al.* 2011, Chen *et al.* 2013). Indeed, New Zealand dairy cattle preferred shade over sprinklers as a mean to cool down in summer (Schütz *et al.* 2011). Others have demonstrated that cattle readily use water cooling (Legrand *et al.* 2011) and prefer feedbunks fitted with sprinklers over those without sprinklers (Chen *et al.* 2013). Lactating cows used a “cow shower” for, on average, 3 h/24 h in Legrand *et al.* (2011) where shower use increased by 0.3 h for every 1°C increase in air temperature. Differences between studies are likely due to weather conditions and the manner in which the water cooling was provided. For example, systems that produce fine droplets to cool the air by evaporation are not efficient in humid climates and can contribute to heat stress as humidity levels increase (Shearer *et al.* 1991). In order for spray or sprinklers to be efficient, droplets need to be large enough to penetrate the coat and wet the skin, thereby causing evaporative cooling, drawing heat away from the body (Tresoldi *et al.* 2018).

Cold stress

Cattle of *Bos taurus* breeds have a high resistance to cold weather in general (Young 1981) due to the fermentation of roughage that results in considerable heat production, which in turn reduces the net energy required for maintenance of body temperature (values for performance loss and lower critical temperature for dry cows are 5° and -15°C, respectively, Hahn 1985). However, cold winter temperatures in combination with wind, and rain, cause cattle to lose heat to the environment and increase metabolic requirements (Degen and Young 1993, Tucker *et al.* 2007). Cattle will try to maintain normal body temperature, by changing behaviour (e.g., seeking shelter in wet and windy conditions, Schütz *et al.* 2010b) and by physiological changes, however, when this is insufficient, the accumulated effects of cold weather can decrease body temperature below normal, which will result in cold stress. Because cold stress requires an animal to raise its regulatory heat production to maintain a normal body temperature (Christopherson 1985), it will lead to altered feed intake and negatively affect weight gain and milk production (Young 1981, Bryant *et al.* 2007), reduced reproductive function (Gwazdauskas 1985), and can lead to death (Mader 2003, Stull *et al.* 2008).

Adaptation of ruminants to cold exposure seem to depend on available feed, for example an increase in resting metabolic rate can be seen if feed is abundant, whereas a decrease in metabolic rate and activity occurs if feed is restricted (Malechek and Smith 1976, Adams *et al.* 1986, Prescott *et al.* 1994, Ekpe and Christopherson 2000). In New Zealand, cattle are likely experiencing cold stress for periods of time, but if they are healthy, in good condition and well fed they can generally tolerate low air temperatures. However, if animals have to lie down on wet, muddy surfaces in cold conditions this will increase heat loss due to convection to the colder surface, and may lead to issues with thermoregulation and cold stress

(Morrison *et al.* 1970, Holmes *et al.* 1978, Muller *et al.* 1996, Fisher *et al.* 2003). In cold, wet and windy conditions cattle adopt more tucked lying postures (front and hind legs tucked close to the body), which could be an attempt to preserve body temperature and reduce heat loss (Tucker *et al.* 2007, mean air temperature was 5°C, wind chill was -10°C). Similar lying postures have also been observed in calves in winter (Gonzalez-Jimenez and Blaxter 1962) and more recently in dairy cattle lying in muddy conditions (Chen *et al.* 2017, mean air temperature was 14°C). These recent findings suggest that cows find mud and wetness aversive also for other reasons than its reduced thermoregulatory properties.

Health, production and welfare in wet and muddy conditions

Muddy and wet conditions are detrimental to the health and welfare of animals. Mud and rain reduce the performance of cattle even in relatively mild air temperatures (Morrison, 1970; Mader, 2011), however, production losses may be minimised if animals have access to a dry lying area which may be more important than shelter from wind (Bond *et al.* 1970, Morrison *et al.* 1970). In dairy cattle, milk yield is reduced in months with greater precipitation in California, particularly in open dirt corral systems (Stull *et al.* 2008). Decreased productivity may, in part, be mediated by the additional energy requirements associated with thermoregulation in wet environments (Degen and Young 1993) or walking in mud (Dijkman and Lawrence 1997). Also, feed intake in cattle is likely to be reduced in muddy conditions (Fox and Tylutki 1998) and fat metabolism may increase to meet energy requirements, as evidenced by higher circulating non-esterified fatty acid (NEFA) levels in inclement weather (Tucker *et al.* 2007).

Lameness is one of the most costly diseases on farm (Kossaibati and Esslemont 1997) and moisture softens claws and increases the risk of lameness (Borderas *et al.* 2004, van Amstel *et al.* 2004). Studies undertaken in winter have recorded poorer hygiene scores in muddy conditions (Muller *et al.* 1996, Fisher *et al.* 2003). The lack of cleanliness, in particular poor udder hygiene is associated with higher somatic cell scores (Reneau *et al.* 2005) and uterine and intra-mammary environmental pathogens (Schreiner and Ruegg 2003), which predispose dairy cattle to endometritis (Lewis 1997, Heuwieser *et al.* 2000) and mastitis, respectively. While mastitis is primarily a concern for lactating cows, infections during the dry period may persist into lactation and become clinical cases. Therefore, dry cows will also benefit from a clean, dry environment.

It is well-known that dairy cattle in off-pasture situations prefer and spend more time lying on soft, well-bedded (Tucker *et al.* 2003, 2009, Schütz and Cox 2014), and dry (Fregonesi *et al.* 2007, Reich *et al.* 2010) surfaces. Lying behaviour is an important welfare indicator in cattle (Haley et al., 2000) and studies have demonstrated that cattle are highly motivated to lie down for up to 14 h per day (Jensen *et al.* 2005, Munksgaard *et al.* 2005).

Reduced lying and lying deprivation is associated with acute stress responses, including increased plasma cortisol concentrations (Fisher *et al.* 2002, Tucker *et al.* 2007, Webster *et al.* 2008) and fecal glucocorticoid metabolites (Fisher *et al.* 2003, Tucker *et al.* 2007, Webster *et al.* 2008), as well as pituitary down-regulation in response to a corticotropin-releasing hormone challenge (Munksgaard *et al.* 1999, Fisher *et al.* 2002). Acute stress also reduces circulating lymphocytes (Davis *et al.* 2008), which may explain why lower lymphocyte and basophil counts have been measured in cows in muddy conditions (Chen *et al.* 2017) or in wet winter conditions in New Zealand (Webster *et al.* 2008). Reductions in circulating lymphocyte counts are sometimes interpreted as a sign of immunosuppression (Davis *et al.* 2008).

Several studies have reported severely reduced lying times on muddy surfaces by 50 to 75% compared to dry surfaces (Tucker, 2010), which is similar to the magnitude of reduction in lying times when cows are managed on concrete. The majority of studies that have investigated the effects of wet conditions have not described the effects of exposure to muddy surfaces alone. Recent research, however, demonstrates that it is the moisture content of the surface that is largely driving the aversion to lie down on muddy and wet surfaces (Chen *et al.* 2017, Schütz *et al.* 2018). For example, Chen *et al.* (2017) exposed dairy cattle to 3 levels of soil moisture: 90% (dry), 75% (muddy), or 67% (very muddy) dry matter for 5 days each in a replicated 3 x 3 Latin square design. The animals were managed in pens with dirt floors and a concrete feed apron. Those authors found that cows spent less time lying down in muddier conditions, especially in the first 24 h of exposure, when cows and heifers spent only 3.2 and 5.8 h, respectively, lying down in the muddiest treatment compared to 12.5 and 12.7 h on dry soil. When the soil was dry, cattle never chose to lie down on concrete, but in muddier conditions they spent a greater proportion of their lying time on concrete (Chen *et al.* 2017).

In addition, recent evidence from New Zealand suggests that it is the wetness of a muddy surface, rather than any contamination with manure, that is aversive to cattle (Schütz *et al.* 2018). In that study, cattle were managed on either a wet, dirty, or clean woodchip surface in a simulated stand-off situation; 18 h on the surface, and 6 h on pasture to allow for daily feed intake (pasture and silage). Cattle on the wet surface spent 3.7 h/18 h across 5 days of exposure, compared to 10.3 h and 11.5 h/18 h for cows on the dirty and clean bedding, respectively (Figure 3).

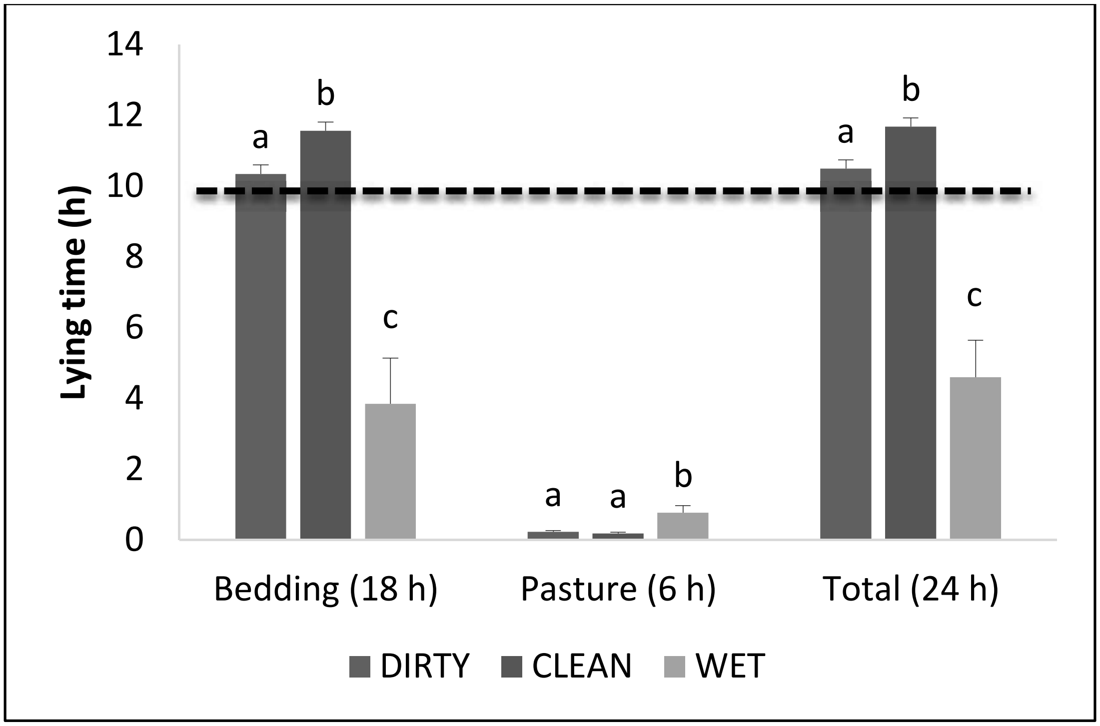

Figure 3. Lying times (h) of non-lactating, pregnant dairy cattle exposed to 1 of 3 surface types for 18 h per day for 5 consecutive days between 1500 and 0900 h (n=12 per surface type); CLEAN, DIRTY, or WET wood chip. Values are mean lying times and SEM of total time on 1 surface type (18 h), when on 6 h on pasture in between treatment exposures (0900 to 1500 h), and total lying times (24 h). Different letters (within surface (18 h), pasture (6 h), and total (24 h)), indicate $P < 0.05$, Schütz *et al.* 2018).

The cows on the wet bedding spent more time resting when on pasture, a time when ideally they should be grazing. When given a free choice, cows showed a clear preference for a dry, clean surface over the wet and dirty surfaces (98% of the time was spent on the dry and clean surface compared to the wet and the dirty surfaces). The aversion against the wet surface was particularly marked. In addition, our research suggests that wet surfaces not only influence the duration of rest but also the quality of rest. Cows on wet woodchip spent less time lying in a lateral position and with their heads supported, indicating reduced cow comfort and quality of rest on this surface (Schütz *et al.* 2018). Having the head supported is an important part of the quality of sleep, as REM only occurs when the head is supported (Ternman *et al.* 2014). The results suggest that wet surfaces are less comfortable and provide cows with fewer opportunities for quality sleep.

Conclusions

- Thresholds for when cows are affected by warm weather are lower than previously believed.
- Cows should have cooling opportunities at air temperatures >20°C depending on humidity levels, to protect welfare and production.
- More information is needed on how to best provide practical cooling in pasture based dairy systems.
- Cattle can generally withstand low air temperatures, but seek shelter in wet and windy conditions, thereby suggesting that protection from inclement winter weather is important.
- Wet and muddy conditions in winter may result in:
    - Reduced lying times, which may result in chronic stress and immunosuppression
    - Increased risk of infection and lameness
    - Increased energy requirements
    - Decreased production
- Changes in affective state likely underlie behavioural responses to wet and muddy conditions. For example, cattle show rebound responses after being kept short-term on wet and muddy surfaces (i.e., they will try and compensate for low lying times) thus indicating that the motivation to rest is

not fulfilled on such surfaces. Also, when given a choice, cattle clearly avoid wet and muddy surfaces to the extent that they will choose to lie down on concrete (a surface they also find aversive) rather than in mud. The changes in behaviour seem to be largely driven by the moisture content of the surface.

- A shelter with a dry, soft bedding area for all cows to use simultaneously can enable good welfare and health and mitigate the negative effects of inclement weather and wet and muddy underfoot conditions.

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THE ROLE OF DAIRY CATTLE FEEDING ON THE OPTIMIZATION OF PRODUCTIVE AND ENVIRONMENTAL ASPECTS

El papel de la alimentación de ganado lechero en la optimización de aspectos productivos y ambientales

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Resumen

Los rumiantes contribuyen a la generación de productos de alta calidad nutritiva para la alimentación humana. En sistemas pastoriles, estos animales son eficientes convertidores de fibra y proteína vegetal no comestible para humanos en productos lácteos. A pesar de esta importante contribución, los sistemas de producción basados en rumiantes sufren constante escrutinio público debido a la emisión de gases de gases de efecto invernadero (e. g. metano y óxido nitroso) y la excreción de nutrientes (ej. nitrógeno) que contaminan mantos freáticos. La supervivencia de sistemas de producción lecheros requiere una visión que considere los desafíos de manera integrada, de tal manera que las metas del productor sean satisfechas al mismo tiempo que se satisfacen las expectativas sociales de protección medio-ambiental y las expectativas del consumidor con respecto a la calidad de los productos animales. En esta contribución discutimos avances hechos para controlar la emisión de gases de invernadero y la excreción de nitrógeno al medio ambiente en Nueva Zelandia y Chile. Aunque los avances son significativos, todavía no contamos con una solución para los múltiples objetivos buscados. Sin embargo, postulamos que el conocimiento generado acerca del efecto de alimentación y de las interacciones entre los objetivos a lograr ayudan a formular investigación futura que optimice los sistemas de alimentación para llenar, simultáneamente, las expectativas de productores, sociedad y consumidores.

Abstract

Ruminants generate products of high nutritional quality for human consumption. In pastoral systems, these animals efficiently convert human-inedible fibre and protein into dairy products. Despite this important contribution, ruminant-based production systems are under increased public scrutiny due to the emission of greenhouse gases (e. g. methane and nitrous oxide) and the excretion of nutrients (e.g. nitrogen) that contaminates groundwater. The survival of dairy production systems requires a vision that considers the challenges in an integrated manner, so that the farmer's goals are met while meeting, at the same, the societal expectations of environmental protection and the consumer’s expectations regarding quality of animal products. In this contribution, we discuss advances made to control the emission of greenhouse gases and the excretion of nitrogen to the environment in New Zealand and Chile. Although the advances are significant, we still do not have a solution that covers the multiple objectives sought. However, we postulate that the knowledge generated on the effect of feeding and the interactions between the objectives to be achieved help to formulate future research that optimises the feeding systems to simultaneously fill the expectations of farmers, communities and consumers.

Introduction

Grazing ruminants around the globe transform human inedible fibrous components from forages into foods with high nutritive value. Despite this ability, ruminant production systems are under scrutiny as sources of human food because of the impact that they have on the environment. Despite the ‘negative press’ received, ruminants in grazing systems have an advantage over livestock such as pigs and poultry when it comes to the transformation of human-inedible carbohydrates and proteins into high-quality human-edible protein (Laisse et al., 2018).

Some issues, such as the low efficiency of N utilisation leading to environmental pollution have been identified for a while and discussed at this forum (Pacheco et al., 2008). More recently, the contribution of ruminant livestock to anthropogenic greenhouse gas (GHG) emissions has received global attention. It is important to note that ‘sustainable production’ has moved from a ‘nice to have’ to a ‘must have’ in the eyes of discerning consumers. For example, the red meat sector of Australia has announced a target to be carbon-neutral by 2030 as a competitive advantage for their products. What is the driver for this initiative? The consumer. The rationale for the initiative is “to give consumers even more confidence in the quality and integrity of Australian red meat and turning environmental criticism of the industry on its head”. It can be predicted that similar initiatives will be considered by other livestock sectors around the globe.

Consumers want more and more from their food purchases. The food has to be flavoursome, tender (in the case of meat), have health and nutritional benefits, ethically produced, sustainably produced, of known origin, free of chemicals and safe to eat. Fulfilling as many of these multiple attributes is perhaps the next biggest challenge for the agricultural sectors of countries such as New Zealand and Chile, which rely on export markets. Within the context of this article, we will discuss how feeding and nutrition management plays a role as a central hub underpinning a number of key attributes demanded by consumers.

The role of this manuscript is to revisit progress towards addressing some of the challenges described a decade ago at this Conference (Pacheco et al., 2008). As we take stock of progress towards improving N utilisation in pastoral dairy systems, we will discuss interactions and relationships emerging while trying to achieve multi-target objectives in animal production. The intention is to illustrate the need to understand the complexity of the interactions between environmental protection, greenhouse gases and product quality to foment the development of feeding systems where multiple objectives can be met to satisfy producers, processors, consumers and communities.

Which one is the most important issue in dairy nutrition in pastoral systems?

Ten years ago, in this forum, the low efficiency of N utilisation was discussed as a key challenge for pastoral dairy systems. When asked about what are the next challenges to address in this sector, we propose that is not one, but many concurrent ones as a result of the multiple dimensions (economic, environmental, social) that interact with farming systems. Feeding is still a major cost in animal production, and grazing systems are still very cost effective (Dillon et al., 2005). Farms need to be productive and profitable, of course. However, nutrition on-farm now needs to consider other stakeholders such as consumers, processors, and the planet (Figure 1).

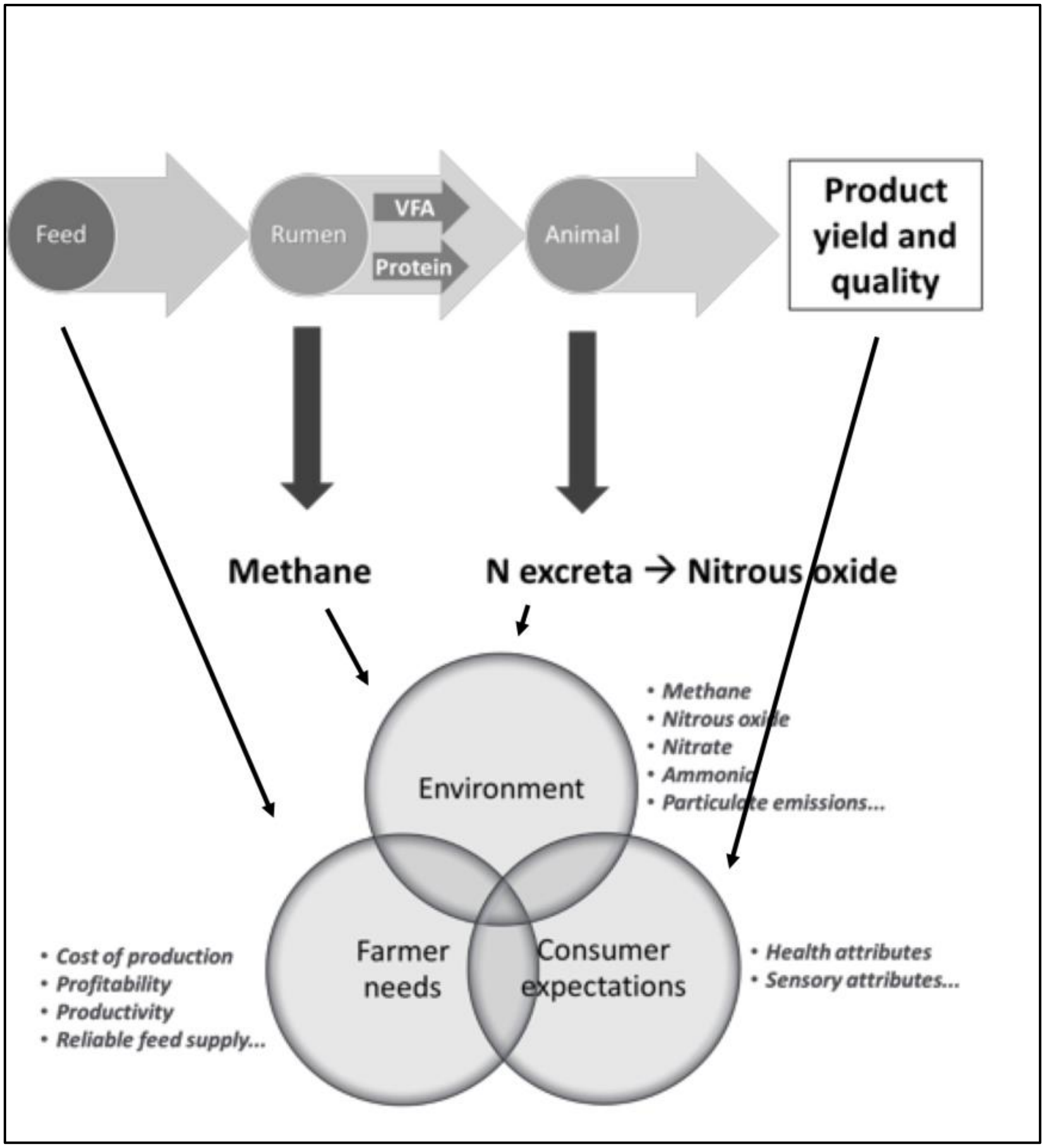

Figure 1. Feed is a key driver of productivity and environmental impacts from ruminant production systems because of its effects on the rumen-animal interface. This makes feed also a key tool to positively impact what farmers, societies and consumer expect from livestock systems.

Reducing the contribution of animal agriculture to climate change

In recent years, there has been an increasing focus on evaluating the environmental effects of dairy production systems, including their impact on greenhouse gas (GHG) emissions, which continue to be a global concern because of their contribution to climate change. In contrast to the greenhouse gas of other developed countries, the agricultural sector in New Zealand contributed to almost half of the greenhouse gas (GHG) emissions of the country in 2015 (Ministry for the Environment, 2017). The two majors agricultural GHG are enteric methane (73% of the agricultural GHG) and nitrous oxide (N_2O) emissions from agricultural soils (20% of the agricultural emissions), expressed as carbon dioxide equivalents. Overall, the dairy sector contributes to approximately a third of all the agricultural emissions, which have grown in absolute terms since 1990, a benchmark year used globally to account for national emissions (Ministry for the Environment, 2017). Agricultural emissions are projected to rise as animal production and N fertiliser use continues to increase. Given the large contribution of agriculture to the GHG profile of the country, efforts to reduce GHG emissions across the agricultural sector are required to support New Zealand's commitment to global initiatives to reduce GHG as a means to slow global warming caused by human activities. In Chile, the livestock GHG account for ~10% of the agricultural GHG emissions, which represent a smaller proportion of the national inventory (~21%) than in New Zealand thanks to the capture of carbon by forestry. Still, for the Chilean livestock sector, methane (~74%) and nitrous oxide (26%) are the main GHG gases to be mitigated (Ministerio del Medio Ambiente, 2017).

Interactions in practice

Reducing N excretion to the environment via nutritional means

Out of the several pathways to reduce excretion of N to the environment summarised by Pacheco et al. (2008), the reduction in dietary N intake is one that has been pursued in research programmes in New Zealand. Limit setting for N leaching losses from farms is either already in place or in the process of being implemented into regional policy throughout New Zealand. In some regions, significant management changes are required on-farm to meet new nitrogen limits including reduced N inputs, increasing effluent area, alternative forages, reducing stock numbers and restricting grazing by using stand-off pads. Large research programmes such as Pastoral 21 (P21) and Forages for Reduced Nitrate Leaching (FRNL) are introducing new technologies to reduce N losses from farms.

For example, P21 designed and implemented four regional dairy farmlet studies in Otago/Southland, Canterbury, Manawatu and Waikato comparing a system typical of that region (‘Current’) with a modified system (‘Future’) designed to test whether modelled benefits for environment and profitability could be delivered in practice (Shepherd et al., 2017). Reducing dietary N content by replacing pasture with lower N containing supplements (silage, grain, etc.) can reduce N intake and N excretion (assuming the same DMI). For example, on the P21 Waikato farmlet the “Future” herd ate more supplement than the “Current” herd but it had a lower N content so N intake from supplements was similar (Selbie and Shepherd, 2016). However, there is a possibility that this system of pasture allocation may unintentionally increase the total N intake by the herd if the total DMI from supplements with moderate amounts of CP (e.g. PKE) is above the likely intake of pasture if the cows were grazing.

The initial phase of the FRNL programme also included research on determining the effects of supplementing pasture with fodder beet, a crop that contains low concentrations of N in the dry matter. Because of its low protein content, feeding fodder beet can reduce the amount of dietary N intake, which when fed in excess to the cows’ requirements becomes the main driver for urinary N excretion. In late-lactation dairy cows, fodder beet can reduce the urinary N excretion by half when fed at 40% of the diet during late lactation in short-term trials (~3 weeks) without affecting negatively production (Waghorn et al., 2019). However, more long-term studies are required to understand the suitability of this feed as an N excretion mitigation tool. For example, studies with non-lactating cows indicated that feeding 85% of fodder beet in the diet plus straw (as recommended by some people in New Zealand) resulted in cows entering into negative N balance (Waghorn et al., 2018). A diagram of the generalised responses to supplementation with readily fermentable carbohydrates is presented in Figure 2, illustrating the challenges of addressing methane emissions and nitrogen excretion concurrently when using a single feed as a solution for one trait (N excretion in the case of fodder beet). The studies with fodder beet help to illustrate that potential trade-offs may occur when trying to solve an issue.

Furthermore, the implications of physiological changes beyond milk yield and N excretion need to be understood. Pacheco et al. (2016) reported reductions in the circulating concentrations of arginine, a key amino acid involved in a number of metabolic pathways (Hou et al., 2015). While the reduction in circulating Arg concentrations could not be attributed to an increased utilisation or to a lower production of this amino acid, recent studies have linked increases in duodenal supply to blood concentration when methionine is supplied to lactating cows (Schwab et al., 2018). Therefore, it seems plausible that the effects in the fodder beet study indicate a reduction in the supply of some key amino acids. Understanding the implications of low-N diets on amino acid nutrition is required to avoid negative unintended consequences which may be difficult to understand in short-term studies.

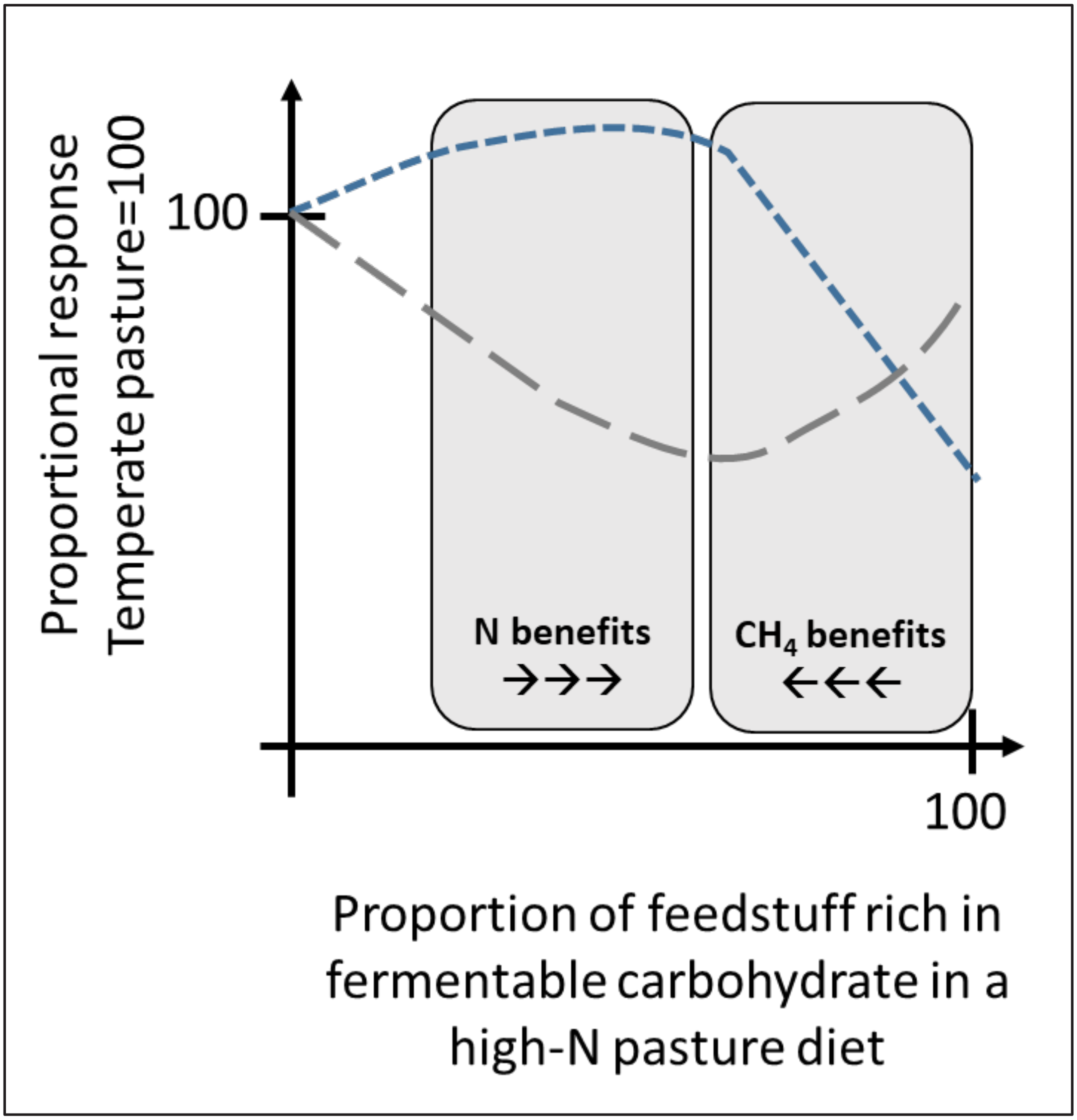

Figure 2. Simplified diagram of the interactions between methane and nitrogen emissions when supplemented a temperate pasture rich in nitrogen (N) with a feed rich in readily fermentable carbohydrate. High inclusions of the carbohydrate are required to reduce the enteric methane emissions. The inclusion of the carbohydrate ameliorates the N excretion by dilution or by increased capture in the product. However, at high levels of inclusion some of the benefits in N excretion are eroded if the animal enters in negative N balance. The challenge is to encounter a 'sweet-spot' where both methane emissions and N excretion are ameliorated.

Fodder beet is a carbohydrate-rich feed, and their effect on rumen fermentation pose both challenges and opportunities. On the one hand, results from controlled studies in metabolism stalls suggest that feeding more than 40% to lactating dairy cows increased the risk of acidosis (Waghorn et al., 2019), most likely as a result of the high concentration of sugar in the fodder beet bulb. On the other hand, reductions in ruminal pH have been associated with reductions in methane emissions when feeding grains and crops (Moate et al., 2012; Sun et al., 2015a). Low pH impacts methanogen growth rates, leading to greater hydrogen concentrations in the rumen, which in turn elicit a reduction in the amount of hydrogen produced by fermentative bacteria. Hence, methane production is reduced as a consequence of the lower hydrogen production under low rumen pH conditions (Janssen, 2010). In grazing studies, Jonker et al. (2017) reported that feeding approximately 20% of the diet has resulted in reductions of ~18% methane yield and between 16 and 28% emissions intensity (i.e. the amount of methane per unit of fat- and protein-corrected milk).

In addition to the changes in methane production, the effect of feeding fodder beets on rumen fermentation will lead to downstream effects on milk quality, and the connection with product attributes desired by consumers needs to be understood. In studies with basal diets of forage, fodder beet supplementation at ~ 20% of the DMI has resulted in more saturated fatty acids (SFA), mainly as medium-chain fatty acids (MCFA) (Baars et al., 2012; Fleming et al., 2018). The increase in SFA has health connotations for consumers. Furthermore, the impact of feeding regimes on other aspects, such as milk processing, needs to be considered. In the study of Baars et al. (2012), the greater ratio C16:0 to C18:1c9 produced in milk from cows fed beets was also associated with a poorer spreadability of butter made from this milk fat.

Identification of crops with low-methane production properties

As seen in Figure 1, the feed is an important determinant of greenhouse gas emissions from ruminants. The fermentation of feed in the rumen leads to the formation of carbon dioxide and hydrogen, which are used by methanogenic archaea to produce their energy, with methane as a by-product. It is generally accepted that nutritional management is a key strategy for methane mitigation (Hristov et al., 2013). Intensive indoor systems provide the opportunities for dietary manipulations such grain-feeding (Sauvant and Giger-Reverdin, 2009), lipid addition (Grainger and Beauchemin, 2011) or dosing of methane inhibitors such as 3-nitrooxypropanol (Hristov et al., 2015). However, the application of dietary manipulation has more constraints in pastoral systems where no or few supplements are fed. Reiterating the advantages that ruminants have in terms of transforming human-inedible feedstuff such as grazed forage into milk and meat, it could be proposed that the preferred mitigation option in pastoral systems should be the forage itself.

Efforts to identify ‘low-methane’ forages have included screening of material using *in vitro* systems. For example, screening of forages in Australia led to the identification of *Biserrulla pelecinus* as a plant with anti-methanogenic properties (Banik et al., 2013). The anti-methanogenic effects of *Biserrulla* have been linked to the presence of secondary metabolites, namely terpene glucosides (Ghamkhar et al., 2018). In New Zealand, *in vivo* screening of forages using sheep in respiration chambers led to the identification of members of the Brassica family as ‘low-methane’ crops (Sun et al., 2016). Studies into the mechanisms behind the effect on methane emissions indicated that the known secondary plant metabolites (e.g. SMCO and glucosinolates) present in this crop (Barry, 2013) are not the cause of the anti-methanogenic responses reported by Sun et al. (2015a). The finding that the methane effects of forage brassicas are not related to these secondary metabolites is actually encouraging because these compounds have been known to have detrimental effects on animal health and productivity (Barry, 2013).

This means that cultivars developed for improved animal health outcomes would still be effective with regards to methane mitigation. Sun et al. (2015a) proposed that the amount, type and rate of ruminal degradation of carbohydrates in Brassica crops, and specifically, in forage rape (*Brassica napus*) result in a fermentation pattern that leads to less methane produced (i.e. reduced acetate to propionate ratio, reduction in ruminal pH). Confirming these results, Keim et al. (2019) reported fast fermentation and a lower acetate to propionate ratio of summer brassicas (turnips and rape) compared to permanent pastures during summer in Chilean studies. Compared to perennial ryegrass, winter varieties of forage rape have resulted in ~25 to ~40% less methane formed per unit of dry matter eaten, when fed as the sole diet to sheep and cattle (Sun et al., 2016). In contrast to the curvilinear effects reported for starch-rich supplements (Sauvant and Giger-Reverdin, 2009), the methane mitigation properties of forage rape appear to be linearly related to its inclusion in the diet (Sun et al., 2015c). Feeding sheep with forage rape resulted in a shift in the bacterial communities compatible with a greater production of propionate, such as *Selenomonas, Quinella* and *Sharpea* (Sun et al., 2015a), which suggest a shift to a new ‘set-point’ for the rumen. Interestingly, these microbial changes mirror those reported for sheep genetic lines that naturally produced less methane (Kittelmann et al., 2014).

The establishment of different bacterial community structure is also compatible with methane reductions still observed even after a feeding period of 15 weeks in growing lambs. The New Zealand studies did not include studies with lactating dairy cows. However, research conducted in Australia by Williams et al. (2016) with dairy cows indicate that feeding ~40% of the dietary DM as forage brassica resulted in 23% more energy-corrected milk (ECM) with no change in DMI and a lower methane emission intensity (17 g methane/kg ECM) than a lucerne-based control diet or a diet containing ~40% of chicory (19 and 23 g methane/kg ECM, respectively). The potential of forage brassicas for dairy production is being investigated in Chile, as well. First, it was shown that brassica supplementation (either with turnips, rape, swedes and kale) at 20% of the diet maintains milk production levels of pasture fed dairy cows with a lower DM intake (Keim et al., 2018a, b. Further studies demonstrated that feeding forage rape between 30-45% of the diet DM tended to increase milk production, without affecting DMI (Daza et al., 2018); thereby resulting in a significant improvement in the efficiency of milk production during the early and mid-lactation.

While methane emissions were not measured in the Chilean experiments, it could be expected that at least the methane emission intensity would be lower in the brassica groups. This is because the increased milk production was achieved without increasing DMI, and DMI is the major determinant of methane production in cattle (Hristov et al., 2013; Jonker et al., 2016). In the New Zealand studies, feeding forage rape improved N retention and live weight gain in growing lambs (Sun et al., 2015b). This observation has been mirrored in the Chilean studies with lactating cows, whereby the supply of forage rape at 30 or 45% of the DMI resulted in a 7% increase in capture of N in milk, compared to a control diet of grass silage and supplements (Beltran et al., 2018). This effect is compatible with a measured trend to increase microbial protein synthesis with forage rape at 30 or 45% of the DMI and a significant shift when offered at 20% (Beltran et al., 2018). The effects on N partitioning are compatible with the greater ratio of readily fermentable carbohydrates to structural carbohydrates that characterise this family of crops (Barry, 2013; Pacheco et al., 2014).

With cautious optimism, these results on productivity and methane emissions aspects of forage brassicas are encouraging. However, within the context of multi-objective solutions, the brassica crops are far from being a ‘silver bullet’, a solution to all challenges. For example, the New Zealand measurements of nitrous oxide emissions in lysimeters suggested that the nitrous oxide (N_2O) emission factors (i.e. the proportion of urine N that can be accounted for by N_2O) tended to be greater for urine produced by sheep fed forage rape, compared to urine produced by sheep fed perennial ryegrass (Hoogendoorn et al., 2016). Management practices used to fed forage brassicas (winter conditions, with saturated soils and high soil compaction due to high stock densities) are known to increase N_2O emissions (De Klein and Eckard, 2008), which is also a potent a greenhouse gas. Therefore, under such conditions, a process of ‘pollution swapping’ could occur where the reductions in one GHG (e.g. methane) are counteracted by increases in another (e.g. N_2O). A review of the available studies concluded that the data available do not permit to confirm if this ‘pollution swapping’ will occur in grazing systems (Thomson et al., 2016) and more research is required before reaching a verdict on the potential of Brassicas as a tool to mitigate total GHG at the farm level.

It is well known that the choice of feeds influences the composition and sensory aspects of milk (Wilson, 1993a; Wilson, 1993b; Bendall, 2001). Feeding of turnips and swedes (also members of the Brassica family) was reported to have caused flavour taint in the milk of cows from herds in the Hawkes’ Bay region of New Zealand (Stuff NZ, 2017). Similar effects were described from Chilean studies presented last year in this conference by Vargas-Bello-Perez et al. (2017a, b): cheese from brassica-fed dairy cows had a different flavour compared to cheese from cows fed grass silage and fresh pasture. Guidelines for feeding of turnips to cows indicated that not more than 50% of the DM intake should be offered, citing milk taint as a reason (McFerran et al., 1997). Similar to the studies with fodder beet mentioned above, brassica supplementation modified the fatty acid profile of milk and cheese, increasing SFA and reducing mono-unsaturated fatty acids (MUFA) and PUFA (Seguel, 2018). While the amount of brassicas consumed by dairy cattle may be small when calculated on an annual basis, it is important to note that brassica crops may represent a large proportion of the diet of cows during certain times of the year (e.g. summer feeding in the central North Island of New Zealand) or even within a day (e.g. strategic restricted grazing). In those conditions, the proportion of the diet given by these crops can be significant and may lead to the sporadic or seasonal reports of taints in milk.

Turning challenges into opportunities

The two examples presented above described feeds that, while having a positive aspect on GHG emissions or N excretion, ended up with a detrimental effect on milk quality. However, the effect of feeds on aspects of milk composition could be used as an advantage in pastoral systems. For example, meat from grass-fed cattle is marketed as a premium product because of the greater proportion of PUFA acids and also because of the association of grazing feeding with ‘naturalness’ of production systems, Equally, the changes in milk composition as a result of feed cannot be only negative. Changes in fatty acid composition could be associated to better health attributes, or some changes in sensory characteristics of milk could have positive implications as indicators of ‘naturalness’, specific provenance, or consumer’s perception of environmental impact. While such claims could be dismissed as ‘marketing ploys’, let’s not deny the potential of providing a scientific base to the evidence required to influence consumer’s perception.

Integration of knowledge

We have presented a couple of examples of dietary management strategies designed to mitigate issues in dairy production from pastoral systems. Using those examples, we discussed the ‘ripple effects’ of such feeding regimes within the context of multi-trait demands from ruminant production. The intention of this contribution is to encourage research that leads to achieving as many benefits across the productivity, environmental and consumer demands aspects of dairy production while minimising trade-offs or unintended consequences of implementing feeding regimes aimed at a single target. Hitting the ‘sweet-spot’ requires the development of integrative tools that take into account the multivariate nature of ruminant production systems. Such integrative approaches are now available to simultaneously assess the nutritive (e.g. N utilisation) and environmental aspects (e.g. enteric methane and excreta) for dairy cattle (van Lingen et al.). As our understanding of consumer demands increase, we can envisage such multi-criteria approaches expanding to include other traits such as milk composition and sensory attributes, etc.

Conclusion

The challenges related to feeding of dairy cattle in grazing systems are many and are determined by both rumen and animal physiological processes which in turn are driven by diet. The other side of each challenge is an opportunity for the sector, provided that research and development allow for early identification of trade-offs amongst traits and proactive identification of co-benefits.

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