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A CHANGING CLIMATE FOR DAIRY SCIENCE

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Cover photo: Cows grazing lablab, Dr David Barber, DairyNEXT Consulting Services

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Foreword to the Proceedings of the Australasian Dairy Science Symposium 2022

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The Australasian Dairy Science Symposium is the largest technical meeting of dairy scientists in the southern hemisphere and is the largest technical meeting focused on pastoral dairy production in the world. It is held alternatively in New Zealand (previously Palmerston North in 2018) and Australia (previously Sydney in 2016). The 2022 Australasian Dairy Science Symposium saw the event held on the Sunshine Coast in Queensland, Australia for the very first time. The tropical environment and diverse and unique feedbase and overall dairy production system of the Queensland Dairy Industry provided a relevant backdrop to the event's overall theme of "A changing climate for dairy science". This theme not only covered the imminent and obvious challenges of climate change, but also the challenges and changing operating environment in terms of markets and competition from plant based dairy alternatives, attracting and retaining staff, social licence to operate challenges and maintaining productivity with reducing resources. While these sub themes highlight the diverse challenges facing the pastoral dairy industry and the scientists supporting the industry, the research presented at the symposium provides considerable optimism that the industry through research can, and will rise to overcome them.

There were 51 keynote, 10-minute oral and three-minute thumbnail presentations given at the symposium. These proceedings along with two special issues published in the Journal Animal Production Science (https://www.publish.csiro.au/an) that contain the keynote and selected offered papers, provide a written record of the innovative and cutting edge research presented at the meeting.

The conference also included a one-day field tour to the hinterland of the sunshine coast where delegates visited two dairy farms and a dairy processor. Delegates saw firsthand the approaches used to run a profitable dairy business in a tropical environment. This was complemented by the opening keynote of the symposium which was jointly given by an Australian and New Zealand dairy farmer where they outlined the challenges they foresee and how they are adapting their farming systems and business to meet them.

All papers that appear in these proceedings were peer reviewed to ensure scientific rigour and suitability for presentation at the symposium. We would like to thank these anonymous reviewers for the diligent efforts to ensure these papers were of the highest scientific standard.

The symposium also provided an opportunity to acknowledge the significant contribution of three individuals to dairy science through the "Lifetime Contribution to Dairy Science" award. These were:

- Prof. Bill Fulkerson for his outstanding contribution to dairy science in the field of pasture and nutrition management.
- Dr Richard Stockdale for his outstanding contribution to dairy science in the field of nutrition management.
- Dr Kevin Kelly (dec.) for his outstanding contribution to dairy science in the field of pasture and forage management.

We extend our congratulations to these individuals on this achievement.

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Strategies to Reduce the Environmental Footprint of Dairy Production by Utilizing the Dairy Beef Integration

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ABSTRACT

In the coming decades, there is expected to be a significant increase in the need for animal protein throughout the world. With this growing demand, both the dairy and beef industries will need strategies in place that are adaptable and consider economic efficiency balanced with environmental impacts, animal welfare outcomes and social perceptions. There is a compelling economic case for pasture-based dairy farm businesses to invest in genetics to reduce animal wastage due to reproductive failure, mastitis, and surplus calf wastage. The utilization of genomic selection, sex-sorted semen, and potential dual-purpose breeds can improve growth rates compared to traditional dairy cattle while maintaining similar milk solid production, fertility, and cow size. Currently, it is estimated over two million surplus calves from the dairy industry are slaughtered at four days of age in New Zealand annually. Targeted incorporation of sex-sorted semen to reduce surplus male calves, and the use of double-muscled terminal sires to increase carcass yields in the remaining calves. This reduction of animal wastage is an effective way to reduce Greenhouse Gas Emissions in both the dairy and the beef industry. This review aims to present strategic breeding objectives and solutions including sex-sorted semen, genomics selection, using dual purpose and double muscled terminal sire and slaughtering beef animals at a younger age to maximise genetic gain reducing surplus calf wastage.

Keywords: Breeding Programs, Selection Objectives, Animal Welfare, Dairy and Beef

INTRODUCTION

The emphasis on the sustainability of beef and dairy farming is increasing. The New Zealand beef and dairy industries have an opportunity to implement breeding strategies that go beyond reducing stocking rates and maintaining productivity. Beef production in single-purpose beef farming systems has potentially four to five times higher GHG emissions than beef produced out of dairy cows (Zehetmeier et al, 2012). There is significant potential for the New Zealand Beef Industry to grow a further two million surplus dairy calves traditionally slaughtered within seven days of birth into valuable finished beef animals (Bolton et al., 2021). It is preferred these animals are sired by high genetic merit beef sires for better financial outcomes for the finisher.

The quality, digestibility, and composition of feed rations affecting enteric emissions is difficult to control in grazing systems, selecting genetics to increase feed conversion ratios affects emission intensity levels. Reproductive techniques (replacement, age at first calving) are another significant aspect of emission intensity in minimizing the proportion of unproductive animals in the herd and corresponding emissions per unit of product generated. Dual-purpose dairy cattle, and sex-sorted semen, myostatin NT821 carriers provide dairy and beef farmers in New Zealand with huge opportunities to eliminate surplus calves simultaneously increasing efficiency and profitability in the New Zealand Beef Industry, changing the perception of the public in terms of ethical and sustainable dairy farming, and reducing carbon footprint.

MATERIALS AND METHODS

In this study, we reviewed the techniques available to improve efficiency in the management of resources to reduce the intrinsic emission per kilogram per production.

Sex-Sorted Semen

Sex-sorted semen can be utilised in both beef and dairy production to predetermine the sex of the calve with accuracy greater than 90%. A sperm with X-chromosome has approximately 3.8% more DNA than a sperm with Y-chromosome (Johnson, 1995). This feature enables easy identification between sperm carrying Y- and X-chromosomes. The strategic use of sex-sorted semen products has the potential to substantially increase the rate of genetic gain, reduce animal waste, improve outcomes in animal welfare and enhance profitability compared with traditional semen (Holden & Butler, 2018). Genetic gain is effectively made by selecting a small portion of elite males to use as AI sires. Little selection is feasible on the cow side when all heifer calves from cows need to be raised as replacement heifers. With the use of sex-sorted semen elite females can be targeted for breeding replacement dairy cows, and the lower genetic merit females mated to beef lead to a reduction in the number of male dairy calves with lower economic value.

Genomics Selection

Genomic selection improves the accuracy of genetic predictions in young animals, decreasing generation intervals and increasing the contribution of young, superior genetic sires. It has been shown that the rate of genetic gain has increased in Australia and the United States (Scott et al., 2021; Garcia-Ruiz et al., 2016). Genomic selection has dramatically increased genetic gain in dairy cattle. Accessing other populations that are achieving high levels of genetic gain can significantly impact genetic progress in the local populous (Matthews et al., 2019).

Dual Purpose

It was suggested by Muller et al (2015) that dual-purpose cattle increased overall efficiency by dividing the emissions over both beef & dairy products. Approx. 57% of the world's beef supply is produced from animals of dairy breed origin (Gerber et al., 2010). Around 80% of European beef is from surplus dairy calves raised for beef production combined with cows that have finished their productive life on a dairy farm. This accounts for a low emission intensity for European beef (Opio et al., 2013). Due to the high contribution of dairy cattle to beef production, European beef is among the world's lowest rates of greenhouse gas emission (Greenwood, 2021; Buleca et al., 2018). Approximately 60% and 40% of New Zealand beef comes from beef farms and dairy farms (cows at the end of their productive life and excess male and female calves (slaughtered from 4-days old)), respectively (Data | NZ Government, 2018). The origin of cattle slaughtered from 1st July 2017 to 30th June 2018 in New Zealand (per kilogram of beef produced); calves processed for beef of dairy origin have decreased emission intensity (kg CO_2 equivalent) relative to their suckler-beef counterparts. This is due to suckler-beef emissions being dominated by the maintenance cost associated with the breeding cow; on the other hand, the dairy-based beef emissions get attributed to milk production (de Vries et al., 2015). GHG emissions have been calculated between 29% and 41% reduced in beef animals from the dairy herd (16.6 kg CO_2e per kg CW) in comparison to suckler-beef (23.4 kg CO_2e per kg CW) (van Selm et al., 2021; de Vries, M. et al., 2015). Integration of dairy and beef production from dairy beef calves could reduce New Zealand's beef sector GHG emissions annually from beef production by 2000 kt kg CO_2e, or 22% (based on 2017/2018 statistics).

Reducing Age at Slaughter (Dairy Beef)

Kirkland et al., (2007) reported reduced GHG emission advantages from slaughtering beef animals at a younger age; bulls slaughtered at 610 days had an increased maintenance of 111 kg compared to 485 days bulls. This accounts for the over 6% reduction in growth for the bulls slaughtered at 610 days compared with 485 days bulls across the total finishing period. The reduced growth rate of bulls slaughtered at 610 days in comparison to 485 days bulls is associated with increased maintenance requirements of 610 days bulls. Slaughter at 610 days compared to 485, causing a reduction in live-weight gain, feed conversion efficiency, and increasing body fat deposition.

Double Muscled Terminal Sire

The use of double muscled terminal sire could enhance the value of a large portion of the excess dairy calves currently slaughtered from 4-days old providing substantial advantages to both sectors (van Selm et al., 2021). The beef produced from dairy animals contributes considerably lower GHG emissions per kg of meat produced compared to breeding beef cows in feedlot or extensive production systems due to the dual-product effect (<10 vs. 15 to 70 kg of CO_2e/kg of meat) (Zehetmeier et al., 2012; Gerber et al., 2013). It is consistent across studies that the benefits of the myostatin NT821 variant in cattle has significant benefits when crossed with dairy breeds (Bellinge, 2005; Allais et al., 2010). The myostatin NT821 gene can be effectively employed as a marker to improve carcass traits such as confirmation, kill-out percentage, and meat tenderness. Double Muscled animals are characterised by an extremely high carcass yield, coinciding with a reduced organ mass. Therefore, voluntary feed intake is decreased, and feed efficiency is considerably improved. However, maintenance requirements are not decreased (Fiems, 2012). Myostatin NT821 gene carriers not only have a higher carcass yield but also have a higher cutability with more expensive cuts in the meat yield (Fiems, 2012). This study demonstrated this by comparing Belgian Blue bulls with either a DM or a normal genotype, weighing 600 kg at slaughter. Dressing averages of 70% and 64% resulted in cold carcass weight of 420kg and 384 kg, respectively. Due to the increased meat content of the carcass (76% vs. 65%) and the total meat is 28% more for DM animals.

DISCUSSION AND CONCLUSIONS

The technologies reviewed in this paper could help reduce greenhouse gas emissions and nitrogen leaching. Utilisation of genomic selection, sex-sorted semen, dual purpose, integrating the use of homozygous Myostatin NT821 terminal sires will aid in the reduction of cow and surplus calf waste. The environmental outcomes could be improved through increased feed efficiency leading to lower environmental nutrient loads through less effluent nutrient per kg product output, increased profitability through lower feed cost (Net Feed Intake). Incorporation of homozygous Myostatin NT821 terminal sires and better-utilizing surplus dairy pregnancies would establish a sustainable, viable, and ethical value chain. The methods put forward in this paper are intended to reduce all scopes of greenhouse gas emissions across the entire value chain and meet all animal welfare metrics.

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CONFLICT OF INTEREST DECLARATION

Hamed Amirpour Najafabadi, Craig Mckimmie and Ute Rank are employees in Samen NZ. The remaining authors have not stated any conflicts of interest.

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A dedicated maize block as a nitrogen leaching mitigation strategy for Waikato farms

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ABSTRACT

This study examined the cost-effectiveness of growing maize silage on a dedicated block on the milking platform using effluent as a fertiliser source and annual ryegrass as a catch-crop. A dedicated maize block strategy has the potential to recycle nutrients, minimise mineralisation and utilise residual nitrogen (N) in the soil after crop harvest, thereby reducing N losses to the environment. A Waikato farm with a dedicated maize block was simulated and compared with the two Waikato P21 farmlets using DairyNZ's Whole Farm Model (WFM), APSIM and the Urine Patch Framework (UPF) over five consecutive seasons (2013/14 to 2017/18). The three simulated farms represented 1) the P21 Current Farm (CF) with a stocking rate of 3.2 cows/ha, applying 125 kg N/ha fertiliser on pasture, harvesting grass silage for use during periods of feed deficits, 2) the P21 Future Farm (FF) with a stocking rate of 2.6 cows/ha, applying 85 kg N/ha fertiliser, high genetic merit cows, imported maize grain as low-N feed, with a standoff pad, and 3) the maize silage-block farm (Future Farm Plus = FFP) with a stocking rate of 3.2 cows/ha, high genetic merit cows, applying 85 kg N/ha fertiliser on pasture, feed pad, maize silage grown on a dedicated block occupying 15% of the effective farm area followed by annual ryegrass. The modelling results showed that adding a dedicated maize silage block on the milking platform can cost-effectively reduce N leaching by an average 26% compared with the CF baseline, provided the crop is followed by a catch-crop (annual ryegrass in this case), effluent captured on the feed pad is recycled as a fertiliser source, crop yields are above 20tDM/ha, and the low-protein maize silage is used to reduce imported feed-N. The FF system achieved an average 31% N leaching reduction compared with the CF but forfeited $16 profit per kg N reduction compared with $9 for the FFP.

Keywords: stacking mitigations, profitability, dairy systems, off-paddock facility.

INTRODUCTION

Mitigating nitrogen (N) losses from a dairy farm generally comes with costs to the business (Beukes *et al.*, 2017). A valid goal is, therefore, to keep reducing dairying's environmental impact, while simultaneously maintaining or improving profitability.

Pastoral 21 (P21), a set of national farm systems trials, took place over a 5-year period (2011- 2016) and evaluated various management strategies expected to reduce the environmental impact of dairying while maintaining profitability (Beukes *et al.*, 2017). The P21 trial in Waikato compared two farms over the 5-year period, 1) a typical farm (Current Farm = CF) with 3.2 cows/ha, average genetics, replacement rate 22%, 150 kg N/ha, no standoff, and 2) a future farm (Future Farm = FF) with 2.6 cows/ha, high genetics, replacement rate 18%, 50 kg N/ha, and a standoff used from March to June. The measured annual N leaching loss from the FF was 43% less than from the CF. However, less N cycling through the system also meant less pasture produced, resulting in 4% lower milk production from the FF and a 13% reduction in profit (Clark *et al.*, 2019). While the FF included a standoff pad and feeding of low-protein supplements (imported maize grain) when required, the trial did not investigate the option of using home-grown maize silage fed on a feed pad.

Maize (*Zea mays* L.) is a high yielding (18-28 t DM/ha) crop that requires a significant amount of nitrogen to grow. Every tonne of DM produced, requires 12 kg of N, so a 20 t DM/ha maize silage crop will require 240 kg N/ha (Worku *et al.*, 2007). Maize silage is a low crude protein (7-8% CP) feed which can be used to dilute excess protein from pasture. Maize is a deep rooting plant with roots recorded at depths of 1.8 m (Kristensen and

Thorup-Kristensen, 2004), capable of utilising N well below the ryegrass root depth. When effluent N is used on the maize silage crop, more N is recycled inside the farm gate, which can reduce the need for imported N fertiliser.

The objective of this study was to evaluate an alternative to the FF system by adding a dedicated crop block on the milking platform (maize silage followed by a catch-crop), utilising effluent as the fertiliser on the crop block, and replacing the standoff pad with a feed pad. The three systems CF, FF and FF plus maize silage block (FFP) were modelled over consecutive years with different climate and milk prices, which allowed the assessment of differences in production, profit and N leaching between systems as well as variability across years.

MATERIALS AND METHODS

The DairyNZ Whole Farm Model (WFM), linked to APSIM (Holzworth *et al*., 2014) was used to simulate a typical Waikato Farm (CF), a Future Farm (FF) as used in the P21 trial, and a Future Farm with a feed pad and a dedicated cropping block comprising 15% of the milking platform (FFP). Key model inputs are summarised in Table 1.

Table 1. Model inputs.

	P21 Current Farm (CF)	P21 Future Farm (FF)	Dedicated maize block, Future Farm Plus (FFP)
Area (ha)	80	80	80
Stocking rate (cows/ha)	3.2	2.6	3.2
Off paddock infrastructure	NA	Standoff pad	Feed pad
Pasture N fertiliser (kg/ha)	125	85	85
Crop N fertiliser (kg/ha)	N/A	N/A	230 (Effluent only)
Cropping proportion (%)	0	0	15
Cow genetic merit	average	high	high
Annual ryegrass (t DM/ha)	N/A	N/A	5
Maize yield (average predicted t DM/ha)	N/A	N/A	21

Each system was simulated over five consecutive seasons (2013/14 to 2017/18) using observed climate (1187±281 mm rainfall) and milk price data (NZ$6.06±1.84/kg MS) for those seasons with the models predicting pasture, crop and milk production, N leaching under pasture (below 55 cm) and crop areas (below 162 cm because of deeper rooted maize), and operating profit.

The WFM was initialised with a Horotiu silt loam soil (allophanic, moderately well drained) and daily climate data from the NIWA meteorological station at Ruakura, Hamilton. For each of the five seasons actual milk fat and protein prices and farm operating costs from Economic Farm Surveys (www.dairynz.co.nz) were used as inputs to the model. In the FFP system, the feed pad was costed at $600/cow for construction and interest on borrowed capital at 5%, with depreciation over 25 years ($77/ha/year was added to farm working expenses). Feed pad maintenance was estimated at $3/cow/year (~$10/ha/year) and feeding out costs $45/t DM. In the FF system the standoff pad was costed at $875/cow ($112/ha) and $69/cow ($222/ha/year) for maintenance (Beukes *et al*., 2017). The high maintenance cost of the standoff was mainly driven by the cost of replacing the woodchip bedding. Standoff and feed pad costs were kept constant across the five simulated seasons.

The crop rotation on the FFP farm consisted of maize being direct drilled in October and harvested in March. Annual ryegrass was direct drilled in early April, harvested and ensiled with the last cut in September, before the block going back into maize. No N fertiliser, other than effluent collected from the dairy shed and feed pad, was applied to the crop block (approximately 230 kg N/ha/year). All feed from the crop block was cut-and-carried and fed on the feed pad with assumed losses of 13% for maize and 15% for pasture silage. Maize and ryegrass yields were climate-driven in both WFM and APSIM models, which used daily input of actual climate data. Maize growing plus harvesting costs were assumed to be $3230/ha (for high fertility land) and for annual ryegrass at $530/ha. These cropping costs were kept constant across the simulated seasons. Maize silage yield was model-predicted and ranged between 18 and 22 t DM/ha over the five years. Since there is no annual ryegrass model in the WFM, a user-defined yield of 5 t DM/ha was used.

RESULTS

Average pasture yield of the FF was lower than for the CF mainly because of less N fertiliser used (Table 2). Pasture yield for the FFP was higher than for the FF. Although similar amounts of N fertiliser were used, stocking rate on the FFP was higher than on the FF and 15% of the pasture area was taken out for the crop block. This combination resulted in a higher grazing pressure on the FFP with a resultant higher pasture yield. The addition of the cropping lifted production on the FFP by 141 kg MS/ha compared with the CF, and 275 kg MS/ha compared with the FF. This was due to the FFP having the same stocking rate (SR) as CF but higher genetic merit cows producing more milksolids per cow and compared with the FF having the same genetic merit cows but a higher SR, supported by the extra feed grown on the crop block.

Nitrogen leaching from pasture was highest for the CF (70±37 kg N/ha) and lowest for the FF (49±27 kg N/ha) with the FFP intermediate (57±31 kg N/ha). Because of the ability of the maize to capture more of the recycled N and keep it on the farm, more N cycled through the FFP herd and some of it was deposited on the pasture resulting in slightly higher leaching. In the case of the FFP the feed pad contributed to the recycling because of the time cows spent on this structure (3 hrs/day) and the large proportion of urinary N recycled as effluent (assumed 84%). The average N leaching from the crop block was 26±21 kg N/ha (range 8 to 62), skewed by the relatively high leaching in the above-average drainage year of 2017/18. However, leaching from the crop block was generally lower than from the pasture block because of effluent used to grow the crop, the stable state of the soil with very little extra N mineralisation, the deep rooting nature of maize (leaching below 162 cm), winter growth of the catch crop, and the absence of grazing animals on the block. The dilution effect of the crop block on the overall farm leaching meant that the FFP had a weighted average N leaching loss of 52 kg N/ha compared with the 49 kg N/ha for the FF and the 70 kg N/ha for the CF (Table 2).

Compared with the CF as a baseline, the FFP scenario achieved an average N leaching reduction of 26% while the FF achieved 31%. However, FFP had an operating profit reduction of 4% compared with 11% in the FF, resulting in the FFP having a cost of mitigating N of $9/kg compared with $16/kg N mitigated in the FF. Both the FF and the FFP scenarios were more efficient, 31 and 36 kg MS/kg N leached compared with 23 kg MS/kg N leached in the CF (Table 2).

Table 2. Predicted results (mean ± SD) for five consecutive seasons from 2013/14 to 2017/18 for Waikato dairy systems. Current Farm = CF, Future Farm = FF, Future Farm Plus maize crop = FFP.

	CF	FF	FFP
Pasture yield t DM/ha	16.6±0.5	14.8±0.8	15.5±0.9
Milk prod kg MS/cow	392±4	433±2	435±2
Milk prod kg MS/ha	1266±13	1132±6	1407±7
N leaching weighted average kg N/ha	70±37	49±27	52±29
N leaching reduction from CF %	-	31±4	26±3
N efficiency kg MS/kg N leached	23±13	31±18	36±21
Profit $/ha	3049±2123	2721±2071	2918±2220
Profit reduction from CF %	-	11±23	4±24
$ forfeited/kg N mitigated	-	16±8	9±10

DISCUSSION AND CONCLUSIONS

The N efficiency (kg MS/kg N leached) of the FFP system shows that a dedicated crop block with maize silage followed by a catch-crop (annual ryegrass in this case), can recycle more N within the farm, with more N exported as product per unit N lost to the environment. This positive outcome for a maize block on the milking platform in the Waikato can probably be generalised provided the same block is cropped reducing the chance of accelerating rates of N mineralisation, maize is established with minimal cultivation, only effluent N is recycled onto the crop, yields are above average, and the catch crop is cut-and-carry harvested and not grazed in winter (Williams *et al.*, 2019).

Results from the P21 trial (2011/12 to 2015/16), using actual milk prices (average of \$6.08/kg MS), showed average operating profit of \$2086 for the CF and \$1807 for the FF, a reduction of \$279/ha (13%) (Clark *et al*., 2019). Measured leaching reduction in the FF compared with the CF was 43%. Our modelling study differed from P21 by running over a different set of five years (2013/14 to 2017/18). However, our predicted reductions, in the FF compared with the CF of \$328/ha for operating profit (average milk price of \$6.06/kg MS) and 31% for N leaching indicate that our models captured the main effects of mitigation options on N leaching and operating profit. This provides confidence that the models can be used to extrapolate the P21 results, including the alternative FFP system, into untested climate and price scenarios.

A typical Waikato farm can achieve N leaching reductions of 30+% but the associated profit reduction can be substantial. Adding a dedicated maize block to the milking platform of this system can achieve worthwhile leaching reductions of 25%, while softening the negative impact on profitability. A dedicated crop block as part of the mitigation approach can be favourable when leaching targets are moderate and when there are reasons to maintain stock numbers and milk production. Caveats are that the crop block should not be migrated across the farm to reduce the risk of N mineralisation, the maize should be followed by a catch-crop (e.g., annual ryegrass), a feed pad is required to reduce feed-out wastage and capture effluent for recycling as a fertiliser source, and the home-grown crops are used to reduce imported feed-N.

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CONFLICT OF INTEREST DECLARATION

There are no real or perceived conflicts of interests to declare.

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Evaluating implications of alternative milking frequencies for New Zealand dairy farms

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ABSTRACT

Attracting and retaining workers for New Zealand dairy farms is a key focus for the dairy sector. Farmers are considering alternative milking frequencies to reduce the milk harvesting workload and improve work-life balance. Less frequent milking (milkings per day) is likely to affect milk production per cow and per hectare and, depending on the cost savings, could affect profitability. Farmers want to know the magnitude of these effects so that they can make informed decisions about either cutting costs to maintain profit, or trade this off for the benefit of improved work-life balance and staff morale. We used a modelling approach with a calibrated mechanistic cow model that captures effects of reduced milking frequencies on mammary physiology to evaluate farm-scale effects of alternative milking frequencies. The model was simulated for a typical Waikato farm over five consecutive farm seasons with observed daily weather inputs, farm costs and milk prices. Milking three times every two days (3-in-2) across the whole season was predicted to reduced average operating profit (OP) by 9% compared with twice-a-day (TAD), without reducing the cost of wages. Our modelling suggests for a typical 120 ha farm the full-season 3-in-2 system must reduce paid working hours by approximately 15 hrs/week at $30/hour (~0.25 labour unit) to maintain profit similar to TAD. Milking 3-in-2 for 8 weeks after the planned start of calving, then TAD, then 3-in-2 again from 1 February until dry-off at the end of April reduced OP by 6%. A change from TAD to 3-in-2 from 1 February till dry-off had a minimal negative effect on OP of 1%. Compared with full-season 3-in-2, a system with 3-in-2 from calving with a switch to once-a-day (OAD) in the second half of the season reduced OP by 10-15%. A flexible system with 3-in-2 for the first month after calving, the busiest time on a dairy farm, then TAD through peak milk, and again 3-in-2 from 1 February until dry-off could be a balanced approach to minimise profit loss but also achieve a more attractive work environment for staff.

Keywords: flexible milking, milk production, labour, reproductive performance.

INTRODUCTION

The New Zealand dairy industry faces challenges with cost control and a shortage of farm labour. Work on a dairy farm involves long hours, which is strongly influenced by the milk harvesting process. Milk harvesting times are often early in the morning and late in the afternoon, creating limitations on suitability of some members of the community for filling these roles. As a result, some farmers are changing from the traditional twice-a-day (TAD) milking to milking three times in two days (3-in-2) or once-a-day (OAD) for all or parts of the season.

Previous studies (e.g., Edwards *et al*., 2022) have shown that extending milking intervals i.e., reducing number of milkings per day, when all other parts of the farm system are unchanged, inevitably results in production losses. The more milkings missed per season the greater the loss.

Consideration should be given to potential savings in labour, dairy parlour expenses, electricity, repairs and maintenance. Other potential savings are higher body condition scores in OAD and 3-in-2 cows that could result in reduced winter feed requirements, reduced costs for lameness treatments, and potential improvements in reproduction leading to a lower not-in-calf rate and fewer replacements required (Edwards *et al*., 2022).

Some farms start the lactation season with 3-in-2 or OAD to reduce time pressure on staff during the busy calving season, then switch to TAD for varying periods before switching back to either 3-in-2 or OAD for the remainder of the lactation to create more free time for staff.

The objective of this study was to evaluate the economic implications of reducing the number of milkings per day by implementing combinations of TAD, 3-in-2, and OAD across a lactation season on a typical Waikato farm. The purpose was to determine the scale of cost saving that is required to maintain profitability or identify the cost of lifestyle benefits.

MATERIALS AND METHODS

Farms were modelled using the DairyNZ Whole Farm Model (WFM) over six consecutive seasons (2012/13 to 2017/18, excluding output from the first season as a run-in year) using actual weather, input costs and milk prices, which varied from $4.06 to $8.68/kg MS. The WFM includes the Molly cow model that integrates physiology and metabolism of a dairy cow. Molly's mammary module was recently updated to better represent the short-term and carry-over effects of changes in milking frequency (Rius *et al*., 2019). The first step was to calibrate Molly's mammary settings for full-season 3-in-2 by following the MS reduction of approximately 4% measured in a farmlet experiment run in 2019/20 season (Edwards *et al*., 2022). Mammary settings were also derived for full-season OAD by aiming to achieve approximately 18% reduction in MS production. This was deemed an average considering the range of reductions obtained from several sources (Westbrooke *et al*., 2003; Clark *et al*., 2006; Rius *et al*., 2019).

The WFM was used to simulate a typical Waikato farm with 3.2 crossbred cows/ha of average genetic merit, 125 kg N fertiliser/ha, with mainly imported grass and maize silage to fill feed gaps. Planned start of calving (PSC) was 1 July and dry off and culling rules were kept the same across the different scenarios to avoid any bias at the end of the season as dry-off and culling rules affect days in milk. All cows were dried off on 26 April every year with all culling happening on 27 April. This scenario simulated full-season TAD over the five recorded seasons as the baseline or reference point for comparing production and operating profit of the alternative scenarios. The first alternative was a full-season 3-in-2 scenario. For the second, the baseline scenario was altered to 3-in-2 during the busy calving months of July and August, switching to TAD on 1 September until on 1 February switching back to 3-in-2 to give the milking team some time off for the remainder of the lactation. We also evaluated a limited 3-in-2 scenario with TAD for most of the season then 3-in-2 from 1 February until dry off. With these scenarios established we ran a matrix in the WFM to explore the best combination of switching dates with options for switching from 3-in-2 to TAD during calving (4, 6, or 8 weeks after PSC), and options for switching from TAD to 3-in-2 during the second half of the lactation (1 Dec, 1 Jan, 1 Feb, 1 Mar). We also evaluated an option of OAD during calving for the first three weeks (3 weeks since PSC until 21 July) followed by TAD and then back to 3-in-2 in the second half of the lactation.

For the WFM economic input we used data from DairyNZ's economic surveys for the five seasons including Fonterra fat and protein prices (dairynz.co.nz/economicsurvey). We assumed that farmers would reduce milking frequency to attract and retain quality staff, rather than reduce labour costs, and therefore did not change the cost of wages in any of the options. Dairy parlour and electricity costs for full season 3-in-2 were reduced by 15% considering that over a full season 3-in-2 will result in 25% fewer milkings, but each milking is longer. For part-season 3-in-2 or OAD scenarios we assumed 7.5% reduction in dairy and electricity costs.

RESULTS

Pasture grown and eaten was minimally affected by the alternative milking strategies (Table 1). The amount of supplements fed was noticeably lower (4%) in the full-season 3-in-2, but not in part-season 3-in-2. Model predictions for a high-producing Waikato farm on full-season 3-in-2 showed a decrease in production per cow of 5%, production per hectare of 4%, and operating profit (OP) of 9% compared with TAD. The decrease in production for full-season 3-in-2 reflected a combination of the negative effect of 3-in-2 on the physiology of milk secretion and the positive effect of more days in milk in this system (Table 1). With full-season 3-in-2 the cows had higher BCS at start of calving on 1 July, which had a positive effect on their reproductive performance in the following mating season starting 23 September. The 6-week in-calf rate was higher and number of days to 50% calved lower reflecting a more compact calving spread. This led to further flow-on effects of more days in milk and a final not-in-calf rate that trended lower (Table 1). Changing to 3-in-2 during calving and late season resulted in 6% reduction in OP, while 3-in-2 only in late season had a minor negative effect on OP (-1%). The negative effect of 3-in-2 on milk income and operating profit was buffered to some extent by lower farm working expenses due to less imported supplements, and lower dairy parlour and electricity expenses (Table 1).

Table 1. Model results for selected scenarios over five consecutive seasons. Averages with percentage change from full season twice-a-day (TAD) in brackets.

	Full-season TAD	Full-season 3-in-2	3-in-2 Jul-Aug and Feb-Apr	3-in-2 Feb-Apr
Pasture yield (t DM/ha)	15.8	15.7 (-1)	15.8 (0)	15.7 (0)
Pasture eaten (t DM/ha)	15.1	14.9 (-2)	15 (-1)	15.1 (-1)
Supplements fed (kg DM/cow)	1316	1259 (-4)	1298 (-1)	1302 (-1)
Milksolids (kg/cow)	407	389 (-5)	397 (-3)	403 (-1)
Milksolids (kg/ha)	1315	1256 (-4)	1281 (-3)	1303 (-1)
Mean days in milk	275	277 (1)	276 (0)	276 (0)
BCS at calving	4.5	4.8 (7)	4.6 (4)	4.6 (2)
Days to 50% calved	17.4	16.4 (-6)	17.4 (0)	17.2 (-1)
6-week in calf rate (%)	76.2	78.6 (3)	77 (1)	76 (0)
Final not-in-calf rate (%)	8.8	8.6 (-2)	8 (-9)	8.2 (-7)
Farm working expenses ($/ha)	5717	5597 (-2)	5660 (-1)	5662 (-1)
Operating profit ($/ha)	2226	2033 (-9)	2091 (-6)	2198 (-1)

The scenario with 3-in-2 during calving and again in the second half of the season (Table 1) only covered one option for first and second switch dates i.e., 1 September (8 wks after PSC) and 1 February. The next section explores possible outcomes for different combinations of these switch dates.

Earlier switching from TAD to 3-in-2 on 1 December or 1 January both compromised OP by approximately $50/ha compared with later switching dates. Aggregating OP for 1 February and 1 March across the calving switch dates, showed that, on average, the first switch date of four weeks since PSC is preferable compared with the other two options (6 or 8 wks), largely driven by MS production. Once this is established then there is very little difference between 1 February or 1 March as the second switch date. In this case it would be sensible to choose 1 February as second switch date giving a longer period for a more relaxed roster for the milking staff.

DISCUSSION AND CONCLUSIONS

Our modelling suggests that, without savings in labour costs, a full-season 3-in-2 Waikato farm will forfeit approximately $190/ha in profit compared with a TAD farm at an average milk price of $6.77/kg MS. The $190/ha includes cost savings due to 3-in-2 from milking expenses (shed and electricity), the value of higher BCS through effects on milk production and reproduction, and the value of the lower feed requirements in the 3-in-2 herd. In our modelling the effect of BCS at calving on milk production results from the effect of greater adipose reserves on milk production following calving (Roche *et al*., 2009), plus the effect of higher BCS at calving on 6-week in-calf rate, calving spread and days in milk the following season. However, our results did not show a noticeable effect of BCS on final not-in-calf rate and consequently did not capture any savings associated with less culling and a lower replacement rate. Using results from full-season OAD (Hemming *et al*., 2018) we can estimate a lower not-in-calf rate and associated lower replacement rate of 2.5% in full-season 3-in-2, worth a potential saving in the order of $141/ha. Furthermore, assuming 25% reduction in lameness at $250/case, a further $24/ha can be saved. If we include the potential cost savings due to a lower replacement rate and less lameness, then our predicted deficit of $190/ha for full-season 3-in-2 could be negated. This suggests that the profitability of full-season 3-in-2 systems can approximate those of TAD systems even without considering savings in labour costs. However, if the potential savings via replacement rate and lameness are unrealistic then 3-in-2 systems still have the option of reducing labour expenses. If this is the preferred option, then our modelling suggests for a typical 120 ha farm the full-season 3-in-2 system must reduce paid working hours by approximately 15 hrs/week at $30/hour (~0.25 labour unit) to maintain profit similar to TAD. Similarly, for a system with 3-in-2 during calving and again in late season, paid working hours need to be reduced by approximately 10 hrs/week over the full season to break even with a TAD system.

Our analysis showed that the length of time on 3-in-2 since PSC is important. By reducing this period from 8 to 4 weeks, the negative effect of the part-season 3-in-2 on OP of -6% can be reduced to between -4 and -5%. These differences were mainly driven by milk production during the first half of the season. The longer a cow is on a lower milking frequency after calving the more her peak milk production will be negatively affected due to the long-term carry over of the short-term negative effects of reduced milking frequency on the numbers and secretory capacity of active mammary cells (Rius *et al*., 2019).

The value of our study with a mechanistic cow model is that it captured the well-known carry-over effect of reduced milking frequencies, even when switching back to twice-a-day and converted this into monetary terms. These results provide farmers with a ballpark impact on their bottom line (operating profit), so they can make informed decisions on either how much cost-cutting is required to equate with a TAD system or evaluate the price they are prepared to pay for the benefits such as work-life balance.

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CONFLICT OF INTEREST DECLARATION

There are no real or perceived conflicts of interests to declare.

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Prevalence of bloat in cows grazing plantain dominant diverse pastures at dry off: a case study

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ABSTRACT

The purpose of this study was to document the conditions under which bloat was observed in dry cows grazing plantain dominant diverse pastures in autumn. Symptoms were observed in the autumn period when cows grazed diverse pastures containing plantain (46%), clover (18%), and Italian ryegrass (32%). To further characterise the conditions under which bloat occurred an observational study was conducted in May 2019. A group of 28 non lactating Holstein Friesian x Jersey cows were monitored for appearance of bloat and feeding behaviour following a new allocation of diverse pasture. Bloat symptoms were assessed hourly and feeding behaviour (eating, ruminating and activity) was recorded using CowManager SensOor eartags. Although there was active management to avoid bloat such as feeding silage before a new pasture allocation and using bloat oil in troughs, on the first day of the study 18 cows showed medium to critical bloat signs within the first 2 to 4 hours. Cows that experienced bloat, spent less time ruminating but longer time grazing. Our results do not confirm whether plantain contributed to bloat but we speculate that plantain is likely to delay the onset of bloat. Feeding diverse pastures containing low fibre and high moisture species may require adjustments to management of bloat risk.

Keywords: *Plantago lanceolata* L.; *Trifolium repens;* herbs, multispecies pasture; legume, dairy cattle

INTRODUCTION

The occurrence of bloat in dairy cows is a major concern for farmers as, left unattended it can result in death of the animal within hours. Bloat is the rapid build-up of gases and formation of stable foam, usually within 30 to 120 minutes of a new grazing allocation (Johns et al. 1957; Majak et al. 1995). Most of research on bloat has been with lucerne (*Medicago sativa*) with risk factors associated with high soluble protein, reduced rumen clearance, and reduced saliva production (Majak et al. 1995, Jonker and Yu. 2016). Consequently, legumes feature prominently among forages with high bloat risk, except for certain legumes containing tannins which do not cause bloat (Majak et al. 1995).

With the growing interest in use of forage plantain in pastures for environmental N loss mitigation, more farmers are including plantain in their pastures. Plantain has a number of unique features including tannins and antimicrobial properties which may influence bloat (Stewart 1996). The study was implemented following frequent observation of bloat in several cows grazing the diverse pastures. Of interest was the delay -after pasture allocation - with which the bloating appeared in these animals. No bloat signs were observed in the morning after the cows were offered fresh pasture break. However, bloat symptoms developed in cows in the afternoon. This prompted the more detailed study of animals on diverse pastures.

MATERIALS AND METHODS

The study was carried out in May 2019 at the Lincoln University Research Dairy Farm (Canterbury, New Zealand) using animals which were part of a long-term farm systems comparison. The diverse pastures on which bloat occurred had been established by direct drilling following a glyphosate spray in March

2018. The pasture mix consisted of Italian ryegrass (*Lolium multiflorum*), plantain (*Plantago lanceolata*), red clover (*Trifolium pratense*) and white clover (*Trifolium repens*). The study group of cows consisted of 28 non-lactating animals of mixed age which had recently been dried off. The study was conducted between 20 and 23 May 2019 when the cows were being strip grazed in a paddock containing the diverse pasture (0.5 ha).

Grazing management

Cows grazed on the diverse paddock during the day where they could be monitored, and on a ryegrass white clover pasture overnight. The 0.5 ha diverse paddock was divided into four allocations. The pre graze biomass was 2900 kg DM/ha for the 1st and 2nd allocation, and 2700 kg DM/ha for the 3^{ed} and 4th allocation based on the winter equation of Jenquip rising plate meter. This would offer each cow with approximately 8 kg DM of pasture per day above a 1200 kg DM/ha residual, supplemented with 4 kg DM/cow/day as pasture baleage.

While the study aimed to document the prevalence of bloat, common management practices were applied to prevent bloat (Majak et al. 1995). These included bloat oil being added to the trough water; gorging was avoided by feeding silage supplement to cows between 8 and 10 am before offering cows their new allocation at 11am each day.

Because high bloat incidence occurred on the first day of the study, raising welfare concerns, on days two to four, the area was halved and cows were offered the equivalent of 4 kg DM/head/day as diverse pasture with access for only 4 hours/day (from 11:30 am to 3:30 pm) following allocation of supplement in the morning and grazing ryegrass and white clover pasture for the remainder of the day (4 kg DM/head).

Measurements

Prior to and during grazing (2-3 hours after pasture allocation), botanical composition was determined by hand plucking samples of herbage within each allocation. Sown and weed species were separated and dried to a constant weight at 60ºC. Pasture mass was determined pre and post grazing using quadrat cuts to calibrate the rising plate meter (RPM). Visual scores for bloat were carried out every hour after the cows received new pasture. Severity of bloat was visually scored on a 0-3 scale based on the distension of the left-hand side of the animal, where 0 was no bloat, 1 is low (cow is full with slight distension on left) 2 is bloating evident (moderate distension on both sides) and 3 is bloating critical (severe distention both sides, Plate 1).

Plate 1. Cow experiencing bloat on diverse pasture at Lincoln University Research Dairy Farm. Note the strong upward inflation on the animals left (rumen) side

Ingestive behaviour was determined using CowManager SensOor eartags which continuously monitor grazing and ruminating time. Behaviour data between 8am and 4pm was downloaded for each cow for further analysis.

Analysis

Repeated measures analysis was performed on Cow Manager activity data by grouping cows with moderate to severe bloat (score 2 & 3) compared with non-bloating cows (score 0 & 1). Genstat 19th Edition (VSN International Ltd) was used to compare means.

RESULTS

Although the RPM recorded pre graze mass of 2700-2900 kg DM/ha, based on the RPM calibration (kg DM/ha = 118RPM+65, R2=0.8) pre and post grazing of 2050 and 726 kg DM/ha respectively, giving an apparent pasture intake of 6 kg DM/cow on day 1 and 3.5 kg DM/cow on days 2 to 4. The botanical composition of the herbage prior to grazing consisted of 32±11.2%

ryegrass, 46±12.6% plantain, 18±6.6% clover and 3±1.3% dead material. During grazing cows selected for clover and against dead material with little evident selection for either ryegrass or plantain with botanical composition consisting of 27±10.1% ryegrass, 46±12.1% plantain, 3±1.1% clover and 18±9.3% dead material after 2 to 3 hours grazing.

Over the four day observation period, cows displayed bloat only on the first day in the paddock. On the following three days allocation in the same paddock, none of the cows scored greater than a score of 1 due to the remedial action to prevent bloat. On the first day, 18 of the 28 cows displayed bloat symptoms scoring 2 or greater. The majority of cows which had previously been recorded with bloat were observed to again be inflicted on the 20th May (with the exception of #84). However, due to the small population used in this study, it was not possible to detect association between the risk of bloat and animal characteristics such as age, breed, live weight, days since dry off or milk yield.

The prevalence of moderate bloating occurred at three to four hours after fresh pasture allocation (Table 1). Five hours after pasture allocation, several cows developed severe bloat signs so all cows were moved to the yard for drenching. Cowmanager data showed that on 20th of May, cows with bloat (scores 2 to 3) spent less time ruminating than normal cows (scores 0 to 1) during the time from 11am and 4pm (13.8±3.37 vs 34.4±8.55 minutes; P=0.065 respectively). Although there was no difference in total eating time between 8am and 4pm (average 210±8.0 minutes; P=0.24) an interaction between hour and bloat occurrence revealed that cows developing bloat grazed for longer and ruminated less between 1pm and 3pm (Figure 1).

Table 1. Bloat score for dairy cows following allocation of a fresh pasture break at 11am on 20th May 2019. Asterisk denotes cows previously observed with bloat

Cow#	12pm	1pm	2pm	3pm	4pm
25	0	0	1	1.5	**2**
27	0	0	0	0	0
46*	0	0.5	**2.5**	**3**	**3**
61	0	0	**2**	**2**	**3**
80	0	0	0	0	**2**
84*	0	0	0.5	0	0.5
103*	0	0.5	**2.5**	**3**	**3**
106	0	0.5	1	1.5	**2**
118	0	0.5	1	1	1
121	0	1	1.5	**2**	**3**
129	0	0	0	0	0.5
136*	0	0	1	**2**	**3**
141	0	0	0.5	**2.5**	**2.5**
143*	0	0	1	1	**3**
144	0	0	0	0	0
147	0	0	0	0	0
158*	0	0	0.5	**2**	**3**
204*	0	1	**2**	**2**	**2**
206	0	0	0	0	0.5
209	0	0	0	0	1
213	0	1	1.5	**2**	**2**
216	0	0	0.5	0	0
224	0	1	1	1	**3**
234	0	0.5	**2**	**2**	**2**
248	0	1	**2**	**2**	**3**
306	0	0	0.5	0.5	**2**
338	0	0	0	0	1
352	0	1	**2**	**2.5**	**3**

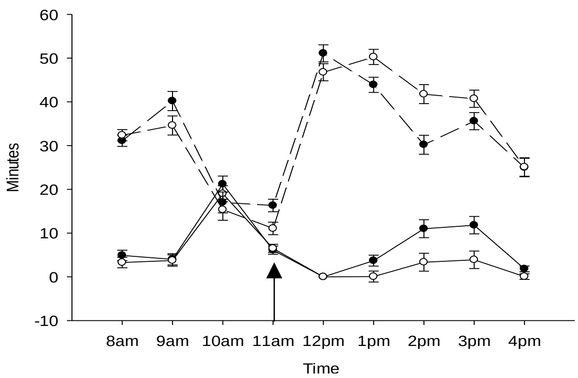

Figure 1. Minutes spent eating (dashed line) and ruminating (solid line) for normal cows (closed symbol) or cows that developed bloat symptoms (open symbol) on 20th May. The arrow indicates when new pasture break was allocated to cows.

DISCUSSION AND CONCLUSIONS

The findings of this observational case study show that cows grazing a diverse pasture containing a high proportion of plantain and legumes are at risk of bloat. Plantain and clover made up approximately 70% of the diet in this study. Both clover and herb contain relatively low fibre content which contribute to lower rumination (Figure 1). The importance of rumination and saliva production for bloat prevention is well recognised as saliva contains anti foaming mucin (Bartley and Yadava 1961;

Jonker and Yu 2016). Bloat-developed cows in the present study spent less time ruminating compared to those cows that showed no signs of bloat. Bloated cows also grazed more during the grazing bout which may reflect higher intake of pasture and/or lower intake of supplement before allocation. The behaviour data is confounded as an increase in one behaviour ultimately results in the reduction of another, making cause and effect difficult to unravel. Insufficient bloat oil ingested by cows grazing diverse pasture may also have contributed to the prevalence of bloat in cows in this study, though this wasn't recorded in the present study. Previous studies have shown that cows grazing diverse pastures drink less trough water due to the lower dry matter content of the forage (Bryant et al. 2018). In addition, selection of clover against other species during first couple of hours after pasture allocation may also have contributed to the development of bloat symptoms in cows in this study.

What was interesting in this research was the delay in the onset of bloat. Generally bloating in cows occurs within 30 to 120 minutes after fresh pasture allocation (Majak et al. 1995), but in this study the appearance of bloat wasn't obvious until after two hours on pasture. There may be several reasons for this delay which relate to the unique plant chemistry of plantain. Stewart (1996) suggested that plantain secondary compounds may alter rumen fermentation through antimicrobial processes, which may also prevent bloat. Bartley and Yadava 1961 suggested that plant mucilages (which plantain contains) may act as anti-foaming compounds and delay bloat. The small sample in this study prevent us from drawing any conclusions about the contribution of plantain towards bloat other than highlighting the interactive effects of combining different forage species. The findings of this research demonstrate the need for additional management of bloat in diverse pastures containing plantain and clover, which include prolonged monitoring and alternatives to trough oils e.g. rumen boli or foliar applied oils.

We cannot conclude whether plantain causes bloat but we offer the hypothesis that plantain does at least delay the onset of bloat or bloat symptoms.

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CONFLICT OF INTEREST DECLARATION

We declare no conflict of interest

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Case study and scenario analyses of resources required for calf rearing on New Zealand dairy farms when mating programmes are altered to increase the use of surplus calves.

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ABSTRACT

On New Zealand (NZ) dairy farms, some calves born are not required for dairy production. The dairy and beef sectors are developing methods to increase the suitability of these calves for beef production, to reduce the number slaughtered before 30-days of age ('bobby' calves). Utilising more beef and sexed semen in dairy mating programmes may result in more calves being sold and reared for beef, and it is important to identify the consequences of these changes for dairy farmers, such as increased resource requirements and altered finances. Data from five Dairy Trust Taranaki case-study herds, with mating programmes designed to reduce bobby calves, were collected and analysed to determine calf outcome and predicted requirements (e.g., feed, labour, and shed capacity). These data were then used in a scenario analyses (SA) with three simulated mating programmes (SA1, SA2 and SA3) aimed at reducing the number of bobby calves from ~40% of calves born to ~20% and ~0%, respectively. Upon simulation, herds in SA2 and SA3 reduced bobby calves to 25% and 7%, respectively. The reduction in bobby calves was associated with a concomitant increase in beef calves and resulted in an increased milk demand (43% greater in SA3 compared with SA1). Peak shed capacity demand increased by 8% and 12%, occurred 13 and 20 days earlier, and lasted 7 and 12 days longer in SA2 and SA3, respectively, compared with SA1. Thus, a change in mating programmes can reduce the number of bobby calves; however, greater infrastructure resources, feed supply and labour input are required for the rearing of the resulting dairy-beef calves. Furthermore, if these mating programmes were adopted at scale, the current NZ beef sector will be unable to accommodate all calves and land use change may be required.

Keywords: calf rearing, mating programmes, seasonal calving systems, bobby calf, dairy-beef

INTRODUCTION

Approximately 35% of calves born on New Zealand (NZ) dairy farms are deemed unsuitable for dairy or beef production primarily due to gender, genetic merit, breed, and markings. These "bobby calves" are transported and slaughtered before 30 days of age (Edwards *et al.*, 2021).

Even though these animals are processed to valuable products such as blood serum for vaccines, high-end leather, veal meat and pet food, the practice raises ethical and animal welfare concerns, both internationally and locally (Ritter *et al.*, 2022). If NZ dairy farm operations are to address these concerns and reduce bobby calf numbers, they need a sustainable farm plan where all calves are reared for a reasonable length of life, e.g., beyond 30 days of age (Pike *et al.*, 2019).

One solution is to alter the mating programme to incorporate more beef and sexed semen and increase the suitability of surplus calves for beef production. However, such a mating programme may increase the resources required for calf rearing (Vicic *et al.*, 2022). For farmers to be prepared and ensure all calves are reared according to best management practices, the risks and opportunities associated with the changed calf outcomes need to be quantified.

The objective of the current study was to compare and analyse different mating programmes aimed at reducing bobby calves and to determine the subsequent resource requirements if these mating programmes were implemented on an average NZ farm.

MATERIALS AND METHODS

Case-study approach

We used an embedded multiple-observational case-study approach to 1) identify and quantify the resources required to house and feed calves, born from mating programmes designed to reduce the number of bobby calves and 2) use these data to predict the resources required on an average NZ dairy farm with mating plans to reduce bobby calves to 20% and 0%. All procedures were approved by the Ruakura Animal Ethics Committee #15343.

Data were collected from five herds (case studies) managed on three Dairy Trust Taranaki (DTT) research farms (an autumn-calving Jersey herd, a spring- and autumn-calving Friesian herd, and two spring-calving Friesian herds) and then compared with NZ national averages. Each herd used a mating programme with a range of sexed and daughter-proven bull semen for heifer replacement and breeds for dairy-beef production (Wagyu- and Speckle Park semen, short gestation Friesian-cross-Jersey and Hereford semen). Quantitative and qualitative data were collected during calf rearing in 2021, including birth weight, growth rates, shed entry and exit dates, farm exit dates, sale details, calf breed, coat markings, outcome and reasons for the outcome, and calf mortality. These data, combined with interviews from 2 calf rearers in autumn and 2 calf rearers in spring were used to determine the minimum infrastructure and resource requirements needed to meet the calves' ethical and welfare needs during rearing.

For all case studies, data were collected on-farm by trained farm staff and cross-referenced with MINDA herd management records (MINDA™, LIC, Hamilton, New Zealand). Data were compiled in Microsoft EXCEL and consolidated in RStudio using R.3.5.0.

Scenario analyses

A 444-cow spring-calving herd was used as a base farm. A mathematical model that incorporated national farm system and reproductive performance averages, and data from the case studies was used to determine the impact of three simulated mating programmes. The mating programmes aimed to reduce bobby calves from industry average (~40%), using conventional semen, beef semen, and bulls (SA1); to ~20% using sexed semen, beef semen, and bulls (SA2); and ~0% using sexed semen and beef semen (SA3; Chauncy, 2022). Shed capacity was determined by allocating 1.5m^2 space per calf and total milk consumption was calculated at 10% of average liveweight of the calf while in the shed, multiplied by the number of days in the shed.

RESULTS

Case studies

Calf outcomes from the five case study herds ranged from 21 to 44% bobby calves, 22 to 25% heifer replacements, and 15 to 37% calves sold for beef rearing. Very few calves were reared on farm for beef (Figure 1).

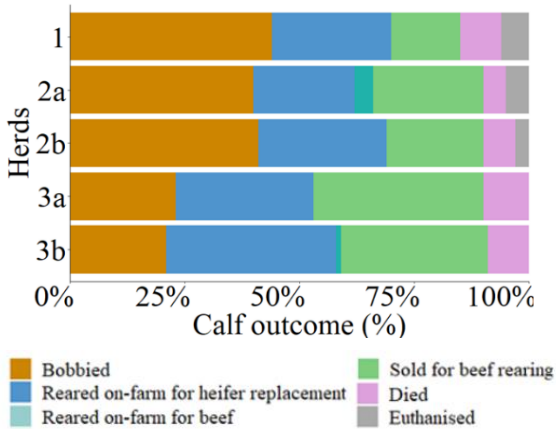

Figure 1. The percentage of calves born in each case study herd that were 'bobbied', reared for heifer replacement, reared for beef, sold for beef rearing, died or euthanised. Herds 1 and 2a were autumn calving, herds 2b, 3a and 3b were spring calving.

Of the calves sired by Jersey bulls, 88% were bobbies; those sired by Friesian bulls had a bobby rate of 32%, and calves sired by beef breeds had minimal bobbies. Shed capacity demand varied on each case study, with calves leaving in cohorts dependent on number (determined by capacity of the portable calf feeder) and weather. Heifer replacements remained in the shed for the longest period; 22 to 45 days in spring and 16 to 18 days in autumn with calves sold for beef rearing dependent on the individual beef rearer's agreement.

The average days in shed and average of liveweight while in the shed varied with breed and outcome. These were 4 days and 35-37 kg (bobbies), 6 days and 41-43 kg (sold for beef rearing), 36 days and 46 kg (daughter replacements sired by conventional semen), 29 days and 43 kg (daughter replacements sired by sexed semen), and 0 days (mortalities).

Scenario analyses

Following simulation of the three scenario farms, calf outcome in SA1 (base farm) was 40% calves bobbied, 29% reared on farm as heifer replacements, 21% sold for beef rearing and 10% mortalities. SA2 reduced bobby calves to 25%, with 25% reared as heifer replacements, 40% sold for beef rearing and 10% calf mortalities. SA3 reduced bobby calves to 7%, and had 25% of calves reared as heifer replacements, 57% sold for beef rearing and 11% calf mortalities.

The base for peak number of calves in the shed was set by SA1 (i.e., shed capacity; Figure 2). Shed capacity increased by 8% (11 calves) in SA2, and by 12% (17 calves) in SA3. The timing of shed capacity was also affected, with peak demand in SA2 occurring 13 days earlier and in SA2 20 days earlier than in SA1 (Figure 2). Peak number of calves in the shed lasted for 7 and 12 days longer in SA2 and SA3, respectively, compared with SA1.

Milk consumption was estimated based on intakes of 10% of average liveweight per days in shed. Total milk consumption increased from 4,884 L in SA1 to 6,111 L in SA2 and 6,977 L in SA3. With a milksolids percentage of 8% and a milk price of $7.70 (average from past four years; DairyNZ, 2021) this equates to a cost of $3,011 in SA1, compared with $3,765 in SA2 and $4,297 in SA3.

DISCUSSION

Data from the case studies and the scenario analyses indicated that mating programmes redesigned to include sexed and beef semen can reduce the number of bobby calves in a herd, but the changes in calf outcome, and calving pattern subsequently alter the resource and management requirements for calf rearing. Other factors with beef breeds such as gestation length and calving ease (LIC, 2022) need to be considered to ensure the productivity of the dairy herd is not compromised.

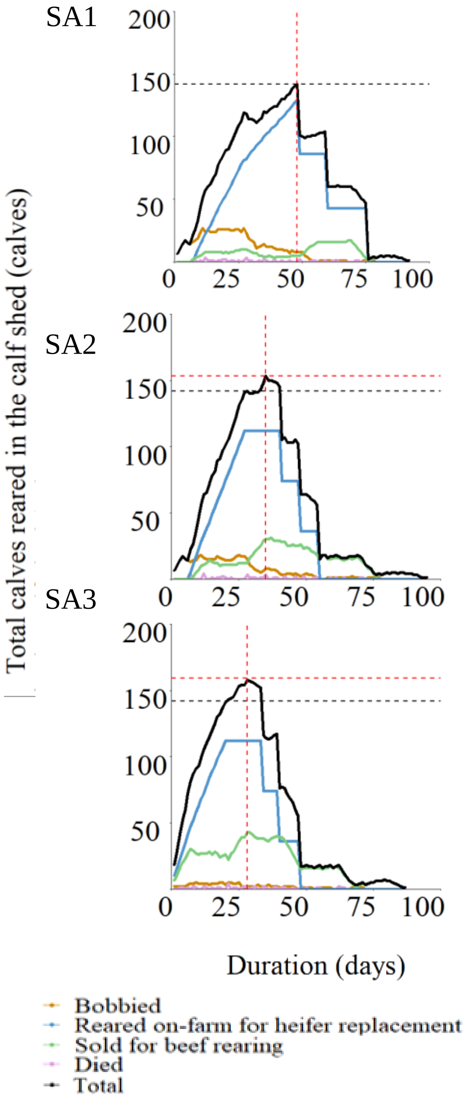

Figure 2. Number of calves reared in shed from three scenarios (SA1, SA2, and SA3, targeting 40%, 20%, and 0% bobbies, respectively). Horizontal lines indicate baseline shed capacity (black; peak demand from SA1) and increased capacity requirements (red) across scenarios. Vertical lines indicate the time that shed capacity was reached.

Incorporation of sexed and beef semen into the mating programmes reduced bobby calves, with a concomitant increase in calves for beef rearing. Although the mating programme for SA3 was designed to produce 0% bobbies, strict selection criteria from beef calf rearers resulted in 7% of calves with undesirable traits for beef rearing (e.g., sex, markings, and carcass characteristics; Coleman *et al.*, 2016; Berry *et al.*, 2018).

Key resource requirements during calf rearing are shed capacity, milk, and labour (Vicic *et al.*, 2022) and these were affected by mating programmes that incorporated sexed and beef semen. A greater peak shed capacity that occurred at an earlier stage and lasted longer, means that many farms would require greater calf holding capacity in shed infrastructure. The ability to remove calves from the shed depends on two key factors: climate and calf sales (bobbies or beef) and there are risks associated with both.

The effect of climate was evident in the case studies with autumn-born calves exiting the shed earlier compared with spring-born calves due to warmer, dryer weather conditions. With the use of sexed semen, the calving pattern changes and there are more heifer replacement calves born earlier. This places more pressure on shed capacity, particularly if poor weather conditions prevent calves from exiting the shed when planned.

Calf sales are dependent on supply chain management and if the use of sexed and beef semen increases at a national level without increase in demand for the resulting dairy-beef calves, there is greater risk that calves bred for beef rearing will not be sold and thus will not exit the farm (shed) at 4 or 6 days old in autumn and spring, respectively. Consequently, the peak shed capacity requirement will increase, as will milk requirements and labour. The greater milk requirement in SA2 and SA3 resulted in a greater cost to the farm, the magnitude of which will be sensitive to milk payout price if vat milk is being used.

In summary, the use of sexed and beef semen in the mating programmes can change the subsequent calf outcome, to produce less bobby calves and more calves sold for beef. However, greater infrastructure, labour and milk will be required on dairy farms, and there needs to be a demand for beef calves. If these mating programmes were to be adopted at scale, the current NZ beef sector will be unable to accommodate all calves and land use change may be required.

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Optimisation of Milking Frequency in Pasture Grazing-Based Single Box Robotic Milking System

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ABSTRACT

In grazing-based single box robotic milking system (GSBM), there is limited research result to show whether there is an adequate milking frequency that contributes to optimal cow voluntary movement (free cow traffic) and milk production. This preliminary study aimed to 1. identify adequate milking frequency to support optimal milk production and 2. understand the inter-relationship between pasture quality, milk production and milking frequency. This study comprised three milking frequency and milk production datasets from GSBM: 1) 24 commercial dairy farms over one year; 2) A three years monthly-data from the University of Melbourne Dookie dairy; and 3) A summer dataset that included measurements of pasture quality. The first two datasets showed that the highest milk production in herd plateaued at ~2.5 milkings/cow/day, although the observed variation was considerable. In the 3rd dataset, there was a trend of milking frequency increased as pasture content of neutral detergent fibre increased. Further study is required to investigate seasonal variation and feeding system (e.g., grazing pasture % in total feed ration) effects on relationship between milking frequency and milk production.

Keywords: automatic milking, voluntary movement, grass, pasture quality

INTRODUCTION

Automatic milking system (AMS) was firstly used by farms in the Netherlands to decrease the labour requirement, because the robotic arms can collect milk automatically (Speroni *et al.* 2006). It was reported that over 25,000 AMS machines were installed worldwide since the first AMS installed (Wagner-Storch and Palmer 2003). The majority of dairy farms that used AMS in European countries were based on indoor feeding system (Lyons *et al.* 2014). When the AMS was introduced to countries with grazing-based systems like Australia, cows were trained to travel voluntarily between milking units and paddocks (Jago and Burke 2010).

Experiments based on indoor milking system showed that when increasing the milking frequency from 2 to 3 times/day, the milk production increased by 3.5 kg/day (Erdman and Varner 1995). Despite that milking frequency is known to have a great impact on milk production and composition (Smith *et al.* 2002; Speroni *et al.* 2006; McNamara *et al.* 2008), there is limited research on defining adequate milking frequency to support optimal milk production and free cow traffic in grazing-based single box robotic milking system (GSBM). Therefore, this preliminary study aimed to 1. identify adequate milking frequency to support optimal milk production and 2. understand the inter-relationship between pasture quality, milk production and milking frequency.

MATERIALS AND METHODS

Commercial GSBM farms data collection

One-year (1/07/2020 to 30/06/2021) data from 24 commercial GSBM Australian farms was downloaded from Astronaut Animal Data Product (AADP) Lely database. The average daily number of milkings and milk production of all lactating cows were recorded.

Dookie dairy GSBM data collection

Individual cow milking frequency and milk yield data were obtained daily from The University of Melbourne, Dookie Dairy for three years (1/1/2017 to 31/12/2019). The Dairy has a pasture-based three-way grazing system (cows have access to a fresh strip of pasture 3 times/day; Cullen *et al*. 2020) for most of the year with approximately 2.2 tonnes of concentrate fed/cow/year, and conserved forage fed on a feedpad in the summer months. The farm has three Lely Astronaut automatic milking robots. During the period of study, the farm milked 78-156 Holstein-Friesian cows, with calving times in Spring (approximately 60%) and Autumn (approximately 40%). The daily individual cow data was averaged for each month.

To investigate the inter-relationship between pasture quality, milk production and milking frequency, the feed sample and milk production data collection were conducted at Dookie dairy from 06/11/2021 to 30/12/2021. The feed samples were collected weekly from three paddocks (three-way grazing system), where cows were going to graze in the next 24 hours. Individual cow milk production data were obtained from three robots after 24 hours of feed sample collections. A total of nine weekly feed samples were collected. The samples were sent to the NSW Department of Primary Industries feed test laboratory (Wagga Wagga, Australia) for NIRS nutritive value analysis.

Data analysis

All correlations between parameters were examined using Excel.

RESULTS

Figure 1 demonstrated that despite a large variation observed from 24 commercial farm dataset, there was a weak, but overall increasing relationship between milk production and milking frequency. However, milk production didn't further increase beyond 2.5 milkings/cow/day. Similar result was shown in Figure 2 with the three years dataset. A moderately strong positive and weak negative relationship were found between pasture neutral detergent fibre (NDF) content and milking frequency, and milk production, respectively at Dookie dairy summer trial (Figure 3).

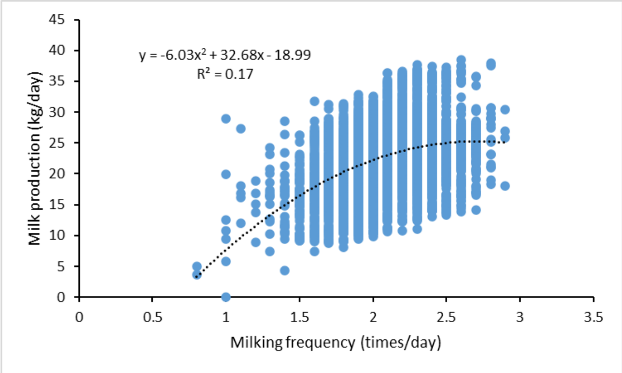

Figure 1. Milking frequency in relation to milk production in 24 commercial farms from 1/7/2020 to 30/6/2021.

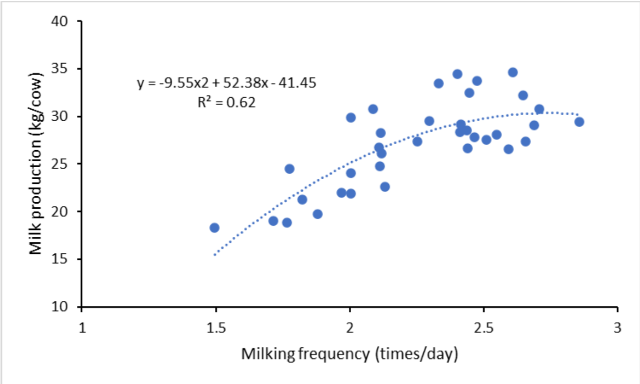

Figure 2. Monthly average milking frequency in relation to monthly average milk yield at Dookie dairy from 1/1/2017 to 31/12/2019.

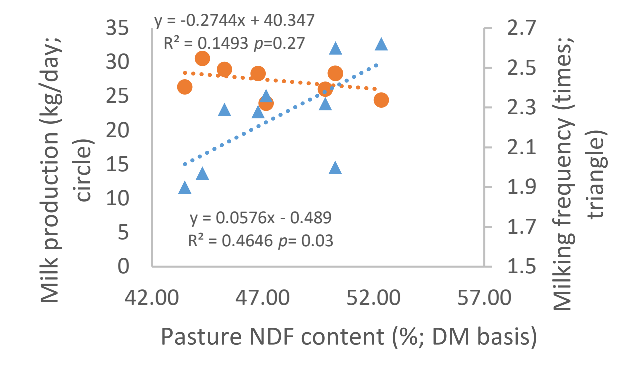

Figure 3. Pasture neutral detergent fibre (NDF) content in relation to milking frequency and milk production at Dookie dairy from 06/11/2021 to 30/12/2021.

DISCUSSION AND CONCLUSIONS

Although variation was considerable, data from both Dookie dairy and 24 commercial farms confirmed that the milk production did not increase after milking frequency reached ~2.5 times/cow/day. This indicates there is limited milk production benefit to milk cows for more than 2.5 times/cow/day in a GSBM. Nevertheless, the data revealed that many farms were not achieving a desirable milking frequency (2.5 times/cow/day), which limited their milk production. The milking frequency variation from 24 commercial farms may be explained by factors that farms used different amounts of concentrate feed (Lessire *et al.* 2017), or different travel distances between paddocks and robots (Lyons *et al.* 2013) or genetic/behavioural difference of cows milked on different farms (Cullen *et al*. 2020).

The positive relationship between milking frequency and pasture NDF content may indicate cows experienced low quality pasture (high NDF) tended to increase their voluntary movement to 1) receive concentrate feed when perform more visits to robots and 2) enter a new paddock to receive a fresh pasture. Such assumption is not in line with previous research, which suggested that concentrate feed levels have no effect on milking frequency (Lessire *et al*. 2017) in low pasture quality situation. Further study is required to investigate seasonal variation and feeding system (e.g., grazing pasture% in total feed ration) effect on milking frequency and milk production relationship considering different lactation stages of cows within a single herd.

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CONFLICT OF INTEREST DECLARATION

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The cost-effectiveness of off-paddock structures as a nitrogen leaching mitigation for pasture based dairy systems.

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ABSTRACT

This study examines the cost-effectiveness of standing cows off paddocks using off-paddock structures as nitrogen (N) leaching mitigation for pasture-based dairy farms. The analysis was done for six case study dairy farms using FARMAX and OVERSEER® models. Each case study farm was first modelled to meet good management practice (GMP) then two alternative options were modelled; 1) Reduce N leaching by 10, 20 and 30% beyond GMP through de-intensification (reduced input and stocking rate), or 2) Invest in an off-paddock structure to match N leaching reductions achieved in option 1. If option 1 reductions were not matched, then further reductions were achieved through a combination of off-paddock structures and de-intensification. Investment in an off-paddock structure was considered cost-effective when the reduction in operating profit through de-intensification exceeded that of an off-paddock structure for the same N leaching reduction. Results indicate that the cost-effectiveness of an off-paddock structure for N mitigation, is driven by N use efficiency measured as farm-gate N surplus, level of targeted N leaching reduction, and the type and cost of the structure. When targeting N leaching reductions of less than 10%, no off-paddock structure is likely to be cost-effective. For reductions greater than 10%, reducing farm gate N surplus and optimising the system should be a priority before considering any off-paddock structure.

Keywords: stand-off, nitrogen surplus, de-intensification, feed pad.

INTRODUCTION

Reducing the time cows spend in paddocks is one way that New Zealand dairy farmers can reduce N leaching, and soil and pasture damage. Routinely standing cows off the paddocks reduces urine and dung deposition, and subsequently N leaching, particularly in autumn and winter (Romera *et al*., 2017). The urine and dung captured during stand-off can be better managed by storing, then evenly spreading it on a large area of pasture when weather and soil conditions are appropriate. The captured effluent can be used as a nutrient, replacing bought fertilisers. For some farms an off-paddock structure is less relevant due to low risk of soil and pasture damage, and little supplement being fed. On these farms introducing off-paddock structures for N leaching will incur cost, increase system complexity, and may be incompatible with the existing farm management. This study evaluates the cost-effectiveness of off-paddock structures for N leaching mitigation in pasture-based dairy systems.

MATERIALS AND METHODS

Farm level modelling was conducted on six representative case study dairy farms across New Zealand farming regions. On these farms, off-paddock infrastructure was not a consideration under current management. The case study farms were modelled using 2016-17 Dairybase financial and physical data (Table 1 & 2). The 2016-17 year represented a season where milk price was close to the long-term average and farm inputs and costs were not greatly altered from normal by adverse events. Farm N use efficiency estimated through Overseer's farm-gate N surplus, was used as one of the selection criteria. Overseer's farm-gate N surplus is calculated as N inputs (fertiliser, purchased supplementary feed, biological fixation (e.g., by clover), irrigation, atmospheric deposition (via rainfall) minus N in outputs (milk, meat, crops sold) (kg N/ha) (Ledgard *et al.*, 2004). Data from 382 farms participating in the 'Baseline' project within DairyBase in 2015/16 season, showed that 25% had an N surplus of less than 139 kg N/ha; 25% were greater than 224 kg/ha; with the median

180kg/ha (Pinxterhuis *et al.*, 2019). Based on this, farms with farm-gate N surplus above 190kg N/ha (farm 1-3) were characterised as high (Table 1) and those below (farms 4-6) as low (Table 2).

Table 1. High N surplus case study farms.

Farm	1	2	3
Cows/ha	2.8	3.2	3.4
N surplus (kg N/ha)	235	253	289
N fertiliser (kg N/ha)	220	246	286
% Bought feed	7.1	12.6	16.9
Operating profit ($/ha @ $6/kgMS)	2284	1227	1478

Table 2. Low N surplus case study farms.

Farm	4	5	6
Cows/ha	2.8	2.8	2.5
N surplus (kg N/ha)	182	151	150
N fertiliser (kg N/ha)	102	86	97
% Bought feed	12.6	7.4	4.8
Operating profit ($/ha @ $6/kgMS)	1239	2205	2007

A combination of the FARMAX (Bryant *et al.*, 2010) and OVERSEER® models **(**Watkins and Selbie, 2015) were used to predict the economic and environmental impact of the mitigations. Farms were first modelled to meet good management practice (GMP), to simulate a similar starting point across all case study farms. GMP mitigations were defined by the following guidelines: 1) Improve irrigation efficiency, 2) Apply not more than 190 kg N/ha as fertiliser on pasture and no N applications during the drainage periods May-August. Fertiliser application rate not exceeding 40 kg N/ha per application, 3) Effluent application based on soil moisture levels and ensuring N applied through effluent does not exceed 150 kg N/ha/year, 4) Where appropriate, use minimum tillage to establish crops and pasture, and use catch crops to minimise period of bare soils after crop grazing, 5) Consider the use of low protein feeds if animal protein requirements are being exceeded.

After achieving GMP, two options were modelled. Option 1 aimed to reduce N leaching by 10, 20 and 30% beyond GMP through de-intensification. De-intensification was defined as the reduction of farm inputs and forage cropping, followed by adjustment of stock numbers to match feed supply to demand. De-intensification mitigations included: 1) Culling early, 90 percent of known culls sold by April, and autumn N fertiliser application reduced due to the lower feed demand. 2) Reducing the crop area by either importing feed to replace crops or reducing stocking rate to match the feed supply to demand or planting higher yielding crops to achieve the same dry matter from a smaller area. 3) Reducing N fertiliser by first targeting applications in autumn and winter, then reducing the stocking rate to match the feed supply to demand.

Option 2 included off-paddock structures, feed pad, stand-off pad or barn where appropriate. The cost of investing in structures included depreciation, interest, and operational costs. The operational costs included the annual cost of replacing the bedding, scrapping, transport and spread of manure and repairs and maintenance. When N leaching reductions did not match option 1, further reductions were achieved by a combination of the off-paddock structure and de-intensification. The total feed eaten was not changed with the introduction of the structure, so as not to increase methane emissions. With the barn, cows were housed for 24 hours per day in winter June-August and 6 hours per day in autumn March-May. Cows on the feed pad were modelled as being stood-off pasture for 4 hours per day for the months March-August, while the stand-off pad enabled cows to be stood off pasture for 16 hours per day in winter June-August and 6 hours per day in autumn March-May. It was assumed the barn was constructed on the milking platform at a cost of $3000/cow, including associated costs, the feed pad at $600/cow, and the stand-off pad at $1100/cow (Askin and Askin, 2016). Maintenance was $85/cow for replacing the bedding, scraping the feeding alley, transport and spreading of manure for the barn and stand-off pad, and $30/cow for the feed pad (Beukes *et al.*, 2013). To improve the financial viability, a feed pad accommodating half the herd was modelled. This assumed the farmer would run two herds which would alternate using the feed pad. However, this was only considered practical for herd sizes exceeding three hundred cows. Herd sizes smaller than three hundred are usually grazed as one herd, so it creates management complexity if split into two.

RESULTS AND DISCUSSION

The GMP mitigations reduced N leaching by 0-45%, with little or no change in operating profit across the six case study farms. GMP mitigations generally did not affect farm productivity or significantly increase farm working expenses, therefore they had little impact on operating profit. De-intensification impacted farm productivity as inputs were reduced, which negatively impacted operating profit. Off-paddock structures added cost to the farm through depreciation, interest repayments and maintenance costs.

No off-paddock structure was cost-effective for N leaching reductions of less than 10%. The costs of these structures always exceeded any cost associated with de-intensification when seeking small reductions. Farms 1-3 could cost-effectively reduce N leaching by up to 25%, through de-intensification before considering any off-paddock structure (Fig. 1). These case study farms (1-3) compared with farms (4-6) tended to have higher stocking rates, higher N surplus, higher N fertiliser application rates and higher levels of imported supplements (Table 1). However, a low-cost structure, like a feed pad, became cost-effective for case study farms 4-6, when the required N leaching reductions were greater than 10% (Fig. 2). These case study farms tended to have lower stocking rates, lower N surplus, lower N fertiliser application rates and lower levels of imported supplements (Table 2). For these farms de-intensification tended to be more costly because of more significant farm system changes required to further reduce N surplus. A feed pad was a better option than a barn or stand-off pad as it was cheaper to construct and maintain, and for larger herds the pad was only constructed for half the herd. Whilst the barn and stand-off pad provided the opportunity to stand cows off for longer periods per day and achieve greater N leaching reductions, high costs made these structures less cost-effective for N leaching reductions below 20%. The amount of time that cows could stand off pasture influenced the predicted N leaching reductions. The barn resulted in the largest N leaching reduction followed by the stand-off and feed pad. Off-paddock structures enabled nutrient recycling as N in cow excreta could be used to replace N fertiliser with associated cost savings. The amount of excreta N captured on the off-paddock structure was related to the amount of time cows spent on it. The barn had more N captured from excreta followed by the stand-off and then feed pad. Grazing costs were reduced in the barn scenario as cows remained on the milking platform in winter. However, even with grazing and fertiliser savings, the barn was prohibitively expensive because of the extra costs associated with supplementary feed, depreciation, interest, and maintenance.

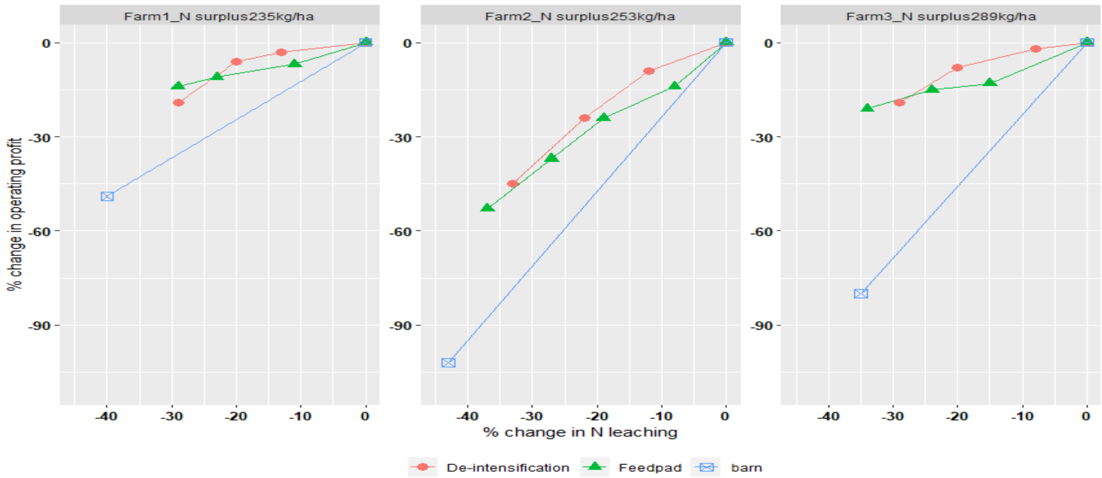

Figure 1. Comparisons of de-intensification versus off-paddock structures for the case study farms with farm-gate N surplus greater than 230kg N/ha. Base is with GMP already implemented.

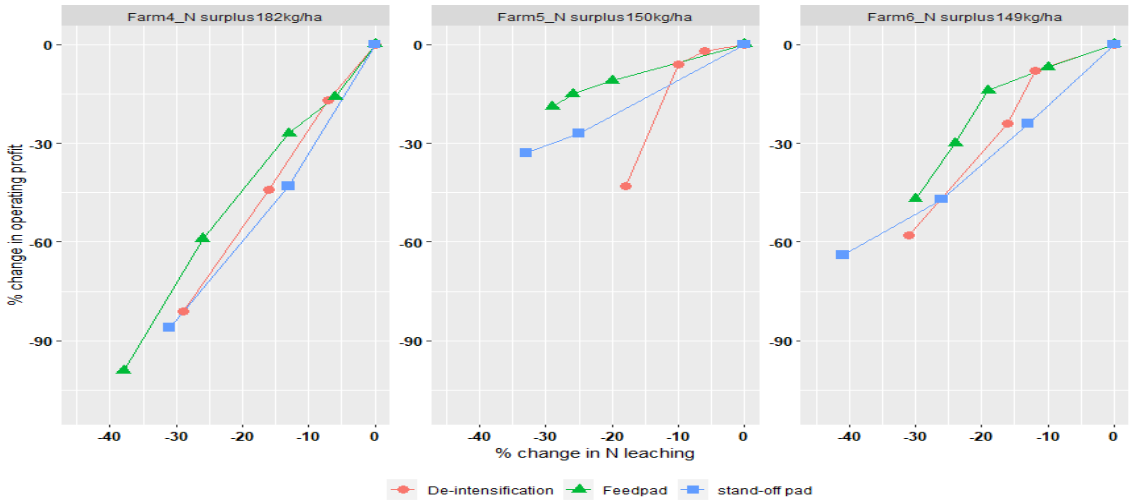

Figure 2. Comparisons of de-intensification versus off-paddock structure for the case study farms with farm-gate N surplus less than 190kg N/ha. Base is with GMP already implemented.

CONCLUSION

The cost-effectiveness of off-paddock structures as a N mitigation option is driven by N-use efficiency measured as farm-gate N surplus, level of targeted N leaching reduction, and the type and cost of the structure. When targeting N leaching reductions of less than 10%, no off-paddock structure is likely to be cost-effective. For reductions greater than 10%, reducing farm-gate N surplus and optimising the system should be the priorities before considering any off-paddock structure.

ACKNOWLEDGEMENTS

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Break-even cost of Virtual Herding Technology in pasture-based dairy production

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ABSTRACT

Virtual herding technology (VHT) is rapidly developing, offering potential to enable more strategic pasture allocation, move cows with reduced labour and manage sub-groups of animals within herds. The cost of VHT is uncertain, so the anticipated benefits in labour and feed efficiency were used to estimate the 'break-even' capital cost for investment in VHT on a pasture-based dairy farm in Gippsland, Australia. The 'break-even' capital cost of VHT was estimated using a partial discounted net cash flow budget over 10 years and assuming a 15% internal rate of return (nominal) was required to justify investing in VHT. A 5-year lifespan of the cow neckbands was assumed. The case study farm had a milking herd of 680 cows with calving from late-July to September, and annual milk production of 430 kg milk solids/cow. The anticipated benefits from two VHT applications were considered. First, a 50% reduction in labour for fetching cows for milking was assumed, with associated reductions in vehicle use. Second, 5% improved milk production (0.075 kg milk solids/cow/day) and improved reproductive performance from only those cows in the latter third of the milking order was assumed by allowing them preferential access to pasture. The break-even cost was $77/cow when only the reduced labour was considered, $238/cow for increased milk production of cows later in the milking order and $319/cow for both applications combined. Other potential benefits of VHT, such as reduced damage to pasture through more controlled grazing during wet periods, could also be included in the analysis.

Keywords: Precision agriculture, grazing management.

INTRODUCTION

Virtual herding technology (VHT) has evolved from a tool that confines animals with a static area to one that enables real time management of livestock (Anderson *et al.* 2014). Many studies have shown that VHT can effectively maintain livestock in static areas (eg. Ruiz-Mirazo *et al.* 2011; Campbell *et al.* 2018), and also when fences are moved (Campbell *et al.* 2017). VHT offers potential to enable improvements in grazing management without additional physical fencing infrastructure, more strategic pasture allocation, move cows and sheep with reduced labour, and more easily manage sub-groups of animals within herds (Anderson *et al.* 2014). Feed and labour are significant costs in most livestock farm systems and VHT offers potential for improved efficiency in both areas. However, there has been little investigation into the economics of adopting this technology in livestock businesses and this is an important component of the value proposition for VHT. The aim of this study was to determine the break even cost of VHT on a pasture-based dairy farm in southern Australia based on the anticipated benefits from implementing VHT on the farm.

MATERIALS AND METHODS

General approach

The use of real case study farms was chosen as the most appropriate method to investigate the potential application of VHT. The role of real farm case studies in farm management economics is well established (Crosthwaite *et al.* 1997; Malcolm, 2001). As all farm models only partially represent reality, case study farms simulated for economic analyses have a good chance of encapsulating the important features if they are based on an actual farm. Real case studies of 'what is' and particularly 'what could be' have been used widely in dairy farm analysis (Malcolm *et al.* 2012). This is particularly helpful in understanding the practical constraints associated with incorporating new technology that interacts with many different aspects of a farm system.

Information on the potential application of VHT for each farm was collected via interview with the farmers. Historic data on production and financial performance data was provided by the farmers and the consulting firms used by the farmers.

Dairy farm case study

The rain-fed case study dairy farm was located in West Gippsland with long-term rainfall of approximately 1,000mm. The milking area has approximately 192 ha available for grazing with a milking herd of about 680 cows (a stocking rate of 3.5 cows/ha on the milking area). There is also a non-milking area of 233 ha grazing area which is located approximately 25 km from the milking area. This area is used to graze replacement stock (about 250 rising 1-year-olds and 250 rising 2-year-olds) and for conserving silage/hay. There are also about 200 additional rising 2-year-olds grazing there on agistment for 6 months of the year. The non-milking area is leased.

The farmers place a great emphasis on directly grazed pastures. The milking area is predominantly sown to perennial ryegrass with about 20% sown to chicory. Pasture consumption ranges from 8 to over 11 t DM/ha, on the milking area. Cows calved from late July until late September, and produced an average of about 430 kg milk solids /cow. In addition to grazed pasture, cows were fed approximately 1.2 - 1.8 t DM/yr of a concentrate supplement and conserved fodder as required.

The non-milking area is predominantly sown to perennial ryegrass with slightly lower pasture consumption per ha than the milking area.

Economic analysis

A partial discounted net cash flow budget over 10 years was used to analyse the economic performance of the VHT in a range of applications for the case study farms. The methods used for farm management economic assessments are described in Malcolm *et al.* (2005). The 'break-even' capital cost of VHT was estimated assuming a 15% internal rate of return (nominal) was required to justify investing in VHT. The capital cost included (cow neckbands and associated infrastructure, but not on-going registration fees). A 5-year lifespan of the cow neckbands was assumed in this study.

RESULTS AND DISCUSSION

VHT applications analysed and key assumptions

The VHT applications and assumptions about the benefits achieved on the case study farm are listed in Table 1 and scenarios below. The VHT requirements assumed for these applications were collars for 680 milking cows and one Base Station (3G).

1. Fetching cows for milking to save labour and ATV use. Approximately 2 hours per day are spent with someone on a vehicle fetching cows for milking. It is estimated that this might be halved with VHT. The benefits assumed were labour savings $9,900/year, fuel/repairs and maintenance savings $3,000/year.

2. Splitting pasture allocation to enable later milked cows to have access to a greater quantity and higher quality of pasture. Cows that are milked last in the herd are away from pasture for longer and tend to produce less as a result of having less quantity and quality of pasture available to graze. If VHT can allow the pasture allocation to be staged, and preferential access given to later milked cows at some stages, then pasture allocation and milk yield would be expected to be much more even across the herd. More even allocation of pasture across the herd would also be expected to improve the reproductive performance of the herd which could have substantial benefits for this seasonal calving herd. Benefits assumed were milk production increase worth $30,294/year and improved reproductive performance worth $8,527/year.

3. Combining the benefits of applications 1 and 2. We assumed that it may be possible to achieve the benefits of both applications described above without any additional capital cost.

Other potential applications on the farm were identified, such as using VHT on the non-milking area to manage young stock with reduced labour and flexible grazing in wet conditions to avoid pugging damage, but they were not included in this economic analysis.

Break even cost

When only the reduced labour and vehicle use was considered (application 1), the capital cost of VHT would need to be $77/cow to achieve the desired 15% internal rate of return (nominal), as shown in Table 1. When only the increased milk production of cows later in the milking order was considered (application 2), the capital cost of VHT would need to be $238/cow to achieve the desired internal rate of return. If both applications were combined (application 3), then a capital cost of $319/cow would result in the desired 15% internal rate of return (nominal).

The results from Application 2 are very sensitive to the assumptions relating to the amount of extra milked produced if the latter milked cows were preferentially allocated pasture (Table 2). A capital cost of up to $429/cow for VHT could result in VHT being a profitable investment, if splitting pasture allocation to feed later milked cows better led to extra milk production from one third of the herd of 0.150 kg milk solids/cow/day (~2 L/cow/day). However, if the extra milk production from one third of the herd was only 0.038 kg milk solids/cow/day (~0.5 L/cow/day), then the capital cost of VHT would need to be below $143/cow.

Table 1. Applications of VHT on a pasture-based dairy, the potential benefits, and break-even capital cost ($/cow) that a farmer could pay to achieve a 15% Internal Rate of Return (nominal).

Application of VHT	Potential benefit	Capital cost ($/head) required to achieve a Nominal Internal Rate of Return of 15%
1. Fetching cows for milking to save labour and ATV use	• Labour savings of 1 hour/day for 330 days per year. • Vehicle fuel, repairs and maintenance savings of $3,000/year	$77
2. Splitting pasture allocation to enable later milked cows to have access to a greater quantity and higher quality of pasture	One third of cows in the herd has: • Increased milk production of 0.075 kg milk solids/cow/day [A] • Improved reproduction to extend the life of cows from 4 to 5 lactations.	$238
3. Fetching cows for milking and splitting pasture allocation to feed later milked cows better	• Combined benefits from applications 1 and 2.	$319

[A] without compromising the production of earlier milked cows.

Table 2. Sensitivity analysis to extra milk production from using VHT to feed later milked cows better on the case study dairy farm (Table 1, Application 2). (Note that benefits in reproductive performance were kept constant)

	Amount of extra milk production from one third of the herd for 300 days		
	0.038 kg MS/cow/day (~0.5 L/cow/day)	0.075 kg MS/cow/day (~1 L/cow/day)	0.150 kg MS/cow/day (~2 L/cow/day)
Break-even cost ($/cow)	$143	$238	$429

CONCLUSIONS

If the only benefits of VHT are reduced labour costs, then the capital cost is unlikely to be low enough to enable an attractive return on investment. However, if the assumed improvement in milk production and reproduction occurs for the later milked cows, then the break-even capital costs are within the range of commercial activity meters for cows. If higher benefits occur, the amount farmers could profitability invest in VHT would increase.

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CONFLICT OF INTEREST DECLARATION

The authors declare no conflicts of interests.

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Grazing management for perennial ryegrass pastures during the mid-spring to early-summer period in northern Victoria

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ABSTRACT

Grazing management of perennial ryegrass (*Lolium perenne*) pastures on dairy farms at the time of reproductive tiller development, in the mid spring-early summer period, must balance pasture dry matter (DM) production with maintaining nutritive characteristics to support dairy production. In this experiment, the effect of four different grazing rotation lengths (RL: 10; 15; 20; and 30 days) on pasture DM production and nutritive characteristics of an irrigated perennial ryegrass-based pasture in northern Victoria, Australia was examined for a 60-day period from October-December 2017. The RL treatments were implemented by cutting pastures to 5 cm height on each harvest day. Nitrogen (N) fertiliser was applied to the experimental site to replace harvested N. The pasture harvested over the experimental period was lower in RL10 compared to RL15 and RL30. Nutritive characteristics (crude protein, DM digestibility and estimated metabolizable energy) were higher in RL10 compared to RL30. There was no difference in the total crude protein yield between the treatments, but RL10 had a lower ME yield than the other three RL treatments. This study found that the RL15 or RL20 (which corresponded to the 1.8 and 2.2 live leaves per tiller, respectively) achieved the best combination of pasture harvested and nutritive characteristics, and so are most suitable for lactating dairy cow production in the mid-spring to early summer period of the year.

Keywords: Nutritive value, leaf stage, regrowth, cows

INTRODUCTION

Grazing management rules for perennial ryegrass-based pastures are well established for the vegetative phase of growth, for example grazing at the 2- to 3-leaf stages (Fulkerson and Donaghy 2001). However, the spring-summer transition period in northern Victoria presents a particular challenge for grazing management of dairy pastures due to rapid growth rates and changes in nutritive characteristics during the phase of reproductive development (Chapman *et al*. 2014). During this time of year, grazing at the 3-leaf stage risks a reduction in pasture quality that may be detrimental to milk production, but grazing too early may restrict herbage intake (Chapman *et al*. 2011). The objective of this experiment was to quantify the changes in pasture mass and quality associated with different grazing rotation lengths during the late spring-early summer period on irrigated perennial ryegrass-based in northern Victoria, Australia.

MATERIALS AND METHODS

Site selection

The experiment was conducted at The University of Melbourne, Dookie campus dairy farm in northern Victoria, Australia, during a 60 day period from October 20th to December 19th of 2017. The farm consists of 41 ha of border check irrigated perennial ryegrass-based pastures. The paddock selected was a perennial ryegrass-white clover (*Trifolium repens*) pasture with a high density of ryegrass. An area of 14 metres by 12 metres was fenced so the cows could not graze it. The area was perennial ryegrass dominant in species composition (91% perennial ryegrass, 3% white clover and the remainder with other grasses and weeds). The paddock was irrigated during the trial period to minimise soil water limitation with a total of 270 mm water applied during the experimental period (70 mm rainfall and 200 mm irrigation).

Experimental design and management

The experiment consisted of 4 grazing/harvesting rotation treatments and 5 replicates of each treatment in a randomised block design. The 4 grazing rotation length treatments were 10 (RL10), 15 (RL15), 20 (RL20) and 30 days (RL30). The 20 plots were 2 meters by 2 meters in size. Mowing to a residual height of 5 cm was used to simulate grazing at each harvest. Mowing of the entire experimental area was carried out on day 0 (20 October 2017) and then plots were mowed every 10, 15, 20 or 30 days depending on the RL treatment. The plots were mowed with an electric cordless lawn mower (RLM18x33SBL, Ryobi ltd, Australia) and the grass was collected in a 35-litre catcher.

The experiment was conducted under non-limiting soil nitrogen (N) conditions. An application on the first day of the experiment of 100 kg N/ha was applied to all plots. During the trial, urea (46% N) was applied on day 26 (November 15th) and day 41 (November 30th) to replace the estimated amount of N harvested in pasture (assuming 4% N in pasture). The average amount of N applied to the rotation length treatments during the experiment was 42-54 kg N/ha.

Pasture measurements

On each harvest date, 10 perennial ryegrass tillers from each plot were randomly chosen and the leaf regrowth stage was measured to the nearest 0.25 leaf. To assess species composition, four areas of 10 cm^2 were manually cut at the simulated grazing height (5 cm) in each plot and the 4 quadrats were mixed together into one sample which was hand sorted into the following categories to estimate botanical composition: perennial ryegrass; white clover; and other grasses and weeds. The samples were then labelled and dried at 60°C for 72 hours and weighed.

At each harvest, the fresh weight of the pasture collected on the plot was recorded. Two subsamples of approximately 200 g were collected, one to measure the dry matter (DM) percentage and one to analyse the nutritive characteristics. The fresh weight of the subsamples was recorded, then dried at 60 °C for 72 hours and weighed. Three replicates of each treatment were selected for analysis of nutritive characteristics on each harvest date. Nutritive characteristics were analysed by NIR at the NSW DPI laboratory, Pine Gully Road, Wagga Wagga NSW 2650. The analyses included crude protein (CP, %), neutral detergent fibre (NDF, %), acid detergent fibre (ADF, %), water soluble carbohydrate (WSC, %) DM digestibility (DMD, %) and estimated metabolizable energy (ME, MJ/kg DM).

Data analysis

Accumulated pasture harvested was calculated by summing the pasture cut on each plot for each harvest date over the 60 days. Nutritive characteristics were measured on three replicates only and were analysed at day 60 only (final day of experiment). Accumulated CP and ME yield were calculated on the three replicates per treatment that had nutritive characteristic measured by multiplying the pasture harvested on each harvest date by the CP or ME content, then summing for each harvest date over the experimental period. One-way ANOVAs were used to test significant difference ($P<0.05$) of rotation length treatments on pasture harvested, nutritive characteristic at day 60, and total CP and ME yields using Genstat 16th Edition.

RESULTS

Leaf stage at harvest, pasture harvested and botanical composition

The average leaf stage at harvest was 1.2, 1.8, 2.2 and 3.4 for RL10, RL15, RL20 and RL30 treatments, respectively. This indicated that it took 8-9 days to produce a new leaf.

The RL10 treatment had lower pasture harvested (kg DM/ha) than the RL15 and RL30 treatments (Figure 1). There was no significant difference in pasture harvested between the RL15, RL20 and RL30 treatments.

The botanical composition was very similar between the treatments, with perennial ryegrass being the dominant species (from 88 to 95% of DM on average for all the treatments).

Nutritive characteristics

Crude protein percentage, DMD and estimated ME were generally the lowest in the RL30 treatment and the highest in the RL10 and RL15 treatments (Table 1). Other nutritive characteristics including NDF, ADF and WSC were not significantly different between treatments.

Total ME and CP yield

The CP yield was not significantly different between rotation length treatments (mean across the experimental period and treatments was 359 kg CP/ha). The ME yield was lower in the RL10 treatment compared to the other three treatments, which were not significantly different to each other (Figure 2).

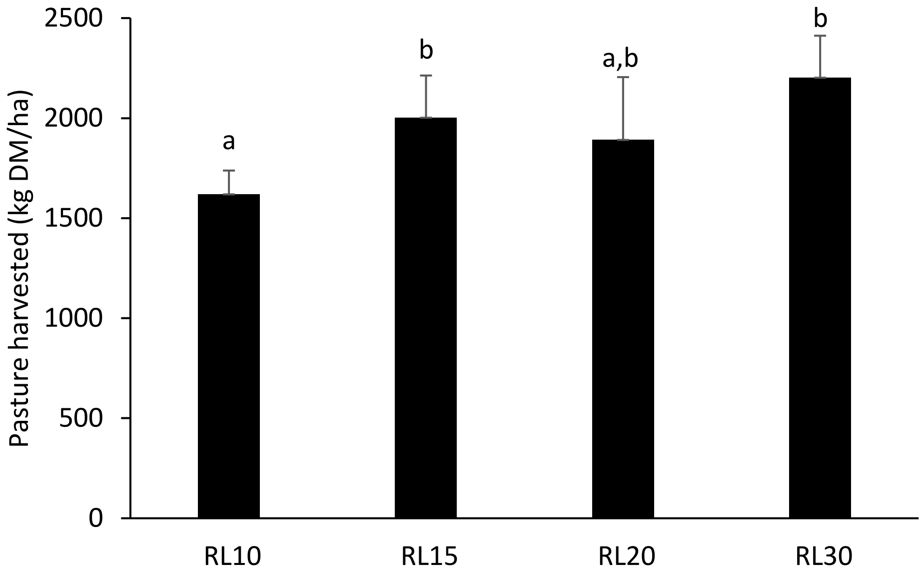

Figure 1. Pasture harvested (kg DM/ha) during the experiment for four rotation length treatments. Error bars show one standard deviation. Treatments with different letters are significantly different (P<0.05, l.s.d. = 318 kg DM/ha).

Table 1. Nutritive characteristics of pasture harvested on day 60 (final day of experiment) in the four rotation length treatments. Treatments with different letters are significantly different (P<0.05).

Treatment	CP (%)	DMD (%)	Estimated ME (MJ/kg DM)
RL10	22.1 ^{c}	78.7 ^{b}	11.9 ^{b}
RL15	21.2 ^{c}	77.6 ^{b}	11.7 ^{b}
RL20	18.5 ^{b}	76.0 ^{a,b}	11.5 ^{a,b}
RL30	16.3 ^{a}	72.9 ^{a}	10.9 ^{a}
l.s.d (P=0.05)	1.5	3.2	0.6

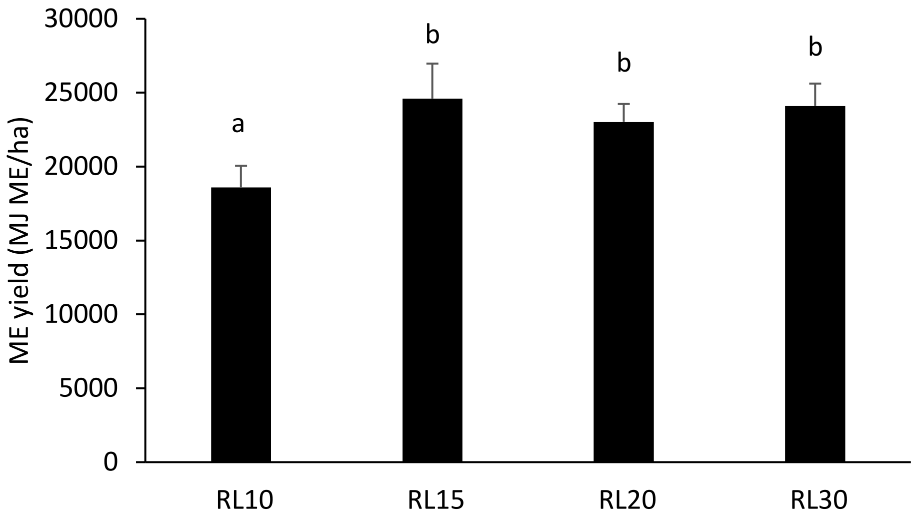

Figure 2. Pasture ME yield (MJ/ha) during the experiment for four rotation length treatments. Error bars show one standard deviation. Treatments with different letters are significantly different ($P<0.05$, l.s.d. = 3852 MJ/ha).

DISCUSSION AND CONCLUSIONS

This experiment demonstrated a trade-off between effects of rotation length on pasture DM production and nutritive characteristics. The shortest rotation length in the experiment (RL10) had the equal lowest pasture DM production but equal highest CP, DMD and estimated ME, while the longest rotation length (RL30) had the equal highest pasture DM production, but equal lowest nutritive characteristics. This was the expected result because ryegrass had more time for reproductive stems development in the longer rotations would increase pasture growth rate, but lower the pasture nutritive characteristics (Chapman *et al.* 2014).

The RL15 and RL20 treatments, grazing at 1.8 and 2.2 leaves per tiller respectively, showed a good combination of pasture DM production and nutritive characteristics. This finding agrees with Chapman *et al*. (2011) who suggested that grazing closer to the 2-leaf stage (rather than 3-leaf stage) after September would optimise pasture mass and nutritive value of pasture for dairy production.

ACKNOWLEDGEMENTS

We acknowledge the assistance from Dookie dairy farm manager, Nick Boyd, in setting up and maintaining the experiment.

CONFLICT OF INTEREST DECLARATION

The authors declare no conflicts of interests.

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Sprain and strain injuries on New Zealand dairy farms during spring

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ABSTRACT

There is an increased focus on health and safety in agricultural workplaces, not only to reduce injuries but also to create more attractive workplaces. Sprain and strain injuries are often considered by farmers to be an unavoidable consequence of physical work. However, data indicates that such injuries can have a large impact on dairy workers, particularly in the busy spring calving period. The objective of this research was to understand causes of sprain and strain injuries on farms to inform solutions and ultimately lead to injury reduction. We conducted a telephone survey from November 2021 to March 2022, involving 119 farm workers who had reported a sprain or strain injury in the 2021 calving season. The results highlighted that the most common sprain or strain injuries were to lower backs (20%), ankles (15%), knees (13%), shoulders (12%) and hands or wrists (9%). Around a third of injuries occurred in the paddock, while a quarter were connected to working with calves. Back injuries from lifting calves or buckets of milk, ankle injuries from uneven ground and two-wheel motorbike accidents were commonly reported. The milking shed was another place where people were often injured, mostly from slippery surfaces or tripping on hoses. Only half of injured people took time off, and this was 13 days on average. However, it took around 26 days on average for injured workers to feel that they had fully recovered, highlighting the wider impacts of injuries on individuals and the wider farm team.

Keywords: work design; footwear; ergonomics, health and safety.

INTRODUCTION

There is an increased focus on health and safety in agricultural workplaces, not only to reduce injuries but also to create more attractive workplaces (Eastwood et al., 2020). Sprain and strain injuries are often considered by farmers to be an unavoidable consequence of physical work. Yet, the costs of these injuries is substantial and the impact of injured workers either taking time off or performing limited duties places an increased workload burden on farm teams (Bentley et al., 2005). The Accident Compensation Corporation NZ (ACC) data from compensation claims indicate that the majority of sprain and strain injuries occur in spring during the busy calving and mating period (Edwards and Kuhn-Sherlock, 2021).

The objective of this research was to understand causes of sprain and strain injuries suffered in spring on farms to inform solutions and ultimately lead to injury reduction.

MATERIALS AND METHODS

Data on the incidence and causes of sprain and strain injuries on dairy farms during spring were collected between November 2021 and March 2022. Farm workers who identified as having suffered from a sprain or strain injury between 1 July and 30 October 2021 were interviewed by phone. Contacts for the interviews were sourced by a third-party contractor during routine farm visits. A total of 3,708 of the estimated 11,034 New Zealand dairy farms were visited, with 303 farmers confirming a sprain or strain injury had occurred on their farm during spring of 2021. The interviews were conducted between 9 November 2021 and 1 March 2022 for 119 farm workers from 108 farms (81% represented by the injured party and 20% by a manager on behalf of the injured party). The phone interviews were conducted by a market survey company complying with the Market Research

Code of Conduct and the New Zealand Privacy Act.

Demographic data were collected on farm region, farm and herd size, ownership structure, number of staff, predominant breed of cow and the date for the planned start of calving. Further data were also collected regarding the injured worker, on-farm infrastructure, and practices related to lifting heavy items on farm. Questions related to the injury included the areas of the body that were injured, the category that best described the task, the category that best described the task action causing injury and whether it involved manual lifting or operating machinery, and time of day. Up to 3 sprain and strain injuries could be recorded per respondent.

The respondent's injury was recorded against one of 17 body parts/areas, based on previous research. Six categories were used to classify the task being undertaken when the injury occurred; i) milking-related such as working in or near the dairy shed, ii) calf-related such as calf pick-up, rearing or feeding, iii) other animal handling, health or reproduction, iv) working in the paddock other than calf or animal health related tasks, such as feeding cows or break fencing, v) office or management related, and vi) other (specified).

The actions causing injury were classified by i) repetitive actions or tasks, ii) lifting or carrying a heavy object, iii) slip, trip or fall, iv) bending, twisting, and reaching, and v) and other. Time of day was divided into early morning, mid-late morning, early to mid-afternoon, early evening, or other (specified).

Two task categories, being milking-related and calf-related, were explored further. Milking related questions determined whether the injury occurred while working in the dairy shed, in the yard, while herding cows to or from the dairy shed or other (specified). The number of hours the person spent milking each day and the milking frequency was also recorded for the injured person. Calf-related questions determined whether the injury occurred while collecting calves from the paddock, assisting a calving, calf feeding or care, or other (specified).

Respondents were also asked how much time, if any, was taken off work because of the injury, whether they sought medical treatment from a health professional, had made a claim to ACC, and how long it took to feel fully recovered from the injury. As an indicator of potential fatigue, respondents were asked for details of their work roster including how many hours per week they were working and how many consecutive days they had worked prior to the injury.

RESULTS

Interviews with 119 farm workers who had experienced a sprain or strain injury recorded 143 injuries of this type in total. All further references to injuries are sprains and strain injuries only. The frequency of injuries per person were 80% with 1, 18% with 2, and 2% reporting more than 2 injuries. Results focus on the details of the respondent's most severe injury (n=119). Extrapolating from the ratio of farms visited to the total number of dairy farms, the interview population (n=119) gives a maximum margin of error of +/-8.6% at the 95% confidence interval. Data outliers above the 95th percentile or below the 5th percentile that had a large impact on means were excluded.

Rosters, time-off and recovery

The number of consecutive days worked without time off varied, with 30% of workers on rosters between 5-1 (5 days on, 1 day off) and 7-3, 32% on rosters between 8-2 and 14-2 and 38% of workers with no scheduled time off. The mean weekly hours worked was 57 (median = 55h), with 22% working 45 hours or less, 54% working 46-65 hours and 24% working more than 65 hours. Outliers below 22 hours and above 90 hours were excluded (n = 9). The mean number of consecutive days worked prior to injury was 16 days (median = 6 days). Workers with rostered time off (mostly employees) averaged 5 consecutive working days prior to injury and a 55-hour week compared with those with no rostered time off (mostly decision makers) who worked 37 consecutive days prior to injury and a 61-hour week (excluding outliers above 79 days; n = 11).

Injuries more commonly occurred in mid-late morning accounting for 45% of all injuries.

During this period 62% of calf related injuries, 53% of injuries while working in the paddock, and 47% of injuries related to animal handling occurred. An additional 30% of all injuries occurred in early morning and included 60% of milking related injuries. The early to mid-afternoon, and early evening time periods accounted for 18% and 4% of all injuries, respectively.

Seventy-one percent of respondents sought medical advice from a health professional and 62% lodged a claim to ACC. Around half (51%) of the people injured took no time off work, yet 71% of this group (mostly decision makers) self-rated the impact of their injury as neutral to high (4-7 on a 1-7 scale). A further 28% of people were off work for up to 7 days and 21% took more than 7 days off work. For those taking time off, the mean number of days away from work was 13 days (median = 6 days), excluding outliers above 56 days off (n = 6).

The mean number of days before the injured person felt recovered from the injury was 26 days (median = 14 days), excluding outliers above 119 days (n=1). Out of all injured workers, 14% reported that they felt 'back to normal' within 7 days, 28% between 8 and 30 days, and 58% took more than 30 days to recover. Recover time was longer for those who didn't take time off compared with those that did, with a mean of 32 days (median = 21 days) and 17 days (median = 14 days), respectively.

Injury descriptors

The most common task category when the injury occurred was when working in the paddock, at 34% of all injuries (Table 1). Most paddock related injuries (62%) were due to a slip, trip or fall, commonly due to slippery surfaces and uneven ground (mostly ankle and knee injuries) and falls from 2-wheel motor bikes (mostly upper body, shoulder, hand/wrist/fingers injuries). The next highest task category was calf related activities (24% of all injuries) where 62% involved manual lifting, and most involved bending, twisting, reaching actions (38%), and lifting or carrying heavy objects (27%). Respondents said they would lift (76%) or carry (82%) objects greater than 20kg during farm work either 'sometimes' or 'often'. Examples of the most common objects greater than 20kg were lifting calves (77% of respondents) particularly when collecting newborn calves from the paddock, bags (68%) such as feed or mineral bags, and buckets (25%) when transporting milk.

Milking related injuries (22% of all injuries) were mostly due to a slip, trip or fall (49%), followed by bending, twisting, and reaching actions (32%). Slippery surfaces, steps and hoses were common slip or trip hazards, while reaching to cup cows was a strain hazard.

Injuries to the lower back/spine were most prevalent (20%) with many of these injuries associated with calf related activities. Ankle (15%), knee (13%) and shoulder injuries (12%) were the next most common area of the body injured (Table 1). Each other body area accounted for 1-4% of all injuries.

DISCUSSION AND CONCLUSIONS

This study has identified the most common types of sprain and strain injuries, and the associated farm tasks, on dairy farms in spring. Only 71% of respondents sought medical attention for their injury, indicating that incidence of these injuries may be considerably higher than previous statistics suggest. The link between fatigue and injury risk has been identified in many studies (Bentley et al., 2005, Caldwell et al., 2019), but in the current study there was not a strong relationship between injury and workers feeling highly fatigued, working long hours or extended rosters. However, decision makers were identified as a group at heightened risk of injury and less likely to take time off when injured, which may be attitudinal or due to worker shortages. While a focus on changing farmer attitudes to sprain and strain injuries will be important, designing engineering or farm system change solutions will be vital for behaviour change (Irwin et al., 2022) and reducing injuries.

Slips, trips, and falls in the paddock and around the dairy shed were the most common cause of sprains and strains, aligning with previous studies (Bentley et al., 2005). To address this, constructed floor surfaces may require improvement and/or footwear more suited to specific tasks should be worn to provide improved ankle support or grip. Lifting

and carrying heavy items is a risk area that requires a redesign of workplace processes, equipment, or a farm system change.
Picking up and carrying newborn calves in the paddock and calf rearing facility, as well as carrying buckets of milk were common examples of tasks resulting in injury. There may be opportunities to redesign the process and equipment for picking up calves.

Milking posture, ergonomics and the repetitive nature of milking processes contribute to sprain and strain injuries, particularly when workers are required to lean forward to cup cows. Fixed height of milking platforms can also pose posture issues. Improved ergonomics with milking processes and supporting devices such as exosuits may reduce injuries at the dairy shed.

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CONFLICT OF INTEREST DECLARATION

We declare no conflicts of interest.

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Table 1. Tasks causing injuries and body area injured, expressed as a percentage of injuries in each farm work activity category (mean values for respondent's most severe injury, n=119)

Injury categories	Milking related	Calf related	Animal handling	Working in Paddock	All injuries
All injuries	22	24	17	34	96
Task action causing injury (% of category)					
Slip, trip or fall	49	19	23	62	42
Bending, twisting, reaching	32	38	59	20	33
Lifting/carrying heavy object	3	27	9	9	12
Repetive action/task	16	14	0	9	10
Not reported	0	3	9	0	2
Involving manual lifting	13	62	21	16	27
Top 5 body parts injured (% of category)					
Lower back/spine	13	41	0	16	20
Ankle	16	6	20	16	15
Knee	13	15	20	14	13
Shoulder	16	9	10	12	12
Hand/wrist	13	3	10	9	9

The decrease in methane emissions from forage rape *in vitro* is driven by lactic acid fermentation and pH decrease

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ABSTRACT

A low rumen pH is thought to be one of the main mechanisms responsible for the decreased methane (CH_4) emissions in ruminants fed forage rape (FR). *In vivo* however, it is difficult to separate the effect of rumen pH from other aspects of rumen function in experimental setups involving dietary manipulations. The objective of this study was to determine the effect of rumen pH on CH_4 emissions *in vitro* by comparing FR and ryegrass (RG) as substrates using buffers of different pH. The forages were incubated *in vitro* using three incubation buffers with starting pH values at 5.5 (LOW), 6.2 (MED), or 6.8 (HIGH). With both forages, the pH decreased by 0.35 (FR) and 0.26 (RG) units after 12 h when incubated in MED and HIGH pH buffers. When incubated in the LOW pH buffer, the pH decreased by 0.18 units with RG and 0.43 units with FR. A lower starting pH decreased total gas, CH_4, total organic fermentation products, and acetate production in the order LOW<MED<HIGH. However, CH_4 production decreased to a greater extent than total gas production when both forages were incubated in LOW pH buffer, but not in MED and HIGH pH buffers. Regardless of the initial pH, FR fermented to a greater extent than RG but tended to produce 17% less CH_4 as a proportion of the total gas. Forage rape produced more acetate and lactate than RG, with greater differences when at LOW pH. Our results suggest that FR decreased CH_4 production via a greater pH decrease, mediated by lactate, likely induced by a greater fermentability compared to RG.

Keywords: Brassicas napus, Lolium perenne, batch culture, CH_4

INTRODUCTION

Forage rape fed to sheep and cattle has consistently resulted in less methane (CH_4) yield compared to animals fed ryegrass (Sun *et al.*, 2016). A rapid and large extent of carbohydrate fermentation might lead to a low rumen pH which is thought to be a mechanism that decreases CH_4 emissions (Sun *et al.*, 2016).

In vivo, the effect on rumen pH when feeding FR is accompanied by changes in other aspects of rumen function (e.g., passage rate, rumen digestibility), making it difficult to assess the contribution of pH by itself to the methane responses observed. The current study aimed to evaluate the effect of pH on CH_4 emissions from forage rape and ryegrass *in vitro.*

MATERIALS AND METHODS

Dry samples of perennial ryegrass (RG: *Lolium perenne*) and forage rape (FR: *Brassica napus*) were used in this experiment (Table 1). The two substrates were incubated in low (LOW), medium (MED), and high (HIGH) pH buffers in an automated *in vitro* batch culture system (Muetzel *et al.*, 2014). LOW and MED pH were buffered with 50 mM 2-(N-morpholino) ethanesulfonic acid. The HIGH pH buffer contained HCO_3^- as a buffering agent, which is the standard buffer described by Muetzel et al. (2014) and was considered as the control. The pH was adjusted with NaOH and equilibrated with CO_2 before incubation. The incubation starting pH value was 5.5, 6.2, and 6.8 in LOW, MED, and HIGH buffers, respectively.

Table 1. Chemical composition of forage rape (FR) and perennial ryegrass (RG)

	FR	RG
Soluble sugars (SS)	17.5	5.5
Crude protein (CP)	20.1	27.1
Crude fat (CF)	2.9	2.9
Pectin	7.0	1.1
Neutral detergent fibre (NDF)	21.6	43.0
Acid detergent fibre (ADF)	16.2	26.1
Lignin	5.9	2.7
Residual fraction[§]	30.9	20.4

Values expressed as % of dry matter
[§] Calculated as 100- (SS +CP+NDF+ CF+ pectin)

Rumen fluid was collected before each incubation run from two fistulated Friesian × Jersey cows grazing ryegrass-based pasture (Animal Ethics Committee Approval 14594). The rumen fluid from each cow was filtered through one layer of cheese cloth and equal parts of each added to the buffers at a ratio of 20:80 rumen fluid: buffer, for all buffers. The preparations were then dispensed in 50 mL aliquots into pre-warmed serum glass bottles containing 500 mg of the substrate (FR or RG), connected to the gas analysing system (Muetzel *et al*. 2014) and incubated at 39 °C for 24 h. Gas production was calculated based on the pressure in the headspace of the bottles. At a threshold pressure of 10 kPa, the gas was released *via* tubing into a gas chromatograph where the CH_4 concentration was quantified, resulting in a time course of total gas production and CH_4 and hydrogen (H_2) measures for each bottle. Duplicate bottles were used in each incubation run and the incubations were repeated in four different runs (statistical replicates) using a different combination of rumen fluid donors.

Sample collection and analyses

As sampling interferes with gas measurements, a second set of two bottles was incubated in each run for liquid sample collection at 0 and 12 h. The pH of these samples was measured immediately after collection with an Orion Star A211 pH meter (Thermo Fisher Scientific, Waltham, MA, USA). A subsample of 1.8 mL was collected at 12 h, transferred to a 2 mL tube, and centrifuged at 21,000 × *g* for 10 min at 4°C. Then, 900 μL of the supernatant was transferred to a tube containing 100 μL of internal standard (20 mM 2-ethylbutyric acid in phosphoric acid 20% v/v) and stored at −20°C until analysis for total organic fermentation products (TOFP: acetate, propionate, butyrate, valerate, caproate, iso-butyrate and iso-valerate, succinate, lactate, formate) by gas chromatography as described by Della Rosa *et al.* (2022).

Data calculations and statistical analyses

The theoretical balance of electron pairs (equivalent to H_2) produced and accepted in the fermentation of glucose was calculated based on rumen TOFP production (Wolin, 1960).

Available H_2 = [(2 × acetate + 2 × butyrate + 2 × caproate) – (1 × propionate +1 × valerate)]. The H_2 recovery was calculated as the ratio of the electrons, expressed as H_2, incorporated per mol of propionate, valerate, CH_4 and H_2 formed and the electrons equivalent to H_2 produced per mol of acetate, butyrate and caproate formed.

The data from the duplicate bottles were averaged and analysed using a mixed linear model including buffer pH, forage type, and the interaction pH buffer × forage as fixed effects; while the incubation run was included in the model as a random effect. Mean comparisons were performed using the ‘predictmeans’ package in R 4.0.3 (R Core Team, 2020) and adjusted by Benjamini-Hochberg. Statistical differences were declared when $p < 0.05$. Data on lactate production were not analysed statistically because the data were not normally distributed and the variance was heterogenous amongst treatments.

RESULTS

The pH decrease in the incubations was affected by the forage × pH interaction ($p = 0.02$), but none of the other variables were affected by the forage × pH interaction ($p \geq 0.05$). The pH in incubations with both forages decreased by 0.35 and 0.26 units between 0 and 12 h of incubation with MED and HIGH buffers, respectively. At LOW pH, the decrease was 0.18 units in RG and 0.43 units in FR

Forages incubated at MED and LOW had a 30% and 70% decreased gas production compared to the HIGH control (Table 2). Methane production (mL/g) in MED and LOW were 20% and 81% less, respectively, compared to HIGH. The proportion of CH_4 in the total gas produced (CH_4%) was similar between MED and HIGH but was less for LOW. Compared to the RG, FR produced 19% more gas at 12 h of incubation, but a similar amount of CH_4.

Overall, TOFP production was 45% and 15% less, in LOW and MED buffer respectively, compared to HIGH. Acetate production in MED was 19% less while production of propionate and butyrate were similar to HIGH. In LOW, acetate, propionate and butyrate production were less relative to HIGH (61%, 30% and 40%, respectively). The available H_2 was 62% and 17% less in LOW and MED compared to HIGH, while the hydrogen recovery was 30% less in LOW compared to HIGH, but similar between MED and HIGH.

Table 2. Total gas (GP), methane (CH_4), total organic fermentation products (TOPF) and individual metabolite production, and hydrogen (H_2) recovery at 12 h of *in vitro* incubation of forage rape (FR) and perennial ryegrass (RG) incubated in low (LOW), medium (MED) and high (HIGH) pH buffers

	Forage (F)		pH buffer (pH)[1]			SED	P- value*	
	FR	RG	LOW	MED	HIGH		F	pH
GP (mL/g)	159.9b	134.7a	65.3a	155.3b	221.3c	10.00	<0.01	<0.01
CH_4 (mL/g)	16.6	16.1	4.7a	19.7b	24.7 c	1.51	0.56	<0.01
CH_4 (% GP)	9.0b	10.9a	6.0a	12.7b	11.2b	1.55	0.05	<0.01
TOFP, mmol/g	4.7b	3.8a	2.9a	4.5b	5.3c	0.21	<0.01	<0.01
Acetate, mmol/g	2.8b	2.4a	1.4a	2.9b	3.6c	0.18	<0.01	<0.01
Propionate, mmol/g	1.0	0.8	0.7a	0.9b	1.0b	0.13	0.10	<0.01
Butyrate, mmol/g	0.5b	0.4a	0.3a	0.5b	0.5b	0.07	0.02	<0.01
H_2 available, mmol/g	5.6b	4.9a	2.7a	5.9b	7.1c	0.40	<0.01	<0.01
H_2 recovery, %	56	62	46a	64b	65b	4.28	0.09	<0.01

Hydrogen emissions were negligible; SED: average error standard of the differences
TOPF: includes acetate, propionate, butyrate, valerate, iso-butyrate, iso-valerate, lactate
*Forage × pH interaction ($p \geq 0.05$).Values within a row with different letters differ significantly
[1]LOW: pH 5.5, MED: pH 6.2, HIGH: pH 6.8

Total organic fermentation products production was 24% greater, while acetate, propionate and butyrate were 17%, 25% and 25% greater, respectively, in FR compared to RG. Lactate production was on average 0.8 mmol/g in FR while lactate was not detected in RG. Furthermore, lactate production was detected only in LOW, not in MED or HIGH.

The available H_2 was 14% greater in FR vs RG and the hydrogen recovery trended to be 10% less in FR compared to RG. Succinate, formate and caproate were not detected in any of the incubation samples.

DISCUSSION AND CONCLUSIONS

The starting pH affected total gas and CH_4 production from both forage rape and ryegrass; this highlights the role of ruminal pH on CH_4 production. A lower pH *in vitro* led to a greater reduction of fermentation as shown by the lower total gas and TOFP production, which was consistent with findings of Fondevila and Perez-Espes (2008). The lower fermentation may be due to the decreased fibre degradation with a lower pH (Sung *et al.*, 2006), which would also explain the proportionally larger decrease in acetate and consequently the decrease in hydrogen availability.

In the MED treatment, the effect of pH on CH_4 was similar to the effect on total gas production, indicating no specific decrease of methanogen activity at pH 6.2 compared to pH 6.8. Decreasing pH to 5.5 (LOW), however, led to a larger decrease in CH_4 production compared to the decrease in total gas production, indicating a specific inhibition of methanogenesis in addition to the general effect of low pH on fermentation. This is consistent with the work of Erfle *et al.* (1982) who stated that a pH below 6 was detrimental for rumen methanogens. Sun *et al.* (2020) observed that FR-fed sheep, in which the rumen pH was below 6 for longer, had lower CH_4 production per unit of dry matter intake than those sheep receiving sodium carbonate to increase the rumen pH.

Regardless of the pH effect, FR fermented to a greater extent than RG, reflected by a greater production of total TOFP per unit of feed incubated. However, CH_4 production did not increase to the same extent as total gas production (fermentation) did. The lower pH caused by the greater concentration of TOFP in FR, and the negative effect of low pH on methanogens, explain the lower proportion of CH_4 production. Acetate production, the main source of hydrogen, decreases when pH decreases (Russell, 1998). Indeed, decreasing the pH decreased acetate production independent of forage type. However, acetate production was greater in FR compared to RG at all three pHs evaluated, resulting in an increase in the hydrogen availability. Acetate production from FR was greater due to not only the greater extent of fermentation but probably also the fermentation of galacturonic acid from pectin (Strobel and Russell, 1986). However, the H_2 recovery tended to be less in FR compared to RG, which suggests that available H_2 was redirected toward other non-quantified fermentation products instead of towards CH_4 production. More lactate production, a propionate precursor, from FR is consistent with a redirection of electrons towards other fermentation products. Lactate production, mainly in FR incubated at pH 5.5, seemed to be a key metabolite in the decrease of pH in FR. Lactate has a lower p*K*a than other TOFP. Thus, when produced in the rumen, a larger proportion of lactate remains dissociated and unabsorbed, causing a reduction in ruminal pH (Williams and Mackenzie, 1965).

In conclusion, lower pH decreased fermentation *in vitro.* Forage rape reduced the proportion of CH_4 in the total gas to a greater extent than ryegrass likely due to a larger pH decrease during incubation, and a formation of lactate.

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CONFLICT OF INTEREST DECLARATION

The authors declare no conflicts of interest.

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Review article: Dairy labour shortages: Could we use UN Sustainability Goals and related frameworks to explore, explain and reduce high dairy workplace attrition rates?

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ABSTRACT

Targeted policy, research, and development has failed to mitigate two decades of labour shortages in the Australian dairy industry, suggesting gaps in academic understanding of this problem. Globally, inferior dairy workforce health and wellbeing is documented. The associations between health and wellbeing factors and attrition rates of other occupations are anticipated but not yet qualified. Newer disciplines, OneHealth and OneWelfare, correlate health and wellbeing of humans, animals and environment; complex inter-affectedness is recognised. Personal wellbeing is associated with occupational factors and governs human capacity to attach to and maintain investment in land and animal stewardship outcomes. Frameworks which characterise affective cultural, social, economic, and other factors of influence to health and wellbeing include the World Health Organisation's Global Determinants of Health, Maslow's Hierarchy of Needs, and the United Nation Sustainable Development Goals. Accurate characterisation and targeted address previously neglected, key factors of influence on dairy workforce health and wellbeing may reduce occupational attrition rates, contributing toward increased labour pool size, stability, sustainability, efficiency, and skill quotient. Better life-long health and wellbeing for animals, families, and communities of farm workers, and numerous, positive economic and social effects may result from this approach. This review overviews how previous health and wellbeing research of the dairy workforce relates to the comprehensive approach of the mentioned frameworks. Knowledge gaps are identified in association with previous, isolated, thematic approaches. The need to comprehensively explore and explain dairy occupation, cause-and-effect human health and wellbeing relationships in a framework context is supported.

Keywords: workforce retention, occupational wellbeing, OneHealth, OneWelfare.

INTRODUCTION

Enterprise economic survival within the Australian dairy industry has required adaptation to significant challenges. Between 1980 and 2000, dairy farm numbers fell from 21,994 to 12,896 (-41.4%) nationally, and 3,052 to 1,545 (-49.4%) in Queensland (Dairy Australia, 2017). From 2000-2020, industry deregulation, drought, milk discounting wars and other events contributed to a further decline to 5,055 (projected) farms nationally, and 327 (projected) in Queensland, reflecting a change of -60.8% and -78.8% respectively (Dairy Australia, 2020). The national herd contracted from 2,171,000 to 1,411,000 cows (-35%), and milk production also decreased - from 10,847ML to 8,776ML (-18.1%). As farm, cow and milk production totals diminished, displaced, skilled and experienced workers largely left industry, and chronic labour shortages emerged and persisted (Kotsios, 2018, Farm Online National, 2022, Davies et al., 2009). Resulting limits to industry productivity persist. To guide development of alternative, targeted, remediate initiatives, this review asks: which systematic, investigative approaches have previously been used to relate workforce health and wellbeing status, as a factor of influence, to attrition and labour undersupply within the Australian dairy industry?

BACKGROUND

Dairy Australia's 2006, People In Dairy (PID) initiative responded to the need for better industry workforce planning (Nettle et al., 2008). Nettle *et al.* cite a 2008 Dairy Australia report stating that in the five previous years, 50% of hiring attempts had failed due to lack of suitable candidates, and 36% of workplaces had reported high staff turnover rates. The PID project has contributed substantially toward academic understanding of human resource management, its limitations, and the need for their address (Nettle and Oliver, 2009, Nettle et al., 2008, Nettle et al., 2006). These records overview labour undersupply factors of the day, e.g. ageing workforce, within-family to hired / external labour sources, poor work role definition, the psychological contract of dairy work, working relationship effectiveness, and the need for planning, development, extension, and training to enable a more effective workforce management strategy. Empirically, initial PID project outcomes were met. Dairy Australia continues to develop and implement increasingly sophisticated, targeted extension and training strategies in this space, yet chronic labour undersupply issues persist (Farm Online National, 2022).

In a subsequent small study, Nettle et al. (2011) focussed on career retention rates, recognising a body of correlated occupational, local and international dairy workforce health and wellbeing literature which served in support of their research. High comparative staff turnover rates compared to relevant other industries, and multiple consequences to enterprises and industry were confirmed. The authors identified eight factors associated with better retention rates. Factors observed relate to positive changes in the lived experience of the subject, e.g., more favourable financial, relational/social and personal conditions than traditional and/or the minimum obligation, legal, workplace standards. Each factor also relates to topic aspects of health and wellbeing theory models, e.g. Maslow's Hierarchy of Needs (HoN) (Maslow, 1954); the Social Determinants of Health (SDoH) (Marmot et al., 2008); and the United Nations' Sustainable Development Goals (SDG)(United Nations, 2015). Before expounding on the theory models, we present a limited summary of dairy occupational health and wellbeing literature.

HEALTH and WELLBEING

Internationally, dairy industry occupations are associated with higher risk of a broad range of physiological, psychological, and social challenges, as well as other maladies, e.g. obesity and other preventable, lifestyle-associated illness (Brumby et al., 2010), poor psychosocial wellbeing (Kolstrup et al., 2013), and stress (Wallis and Dollard, 2008).

Concurrently, Australian animal welfare researchers synthesised that expectation of the capacity of stockpersons to maintain a personal investment in animal care and stewardship outcomes is unreasonable if the stockpersons capacity to maintain their own good health and wellbeing is not afforded through the terms of their work (Hemsworth, 2010).

Meanwhile, veterinary scientists had recognised limits in their capacity to address agricultural animal welfare issues through observed poor welfare of those responsible for agricultural animal care. The OneWelfare discipline resulted (Pinillos et al., 2016). OneWelfare incorporates environmental health centrally in its design and strategy, and places the Sustainable Development Goals at its foundation (Garcia, 2017). As an emerging science, published reports of applications of OneWelfare theory in workforce health and wellbeing were not identified. However, OneWelfare's approach: holistic, ethical, and sustainable succession of current dairy industry into its future representations – is comprehensive and broadly palatable, promoting its favour.

Disadvantages confirmed in the literature to be occupation-associated are likely be contributing to current industry labour undersupply and high attrition rate issues. The comprehensive approaches of SDG and other frameworks may uncover previously overlooked but significant, causative or contributing factors, enabling their address.

THE FRAMEWORKS

UN Sustainable Development Goals

Use of the UN SDGs (**Table 1**) to characterise the state of personal disadvantage, vulnerability, and risk within the dairy workforce has not previously been reported. Dairy Australia's sustainability strategy, which is mapped to some of the UN SDGs, is a whole of industry, consumer-focussed initiative (Dairy Australia, 2022). By design, it omits many UN SDGs and their relation to the dairy workforce, though each of the SDGs can be implicated to some degree with occupation-associated affect to the lived experience of dairy workers. The academic record reflects examples of SDG topic exploration, but none employing the full framework in their characterisations. Therefore, underrepresented, compounding negative effects are possible via discrete, topic-focussed approaches.

Table 1. The full list of seventeen United Nations 2030 Agenda for Sustainable Development Goals.

Goal 1	End poverty
Goal 2	End hunger
Goal 3	Ensure health and wellbeing
Goal 4	Quality education
Goal 5	Gender equality
Goal 6	Clean water and sanitation
Goal 7	Affordable, clean energy
Goal 8	Decent work and economic growth
Goal 9	Industry, innovation and infrastructure
Goal 10	Reduce inequalities
Goal 11	Sustainable communities
Goal 12	Responsible consumption and production
Goal 13	Climate action
Goal 14	Life below water
Goal 15	Life on land
Goal 16	Peace, justice and strong institutions
Goal 17	Partnerships for the goals

Determinants of Health

The Social Determinants of Health is a well-established theory which factorially explores worker risk, vulnerability and disadvantage. This World Health Organisation-commissioned framework consists of ten themes ((Wilkinson and Marmot, 2003) **Table 2**). The authors provide definitions of the factors, which are omitted herein for brevity. Determinants of Health theory, used as a framework to evaluate occupation-associated health and wellbeing within dairy farming, is not yet recorded. Some examples exist of topic papers on several of its factors. Theme overlap with the UN SDGs supports use of SDoH theory in dairy workforce disadvantage status evaluation.

Table 2. Factors within the Social Determinants of Health model for risk of disadvantage and vulnerability. (Wilkinson and Marmot, 2003)

1.	The social gradient
2.	Stress
3.	Early life
4.	Social Exclusion
5.	Work
6.	Unemployment
7.	Social Support
8.	Addiction
9.	Food
10.	Transport

Maslow's Hierarchy of Needs

Abraham Maslow's Hierarchy of Needs theory concerns the capacity for psychological wellbeing. It has been incorporated extensively into occupational health and wellbeing policies and procedures of institutions and organisations globally. There is no record of its study within dairy occupations. Its validated utility to model capacity for psychological health supports its use in seeking to better understand dairy workforce psychological health and wellbeing.

Table 3. Maslow's Hierarchy of Needs

1.	Physiological needs
2.	Safety needs
3.	Love and belonging
4.	Esteem
5.	Self-actualisation

CONCLUSIONS

The academic record reflects that thematic approaches have previously been employed, but a systematic, integrated research approach would offer a comprehensive and contextualised understanding of the role of health and wellbeing – and vulnerability and disadvantage - as contributors to high industry attrition rates. Synthesis of the supporting literature suggests an oversight in separately considering the health and wellbeing status of the dairy workforce to its animals and environment, and multidimensionally beneficial opportunities possible through taking a more holistic approach.

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CONFLICT OF INTEREST DECLARATION

None to declare.

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Adjusting milking intervals to improve workplace attractiveness has implications for milking management

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ABSTRACT

We hypothesised that milking three times in two days (3-in-2) would require changes to milking management relative to twice-a-day (TAD). Data were used from two 6-week experiments with five treatments, cows milked TAD, once-a-day (OAD) and three milking 3-in-2 with differing milking intervals. Milk yield and duration were recorded at each milking and milk samples were taken weekly at the 5-7am (AM), 2-5pm (PM) and 10-11am (MID) milkings. Cluster-on duration per day was reduced by 16% for 3-in-2 and 32% for OAD, compared with TAD. However, there were large differences in milk volume and composition between the AM, PM and MID milkings. This presents a challenge for optimising milking routines. Additionally, farms with daily milk collection should avoid vat collection times between the AM and MID milkings to minimise the risk of exceeding vat capacity or milk processor cell count penalty thresholds. A single AM sample was adequate to estimate daily milk and component yields for TAD, but for 3-in-2, two samples were required to make predictions of 48 h yield.

Keywords: Milking intervals, milk composition, milk sampling.

INTRODUCTION

Attracting, retaining and growing the on-farm workforce is a key goal for the New Zealand dairy sector (DairyNZ 2022). To achieve this goal, ‘changing the job’ is one initiative that aims to reduce the reliance on people and make on-farm work more attractive.

Milking three times in two days (3-in-2) is one option to reduce the length of time spent milking as well as changing the time of the day when the milkings occur. Example milking times are 06:00 (AM), 16:00 (PM) and 11:00 (MID) the next day, then repeated. Farm systems research has indicated an 11% decline in milk yield can be expected from milking 3-in-2 for the whole lactation (Edwards *et al.* 2022b). Milk composition was also affected, resulting in 8% less protein yield but there was no significant effect on fat yield. This result is supported by earlier component work, which also identified an effect of the length of the preceding milking interval (Elliott *et al.* 1960). Therefore, milk composition will probably differ significantly between the PM and AM and MID milkings.

The uneven milking schedule, with two milkings on one day and one on the next, combined with the differences in composition at those milkings could, amongst other factors, affect the time of daily milk collection or individual cow milk sampling for determining animal performance and evaluation. Consequently, we hypothesised that milking 3-in-2 would have implications for milking management.

MATERIALS AND METHODS

Experimental design

Two 6-wk experiments were conducted at Ashley Dene Research and Development Station, Canterbury, New Zealand between 11-Sep-2020 and 22-Oct-2020 (early-lactation, cows 34 DIM) and 15-Jan-2021 and 25-Feb-2021 (mid-lactation, cows 146 DIM) under the authority of Lincoln University Animal Ethics Committee (application #2020-12).

Each experiment consisted of five treatments: 1) herd milked OAD, 2) herd milked 3-in-2 with intervals of 8-20-20, 3) herd milked 3-in-2 with intervals of 10-19-19, 4) herd milked 3-in-2 with intervals of 12-18-18 and 5) herd milked TAD with intervals of 10-14. Two hundred cows were selected from the main research herd (milked TAD), blocked by calving date, pre-experimental fat and protein yield, parity (20% primiparous), and randomly allocated to each treatment (40 cows/herd). Following the early-lactation experiment cows returned to the main herd. Of the 200 cows included in the mid-lactation experiment, 90 had also been used in early-lactation. For these animals, previous treatment was used as an additional blocking factor.

Herds were rotationally grazed. Each experimental paddock was subdivided into five areas with temporary fencing and each treatment group randomly allocated to one of the five areas. These areas were split again to provide grazing for two days. All herds grazed the same experimental paddock on the same days for ease of management and consistency of diet. The allocation of herds to sub-paddocks was randomised between paddocks.

Animal measurements

Milk weight and milking duration was recorded by in-line meters (AfiMilk, Israel) at each milking. Each cow was sampled weekly for milk composition (protein, fat, lactose, milk urea and SCC). The OAD herd was sampled at an AM milking, the TAD herd sampled at AM and the following PM milking and the three herds milked 3-in-2 were sampled at three consecutive milkings; AM, PM and MID milking the next day. Samples were analysed at MilkTestNZ (Hamilton, New Zealand) by CombiFoss equipment (Foss Electric, Hillerød, Denmark).

Analysis

Animal was the observational unit and the herd was the experimental unit, with repeated measures through time (n=6 weeks). Milk data were analysed using a repeated measures model (SAS Institute Inc., Cary, NC, USA). Fixed effects included in the model were covariate period milk production, DIM, breed, parity, treatment, week, treatment × week and experiment. Deming regression (R 4.2.1, package Deming) was used for comparing yield estimates based on single versus multiple samples. This procedure allows for the estimation of proportional (slope $\neq$ 1) and systematic (bias, intercept $\neq$ 0) differences between methods. To investigate potential re-ranking of animals for animal evaluation, single and multiple sample estimates were allocated to deciles. For each multiple sample decile, we calculated the percentage of single sample deciles and illustrated the results together with the percentage of samples found in the same decile for both estimation methods.

Scenario modelling

Least square means of the key milking parameters were used to develop simulated vat-milk properties of a 463-cow herd for three scenarios of different daily vat collection times over six collections. These scenarios were A) collection occurring in the window after the AM milking and before the MID milking (morning), B) collection occurring in the window after the MID milking and before the PM milking (afternoon), and C) collection occurring in the window after the PM milking and before the AM milking (overnight). Values from the three 3-in-2 herds were averaged to simplify the comparison with TAD and OAD.

RESULTS

Cluster-on duration is shown in Table 1 and show large variations between PM compared with AM and MID milking times for 3-in-2. At a daily level, milking times were 10.6 min for TAD, 8.9 min (-16%) for 3-in-2 and 7.2 min (-32%) for OAD.

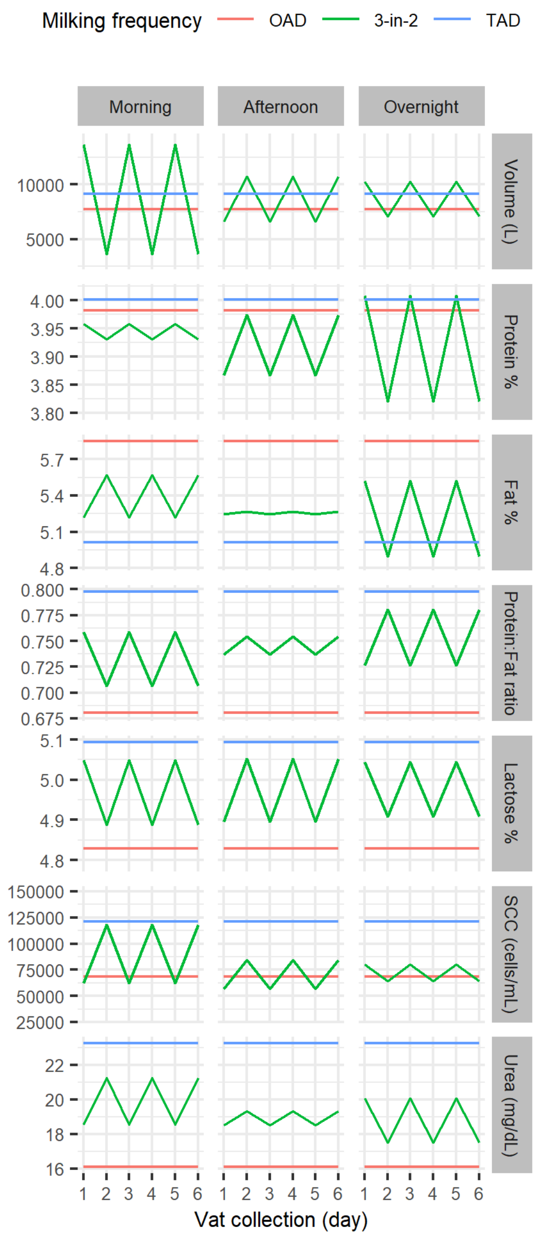
Table 1. Mean milking time (min/cow) at each milking session (AM, PM, MID).

Intervals	AM	PM	MID
10-14	5.8	4.9	-
12-18-18	6.4	5.2	6.6
10-19-19	6.6	4.7	7.0
8-20-20	6.4	4.1	6.8
24	7.2	-	-

The simulated vat-milk properties are presented in Figure 1. The 3-in-2 milking frequency had considerable differences in vat - milk properties between collections.

The Deming regression results (Table 2) revealed that for TAD, a single AM sample was sufficient to predict daily yields accurately, however, a single PM sample was not. Generally, the results for the different 3-in-2 intervals produced the same results and are therefore presented together in Table 2.

Figure 1. Simulated vat-milk properties for three tanker collection windows (Morning, Afternoon, Overnight) and three milking frequencies.



For 3-in-2, the MID milking milk sample provided the best prediction of milk composition over a 48-hr period. No single sample, however, could accurately predict most 48-hr period values that were generated using AM, PM and MID samples combined. Additionally, animal ranking based on deciles (Figure 2) shows that considerable re-ranking occurred.

Collecting either MID and AM, or PM and MID samples produced the best results for predicting 48-hr period yields, albeit with some limitations. Using two samples resulted in less re-ranking than a single AM sample for TAD. For all combinations, fat yield was the most difficult to predict, and was consequently chosen to illustrate re-ranking (Figure 2).

Table 2. Illustration of proportional differences (slope) between single and multiple sample 24/48 hr yield estimates. Numbers represent the t-value for the hypothesis of slope = 1. Values < 2 (95% CI) are highlighted in green, values ≥2 and ≤5 (99.9% CI) in orange, and values >5 in red.

Type	Sample	Milk	Fat	Protein	Lactose	SCC
TAD single	AM	<2	2	1	3	1
	PM	8	4	5	10	<2
3-in-2 single	AM	5	14	3	5	1
	PM	17	4	11	20	<2
	MID	1*	6	6	1*	1
3-in-2 double	AM+PM	9	8	4	10	1
	MID+AM	1	8	2	2	3
	PM+MID	4	1	5	3	3

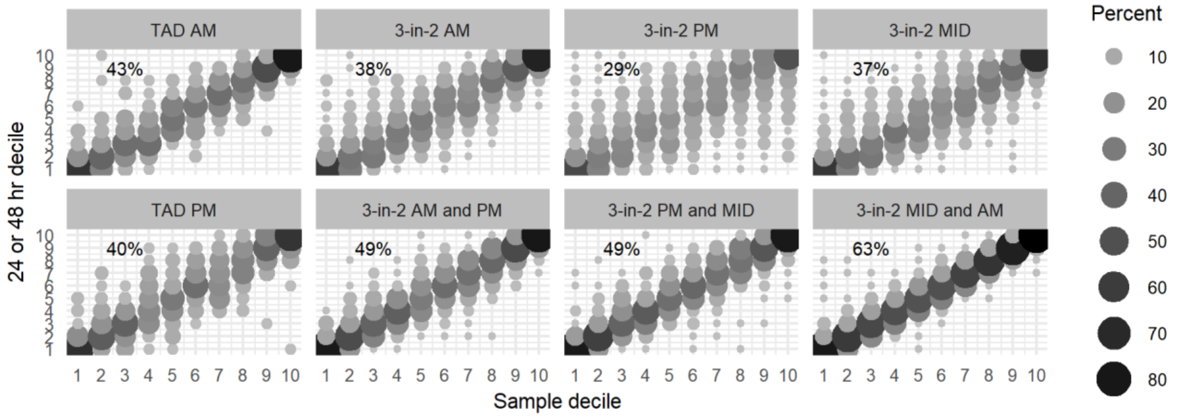
*Slope = 1 but intercept 95% confidence interval is outside 0 indicating a consistent bias.

DISCUSSION AND CONCLUSIONS

Milking 3-in-2 can be expected to require 16% less milking time relative to TAD, half that achieved of OAD.

In terms of dairy operations, there were large differences in individual cow milking time between the PM and the AM and MID milkings (e.g. 2 min/cow). This presents a challenge for optimising milking efficiency because the time required to perform milking tasks and the number of clusters is unchanged between milkings, resulting in overmilking at the PM or milker idle time at the AM or MID milkings. This may be exacerbated in herringbone dairies where the milking time of the slowest cow determines row time. One solution may be to apply a fixed milking time to truncate the longer milkings. However, this may prove challenging if the divergence in the interval between PM and AM and MID is very large (Edwards *et al.* 2022a).

Figure 2. Comparison of single vs multiple sample 24/48 hr estimates for fat yield by decile. Label is percent of single sample estimates in same decile as multiple sample estimates.



The milk collection time had a large effect on vat-milk characteristics for 3-in-2 (Figure 1), which could make quick monitoring of herd performance relative to a previous time reference challenging. Importantly, perhaps, if the farm is on a daily collection cycle due to vat capacity, then a collection between the AM and MID milkings will result in both milkings being in the vat every second day. This could represent 36-40 hrs of milk and may exceed vat capacity, particularly during peak lactation. On alternate days, this collection time would result in only the PM milking being in the vat, the milking with the highest SCC and, depending on the herd, may exceed milk buyer SCC penalty thresholds, particularly in later lactation.

Despite a single AM sample being sufficient to predict 24-hr yields for TAD, this was not the case for 3-in-2. Further, using a single sample for 3-in-2 produced significant re-ranking, which could have implications for animal evaluation. A sample from both the MID + AM or PM + MID milkings was required to estimate 48-hr yields, although not all parameters were accurately predicted. Sampling two milkings for 3-in-2 produced less re-ranking to the single AM sample for TAD. If using portable milk sampling equipment, a MID + AM (and AM + PM) sampling regime would require it to be on-farm for 48 hrs, reducing its utilisation. A PM + MID sampling regime could allow for the equipment to be on-farm for only 24 hrs, depending on the herd milking time. Alternatively, the MID milking could be temporarily brought forward to shorten the time required, or the herd could be briefly milked TAD, which only requires one additional milking (MID replaced with an AM and PM).

Consequently, we conclude that adopting a 3-in-2 milking schedule will require changes to milking management.

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We declare no conflicts of interests.

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Bovine milk sample preparation technology to detect mastitis pathogens at the point-of-need

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ABSTRACT

Bovine mastitis – a persistent inflammation of the mammary gland – is the most common infectious disease in dairy cattle, reducing milk yield and milk quality and costing Australian dairy farmers millions of dollars each year. At present, suspected infections are typically treated by farmers without specific knowledge of the causative agent, which can result in ineffective or inappropriate administration of antibiotics. The milk from cows treated for mastitis will contain antibiotic residues either released into the dairy effluent system or fed to calves, risking the development of antimicrobial resistance (AMR). The aim of this project is to develop a point-of-need test (for identifying mastitis pathogens) that is field portable, cost-effective and can be used with minimal training. Using an innovative polymer-based milk sample preparation technology to rapidly extract pathogen DNA in real milk samples we demonstrated quantitative polymerase chain reaction (qPCR) assays for six common bovine bacterial mastitis pathogens: *S. aureus, S. agalactiae, S. dysgalactiae, S. uberis, M. bovis* and *E. coli* on a point-of-need prototype system in proof-of-concept field trials. We found that our point-of-need prototype system showed good correlation to laboratory-based qPCR for target pathogen detection outcomes, thus potentially removing the need for milk samples to be transported for laboratory testing. Importantly, the polymer-based sample preparation technology enables a sample-to-result turnaround time of within 90 min to quantitatively detect all six target pathogens. The technological development in enabling point-of-need mastitis pathogen testing has the potential to increase diagnostic certainty for common animal disease syndromes at the time of examination and therefore, reducing AMR by appropriate antimicrobial use when required.

Keywords: Mastitis, real-time polymerase chain reaction, antimicrobial resistance, sample preparation, point-of-need

INTRODUCTION

Mastitis is the most prevalent and costly disease in the dairy industry worldwide. Mastitis or inflammation of the cow's udder is a painful condition typically caused by a bacterial infection. Infections impose a financial burden on dairy farmers from lost milk production, increased treatment, and management costs, with further losses due to increased risk of culling and reduced fertility.

The management of mastitis also results in increased and arbitrary use of antibiotics, increased cost of treatment, poor treatment outcomes and lost productivity. The use of non-specific broad-spectrum antibiotics has the potential to increase antimicrobial resistance (AMR).

Point-of-need testing has the potential to increase diagnostic certainty for mastitis at the time of examination and therefore reduce AMR by reducing inappropriate antimicrobial use. Presently, no rapid diagnostic test exists for identifying and quantifying mastitis pathogens at the point-of-need.

This project seeks to deliver a point-of-need cartridge and reader system that utilizes novel polymer-based sample preparation and quantitative polymerase chain reaction (qPCR) for the detection of six common bacterial mastitis pathogens in dairy cattle milk. An early-stage design and development of a prototype system (termed as "GENOSIS"), as well as initial diagnostic performance evaluation against selected mastitis pathogens in real milk samples using laboratory-based qPCR as the gold standard comparison, were completed.

MATERIALS AND METHODS

GENOSIS evaluation of milk samples

This study was conducted under animal ethics approval SVS/415/20. The milk sample (500 µL) was diluted with 500 µL of 5 M guanidine thiocyanate lysis buffer before injection into the GENOSIS cartridge using a 3 mL syringe.

The lysated genomic DNA is sampled, washed and eluted into 30 µL qPCR reactions as below (Table 1), with one well per target containing probes for detection of *S. aureus*, *S. agalactiae*, *S. dysgalactiae*, *S. uberis*, *M. bovis* and *E. coli*, as well as a positive and a negative control. The positive control consists of an unrelated DNA sequence, and the negative control consists of contamination-free salt buffer.

Table 1. Reaction components for a 30 µL reaction with probes for mastitis pathogen targets.

Reagent	Volume (µL) 1x
SensiFAST™ Lyo-Ready No ROX Mix	15
FAM Probe (10µM)	0.45
Primers (10µM)	1.2
ddH2O	13.35
TOTAL	30

GENOSIS target identification was performed with a custom sigmoid curve fitting algorithm of the qPCR fluorescence signal to both identify target amplification and report Cq values.

Validation by gold standard qPCR

As a comparison for results obtained from the GENOSIS evaluation, the same cohort of milk samples were also extracted with conventional spin-column DNA extraction and analysed using standard qPCR. Eluates from were run in duplicate in a standard qPCR thermal cycler (Bio-Rad CFX96) with the reaction components of a singlicate reaction given below (Table 2).

Table 2. Reaction components for a 10 uL singlicate reaction, used for standard qPCR after ConcentreX extractions.

Reagent	Volume (µL) 1x
SensiFAST™ Lyo-Ready No ROX Mix	5
FAM Probe (10µM)	0.15
Primers (10µM)	0.3
DNA Template	1
ddH2O	13.35
TOTAL	10

RESULTS

Mastitis pathogen qPCR assay development and validation

In Australia, the most common pathogens associated with clinical bovine mastitis are *S. aureus*, *S. agalactiae*, *S. dysgalactiae*, *S. uberis*, *M. bovis* and *E. coli*. For use in the GENOSIS prototype, we validated six different qPCR assays to detect these pathogens. The sensitivity, specificity, and limit of detection of these assays is presented in Table 3. The detection sensitivity and specificity for all assays was 100% and the limit of detection ranged from 5-94 copies/µL.

Table 3. Sensitivity, specificity and limit of detection (LOD) of the six qPCR assays.

Assay Target	Sensitivity Target = (%)	Specificity Non-target = (%)	LOD (DNA copy/µL)
E.coli	100 (46/46)	100 (46/46)	5
S.aureus	100 (37/37)	100 (46/46)	31
S.uberis	100 (25/25)	100 (46/46)	15
S.agalactiae	100 (12/12)	100 (77/77)	12
S.dysgalactiae	100 (26/26)	100 (92/92)	94
M.bovis	100 (14/14)	100 (37/37)	47

GENOSIS design and prototype construction

The GENOSIS platform utilise the polymer-based sample preparation technology (WO2014093357A1) to rapidly concentrate and extract pathogen DNA from mastitic milk samples. The GENOSIS technology is developed towards being i) field portable and field robust; ii) able to be used with a minimum of training; iii) cost effective; iv) able to analyse extracted DNA or RNA from a small volume of sample (approx. 1 mL); and v) able to deliver sample-to-result turnaround time of within 90 min.

The GENOSIS prototype system (Figure 1) was designed as 4 inter-connected components: i) a custom-made, refurbishable Cartridge; ii) a custom-made Reader unit; iii) a commercial laptop running a proprietary App, for controlling the Reader; and iv) a custom-made power supply unit, to provide low-voltage power to the Reader systems.

The Cartridge allows the milk sample (approx. 1-2 mL) to be injected into a port using a luer-lock syringe. A small viewing window allows the user to see that the internal sample chambers have been filled. The polymer extraction technology housed within the Cartridge performs automatic sample preparation of the injected milk samples to derive extracted DNA for qPCR through mechanical interaction within the Reader unit. The six different mastitis pathogen targets can then be detected by qPCR via independent wells within the cartridge, and two separate wells are reserved for positive and negative controls.

Proof-of-concept field trials

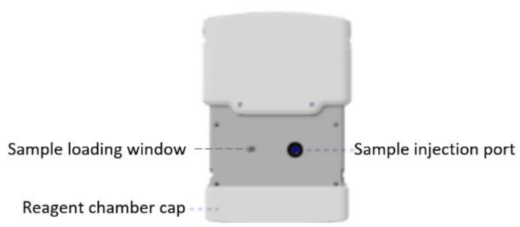
GENOSIS prototype systems were installed at the Gatton Dairy Farm testing site for the trial. A cohort of 31 uncharacterized real milk samples was selected at random (i.e. identity of mastitis pathogen target is unknown) and thus blinded to the experimenters conducting the on-site GENOSIS prototype testing.

These milk samples were subsequently cultured and phenotypic attributes such as growth density and culture purity were recorded. At least one isolate was taken from plates showing growth and identified by matrix-assisted laser desorption ionisation time-of-flight mass spectrometry (MALDI-TOF). Samples with at least one isolate positively identified by MALDI-TOF for the mastitis target panel were considered true positive samples for the purpose of subsequent direct qPCR characterisation and GENOSIS trials. Samples with no growth samples or those not positive for the six target organisms were considered true negative samples.

As a comparison for GENOSIS prototype testing outcomes, the 31 samples were also molecularly characterised using gold standard laboratory-based qPCR methods. Using MALDI-TOF data as the reference, the assay performances of the GENOSIS prototype system and gold standard qPCR were compared for the detection of the six mastitis pathogen targets. (Table 4)

Table 4. Assay performance comparison between GENOSIS and gold standard methodology.

	C.bovis		E.coli		S.aureus		S.agalactiae		S.dysgalactiae		S.uberis	
	qPCR	GEN	qPCR	GEN	qPCR	GEN	qPCR	GEN	qPCR	GEN	qPCR	GEN
TP	0	0	7	1	3	2	1	0	4	1	4	4
FN	2	2	0	6	0	1	0	1	1	4	1	1
TN	28	29	22	22	26	27	25	29	26	25	20	21
FP	0	0	2	2	2	1	5	1	0	1	6	5
Total	30	31	31	31	31	31	31	31	31	31	31	31
Sensitivity	0	0	100	14	100	67	100	0	80	20	80	80
Specificity	10	100	92	92	93	96	83	97	100	96	77	81
Accuracy	93	94	94	74	94	94	84	94	97	84	77	81



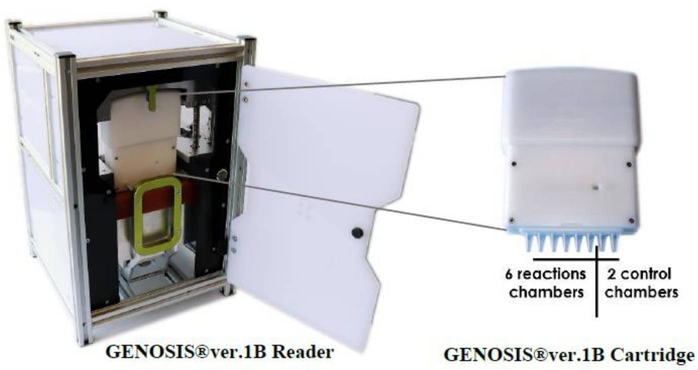


Figure 1. GENOSIS prototype system.

DISCUSSION AND CONCLUSIONS

Point-of-need sensing technologies can cost-effectively provide rapid real-time results for infections allowing for informed, efficacious management of mastitis and better overall antimicrobial stewardship (Fitzpatrick *et al.*, 2021).

A GENOSIS prototype system for rapid qPCR detection of six common bovine bacterial mastitis pathogens was developed and utilised in a proof-of-concept field trial to determine whether this technology is suitable to guide treatment decisions in cases of clinical mastitis.

In the first phase, a patented polymer technology (PET) was successfully integrated into the GENOSIS prototype cartridges for automated raw milk sample preparation. The individual qPCR assays for each of the six mastitis pathogen targets were also independently developed and validated for required levels of detection sensitivity and specificity.

The prototypes were then transported for point-of-need near-field testing of 31 milk samples at a commercial dairy. Although detection specificity (80.8-100%) on the GENOSIS prototype was found to be excellent across the six mastitis pathogen targets, it was identified that the GENOSIS prototype was unable to extract sufficient DNA in milk samples and led to variable detection sensitivity (0-80%)

Generally, qPCR is more sensitive than MALDI-TOF (Koskinen *et al.*, 2010). This is attributed to qPCR detecting DNA from both alive and dead bacteria (Tchamba *et al.*, 2019). The lack of sensitivity suggests the current GENOSIS technology is not able to extract sufficient quantities of pathogen DNA from unprocessed milk samples. To address the lack in detection sensitivity, a pre-concentration step before sample injection into cartridge may address this issue and is currently being investigated.

In conclusion, a point-of-need GENOSIS prototype system was developed and demonstrated to be cost-effective and field portable. Independent user testing commended GENOSIS for its speed of testing and its efficient and straightforward testing protocol. However further time and resources need to be spent to improve assay sensitivity and further optimise user experience.

ACKNOWLEDGEMENTS

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CONFLICT OF INTEREST DECLARATION

K.J.F., H.J.R, W.A. and K.M.K. are employees of XING Technologies Pty Ltd, which holds registered intellectual property used in this project.

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Does Milk Urea Concentration have potential as a Pasture Management Tool in the Tasmanian Dairy Industry?

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ABSTRACT

The success of the Tasmanian Dairy Industry is underpinned by low-cost grazed pasture systems. Improving the production and utilisation of pasture is key to maintaining this competitive industry advantage. However, the efficient production and utilisation of this pasture is often limited by a lack of readily available results from both the quantity and nutritional quality of the pasture. Growing pasture and doing so efficiently needs a measure to combat the overfeeding or underfeeding of protein within the cow diet. Having a simple measure, such as readily available milk urea nitrogen (MUN) concentration, can help understand when dietary protein is either in excess or deficit, and support decisions that refine pasture management as well as feeding decisions that improve productivity and profitability. This paper investigates the potential for mean herd MUN concentrations, to be used as a tool by farmers to improve pasture management, feeding decisions and timing and rates of nitrogen (N) fertiliser application. Herd test data from six dairy regions across Tasmania for three consecutive years from 2014 to 2016 was examined. Mean herd MUN concentrations were calculated from individual cow data, and results compared between seasons, years and regions. In-depth surveys were then conducted from a selection of participating farmers based on a cross section of MUN levels to understand their feeding and nitrogen fertilisation practices during the three-year period. The nutrition model Rumen8 was used to calculate over or under supply of protein based on diets fed. Analysis of herd test MUN data across the experimental period indicated there were significant differences in milk urea concentrations between seasons and years, which strongly correlated with calculated dietary excess protein ($R^2 = 0.8005$). It is recommended an extension tool using herd level MUN levels should be developed, to support better dietary decisions by Tasmanian dairy farmers, and help them in interpret their cows' MUN levels and how these can inform improved management of the cow's diet and their protein intake, and subsequently on pasture nitrogen fertiliser regimes.

Keywords: MUN, Nitrogen fertilizer, dietary protein, grazing management.

INTRODUCTION

Knowledge of crude protein (CP) concentrations in grazing systems, where grazed forage quality changes with time and is dependent on factors such as geographic location, prevailing environmental conditions, species of pasture, type of grazing and fertiliser management imposed on the system, is limited. CP is the total dietary protein calculated by the nitrogen component x 6.25, inclusive of rumen degradable, rumen undegradable and non-protein nitrogen. The value of using milk urea concentration as a management tool in pasture-based systems in Australia for determining an excess of protein in the diet and therefore altering CP dietary intake has not fully been appreciated. For growth and continuing success of the Tasmanian dairy industry there is a need to maintain Tasmania's comparative advantages of high yielding and cost-effective pasture growth but avoiding excess N-fertiliser use which is a main driver of pasture production. Improvements can be achieved by adjusting seasonal pasture management and N-fertiliser levels using milk urea nitrogen (MUN) as a farmer tool for improved grazing management, timing and rates of N-fertiliser application, and improve feeding decisions on farm (Hammond, 1998).

MATERIALS AND METHODS

TasHerd Data Analysis

Tasmanian dairy industry herd test data was collected for dairy farms from the years 2014, 2015 and 2016. After the removal of outliers there were 1204 herd tests from 158 farms with an average of 290 cows per herd test, with weighted averages calculated for each herd test. This data was provided by TasHerd. Milk analysis results were provided for fat%, protein%, lactose%, total solids, SNF%, SCC, MUN and FPD (freeze point depression). The herd test data included a herd code (farm code), area, test date, test time (AM – before midday, PM – after midday) and instrument no. Bentley 500 Infrared Milk Analyzers were used to analyse the results (Bentley Instruments Inc., 2009). A herd test provides milk yields as volume and concentrations as % of weight from volume for each individual animal. To replicate herd averages that are similar to those obtained from analysing bulk milk tank milk samples, weighted averages were calculated for grams of Fat, Protein and Lactose, and mg of MUN for all the obtained herd tests with outliers being removed from the data set such as incomplete results. All MUN results in this report are these weighted averages for each herd test.

Survey Analysis

Farms of contrasting high or low MUN concentrations and for years, seasons and regions were selected to be part of a survey. The summer and winter period were contrasted across years. Three farms in each range of high, middle or lower values for the summer period where selected from each of the years 2014, 2015 and 2016. From the spring period of 2016, five farms with middle range MUN concentrations and two farms with low range MUN concentrations were selected from each of the North-East and Far North-West regions.

The farmer survey asked questions of farmers regarding their farming system, milking herd diet and farm's pasture quality. The survey was presented to 30 farmers selected from the dataset either as having low or average or high MUN results in the data set across regions and years. The results obtained from the farmer survey were used to calculate the inferred diets fed to the milking cows on each farm at the time of each herd test, as best estimated by the farmers. Using Rumen8 (Version 3.4.0.1, July 2019) the 42 inferred individual farm diets were calculated based on diets described by farmers in the survey and the diet information was then matched for: the type of dairy cow (Holstein, Jersey, other), liveweight (kg), liveweight change (kg/d), days pregnant, days in milk, milk yield (l/d), milk fat (%m/v), milk true protein (%m/v), farm terrain (flat, undulating, steep), distance walked (km/d) and provided the individual dietary ingredients with either the relevant DM or "as fed" values. From these data inputs the nutritional intake of each diet fed was calculated.

Statistical Analysis

Box and whisker plots were used to explore the correlations between seasons, regions and milking times using R (R Core Team, 2019) with the package ggplot 2. Statistical analysis was completed in R (R Core Team, 2019) with the linear model (lm) function. Significance was determined using the anova function based on the fitted model. Where required, differences between means were determined using the Tukey test in the emmeans package.

RESULTS

Monthly herd test data was categorised into 4 seasons: summer (Jan-Feb-Mar), autumn (Apr-May-Jun), winter (Jul-Aug-Sep) and spring (Oct-Nov-Dec) (Table 1). The MUN data is presented in mg/dL for each season for the three years 2014, 2015 and 2016. Summer's mean MUN value of 16.5 ± 0.232 mg/dL was significantly ($P < 0.05$) lower than for all the autumn, winter and spring obtained values. Spring mean MUN value was 17.5 ± 0.238 mg/dL, significantly ($P < 0.05$) lower than for both the winter and autumn values. Winter's mean MUN value of 20.0 ± 0.273 mg/dL was not significantly ($P < 0.05$) lower than autumn's mean MUN value of 20.5 ± 0.255 mg/dL.

The summer of 2014 showed lower MUN concentrations from Tasmanian herd test results compared to 2016 results. Diet information for these two differing years obtained from the survey was entered in Rumen8 to calculate the metabolisable protein (MP; true protein absorbed by the intestine), CP % and excess protein. MP (g) showed a correlation (R^2 = 0.618) with MUN mg/dL. Seven of the herds entered in Rumen8 returned negative values for MP and excess protein. CP (%DM) showed a strong correlation (R^2 = 0.8129) with MUN mg/dL. Excess Protein also showed a strong correlation (R^2 = 0.8005) with MUN mg/dL. Excess protein (g/d) showed a stronger correlation (R^2 = 0.8457) with PM data than AM data (R^2 = 0.7683). Excess protein (g/d) had a similar correlation between regions Far North West and North East, (R^2 = 0.7419) and (R^2 = 0.7261) respectively.

Table 1. Statistical significance of seasonal MUN data in mg/dL for the three years 2014, 2015 and 2016. Seasons: summer, autumn, winter and spring and MUN mean value ± standard error. The values with the same letters of the alphabet represent those values that are statistically similar.

Season	MUN
Summer	16.5a ± 0.232
Spring	17.5b ± 0.238
Winter	20.0c ± 0.273
Autumn	20.5c ± 0.255

by using inferred diets and resulting MP balance (mg), CP (%DM), excess protein (g/d) and forgone low and high production (milk L), where relevant, MUN could be compared. MUN has a strong correlation with excess protein and additionally has a stronger correlation with the PM milk yields rather than the AM yields.

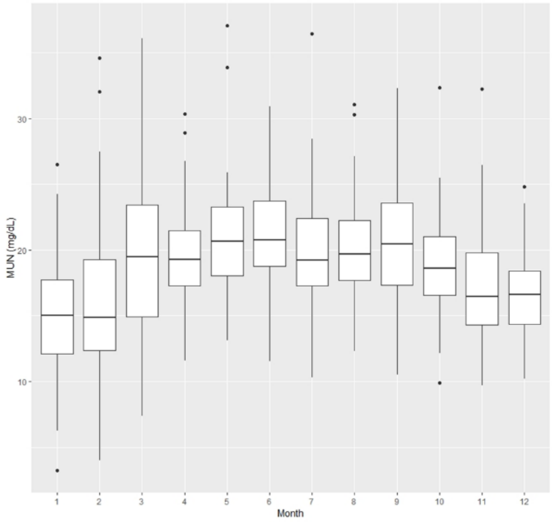

Figure 1. Combined 2014, 2015 and2016 monthly herd test MUN results in mg/dL. Months are January-1 – December-12, box = 25-75% - tile, bars are min – max, excl. outliers shown as dots.

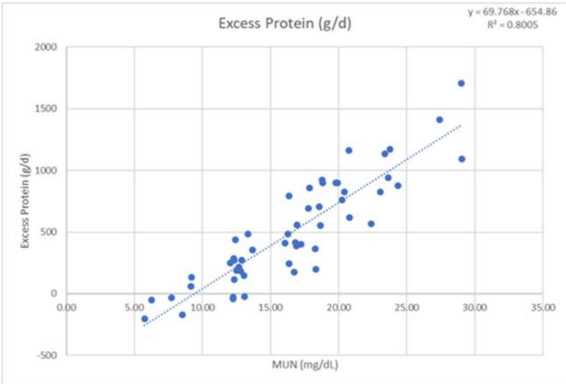

Figure 2. Excess protein (g/d) of all surveyed farms against MUN (mg/dL), (R^2 = 0.8005).

DISCUSSION AND CONCLUSIONS

This study investigated the usefulness of MUN concentrations for formulating dairy cow diets in a Tasmanian pasture-based dairy system, and as such as a pasture management tool. Protein is not only a considerable cost nutrient in a dairy cow diet, but can, if provided in excess of cow requirements, have a negative impact on milk production. This is due to the cow utilising increasing amounts of energy to excrete excess protein in the diet (Hof et al., 1997, Hammond, 1998). And lack of dietary protein limits milk production. MUN concentrations can be used by Tasmanian farmers, with the correct nutritional knowledge, as a tool to indicate if excess consumption of dietary protein is occurring. Although Tasmania differs in its cows' diets when compared to housed systems and other regions in the world such as New Zealand, where MUN is already being used as a tool to estimate the suitability of cow diets, it is a good indicator of dietary nitrogen excess or deficit. Many dry-land farms in Australia supplement a lot of feed in summer, which comes with a high risk of low CP in the diet. Dietary excess and deficits of proteins can be ameliorated once identified, through feeding of different amounts of supplements that contain higher concentrations of protein, and the adaption of fertiliser regimes with reduced or increased fertiliser applications when MUN concentrations are high or low respectively. Protein in the diet is either ruminally degradable or undegradable. The amount of degradable protein and fermentable energy in the diet should be matched, and undegradable protein should be of the correct amino acid composition to be of use to the animal post ruminally.

In addition, pasture management can be adapted through a change in leaf stage at the start of grazing; i.e., varying timing of grazing at lower or higher amount of leaf's (Donaghy and Fulkerson, 2001). This is not a straightforward decision as most dairy farms follow a 'feed wedge' grazing approach. However, it can be achieved through adaptational management such as skipping paddocks that are too advanced and therefore locking these paddocks up for silage or holding off on grazing paddocks for later in the grazing rotation by adding in supplements to slow the rotation down. And findings in the current season can be used to inform pasture management decisions in following years seasons.

Results of this study provide a proof of concept that in Tasmania's pasture based dairy system, MUN, if combined with dietary information including the amount of pasture grazed, can be used as an additional pasture management tool. Extension materials should be developed with decision support models to aid farmers interpret MUN and its correlation to cow diets and with decision making around pasture management and fertiliser regimes. The correlation between MUN and dietary CP in this study highlights that if MUN is known, management strategies can be adjusted to avoid going outside of MUN concentrations that are considered low <10 mg/dL, or high >20 mg/dL (Ishler, 2016). For validation of the results obtained in this investigation, a more in-depth study should test various dairy cow diets with regular milk sampling to establish appropriate MUN concentrations for each diet. This should include herds grazing varying levels of pasture varying in energy as well as CP content. This type of on-farm study with replication would validate the modelled data and support the discussed findings.

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The Economics of Total Mixed Ration Systems in Australia

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ABSTRACT

An increasing proportion of dairy farmers in Australia are looking to transition from pasture-based systems (**PB**) to confinement, zero-grazing or Total Mixed Ration systems (**TMR**) in response to climatic pressures, market volatility or growth opportunities. However, there is little understanding of the economics of these systems under local conditions, and therefore, farmers have typically had to rely on information from overseas to support their decision-making. This study, conducted as part of the DairyUP Program (https://www.dairyup.com.au), aimed to compare the performance of commercial dairy farms operating TMR with those operating PB. Physical and economic data from TMR (n = 7) and PB farms (n = 58) were collected across different regions in New South Wales over five financial years (2016/2017 to 2020/2021) using the Dairy Farm Monitor Project methodology. The TMR farms operated a range of confinement systems (drylots, compost barns or freestalls) and were in different phases of the transition towards zero-grazing (all had transitioned the milking herd to zero-grazing by 2020/2021). Prices were adjusted by inflation and expressed in Australian dollars per kg of milk solids ($/kg MS). Differences between systems were analysed using linear mixed models with farm and year as random effects. Compared to PB farms, the TMR had larger herd sizes (564 vs 356 cows) and total usable area (604 vs 291 ha) and produced more milk per cow (608 vs 491 kg MS/cow). Despite gross farm income ($9.30/kg MS) and earnings before interest and tax ($1.22/kg MS) being similar between both systems, profitability, when measured as return on total assets, was greater for TMR (5.3% vs 2.4%). On average, variable costs, including feed, herd and shed, were similar between TMR and PB ($4.98/kg MS). Both TMR and PB farms had similar total overhead costs ($3.08/kg MS), including total labour costs, depreciation and repairs & maintenance. This research is the first in Australia to investigate the differences in performance between TMR and PB systems. Insights from this study can help improve planning and decision-making of dairy farmers considering or operating TMR systems.

Keywords: confinement, zero-grazing, pasture-based, farm business analysis

INTRODUCTION

Dairy farming systems in Australia are predominantly pasture-based (**PB**), with most farmers relying on grazed pastures for at least nine months of the year (Dairy Australia, 2021). An increasing proportion of these farmers are looking to transition their production systems toward confinement, zero-grazing or Total Mixed Ration systems (**TMR**). Some of the motivations for investing in TMR include opportunities to grow the business, productivity increases, reduction of climatic risk or market volatility, availability of water and labour and animal welfare issues (R. Nettle, University of Melbourne, personal communication).

However, the information available on the economics of these systems is limited. Up to date, there are no studies in Australia that use comprehensive commercial dairy farm data to evaluate the performance of TMR systems. Therefore, farmers have had to rely on farm models or information from overseas to support their decision-making (Pinheiro et al., 2021).

The objectives of this study were to compare the physical and economic performance of commercial dairy farms in New South Wales (**NSW**) operating TMR systems with those operating PB systems.

MATERIALS AND METHODS

Data Collection

This study was conducted as part of DairyUP (https://www.dairyup.com.au), a research and development program in NSW, to improve dairy farm productivity and profitability, de-risk the industry and develop new markets. Physical and economic data from TMR (n = 7) and PB farms (n = 58) were collected across different regions in NSW (Australia) over five financial years (from 2016/2017 to 2020/2021). Some TMR farms participated in the five years of the study (n = 2), while others participated in three years (n = 3) or in two years (n = 2). The final dataset comprised a total of 184 observations from 65 TMR and PB dairy farms over five years. Data were collected following the Dairy Farm Monitor Project (**DFMP**) farm business analysis methodology adapted from Malcolm et al. (2005). Variables analysed included different key physical and economic indicators. Physical indicators refer to production outputs, physical inputs, productivity, and production efficiency measures (e.g., total milk production, number of cows, labour efficiency or milk/ha). Economic indicators refer to income, costs, and business profitability measures (e.g., gross farm income, variable and overhead costs, earnings or return on assets). Prices were expressed in Australian dollars per kg of milk solids (**$/kg MS**) and adjusted by inflation using the Consumer Price Index.

Statistical Analysis

Data collation and statistical analyses were performed with R software version 4.1.2. Linear mixed models were used to compare the differences in predicted means between TMR and PB for each variable. Mixed models were chosen due to their ability to deal with unbalanced datasets, repeated measures, and datasets with hierarchy. Farm and year were included in the models as random effects; however, region was not included as it did not improve the overall accuracy. All models were checked for assumptions of linearity, normality, and homoscedasticity. Significance was determined at $P < 0.05$.

RESULTS

The TMR farms operate using a range of confinement systems, which included drylots, compost barns or freestalls. Over the five year period of analysis, the TMR farms were in different phases of the transition toward zero-grazing; however, all had transitioned to zero-grazing for the milking herd by 2020/2021. On average, the TMR had larger herd sizes (+200 cows), total usable area (+300 ha), and produced 24% more kg of milk solids (**kg MS**) per cow than the PB farms (**Table 1**). Milk solids produced per usable area (kg MS/ha) and labour efficiency (measured as kg MS per full-time equivalent [**FTE**]) were similar between the two systems. When measured as gross income per FTE, labour efficiency tended to be higher for TMR farms ($ 349,632/FTE vs $ 417,873/FTE; P = 0.058). On average, the proportion of homegrown feed in the diet was almost 20 percentage points greater for PB farms. No differences were found between systems in gross or milk income; however, TMR farms had 68% higher livestock trading profit and feed & water sales (**Table 2**). All variable costs, including herd, shed, and feed, were similar for TMR and PB farms. Except for imputed labour, no differences were found in overhead costs (including total labour, depreciation or repairs & maintenance). Profit before and after taxes (expressed as earnings before interest and tax [**EBIT**] and net farm income) were similar for PB and TMR. Overall farm profitability, measured by return on total assets (**RoTA**), was almost three percentage points greater for TMR farms.

Table 1. Physical indicators evaluated

Item	PB[1]	TMR[2]	SED[3]	P-value
Cows (n)	356	564	65	0.039
Usable area (ha)	291	604	67	0.003
Total MS (kg)	179,090	346,590	38,570	0.005
Litres/cow	6,693	8,595	329	<0.001
[4]kg MS/cow	491	608	21	<0.001
kg MS/FTE[5]	38,474	44,820	3,026	0.168
kg MS/ha	665	696	62	0.738
Homegrown feed (%)[6]	59	40	4	<0.001

[1]**PB** = pasture-based systems, [2]**TMR** = Total Mixed Ration systems, [3]**SED** = average standard error of the difference, [4]**kg MS** = kilograms of milk solids, [5]**FTE** = full-time equivalent (2,400 h/yr, calculated as 48 h/wk for 50 wk), [6]Proportion of homegrown feed in the diet.

Table 2. Economic indicators evaluated. Prices are expressed in Australian dollars per kilogram of milk solids ($/kg MS)

Item	PB[1]	TMR[2]	SED[3]	P-value
Gross income	9.19	9.41	0.36	0.540
Milk income	8.21	7.88	0.31	0.262
Livestock trading profit	0.80	1.17	0.11	0.017
F&W sales[4]	0.02	0.21	0.02	0.020
Variable costs	4.79	5.17	0.28	0.221
Herd costs	0.38	0.34	0.04	0.470
Shed costs	0.29	0.35	0.03	0.165
Feed costs	4.12	4.49	0.27	0.185
Overhead costs	3.31	2.85	0.21	0.149
Labour costs	2.04	1.73	0.14	0.151
Imputed labour	1.05	0.41	0.17	0.016
Employed labour	1.00	1.35	0.14	0.094
R&M[5]	0.48	0.43	0.04	0.461
Depreciation	0.38	0.37	0.04	0.868
Other overheads	0.31	0.25	0.04	0.279
Farm insurance	0.11	0.08	0.01	0.119
EBIT[6]	1.07	1.37	0.37	0.497
Lease costs	0.19	0.00	0.07	0.066
Interest costs	0.43	0.51	0.09	0.545
Net farm income	0.48	0.86	0.38	0.387
RoTA[7] (%)	2.42	5.34	0.93	0.009

[1]**PB** = pasture-based systems, [2]**TMR** = Total Mixed Ration systems, [3]**SED** = average standard error of the difference, [4]**F&W** = feed and water, [5]**R&M** = repairs and maintenance, [6]**EBIT**= earnings before interest and tax, [7]**RoTA** = return on total assets.

DISCUSSION AND CONCLUSIONS

This research aimed to compare the physical and economic performance of dairy farms operating TMR and PB systems.

Our study showed that TMR farms were more profitable than PB when measured by RoTA. The level of profitability achieved by TMR systems was above the historical DFMP average and also greater than the 5% target that would sustain industry growth (Australian Dairy Plan, 2020). Profitability was particularly stronger in the years 2019/2020 and 2020/2021, aided by higher milk prices due to intense processor competition for milk. Variability in RoTA, however, was higher for TMR farms, something probably explained by these systems having more exposure to the purchased feed market (data not shown). Despite TMR farms having higher profitability, EBIT was similar for both systems. This is reflective of PB farms being located predominantly along the coastal region of NSW, which typically sees increased asset values and therefore reduces RoTA.

One of the motivations for transitioning to a confinement system is the potential to scale up the business. In fact, our results showed that TMR farms typically managed larger farm areas, had more cows and produced more milk solids than PB farms. The TMR farms were predominantly distributed in the inland or central and southern inland regions of NSW, where large tracts of land are more available. In contrast, and as mentioned before, the PB farms were mainly located in the coastal or hinterland areas of the state, where land is usually more expensive due to competition with other industries, urbanisation and the presence of 'lifestyle' blocks.

Another characteristic of these systems is the potential to increase productivity. In our study, we found that litres and kg MS produced per cow were 28% and 24% higher for TMR, respectively. This can be explained by cows in a TMR usually achieving higher dry matter intake and a more consistent diet (Kolver and Muller, 1998). On the other hand, and contrary to expected, we found no apparent improvements in labour efficiency (kg MS/FTE) for TMR farms, which also appeared to be lower than in previous studies conducted overseas (Caraviello et al., 2006, Salfer et al., 2018). However, it is important to mention that labour efficiency calculated using gross income ($/FTE) tended to be higher for TMR farms. The TMR farms had a larger proportion of the income coming from livestock trading and feed & water sales. This is indicative of labour being used in other areas of the business not directly related to milk production and is not captured when using kg MS/FTE as an indicator. Also, it may indicate a business diversification strategy for some of the TMR farms.

In general, there were no major differences in the cost structures between TMR and PB farms. Variable costs, including feed costs, were similar for both systems; however, we found that TMR farms spent more on purchased feed ($/kg MS), particularly in the 2019/2020 year (data not shown). This was due to a prolonged drought and limited irrigation, which heavily impacted those farms more exposed to the purchased fodder market. Also, it is worth mentioning that despite both systems having similar overhead costs (including total labour costs), TMR offset lower imputed labour costs by a trend to higher employed labour.

This research is the first in Australia to investigate the differences in performance and cost structures between TMR and pasture-based systems. Caution should be taken with these results, as the number of TMR farms is relatively small, not all farms participated in every year of the study, and some were in different stages toward zero-grazing. Additionally, the TMR and PB farms were located in contrasting regions with differences in weather, access to irrigation and feed availability. Nonetheless, insights from this study provide a starting point for dairy farmers considering zero-grazing systems and could help them improve planning and decision-making. Future work will focus on increasing the number of observations and including a social research component to better understand the motivators, challenges, and information gaps related to investing in these systems.

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CONFLICT OF INTEREST DECLARATION

There are not real or perceived conflicts of interests.

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The effect of climate change on a New Zealand dairy system

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ABSTRACT

Temperate pasture-based farming systems are vulnerable to changes in the climate. In New Zealand, there is growing farmer interest in climate change adaptation strategies that will minimise production or profit losses over the coming decades. The objectives of this study were to quantify the effects of two future climate scenarios on the performance of a modelled dairy farm in the Northland region of New Zealand at the middle and end of the century, and to evaluate the impact of adaptation strategies on farm profit. The current farm ('baseline') relies on kikuyu (*Cenchrus clandestinus* (Holst. Ex Chiov.)) and Italian ryegrass (*Lolium multiflorum Lam.*) to maintain year-round pasture production. Mid- and high-emission climate scenarios were sourced from the National Institute of Water and Atmospheric Research (NIWA) to simulate the potential effects of climate change on pasture supply. Future pasture supply and farm profitability were simulated using the mechanistic model DairyMod and commercial Farmax model, respectively. Overall, annual pasture yield increased in all future scenarios compared with the baseline, however, pasture growth patterns were altered. The changes in pasture growth patterns were less severe in the mid-emission than high-emission scenarios, with the end of the century scenario producing 7% more pasture DM than the baseline. In comparison with the baseline, pasture growth increased (11% and 22%) from winter to mid-spring, but reduced in December (30% and 40%) for the high-emission scenario in the middle and end of the century, respectively. The modelled adaptation strategies demonstrated the potential to increase farm profit in all future scenarios compared with the baseline, with the end of the century mid-emission scenario increasing profit by 11%. This suggests that minimal adverse effects are expected from future climate change on the performance of kikuyu-Italian ryegrass-based dairy systems in the Northland region of New Zealand, and that farm profit may be improved by tactically managing changes in feed supply and animal demand. However, the methods applied do not take extreme weather events into account, and implications of these should be investigated in future work.

Keywords: Climate change, adaptation, modelling, farming systems

INTRODUCTION

Climate is a defining feature of pastoral agriculture (Kalaugher *et al.* 2017). In New Zealand, as in the rest of the world, climate change impacts are becoming apparent in the form of rising air temperature, increasing occurrence of extreme climate events and substantial variation in rainfall (Reisinger *et al.* 2014). The New Zealand dairy industry remains relatively low input as grazed pasture is the main source of feed compared with those in Europe and North America that rely on mixed rations (Kalaugher *et al.* 2017). As a result, studies on the impacts of climate change on New Zealand dairy systems primarily focus on pasture productivity, as the amount of dry matter (DM) consumed per hectare is closely linked to profit (Chapman *et al.* 2009).

Climate change projections vary across New Zealand as the mountainous terrain gives rise to considerable regional and localised climate variability (Reisinger *et al.* 2014). Consequently, climate impacts on pasture growth and quality are likely to be non-uniform across the country. Modelling by Kalaugher *et al.* (2017) showed that under a high-emissions scenario, the decrease in ryegrass-based pasture production ranged from 0 to 18% for six farms located across the major dairying regions of New Zealand. Therefore, adaptation analysis must be region-specific.

To minimise production losses over the coming decades, pasture-based dairy systems must adapt to the changing climate (Dynes *et al.* 2010). Adapting to the projected climate could enable farmers to take advantage of new opportunities and minimise any negative risks associated with climate change. Possible adaptations include changing calving dates, supplementary feeding and more efficient pasture conservation practices (Kalaugher *et al.* 2017; Dynes *et al.* 2010). The objectives of this study were to evaluate the effect of climate change on a Northland farm at the middle and end of the century, and to evaluate the impact of adaptation strategies on farm productivity and profitability.

MATERIALS AND METHODS

Site

The Northland Agricultural Research Farm (NARF) (35º56’39” S 173º50’34” E), in the Northland region of New Zealand, was selected as the case study farm for this study. NARF is comprised of small-scale farms (farmlets) to compare different farm systems. The ‘standard’ farmlet consists of 28 ha of pastures dominated by kikuyu ((*Cenchrus clandestinus* (Holst. Ex Chiov.))) and Italian ryegrass (*Lolium multiflorum Lam.*) that are common in Northland to maintain year-round production. Soil types are heavy clay on 25 ha and sandy soils on 3 ha with 180 kg nitrogen (N) per hectare applied annually. The average performance of the ‘standard’ farmlet over three production seasons (2018-19, 2019-20 and 2020-21) was used to form a current baseline. Stocking rate was 3.1 cows/ha, producing an average of 1209 kg milksolids (MS)/ha and 389 kg MS/cow. Supplementary feeds consisted of home-grown pasture silage and palm kernel expeller (PKE).

Future climate scenarios

Climate data from 2010 to 2100 were generated from the National Institute of Water and Atmospheric Research’s (NIWA) virtual climate station network (VCSN), which consists of 5 km x 5 km grid cells across New Zealand. The daily climate variables of minimum and maximum temperature (°C), rainfall (mm), solar radiation (MJ/m^2), atmospheric CO_2 concentration (ppm) and vapour pressure (kPa) were simulated for the NARF. Data for six Global Circulation Models (GCM) were used to model two representative concentration pathways (RCP) that represent possible greenhouse gas trajectories to the year 2100. Capellán-Pérez *et al*. (2016) estimated that the likelihood of exceeding each RCP by 2100 was 100% (RCP2.6), 92% (RCP4.5), 42% (RCP6.0) and 12% (RCP8.5). Therefore, RCP4.5 and RCP8.5 were selected to approximate the 90% and 10% confidence intervals for climate change. RCP4.5 and RCP8.5 represent radiative forcing values in 2100 (4.5 and 8.5 W/m^2, respectively).

Pasture growth modelling

The biophysical model DairyMod (Johnson *et al.* 2016; version 5.8.2) was used to simulate growth rates of the baseline farm in the middle and end of the century under the RCP4.5 and RCP8.5 projections in the middle and end of the century. A multi-paddock simulation was used to replicate the baseline farm in DairyMod. The default kikuyu and annual ryegrass (representing Italian ryegrass) species were selected. Paddocks were grazed on a rotational basis with pre- and post-grazing residuals of 2.5 t DM/ha and 1.8 t DM/ha, respectively. To simulate the annual pasture transitioning from kikuyu to ryegrass, the model was calibrated based on NARF preparation practices. Kikuyu pastures were cut immediately after grazing to 0 t/ha from the 15th of March until the 15th of May annually to allow ryegrass to emerge. DairyMod was run for 10 seasons from 2041 to 2051 and 2081 to 2091, and growth rates for each GCM were averaged to provide pasture curves at the middle and end of the century as affected by RCP4.5 and RCP8.5.

Farm performance and adaptation modelling

Simulated pasture growth rates for RCP4.5 and RCP8.5 in the middle and end of the century were used in Farmax to model the effect of climate change on farm productivity and profitability. The scenarios were run with the same management practices and energy content as the baseline but with the growth rates simulated by DairyMod. To create biologically feasible farms, a range of adaptation strategies were utilised to match pasture supply and animal demand. These included conserving pasture as silage and feeding this during deficits. In addition, calving and dry-off dates were shifted to match pasture supply patterns.

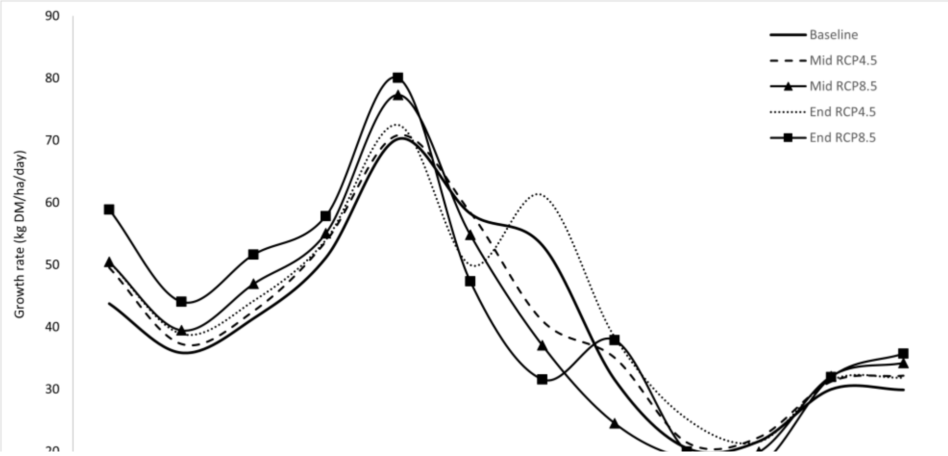

Figure 1. Growth rates for the baseline and the middle (Mid) and end of the century (End) scenarios at RCP4.5 and RCP8. 5.

RESULTS

The effect of climate change on pasture growth simulated by DairyMod is shown in Figure 1. Pasture growth rates were greater from winter to mid-spring (June-October) for all scenarios compared with the baseline. Throughout these months, pasture growth was the highest for the RCP8.5 scenarios, with a 10% (mid-century) and 14% (end-century) greater peak in October than the baseline. Additionally, pasture growth increased (on average 11% and 22%) from winter to mid-spring for the RCP8.5 scenarios compared with the baseline. However, these scenarios had a greater reduction in pasture growth in December than RCP4.5. Overall, the changes in growth patterns were less severe for RCP4.5 compared with RCP8.5 scenarios. As a result, the increase in annual yield was greater for the RCP4.5 scenarios, producing 7% more pasture DM at the end of the century than the baseline (Table 1).

Table 1 shows that the stocking rate was maintained in all scenarios. Farm profitability increased in all future scenarios compared with the baseline. The RCP4.5 end-of-century scenario had an 11% increase in profit compared with the baseline due to the 1 t DM/ha increase in pasture yield, enabling 16 t DM more home-grown silage to be fed. This resulted in 45% less PKE required to produce a similar amount of milk. Additionally, calving date was shifted from July 7th to June 7th (mid-century) to reduce animal demand during the greatest summer pasture deficit, and to July 1st (end-century) in the RCP8.5 scenarios. This matched peak milk production with peak pasture growth to increase the proportion of pasture eaten.

Table 1. The physical farm summary of the baseline, and adapted scenarios at the mid- and end-of-century at RCP4.5 and RCP8.5.

		Mid-century		**End-of-century**	
	Baseline	**RCP4.5**	**RCP8.5**	**RCP4.5**	**RCP8.5**
Stocking rate (cows/ha)	3.1	3.1	3.1	3.1	3.1
MS (kg/ha)	1,207	1,208	1,226	1,209	1,208
Calving date	July 7th	July 7th	June 7th	July 7th	July 1st
Dry-off date	May 14th	May 14th	April 14th	May 14th	May 8th
Days in milk	266	266	264	266	260
Pasture yield (t DM/ha)	14.8	15.1	14.9	15.8	15.7
PKE (t DM)	73	59	75	40	60
Silage (t DM)	24	36	28	40	43
Profit ($/ha)	87,463	90,572	89,855	96,773	89,556

DISCUSSION AND CONCLUSIONS

The increase in DM production for the future scenarios compared with the baseline indicate that climate change may increase the performance of kikuyu-Italian ryegrass-based dairy systems in the Northland region of New Zealand. Modelled scenarios generally displayed elevated pasture growth rates in winter and early spring (June-October), and reduced growth from mid-spring to summer (November-December). These trends were amplified as the severity of climate change increased from RCP4.5 to RCP8.5 with higher temperatures and atmospheric CO_2 causing greater growth in winter, whereas increasing water deficit and higher temperatures depressed summer growth. This is consistent with studies in New Zealand (Kalaugher *et al.* 2017; Dynes *et al.* 2010) and Australia (Harrison *et al.* 2016) that modelled increased winter and early spring growth coupled with summer-autumn lows and shorter spring growing seasons. However, as the total DM produced increased, this indicates that the combination of subtropical (kikuyu) and temperate (Italian ryegrass) grasses may provide a suitable pasture-base in the future.

This study showed that tactical adaptations have the potential to compensate for climate change impacts on dairy farm performance in the Northland region of New Zealand while improving profitability. All future scenarios increased profit compared with the baseline due to earlier pasture conservation, reducing supplementary feeding where possible and altering calving dates. This study supports results reported by Kalaugher *et al.* (2017) and Dynes *et al.* (2010) that utilising surplus pasture for silage minimised the negative impacts associated with climate change and increased farm profit in regions of New Zealand.

This study focused on gradual climate change, using averaging to model future pasture growth rates. This approach likely reduced the effect of extreme events such as heatwaves and droughts (Harrison *et al. 2016*), the frequency of which will adversely affect farm systems. Further modelling of climate projections on agricultural systems should investigate these extreme events.

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Calculation of pasture intake from individual paddocks using cow energy requirements on a commercial farm scale

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ABSTRACT

Direct estimation of pasture growth and utilisation on individual paddocks based on cutting quadrats, use of plate meters, or visual scoring is labour-intensive, and the more rapid methods typically have low accuracy. Emerging technologies such as satellite estimation and GPS devices for determining paddock grazings may also have cost, accuracy, timeliness, or reliability limitations. An alternative, indirect approach is to estimate the energy used for maintenance, production, liveweight change, pregnancy, and activity, subtract any energy supplied from supplements fed, and then infer how much of this energy must have been harvested from each paddock grazed.

We show that for a farm with accurate grazing records, milk yields recorded at each milking, regular liveweight and body condition score (BCS) data, estimates can be made of paddock-level energy harvest that are somewhat consistent with estimates based on direct pasture measurements made with a plate meter ($R^2 = 0.14$). However, the accuracy of the results may not be sufficient to identify high- and low-performing paddocks for the purpose of management intervention. While small sample sizes prevented the identification of differences between cultivars in our study, improvements in the automated recording of some data (e.g., using GPS cow tags to identify paddocks grazed) and in the ease of recording manual data (e.g., mobile apps for recording supplements fed) could lead to these calculations being performed more accurately and across many farms, and so identifying differences in pasture performance.

Keywords: Pasture utilisation; Back calculation; Energetics; Grazing; On-farm data

INTRODUCTION

In countries with temperate climates, such as New Zealand, grazed pasture plays a vital role in farm production and profitability (Neal & Roche, 2020). Despite the importance of pasture, many farmers do not regularly measure pasture cover, or record paddocks grazed (Anderson & McNaughton, 2018). For farmers who conduct regular farm walks, the information is usually used for immediate decisions, such as where cows will graze, but is not retained after these decisions have been made (Stevens & Knowles, 2011). Consequently, the opportunity to determine the performance of individual paddocks at the farm level is lost. This affects the ability to make effective management decisions, such as regrassing poorly-performing paddocks and comparing the performance of different cultivars or species on-farm.

Brookes and Holmes (1988) showed that it is possible to estimate pasture utilisation by calculating the feed requirements of individual animals and adjusting for any purchased feeds or crops fed. We extend this to back-calculate the performance of particular paddocks based on the energy requirements of individual animals. Data from a commercial dairy farm (Southern Dairy Hub (SDH)) was used. Results were compared with rising plate meter estimates of pasture harvest to identify any differences between the back-calculated and plated measurements. Finally, differences between cultivars using both approaches were compared.

MATERIALS AND METHODS

Site Details

SDH is a 299-hectare (effective) dairy farm subdivided into 104 paddocks situated at

Wallacetown, near Invercargill, New Zealand (- 46.311, 168.303).

The data from a trial comparing the performance of four pasture cultivars (described in Hammond, 2021) was used. In the 2020/2021 dairy season, the farm milked 720 cows, divided into four herds at peak and produced 299 000 kgMS (approx. 415 kgMS/cow). Over the period of interest, the farm was milking twice a day.

Measurement of pasture disappearance

Individual paddock herbage disappearance for the six months from 10th October 2020 to 31st March 2021 was determined by the difference between the pre- and post-grazing measurements taken using a rising plate meter (model: Jenquip EC09) before and after each grazing or pasture conservation event (e.g., cutting for silage). At each assessment, 160-240 plate meter measurements were taken in each paddock by walking in a "W" shape and measuring every four steps. Calibration cuts were undertaken fortnightly from selected paddocks to develop plate meter equations to convert the compressed sward height to pasture drymatter yield (Hammond, 2021). Where possible, pre-grazing measurements were taken within 48 hours of grazing. Otherwise, an adjustment was made to the pre-grazing measurement to reflect the likely increase in cover between the pasture measurement period and grazing.

Estimation of energetics back-calculation

Daily individual cow energy requirements were calculated from farm data, including individual cow liveweight, individual milk production, and total supplements fed, using the equations in Nicol and Brookes (2007).

Individual cow liveweights were recorded at each milking using a walk-over weighing system installed at the cowshed. To correct for changes in gut fill and missing weights, the average daily liveweight of each treatment group was smoothed using the loess function (with span = 0.8) in the R statistical software (R Core Team, 2022) to provide a more reliable representation of individual treatment liveweights and liveweight change over time.

Milk production data were recorded at each milking using inline milk meters as part of a DeLaval DelPro system. As individual cow milk fat and protein percentages were unavailable, the average herd milksolids (i.e., milk fat plus protein) percentage (9.1%) for the season was applied across the daily milk total to estimate the daily milksolids production for each treatment group.

Metabolisable energy (MJME) from individual supplements fed was based on Near Infrared Reflectance Spectroscopy (NIRS) testing of feed samples. The total energy obtained from supplements fed was then adjusted based on typical on-farm utilisation of that supplement (Table 1), with higher utilisation values being used for meal fed in the cowshed (95%) compared with silage and crops fed (90%) in the paddock.

Table 1. Supplement and pasture metabolisable energy values (MJME /kgDM) and utilisation factor used in the backcalculation of pasture harvest.

Supplement	MJME	Utilisation %
Silage Bales	9.8	90
Fodder Beet	12.9	90
PKE	10.5	95
PKE Blend	11.5	95
Pasture	11.7	-

After subtracting the energy provided by supplements, the remaining energy balance was assumed to have come from paddocks grazed. If the cows were offered two different paddocks on the same day (i.e., different night and day paddocks), the energy was assigned 50/50 between the two paddocks, a method previously used by Haultain (2014). The average MJME content of the perennial ryegrass (*Lolium perenne*) white clover (*Trifolium repens*) pasture was 11.7, as assessed by NIRS during the trial period, with no adjustment being made for pasture utilisation. In this way dry matter harvested from each paddock was calculated.

Where pasture was conserved as silage during the trial period, the pasture drymatter harvested per hectare was calculated as the number of bales per paddock multiplied by 220 kgDM per bale and divided by paddock area. This was then added to the back-calculated estimate of dry matter harvested from each paddock to estimate the total drymatter harvested in each paddock over the six months of the study.

Finally, the pasture harvest estimates (based on energy back-calculation) were compared with pasture disappearance measured by the rising plate meter, for individual paddocks and for each cultivar.

RESULTS

The correlation between the back-calculated estimates of dry matter harvested and rising plate meter estimates of dry matter disappearance was positive, as expected, but weak (R^2=0.14, Figure 1). Back-calculated harvest was generally higher than pasture disappearance based on plating, even though the latter did not include an adjustment for utilisation.

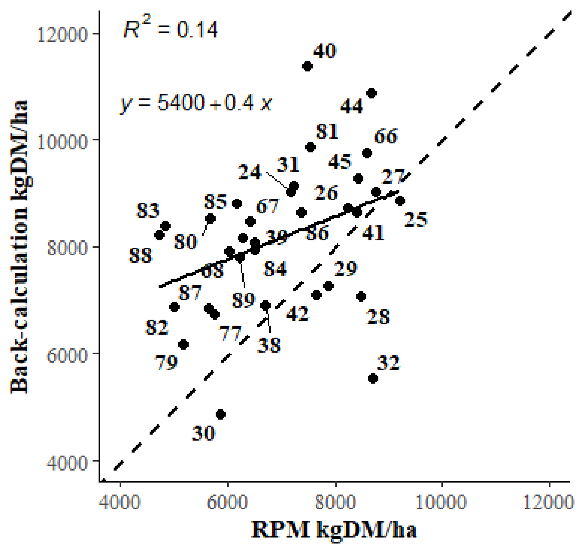

Figure 1. Comparison of paddock level pasture harvest from energetics back-calculation with pasture disappearance from rising plate meter (RPM) differences. The dashed line is the 1:1 line, and the solid line is the regression line.

Using the back-calculation approach, yields from the four cultivars were not statistically different for the period analysed. Likewise, no significant differences were found using the pasture disappearance approach for the same period. This is not surprising given the small number (8) of paddocks per cultivar and the typically high between-paddock variation on farm.

DISCUSSION AND CONCLUSIONS

Methodology

This paper established an energy back-calculation method for estimating pasture harvest from individual paddocks on a commercial-scale dairy farm. Although the predictions of pasture harvest were only weakly correlated with those based on direct rising plate meter measurements, this could be improved if more detailed feed quality and utilisation information and more accurate cow liveweight data were available. Similarly, had daily milk fat and protein percentages been available for individual animals, the daily estimate of milksolids production could have been improved. However, unfortunately, multiple herds were milked into one vat.

Commercial application

Although the SDH farm is a commercial-scale farm, it is also a research farm with unusually detailed data collection. For example, during this study, each treatment only had a single herd. If there were multiple herds (grazing different paddocks), without records of animal count per herd, and no herd-level measurement of milk production (e.g., milking into one vat, no individual milk meters), further assumptions on the energy source used to produce the milk would be required. Animal-level milk yield is often determined from herd test data, typically performed only three to four times per year on commercial farms.

Some of the other data required are also unlikely to be as readily available for commercial farms, including the quantity of supplement fed per day and the number of grazings per paddock. In addition, most commercial dairy farms do not have in-shed walk-over scales; therefore, daily liveweight and liveweight change would have to be estimated (e.g., from published studies) to calculate daily metabolisable energy requirements for maintenance and liveweight change. While liveweights would generally be similar at the start and end of an annual period (and so balance out), they will vary throughout the year and thus could impact the estimates of paddock level energy utilisation, particularly when only looking at a proportion of the year, such as in this study.

Despite limitations, this approach provides a logical framework to estimate the dry matter production of individual paddocks on-farm. With the increasing use of technology on-farm, many components of the data set can be automatically collected, such as the daily milk volume of the herd and the paddocks grazed. If this data can be integrated with other farm data, calculating the energy required per paddock can be a semi-automated process.

Potential for cultivars

Pasture yield is usually measured at plot level with calibration cuts (for evaluation of forage species and cultivars) or estimated with devices (e.g., rising plate meter) for operational decision-making. However, cut data may not reflect paddock-level yields under farm-scale grazing conditions, and device measurements may also be labour-intensive or uncalibrated. Additionally, these methods are typically costly when conducted to a high standard of rigour and do not scale well to multiple farms, which would be a requirement to determine performance under different environmental conditions (e.g., climate, pest pressure, etc.). The energy back-calculation method presented here has the potential to (with further development) leverage largely-existing farm data recording systems to estimate the performance of individual paddocks sown in existing or new forage species and cultivars. This information could be invaluable for developing more productive grazing systems in the future.

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CONFLICT OF INTEREST DECLARATION

There were no real or perceived conflicts of interest to report.

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Composition of kikuyu and ryegrass based pastures during summer and autumn in Northland, New Zealand

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ABSTRACT

Kikuyu pastures are common on dairy farms in the north of New Zealand. Intensive management systems for kikuyu pastures have been developed to optimise pasture quality for livestock performance. The objective of this study was to compare the composition of intensively managed kikuyu (IMK) and extensively managed kikuyu (EMK) pastures, and ryegrass-based pastures (RGP), sampled five times during summer and autumn (January – June) 2022 on a Northland dairy farm. The chemical composition of the samples was analysed using near-infrared spectroscopy and values compared to pasture values used for the national GHG inventory. The EMK and RGP contained more than twice as much dead matter as IMK (P=0.048). The crude protein (CP) content of IMK was similar to that of RGP, and both contained nearly double the CP concentration compared to EMK (P=0.007). The neutral detergent fibre (NDF) and acid detergent fibre (ADF) were greater (P<0.005) in EMK than in IMK and RGP. The composition of the NDF, in terms of hemicellulose, cellulose and lignin, was, however, similar among the three pasture types. Organic matter digestibility (OMD, DOMD) and metabolisable energy content of EMK tended to be less (P<0.10) than in IMK and RGP. In conclusion, intensive management of kikuyu pasture is a tool to decrease the dead matter content of these pastures and improve the quality (more protein and less fibre) of kikuyu pastures, similar in nutrient composition to ryegrass pasture. The CP and ME values observed in both IMK and RGP were, however, less than currently used as part of the calculations of GHG emissions in the national GHG inventory.

Keywords: *Cenchrus clandestinum*, tropical grass, climate change, global warming, greenhouse gas

INTRODUCTION

The changing climate in New Zealand (NZ) resulting from global warming is projected to increase the dominance of (sub)tropical C4 forages in NZ (Kenny 2001). *Cenchrus clandestinum* (known as, kikuyu grass and *Pennisetum clandestinum*) is already dominant in many pastures during summer and autumn in Northland and other coastal locations in the upper North Island (DairyNZ 2019) and is expected to move further south with the warming of the climate (Kenny 2001). Kikuyu is a tropical grass with a C4 photosynthetic pathway which generally has a lower quality than temperate grass species such as ryegrass. However, kikuyu maintains a much greater pasture growth during summer (DairyNZ 2017). A kikuyu management guide has been developed by the Northland Dairy Development Trust to improve its pasture quality (DairyNZ 2019) and well-managed kikuyu-based pasture is a key component of many profitable Northland farming systems (Boom *et al.* 2015).

The objective of this study was to compare the composition parameters of intensively managed kikuyu (IMK) and extensively managed kikuyu (EMK) pastures, and ryegrass-based pastures (RGP), sampled five times during summer and autumn. These values also were compared to monthly pasture quality parameters used in the New Zealand greenhouse gas (GHG) inventory to estimate dairy cattle enteric methane emissions (Pickering *et al.* 2021).

MATERIALS AND METHODS

The samples of intensively managed kikuyu (IMK), extensively managed kikuyu (EMK) pastures, and ryegrass-based pastures (RGP) were collected on the Northland Agricultural Research Farm (NARF; Dargaville, NZ). The IMK pasture was managed according to best practice (DairyNZ 2019) which includes maintaining a moderate to high stock pressure and low post-grazing residuals from January to March when kikuyu is the dominant pasture species, then mechanical mulching of kikuyu pasture to near ground level in autumn and sowing in Italian ryegrass.

Samples of the IMK and RGP pastures were collected from multiple paddocks that were next to be grazed (after 40±11 days of regrowth) as part of the NARF dairy farm, similar to that described by Boom *et al.* (2015). The EMK pastures were not grazed since onset of spring growth and represent pastures outside a rotational grazing dairy block, which might be used for other livestock categories or harvesting. Samples were collected by cutting pasture to a height of 4 cm at >20 sites across the paddock. Sampling occurred on 20 January, 28 February, 29 March, 2 May and 27 June 2022. Weather data was collected using a weather station located at the farm (Table 1). Pasture cover in the sampled paddocks was estimated using a rising plate meter with a calibration equation for ryegrass-based pasture: compressed pasture height × 140 + 500. No specific calibration for IMK and EMK swards were available.

Table 1. Average temperature (temp) and the sum of precipitation (rain) per month at the farm between December 2021 and June 2022 and the long-term average values for Whangarei (NIWA 2022).

	2021/2022		1981-2010	
	temp (°C)	rain (mm)	temp (°C)	rain (mm)
Dec.	20	80	19	96
Jan.	20	40	20	81
Feb.	21	64	20	95
March	19	108	19	118
April	17	71	17	99
May	15	83	14	111
June	13	120	12	132
Mean	18	81	17	105

After sampling, an aliquot was dissected in the different forage species present in each of the pastures and dead matter content. Another aliquot was dried at 65°C for >36 h and then submitted for Near Infrared Spectroscopy analysis to Hills Laboratory (Hamilton, NZ).

Data was analysed using one-way ANOVA in GenStat (19th edition; VSN International, Hemel Hempstead, UK) with multiple-treatment comparison using the Tukey statement at P<0.05.

RESULTS

The herbage mass of pasture sampled was on average more than 1.5 times greater (P<0.001) for EMK than for IMK and RGP (Table 2). The RGP samples consisted mainly of ryegrass (>78%) and EMK and IMK consisted mainly of kikuyu (>85%), except during the last sampling of IMK which consisted of 68% ryegrass plus white clover. The EMK and RGP contained on average more than twice as much dead matter as IMK (P=0.048).

The crude protein (CP) content of IMK was similar to that of RGP, and both contained nearly double the CP concentration compared to EMK (P=0.007). The neutral detergent fibre (NDF) and acid detergent fibre (ADF) were greater (P<0.005) in EMK than in IMK and RGP. The composition of the NDF, in terms of hemicellulose, cellulose and lignin, was, however, similar among the three pasture types. Organic matter digestibility (OMD, DOMD) and metabolisable energy content of EMK tended to be less (P<0.10) than in IMK and RGP.

DISCUSSION AND CONCLUSIONS

The main findings of the current study were that IMK pasture had less dead matter and similar nutritional composition compared to RGP sampled at the same farm. This suggests that it would be possible to achieve similar per animal milk solids production performance on these two pasture types, as was observed in farmlet trials at the same farm (Boom *et al.* 2015). At the same time, pasture production would be expected to be 1.2 to 1.5 times greater for IMK than for RGP from January to June in Northland (Dargaville) (Boom *et al.* 2015;

DairyNZ 2017), which would therefore support a greater milk solids production per ha.

The EMK pasture contained less CP and ME and more fibre than RGP and IMK. This trend was similar to that previously found for leaves of kikuyu and ryegrass sampled in three regions of New Zealand (Jackson *et al.* 1996). The dead matter content of EMK pasture was similar to that in RGP pasture and therefore does not explain differences in chemical composition. However, the major difference of EMK with RGP and IMK was the much lower leaf-to-stem ratio, of 1.2 for EMK compared to 5.2 for RGP and 4.7 for IMK (data not shown), and the >1300 kg DM/ha greater pasture mass. Fulkerson *et al.* (2010) described that both CP and ME were less in kikuyu stems than in leaves.

Table 2. Mean (±standard deviation) pasture mass, botanical composition and chemical composition of intensively managed kikuyu pasture (IMK), extensively managed kikuyu pasture (EMK) and ryegrass based pasture (RGP) sampled five times between January and June 2022

	Intensively managed kikuyu	Extensively managed kikuyu	Ryegrass
Pasture-mass (kg DM/ha)	$2356^{a}\pm105$	$3661^{b}\pm472$	$2130^{a}\pm218$
Botanical composition (%DM)			
Kikuyu	$75.5^{b}\pm30.1$	$99.3^{b}\pm1.3$	$3.1^{a}\pm5.0$
Ryegrass[1]	$11.3^{a}\pm18.2$	$0.6^{a}\pm1.1$	$87.7^{b}\pm7.0$
White clover	8.5±9.9	0.2±0.0.2	2.4±2.9
Other	4.7±4.9	0.0±0.0	6.8±5.0
Dead matter (% of sample DM)	$5.6^{a}\pm3.8$	$23.0^{b}\pm9.1$	$19.8^{b}\pm15.1$
Dry matter (%)	19.0±3.2	25.3±2.5	27.3±9.8
Ash (%DM)	$11.4^{ab}\pm2.4$	$10.2^{a}\pm0.8$	$13.2^{b}\pm1.6$
Crude Fat (%DM)	$3.5^{b}\pm0.4$	$2.2^{a}\pm0.3$	3.1b±0.6
Protein (%DM)	$20.3^{b}\pm4.3$	$11.2^{a}\pm1.6$	$20.8^{b}\pm6.1$
Acid detergent fibre (%DM)	$27.0^{a}\pm2.3$	$32.1^{b}\pm1.4$	$26.1^{a}\pm3.2$
Neutral detergent fibre (NDF; %DM)	$50.8^{a}\pm4.8$	$60.8^{b}\pm2.5$	$45.9^{a}\pm4.7$
Cellulose (%NDF)	38.7±4.7	40.2±3.9	38.7±3.4
Hemicellulose (%NDF)	$46.8^{b}\pm2.7$	$47.1^{b}\pm1.3$	$43.2^{a}\pm1.7$
Lignin* (%NDF)	14.4±4.5	12.7±2.9	18.1±2.8
Soluble sugars and starch (%DM)	8.0±2.0	9.8±3.2	8.5±0.8
Non-fibre carbohydrates (%DM)	14.0±2.6	15.7±2.7	17.0±4.0
Organic matter digestibility* (OMD; %OM)	66.8±8.0	55.7±7.0	69.3±11.5
Organic matter digestibility* (DOMD; %DM)	59.0±5.4	50.1±6.5	60.1±9.2
Metabolisable energy* (MJ/kg DM)	9.4±0.9	8.0±1.0	9.6±1.5

[1]Perennial plus Italian ryegrass. *P<0.10; [ab]Mean values within a row with a different letter are significantly different P<0.05.

Although pasture composition was similar for IMK and RGP, the CP and ME values of these pastures from January to June were on average less than those used in the national GHG inventory for dairy pastures. The average CP and ME values were 20.3 %DM and 9.4 MJ/kg DM for IMK, 20.8 %DM and 9.6 MJ/kg DM for RGP and 23.1 %DM and 11.2 MJ/kg DM in the GHG inventory (Pickering *et al.* 2021). The CP and ME values of IMK and RGP were in fact more similar to values used in the national GHG inventory for beef and sheep pastures, being CP of 18.8 %DM and ME of 9.9 MJ/kg DM. The average values of CP of 11.2 %DM and ME of 8.0 MJ/kg DM were even lower in EMK. Northland has a warmer climate and less rainfall during summer than the rest of New Zealand (NIWA 2022), which likely explains the on-average lower pasture quality observed in the current study. The current summer was also, relatively warmer and with less rain than the long-term average of the region. Pasture should be sampled for multiple years before making a firm conclusion.

In the GHG inventory methodology, animal ME requirements are divided by pasture ME to estimate DMI. The DMI is then multiplied by 21.6 g/kg DMI to calculate daily CH_4 emissions and by CP content to calculate CP intake, which is consequently used to calculate urinary and faecal N excretion, the main sources of N_2O emissions in pastoral systems (Pickering *et al.* 2021). Therefore, if the current GHG inventory methodology is used, including animal production statistics and pasture composition, then N_2O emissions would be overestimated and CH_4 emissions underestimated based on the average pasture composition in the current study. However, the national monthly milk solids production (the main driver of dairy cow ME requirements) used in the GHG inventory is likely also not reflective of the regional milk production profile due to the use of different pasture type and growth pattern.

In conclusion, intensive management of kikuyu pasture is a tool to decrease the dead matter content of these pastures and improve the quality (more protein and less fibre) of kikuyu pastures, similar in nutrient composition to ryegrass pasture. The CP and ME values observed in both IMK and RGP were, however, less than currently used as part of the calculations of GHG emissions in the national GHG inventory.

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CONFLICT OF INTEREST DECLARATION

The authors declare to have no conflict of interest.

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Sward canopy effects on simulated urine events and subsequent urine patch area

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ABSTRACT

In this study, we investigated the effects of grazed pasture canopy characteristics on urine patch area. The experiment was conducted during autumn in Canterbury, New Zealand. Warm water was used to simulate urine events, ranging in volume from 1 to 8 L, onto either partially (Lenient, 6-15 cm) or fully (Hard, <6 cm) grazed perennial ryegrass and white clover (PRG) or plantain (PL) pastures. A thermal digital camera and imaging software were used to calculate the wetted area of each urine event. When a mid-range volume (4 L) was poured onto Lenient pastures, PL had a greater wetted area than PRG (0.30 ± 0.11 m^2 and 0.16 ± 0.08 m^2, respectively; mean±standard deviation). However, the wetted area was similar for PL and PRG under Hard grazing (0.36 ± 0.16 m^2 and 0.31 ± 0.13 m^2, respectively). Irrespective of pasture type and grazing intensity, the relationship between water volume and wetted area was curvilinear, with no significant increase in wetted area for simulated urine events greater than 4 L. Our results indicate that both pasture type and grazing intensity (i.e., residual pasture canopy) affect urination coverage, which could have potential implications for the nitrogen load per urine patch.

Keywords: urine event, urine volume, pasture height, pasture type

INTRODUCTION

In pastoral farming systems, soil nitrogen (N) load from livestock urine patches is a major source of nitrate, which is at risk of leaching during drainage events, leading to eutrophication of waterways (Di and Cameron 2002). Dairy farm systems are especially at risk of nitrate leaching due to synthetic N inputs and large animals, which can excrete over 30 L of urine per day (Di and Cameron 2002; Selbie *et al.* 2015). The N loading rate (amount of N deposited onto the soil surface, kg N ha^{-1}) and subsequent leaching risk depend on the N concentration of the urine, urine volume and affected area (Li *et al.* 2012; Selbie *et al.* 2015). Urine volume is important because it influences the area covered by the N and the depth of N infiltration (Li *et al.* 2012). Previous research investigated variation in urinary N excretion in dairy cattle and identified forages and mineral supplements that reduce N load per urine patch by altering urine volume and urination frequency (Ledgard *et al.* 2015; Mangwe *et al.* 2019). However, dairy cows naturally urinate variable amounts at each urination event, ranging from 0.5 to 10 L per event (Shepherd *et al.* 2017), and manipulation of the circadian urination patterns is difficult to achieve through diet manipulation (Bryant *et al.* 2018).

Plant morphology can also affect the spread of urine and, therefore, determine the area and distribution of urine patches across the paddock. For example, the difference in tiller density and leaf area (plant canopy) between perennial ryegrass and plantain is expected to influence the wetted area. Although there is considerable knowledge of soil processes and fate of N (Cameron *et al.* 2002; Haygarth and Jarvis 2002), very little is known about the effects of pasture canopy on urine patch characteristics.

Few studies have investigated the effects of pasture canopy characteristics through management strategies on urine patch area and how these practices can be implemented at key periods of the year to limit the potential risk of nitrate leaching. In this study, we determined the relationship between urine volume, pasture type and pasture height on the urine patch area.

MATERIALS AND METHODS

Experimental site and treatments

The study was conducted on 8 and 9 March 2017 at Lincoln University Research Dairy Farm (LURDF), Canterbury, New Zealand (43°38′S, 172°28′E; 17 m above sea level), on Paparua silt loam soil. Mean air temperature, at 9 AM when measurements were taken, was 13° C, wind speed was 4 km/h and soil moisture averaged 44% (NIWA 2017).

The experiment consisted of a 2 x 2 x 8 multi-factorial design including: two pasture types (*Lolium perenne* and *Trifolium repens* pasture mix, PRG; or *Plantago lanceolata* L., PL); two grazing intensities (Hard [H], <6 cm residual; or Lenient [L], 6 – 15 cm residual) and eight volumes of water (1, 2, 3, 4, 5, 6, 7, or 8 L). Details of pasture establishment and management are described by Box *et al.* (2017). In brief, pasture treatments (1.5 ha per treatment) were previously established in 2014 and had been under centre pivot irrigation and rotationally grazed by dairy cows.

Urine patch area

Full details of urine patch measurements are described in Beatson (2017). The experimental area was strip-grazed by cows when measurements took place. Urine patch measurements were conducted at time points that reflected L and H grazing pasture residuals at mid and end time points for each 24-hour grazing allocation. For the L treatment, pasture allocation occurred in the afternoon (after milking) and cows grazed the area for 17 hours (between the pm and am milking) before data were collected the following morning, during milking. Concurrently, for the H treatment, data were collected from pasture allocated the previous morning. This process was repeated and the results for the two paddocks per treatment were averaged. The average post-grazing height for each pasture type was estimated from 20 readings of a sward stick at mid (L grazed) and end (H grazed) of grazing.

A urination event was simulated by pouring a known volume of water (1-8 L, 4 repeats per volume) onto forage through a funnel with a 26 mm diameter opening, from a height of 1.65 m. To capture a clear thermal image, hot water (40 to 90°C) was used. Within 30 seconds of water application, a thermal image of the wetted area was captured using a FLIR for IOS thermal camera. The camera was connected to an iPad and the iron filter applied to the images. Each image included a standard scale card for subsequent area analysis. Images were analysed using the 'Huang thresholding method' (Huang and Wang 1995).

Statistical Analysis

Statistical analysis was performed using R 4.0.5 (R Core Team 2021); R-Studio version 1.4.1106 (RStudio Team 2021). T-tests were performed to quantify the effect of pasture type (PL vs PRG; n=128) and pasture height (H vs L; n=128) on the wetted area of the simulated urine patches. ANOVA-THSD was performed considering pasture type and pasture height together at different volumes (n=32).

RESULTS

The range in wetted area was larger for PL pastures than PRG pastures (0.08-0.75 m^2 vs 0.06-0.67 m^2, respectively), which may be due to the lower grazing residuals of PL ($P<0.05$). The residuals for PRG and PL were 12.2±2.6 cm and 7.5±3.0 cm under L grazing and 4.8±1.4 cm and 1.8±1.6 cm after H grazing, respectively. The interaction between pasture type and grazing intensity was significant (Figure 1; $P<0.05$). Under L grazing, the wetted area was larger for PL pastures than PRG pastures (0.31±0.13 vs 0.16±0.08 m^2, $P<0.05$). However, there was no difference in the wetted area between PL and PRG pastures under H grazing (0.36±0.16 vs 0.31±0.13 m^2, $P>0.05$). Further analysis indicated that the wetted area did not significantly increase beyond 4 L events ($P>0.05$).

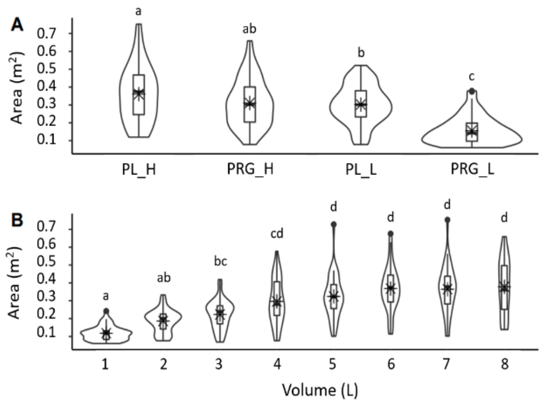

Figure 1. A) Effect of pasture type (Plantain, PL; or Perennial ryegrass / white clover, PRG) and grazing intensity (Lenient [L], 6-15 cm; or Hard [H], <6cm) on wetted area across a range of volumes (1 – 8 L). **B)** Effect of different volumes of water (1 – 8 L) poured on two types of pasture (PL or PRG) at two grazing intensities (L or H). Different letters (a, b, c, d) indicate a significant difference (P<0.05, ANOVA-THSD) in wetted area between each treatment. The asterix (*) represents the mean wetted area for each treatment.

DISCUSSION

Simulating urine patches onto H grazed pasture resulted in a 32% larger wetted area compared with L grazed pasture. This seems counter-intuitive, as we expected the canopy characteristics of L grazed pasture to increase wetted area size due to leaf surfaces causing a splashing effect. Our result can, perhaps, be explained by the measurement approach used. Splash droplets have a high surface area and would likely cool rapidly, meaning they may not be detected under the thermal criteria used for imaging. This could have resulted in an underestimation of the area covered by urine. We detected an important relationship between volume and area, whereby increasing volume between 1 and 4 L resulted in larger wetted areas, which increases the risk of N leaching due to less edge effects of plant N uptake (Shepherd and Carlson 2018).

Previous authors simulated urine events and reported a two-fold range in urine patch wetted area of 0.20-0.42 m^2 for 2 L events (Williams and Haynes 1994; Shepherd and Carlson 2018). Among the influencing factors reported were urine volume deposited, vegetation cover, slope, wind, soil moisture and physical properties of the soil. In the present study, the average urine patch area across the treatments varied between 0.08 and 0.75 m^2, which is a greater range than the forementioned studies due to the applied differences in volume, pasture type and pasture cover.

The average urine volume for a dairy cow is 2 L/event (Williams and Haynes 1994; Selbie *et al.* 2015). In this study, we demonstrated that the wetted areas from a 2 L event were similar (0.22 m^2) for PL and PRG pastures under H grazing, but smaller for PRG pastures relative to PL pastures under L grazing (0.10 vs 0.21 m^2, respectively). Hence, the wetted area increased at a greater rate for PL than PRG pastures under L grazing and with increasing volumes. Bulk density is lower down the sward profile for PL than PRG, with less leaf mass available after a defoliation event. This allows urine to spread across a larger surface area, which is detected by thermal imaging. The increased width of PL leaves may also increase the splash area of urine, increasing the spread.

If high N load and volume urine events occur early morning before morning milking, then allocating PRG in the afternoon may help distribute N more evenly across the paddock. Conversely, grazing PL during the day (i.e. allocating after morning milking) when smaller, more frequent urination events occur may have a similar impact and reduce the N leaching risk (Bryant *et al.* 2018; Mangwe *et al.* 2019).

CONCLUSIONS

This study demonstrates that both pasture type and pasture height influence the size of the wetted area from simulated cow urination events. Importantly, management practices can potentially manipulate urine patch area to reduce the N load onto soil and, therefore, the N at risk of leaching.

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On-farm diagnostics in sub-tropical dairies: The Mastatest®

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ABSTRACT

Laboratory culture of milk samples is the most common diagnostic procedure for identifying the pathogenic causes of bovine clinical mastitis. Culture is rarely used to guide treatment of individual cases due to the time delay in receiving results. On-farm diagnostic tests allow for the rapid identification of pathogens. The Mastatest® (Mastaplex Ltd, Centre for Innovation) is an on-farm test that identifies mastitis-causing pathogens and their *in-vitro* antimicrobial sensitives within 24 hours. The objective of this study was to compare the agreement of identifying mastitis-causing pathogens between the Mastatest and bacterial culture.

Ninety-one milk samples from cases of clinical mastitis were submitted from 19 commercial subtropical dairy farms in northern NSW and Queensland. Samples underwent bacterial culture and were concurrently tested with the Mastatest on-farm diagnostic tool. Culture results were classified into six possible categories; coliform/gram-negative bacteria, *Streptococcus uberis*, *Staphylococcus aureus*, coagulase negative staphylococci (CoNS), other gram-positive bacteria, or no bacteria detected. Culture identified 64 isolates from 53 of 91 milk samples. The remaining 38 samples were classified as either no significant growth (26/91) or no bacteria detected (12/91). For the Mastatest, 23 of the 91 samples had no bacteria detected. The most common results for both tests, classified into Mastatest targets, were coliform/gram-negative bacteria (47.5% Mastatest, 39% culture) and other gram-positive bacteria (22.5% Mastatest, 33% culture). The Mastatest correctly identified 75% of *S. uberis*, 73% of coliform/gram-negatives, 43% of CoNS, 21% of other gram-positive bacteria and none of the *S. aureus* that were isolated on bacterial culture. The large number of no bacteria detected, and coliform/gram-negative results indicate a subset of mastitis cases which do not require antimicrobials. The major benefit of on-farm diagnostic tools may be to identify these cases, improving antimicrobial stewardship and reducing on-farm costs.

Keywords: Animal health, antimicrobial resistance, cattle

INTRODUCTION

The treatment of bovine mastitis is the most common reason for antimicrobial use in dairy cattle (Bryan & Hea, 2017). The prudent use of antimicrobials is an increasingly important issue in production animal health. Reducing the risk of antimicrobial resistance is a major reason to improve antimicrobial stewardship. However, there are also several on-farm benefits, such as a reduction in treatment costs, a decrease in discarded milk and a decreased risk of antibiotics entering the bulk milk tank (Bates et al., 2020; Lago et al., 2011).

Targeted treatment of mastitis could decrease the use of antimicrobials on a dairy farm. Currently, bacterial culture is the most common diagnostic method of pathogen identification. However, this is generally only used for unusual outbreaks or in cases of treatment failure. Laboratory culture is not used as a guide for individual case treatment due to the time delay in receiving results (Lago et al., 2011).

Recent research has been focused on the development of on-farm diagnostic tests for mastitis-causing pathogens. The Mastatest is a commercially available, on-farm diagnostic test which can rapidly identify mastitis-causing pathogens from milk samples and provide antimicrobial susceptibilities. The aim of this study was to compare the agreement of identification of mastitis-causing pathogens in milk between the Mastatest and bacterial culture.

MATERIALS AND METHODS

Sample collection

Milk samples were provided from 19 commercial dairy farms from the subtropical dairy region in Queensland and northern New South Wales. Farmers collected milk samples from cases of clinical mastitis, detected by visible changes to the milk, the quarter and/or the cow. Each sample was collected into a 15 ml sterile tube. Samples were frozen and shipped monthly to Veterinary Laboratory Services (VLS) at the University of Queensland (UQ) Gatton Campus.

Milk culture and bacterial identification

A 100µl milk aliquot was used to inoculate a sheep blood (PP2133; Thermo Fisher Scientific, Australia), MacConkey (PP2130; Thermo-Fisher) and Edwards Media agar plate (CM0027, Thermo-Fisher, made in-house). Plates were incubated aerobically at 37°C. Bacterial growth was examined after a 24 hour incubation with the degree (light, moderate, heavy) and purity recorded. If colony morphology was consistent with a significant mastitis pathogen, they were sub-cultured onto SBA and incubated at 37°C for 24 hours.

After 48 hours of incubation plates were re-examined for slow growing organisms (e.g., *Corynebacterium* spp.). Samples were classified as no bacteria detected, no significant growth (≥3 colonies with no growth of *S. aureus* or *S. agalactiae*) or positive for bacterial growth. For positive cultures, a pure culture was obtained and transported on SBA to the Department of Agriculture and Fisheries Biosecurity Sciences Laboratory, Coopers Plains, Queensland, Australia where isolates were identified by matrix-assisted laser desorption/ionization time-of-flight mass spectrometry (MALDI-TOF-MS) (Bruker Biotyper). Isolates which were noted to be predominant on culture but could not be identified by MALDI-TOF were classified as no identification possible. These isolates (n=3) were Gram stained to allow Mastatest categorisation.

Mastatest

For the Mastatest, one of two methods was used, 1) 40 frozen samples from 18 farms were tested at VLS, or 2) 51 fresh samples were tested on-farm, as Farm A had a Mastatest machine. Milk used for method 1 was randomly selected from 400 samples submitted as part of a larger project. Farm A tested every case of clinical mastitis and 51 samples had corresponding bacterial culture results.

Analysis

Each milk sample was classified as being either positive on both Mastatest and culture (++), negative on Mastatest and positive on culture (-+), positive on Mastatest and negative on culture (+-) or negative on both (--).

RESULTS

Bacterial culture identified 64 isolates from 53 of the 91 milk samples (55%). The remaining 38 samples were classified as no significant growth 29% (26/91) and no bacteria detected 13% (12/91). For the Mastatest, 25% (23/91) of samples had no bacteria detected. The most common positive results for both tests were coliform/gram-negative bacteria (47.5% Mastatest, 39% culture) and other gram-positive bacteria (22.5% Mastatest, 33% culture) (Table 1).

Of the positives detected by bacterial culture, the Mastatest also identified 75% of *S. uberis*, 73% of coliform/gram-negative, 43% of CoNS, 21% of other gram-positive bacteria and none of the *S. aureus* (Table 2). For no bacteria detected there was agreement between culture and Mastatest for 13 samples, 24 samples were negative on culture but positive on Mastatest and 10 samples were positive on culture and had no bacteria detected on Mastatest.

Table 1. Number and percentage of positive test results for Mastatest and bacterial culture classified into the five Mastatest targets.

Target	Mastatest	Culture
S. uberis	11(14%)	8 (12%)
CoNS	12 (16%)	7 (11%)
Coliform/gram -ve	36 (47.5%)	25 (39%)
Other gram +ve	17 (22.5%)	21 (33%)
S. aureus	0 (0%)	3 (5%)
Total	**76**	**64**

Samples from Farm A made up 56% (51/91) of the total samples. Farm A results compared to other farms can be seen in Table 3.

Table 2. Test results for 91 milk samples. ++ indicates positive on both tests; -+indicates negative on Mastatest and positive on culture; +- indicates positive on Mastatest and negative on culture; -- indicates negative on both tests.

Target	++	-+	+-	--
Strep. uberis	6	2	5	78
CoNS	3	4	9	75
Coliform/gram - ve	16	6	20	49
Other gram +ve	4	11	14	62
Staph. aureus	0	3	0	88

Table 3. Number of positives for each target divided into results from Farm A and all other farms. ++ indicates positive on both tests; -+ indicates negative on Mastatest and positive on culture; +- indicates positive on Mastatest and negative on culture; -- indicates negative on both tests.

Target	++		-+		+-		--	
	Farm A	Other farms	Farm A	Other farms	Farm A	Other farms	Farm A	Other farms
S. uberis	2	4	1	1	3	2	48	30
CoNS	2	1	2	2	4	5	46	29
Coliform/gram -ve	12	4	3	3	17	3	22	27
Other gram +pos	4	0	6	7	12	2	32	28
S. aureus	0	0	0	3	0	0	54	34

DISCUSSION AND CONCLUSIONS

Agreement between Mastatest results with culture results for some targets were similar to a study conducted by Jones et al. (2019). They found, 77% (151/195) of *S. uberis*, 62% (5/8) of coliform/gram-negative bacteria, 50% of *S. aureus* (9/18) and none (0/14) of the CoNS that were positive on culture were detected by the Mastatest. In the present study, the Mastatest correctly identified 75% of *S. uberis*, 73% of coliform/gram-negative, however, none of the *S. aureus* and only 43% of CoNS were detected. A limitation of this study was the absence of a gold standard test to determine true positive samples. However, MALDI-TOF has a high specificity (Carbonnelle et al., 2012) and as a consequence bacterial culture and MALDI-TOF are used as the criterion to define an animal's disease status in this particularly study.

In this study, the Mastatest was performed on both frozen and fresh milk samples whereas culture was always performed on frozen samples. Freezing milk samples can have various effects on results depending on the bacteria present. Freezing is known to reduce the probability of culturing *E. coli*, with viability decreasing the longer the samples are stored (Schukken et al., 1989). This may explain why the Farm A Mastatest detected more coliform/gram-negative bacteria than culture. Future studies should compare culture performed on fresh milk samples; however, this is often not possible as samples may take days to reach a laboratory.

Overall, the Mastatest detected more targets than bacterial culture. This may be due to the identification of mixed and contaminated samples. The significance of bacterial growth was determined by veterinary microbiologists. Bacterial cultures with greater than 3 colony types and no growth of *S. aureus* or *S. agalactiae* were classified as no significant growth. However, this does not mean that bacteria were not present but rather the were not deemed clinically significant. The Mastatest is unable to make this differentiation and identifies all targets present.

On-farm diagnostics may be most useful to determine which mastitis cases do not require antimicrobial treatment. This includes cases where no bacteria and gram-negative bacteria are detected (Erskine et al., 2003; Pyörälä et al., 1994). Over 50% of the samples we tested returned a Mastatest result in these categories. Previous research has shown that for mild to moderate mastitis cases, selective treatment based on Mastatest results decreased antimicrobial usage by 24% when compared to a control group, with no difference in bacteriological or clinical cure rate between the two treatment groups (Bates et al., 2020).

Further research on a larger sample size is required to determine the usefulness of this on-farm diagnostic tool, especially in relation to the identification of contagious pathogens such as *S. aureus*. Despite some discrepancies, this test shows promising results for the potential reduction of antimicrobial use on-farm by identifying cases which do not require treatment.

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Using technology to identify factors impacting the growth of calves reared using automated calf feeders

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ABSTRACT

This study focused on unlocking the future potential of dairy calves using data which are readily available on farms using automated calf feeders (ACF) to feed milk. Decisions made early in an animal's life can have a flow on effects on welfare, productivity, longevity and profitability. Precision technology such as ACF are being increasingly used to focus on individual animal development. However, large variation in weaning-weights (WWT) of calves are common. We used a 3-year dataset from an intensive farm using ACF to: determine the variability in WWT, identify contributing factors responsible for the variation in WWT and determine intervention points which could improve the performance of calves within the system. We found a large range of WWT (41–118kg/head) at ~60 days-of-age despite strict management protocols being applied. WWT was significantly and positively linked to birthweight (BWT), with low BWT calves(<35kg) likely to only reach ~65 kg/head on average at weaning which highlighted a trend in which low BWT calves have better outcomes with greater consumption. We also showed that heavier BWT calves (>39kg) will have a better outcome predicted at day 5, achieving a mean of no less than ~85 kg/head at weaning. Cumulative milk consumption (>30kg), cumulative unrewarded visits (visits not rewarded by milk) to the feeder at day-5 and BWT were identified as indicators of WWT. These results showed that calves visiting the feeder more frequently (even if not rewarded with milk) had a greater WWT.

Keywords: Dairy calves, automated calf feeders, performance, weaning weight

INTRODUCTION

Automated calf feeders (ACF) are an alternative to manual milk feeding. Computer-controlled systems control the amount of milk offered and typically are associated with housing calves in groups while providing individualised feeding of milk. Providing a method to rear calves in groups especially in intensive systems, by allowing variable amounts of milk to be fed individually several times a day, resulting in an improved rate of weight gain and welfare (Fujiwara et al., 2014) and reducing health-related issues (Jensen , 2003). However, anecdotal evidence suggests that the variability among individual calves (within a group or pen) is greater than what would be expected, although such variability has not been properly quantified yet.

ACF systems have greater data outputs than conventional calf-rearing systems. In fact, most ACF register, for each calf, the time and number of visits to the feeder, whether or not the visit was rewarded with milk, the total time spent feeding and total milk consumption and the speed of milk consumption in ml/minute. However, these data have been predominantly used for the surveillance of calf health rather than to identify factors affecting individual variability; or to predict future productivity or key points of intervention for calves that are underperforming (Lowe et al., 2019). The increased focus on health is not surprising, as good management practices are required when using ACF because there is some potential for intensive group housing to have an increased spread of disease from using the same teat (Costa et al., 2016; Jensen, 2003). While the health and welfare of calves in group housing is essential to the dairy industry, the performance and growth of calves is known to have an impact on future productivity (Heinrichs & Heinrichs, 2011). The main objective of this study was to understand and quantify the variability of WWT within ACF systems.

MATERIALS AND METHODS

Data collection

Data were collected from 2,623 Holstein Friesian calves on a single intensive commercial dairy farm near Camden, NSW, Australia, from February 2017 to June 2019. Data were collated from the automated feeding system as well as the herd management program used on farm. Holm and Laue calf feeder database and Dairy Comp 305 (Valley Agricultural Software, Tulare, CA) respectively. After cleaning the data, 1,440 calves remained in the dataset for analysis.

The Dairy Comp system provided information such as birthweight (BWT), birthdate (BDAT), weaning weight (WWT) as well as weaning weight date (WWDAT). From these variables average daily gain (ADG) for each animal was calculated. The Holm and Laue system included data sorted into 12-hour periods within the calf feeders, each period included: amount of milk consumed (kg), number of visits to the feeder with available ration and drinking (rewarded), visits without drinking (unsuccessful), visits without available ration (unrewarded) and average milk consumption speed (mL/min) for that 12-hour period for each calf in the system.

Statistical analysis

All analyses were performed using R Studio statistical software. For descriptive analysis and visualization, the WWT was categorized into four groups using the quartiles as break points. This formed the "Low", "Medium", "High" and "Very High" weaning weight categories. Two linear models were built to analyse the data; the first of which [1] was to determine the source of variability in WWT and the second [2] which was to identify potential early indicators of performance.

$$WWT = \beta_0 + \text{Year} + \text{Season} + \text{Year} \times \text{Season} + s(BWT) + s(AHDC) + \varepsilon \qquad [1]$$

where WWT is the weaning weight of the calf (kg); Year is a three-level factor for year of birth (2017, 2018, 2019); Season is a four-level factor for season of calving (Spring, Summer Autumn, Winter); BWT is the calf's birth weight (kg); AHDC is the average half-day consumption (kg) from calving to weaning; and ε is the random error. The s() functions refer to splines of BWT and AHDC, with four knots specified at their quintiles, to allow for possible nonlinear associations with WWT.

$$WWT = \beta 0 + \beta 1BWT + \beta 2HDCh + \beta 3NUVh + \varepsilon \qquad [2]$$

where HDCh is the cumulative consumption up to half-day h, and NUVh is the cumulative number of unrewarded visits up to half-day h.

RESULTS

The range of WWT varied from 41 to 118 kg with an average of 76.2 kg demonstrating the large physical size differences between calves at weaning. The range of BWT was 15 to 63 kg with an average of 38.9 kg.

It was found that all terms significantly affected WWT, namely BWT ($P < 0.001$), Average half-day consumption ($P < 0.001$), Year ($P < 0.001$), Season ($P = 0.002$) and a significant interaction between Year and Season ($P < 0.001$). There was a strong linear relationship between BWT and WWT. However, there was a nonlinear relationship between milk consumption (L/half-day/calf) and WWT.

Eqn. [2] shows that, as early as half-day 10 (day 5), low BWT calves (BWT 15 kg – 36 kg) are likely to only reach ~65 kg/head on average at weaning and demonstrates a trend in which low BWT calves have better outcomes with greater consumption.

Calves within different WWT categories after half day 10 did not overlap in their averaged cumulative consumption (Figure 1).

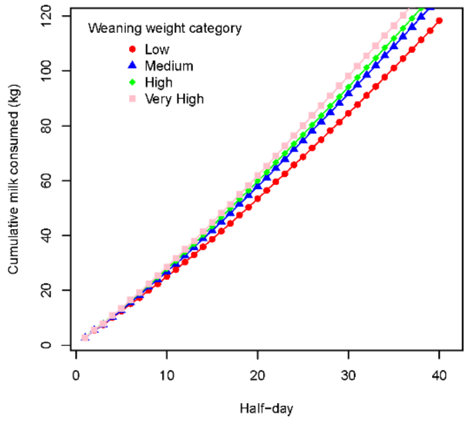

Figure 1. Mean cumulative consumption of calves based on their weaning weight category.

*half-day is each 12-hour period of allocation while each calf was within the automatic feeder.

**weaning weight categories defined as four distinct groups using the quartiles of WWT as break points between each group.

*** cumulative consumption average is derived from the empirical means.

The relationship between consumption and WWT was explored in the model specified in Eqn. [1]. This separation between WWT categories is also seen in the cumulative unrewarded visits (Figure 2).

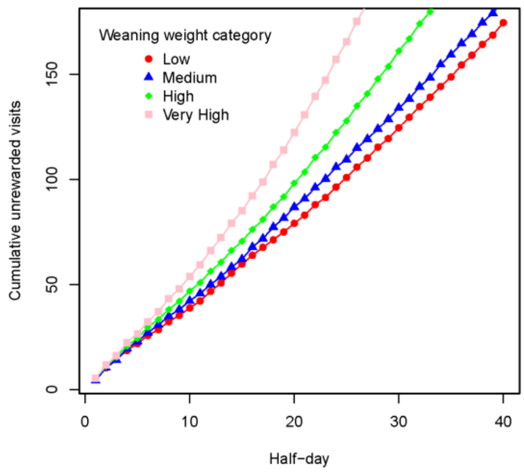

Figure 2. The mean cumulative unrewarded visits of calves based on their weaning weight category.

*half-day is each 12-hour period of allocation while each calf was within the automatic feeder

* weaning weight categories defined as four distinct groups using the quartiles of WWT as break points between each group

DISCUSSION AND CONCLUSIONS

Weaning weights ranged from 41 to 118 kg with a mean WWT of approximately 198% of BWT on average, but ranging from 105% to 487%. The factor most associated with WWT was BWT with heavier calves at birth being heavier at weaning. The association between WWT and milk consumption was linear only between the most commonly used commercial range of ~3 to 4 kg/half-day (6 to 8 kg/day) followed by a nonlinear trend of consumptions greater than this. While milk/milk substitute consumption is often identified as the most significant in the literature (de Passillé et al., 2011; Jensen , 2006), this study demonstrates that consumption alone is not responsible for the performance of calves.

Within our study, a deeper analysis was needed into the weaning weight and consumption behaviour of calves within the data set to assess if there were any significant differences between the high and low performing animals. The initial analysis [1], revealed the differences between calves consumption and BWT and the impact on weaning weight, the further impact of this on lactation performance is unknown and should be investigated to determine if season of rearing has lasting implications on dairy cattle at this commercial farm.

Our study also sought to identify early points in time that could be indicative of future animal performance. Cumulative unrewarded visits showed high levels of differentiation between WWT categories (Figure 2). In agreement with Benneton et al. (2019). self-determined step-down weaning showed that calves with high levels of unrewarded visits were likely to wean at greater weights with the same calves also more likely to consume solid feed more readily (Benetton et al., 2019). When milk consumption was combined with BWT the WWT was most impacted by half-days 5-39 which equate to the days ~3-20 in the calf feeders. This was likely due to the lack of development of the rumen and the reliance on the consumption of milk (Khan et al., 2011). During this period, the number of visits and level of milk consumption were highly associated with WWT. Our study suggests that it would be sufficient evidence for the farmer to intervene after the first 5 days (10 half-days).

This study demonstrated that the variability in WWT was associated with both management factors and behaviour within the calf feeder, in particular the number of unrewarded visits between days 3 and 10. Also, the cumulative consumption at day 5 could be used to predict the WWT of calves when assessed with their BWT.

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CONFLICT OF INTEREST DECLARATION

A full version of this research has been submitted to the Journal of Dairy Science.

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Assessment of Grazing, Rumination, and Other Activities in Dairy Cow by Using RumiWatch Noseband Sensor in Automatic Milking System

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ABSTRACT

Sensor technologies have been widely used in dairy production for precision dairy production. The sensor can provide many data that have not been well used to improve the efficiency of dairy production systems. This study aimed to validate the RumiWatch noseband sensor predictions of grazing and rumination duration and explore the correlations between animal behaviours and animal production parameters in automatic milking system (AMS). The experimental data were collected from 20 RumiWatch nose band sensors on 20 lactating Holstein cows for 14 days. The sensors were validated with seventy-three 10-minute-interval video recordings. The RumiWatch sensor performed well in recording grazing duration (CCC=0.84), rumination duration (CCC=0.92) and other activities (CCC=0.80), but it was less accurate in recording the duration of drinking behaviour (CCC=0.51). The sensor recorded that the cow grazed for 504.6±103.10 minutes per day and ruminated for 461.2±76.77 minutes per day. The grazing duration had weakly positive correlations with the milking frequency (R^2=21.4%, p<0.001), and milk production (R^2=17.1%, *p*<0.001) of lactating cows in the AMS during the day. This suggests that increasing the grazing duration of lactating cows in an automatic milking system may increase milking frequency and milk production. However, further research is needed to improve the model in predicting cow production from behaviours in AMS.

Keywords: Ingestive behaviour; robotic dairy, grazing time, rumination time.

INTRODUCTION

Sensor technology has become an important part of precision dairy production. The nose-band pressure sensor data can potentially help farmers better understand animal behaviours related to production (Pahl et al., 2016). However, in commercial farms, only limited behaviours are measured by pressure sensors and used for the analysis of production (e.g., grazing duration) (Greenwood et al., 2017) due to the insufficient validation in grazing conditions and unclear correlations between cow behaviours and production parameters. Therefore, this study had two aims. Firstly, to assess the accuracy of one pressure-based sensor: the RumiWatch Noseband Sensor (RWS; Itin+Hoch GmbH, Liestal, Switzerland) to predict grazing duration, rumination duration, and other activities duration in dairy cows. Secondly, to analyse the correlation between the duration of a given behaviour and production parameters in a pasture-based automatic milking system (AMS). These findings will help future scientists and farmers carefully consider the behaviours as indicators for production purposes.

MATERIALS AND METHODS

Background Information

The experiment was conducted at The University of Melbourne, Dookie Dairy, with an AMS from 22nd September to 6th October 2020. All the procedures were approved by The University of Melbourne, Animal Ethics Committee (ID: 2015150.1). Three Lely Astronaut T4C automatic milking machines (Lely Industries NV, Maasland, The Netherlands) milked 136 cows up to three times a day in the dairy farm. Cows grazed in three-way grazing AMS, and the automatic milking system recorded the production data, including milking frequency, milking production, milk quality parameters and concentrate feed intake. The cows were grazed on ryegrass dominant pasture (16.0 kg DM/cow/day) and fed with concentrate feed (7.6 kg DM/cow/day) and grass straw (1.0 kg DM/cow/day).

Experimental Animals

A total of 20 early lactating Holstein cows were selected for the experiment (lactation days: 41.5 ± 16.20 days; body weight 581 ± 55.6 kg; milk production: 31.6 ± 10.41; average ± standard deviation). Each cow wore the RumiWatch sensor for 14 days, including two days of adaptation and 12 days of data collection. All the experimental animals were kept in the main herd to observe the behaviours in natural grazing conditions.

Video Observation and Sensor Detection

Behaviours were recorded in continuous 10-min intervals. A total of 73 intervals of valid video observations were recorded by a time-synchronised iPhone SE2 (iPhone SE2; Apple; Cupertino, CA, USA). Behaviours were defined in the previous study (Pereira et al., 2021) counted by reviewing the video recordings.

The Rumiwatch sensors were time synchronised before use. All experimental cows wore one RumiWatch sensor with a pressure sensor on the jaw to detect jaw movement. The behaviour classification and data preparation were the same as in the previous study (Li et al., 2021).

Statistical Analysis

The agreement between video observation and sensor detection were determined using the Lin's concordance correlation coefficient (CCC) of Genstat 18th Edition (Genstat 18th Edition, VSN International, Hemel Hempstead, UK). The daily average behaviour durations and standard deviation were analysed by Genstat 19th Edition. A matrix of Pearson correlations between the behaviour durations and production parameters was analysed by GraphPad Prism (GraphPad Software, CA, USA).

RESULTS

Agreement of Video Observation and Sensor

Table 1 shows the Pearson correlations, bias correction factor, CCC, and confidence interval (CI) between the video observation (VO) and RumiWatch Sensor (RWS) data. The correlation for grazing was 0.85 and the CCC was 0.84 between VO and RWS. The correlation for rumination was 0.92 and the CCC was 0.92 between VO and RWS. The correlation for other activities was 0.83 and the CCC was 0.80. However, the correlation for drinking was 0.52, and the CCC was 0.51 with no significance.

Table 1. Lin's concordance correlation coefficient (CCC) and correlation coefficient (r) result of each behaviour between the video observation (VO) and recognized by RumiWatch sensor (RWS).

Behaviour duration[1]	n	r	CCC	C_b^2	Lower (95% CI)	Upper (95% CI)
Grazing ***	60	0.85	0.84	0.99	0.75	0.90
Rumination ***	30	0.92	0.92	1.0	0.84	0.96
Other activity ***	26	0.83	0.80	0.97	0.63	0.90
Drinking [NS]	6	0.52	0.51	0.99	-0.38	0.91

1. NS means P-value related to association between OV and RWS is not significant; Behaviour*** means association between RWS and VO is very significant, p<0.01.
2. C_b means Bias Correction Factor, ideal = 1, lower absolute value indicate bias away the 1:1 line.

Daily Behaviour of Cows

In the three-way grazing AMS, on average, In the three-way grazing AMS, on average, the

Rumiwatch sensor predicted cows to be grazing for 504.6 ± 103.10 minutes a day. Cows ruminated for 461.2 ± 76.77 minutes per day and performed other activities for 466.4 ± 141.3 minutes daily. The major grazing was shown from 0600 to 1000 after major rumination happened from 0000 to 0600. Other 4-5 minor ingestive behaviours (grazing and rumination) were distributed during the day.

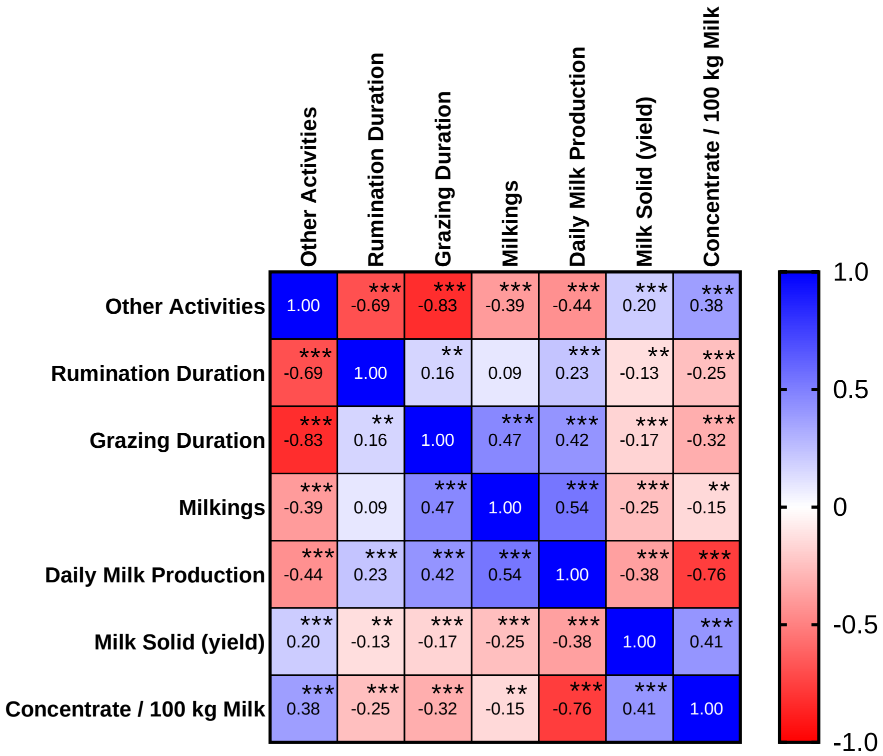

Figure 1. Matrix of Pearson correlations of cow vehaviour durations and production

Correlation Between the Behaviour and production

Figure 1 shows the significant relationships between different behaviours and between behaviours and production parameters. Other activities were significantly negatively correlated with milking frequency (milkings), and daily milk production. However, grazing duration had weakly positive correlations with milk production (R^2=17.1%, p<0.001) and milking frequency (R^2=21.4%, p<0.001).

DISCUSSION AND CONCLUSIONS

The Rumiwatch performed well with high correlation and accuracy in predicting grazing duration, rumination duration and other activities, but was not accurate at predicting drinking duration.

Other activities were easy to be identified with no jaw movements. The CCC of grazing duration were reported as 0.51 and 0.90 for grazing lactating cows in Pereira et al. (2021) and Werner et al. (2018), respectively. The definition of other activities in this experiment is similar to that described by Werner et al. (2018) as any behaviour not associated with ingestive behaviours. The CCC of grazing and rumination durations ranged from 0.71-0.96 and 0.75-0.99 in beef cows and dairy cows in previous studies (Pereira et al., 2021; Poulopoulou et al., 2019; Ruuska et al., 2016; Werner et al., 2018). Overall, the RumiWatch sensor accurately recorded both grazing and rumination duration.

The different duration of grazing and rumination may relate to the pasture abundance, pasture types and nutritive values (Cullen et al., 2017; Norbu et al., 2021).

In terms of correlations between the behaviours and production parameters, other activities reduced the ingestive behaviours during the daily time budget, which further caused the decrease in milk production. In contrast, increased grazing behaviour promoted increases in daily milk production and milking frequency (milkings). Therefore, grazing duration and other activities are important parameters to evaluate cow efficiency in AMS. Future studies can explore the other major variations in the relationship between animal behaviour and animal production. Also need to explore the multi-factor model to increase the correlation of estimating the production parameters using animal behaviour parameters.

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CONFLICT OF INTEREST DECLARATION

The authors declare no conflict of interest.

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Twenty years of learnings for improving water quality in Aotearoa New Zealand

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ABSTRACT

Few data exist on the success of implementing strategies to improve water quality. The Best Practice Dairy Catchments project commenced in 2001 in five small dairy-dominated catchments and monitored the implementation of management strategies to mitigate declining water quality. Although ending in 2010 water quality data and farm practice data have continued to be collected. Analysis of the 20-year dataset indicates that water quality has improved in all contaminants except nitrogen and *E. coli* because of better effluent management, changing irrigation practices from flood to spray, and stock exclusion. This study is currently revisiting dairy farms in the five catchments, 20-years on, to capture further details on practice change (including cost-effectiveness of mitigations) to see if other actions might be linked to the observed changes in catchment water quality.

Keywords: dairy, practice-change, nutrients, sediment.

INTRODUCTION

The New Zealand Government has signalled a need and desire to address water quality within a generation and to show marked improvements within 5-10 years. The dairy sector, through the Dairy Tomorrow Strategy is committed to sustainable dairying and farming within environmental limits. Although much science exists on what and how to mitigate contaminant loss, few data exist on the success of implementing such strategies.

The Best Practice Dairy Catchments project commenced in 2001 involving five small dairy-dominated catchments (Waiokura, Toenepi, Waikakahi, Bog Burn and Inchbonnie) and connected the best science at the time to the implementation of mitigation strategies, via farm plans. It ended in 2010 when the implementation of mitigation practices were consistent with improving in-stream concentrations of phosphorus, suspended sediment, and *E. coli* (Wilcock et al., 2013).

Water quality data has continued to be collected on a regular basis, while farm practice surveys have been replicated twice in the last 10 years. We now have an opportunity to assess the relative success of extension efforts from 2001-2010 on the uptake of farm mitigation of contaminant losses and what effect this has had on in-stream water quality.

MATERIALS AND METHODS

Sites

Details of each of the five dairy catchments studied are available in previously published literature (e.g., Wilcock et al., 2007). Briefly, all were flat (<7°) to rolling (<15°) but had a wide range of rainfall from 543 mm in Waikakahi to 3,578 mm in Inchbonnie. The North Island catchments Toenepi (Waikato) and Waiokura (Taranaki) are underlain by volcanic silt loams with high anion storage capacity (>70%), while the South Island catchments Inchbonnie (West Coast) and Waikakahi (South Canterbury) are free draining alluvial, stony silt loam soils. Bog Burn (Southland) is dominated by poorly draining sedimentary silt loam soils that required artificial drainage to be productive.

Farm practice surveys

Farm practice data was collected via periodic surveys. Surveys were conducted in 2001, 2003, 2006, 2009, 2016 and 2021. The surveys collected data for productivity metrics such as animal stocking rates, purchased feed, and milk solids produced, farm management practices such as nitrogen (N) and phosphorus (P) fertiliser use, Olsen P, winter grazing practices, irrigation, and effluent. In addition to the farm surveys, data on practice change information came from regional authorities who monitored regulation compliance.

Water quality data

In 2001, water samples were collected fortnightly for 18-24 months and thereafter at monthly intervals at the outlet of each catchment. These samples were analysed in-situ for pH, temperature, and dissolved oxygen and in the laboratory for nutrients (nitrate-nitrite-N, NNN; ammoniacal-N, NH_4-N; dissolved reactive P, DRP; and total P, TP) and suspended sediments (SS) using standard methods. Concentrations of the faecal indicator bacterium - *Escherichia coli* (*E. coli*) were determined via the Colilert (IDEXX Labs, USA) most probable number method and expressed as coliform forming units per 100 mL^{-1}. Flow was measured at water quality monitoring sites continuously (and reported every 15 minutes) using a level recorder and telemetry.

Data analysis

Median concentrations (or 95th percentiles for *E. coli*) and percent annual change in median concentration were determined for catchments for two time periods. The first was from 2001 to 2010 and termed the "extension" period, and the second from 2011 to 2021 termed the "post-extension" period. Statistical differences ($P<0.05$) in median concentrations between the two periods were determined ($P<0.05$, Mann-Whitney U test).

RESULTS

In the extension period, 70% of contaminant concentrations improved across the five catchments (in 21 out of a possible 30 contaminant – by – catchment combinations) (Table 1). This declined to 60% in the post-extension period (in 18 out of a possible 30 combinations). The most significant decreases in contaminant concentrations (NNN, DRP, TP and SS) were detected in the Inchbonnie catchment during the extension period. The most notable increases were for NNN in Waikakahi, Inchbonnie and Waiokura catchments.

Significant changes in farm management strategies were noted between the two periods in each catchment. These were: an increase in effluent storage and deferred application in Bog Burn and Waikakahi; a shift from flood to spray irrigation in Waikakahi; the capture of effluent from stock wintered on off-paddock infrastructure and a shift from direct discharge to land application of effluent in Inchbonnie; an increase in the area receiving applied effluent in Waiokura; and a shift from direct discharge of effluent to land application in Toenepi.

Table 1. Median contaminant concentrations and percent annual change in median concentration for the two time periods (extension vs. post-extension). Bold text indicates a statistical difference ($P<0.05$) in median concentrations between periods.

	Extension		Post-extension	
Catchment/contaminant	Median[1]	Change (%)	Median[1]	Change (%)
Bog Burn				
Nitrate-Nitrite-N	0.770	4.8	**1.050**	-2.2
Ammoniacal-N	0.020	0.0	**0.014**	0.0
Dissolved Reactive P	0.026	-1.3	**0.020**	0.0
Total P	0.050	-0.8	**0.055**	3.0
E. coli	700 (6000)	5.8	800 (5830)	-3.1
Suspended Sediments	3.90	-7.2	3.26	-0.9
Waikakahi				
Nitrate-Nitrite-N	1.800	3.7	**3.050**	5.5
Ammoniacal-N	0.021	-9.1	**0.010**	0.0
Dissolved Reactive P	0.072	-1.4	0.060	0.1
Total P	0.111	-2.9	**0.069**	-1.4

E. coli	291 (2640)	-4.3	260 (2464)	-2.0
Suspended Sediments	7.20	-2.6	**2.60**	5.8
Inchbonnie				
Nitrate-Nitrite-N	0.035	-32.3	**0.168**	3.1
Ammoniacal-N	0.256	-9.6	**0.130**	-9.1
Dissolved Reactive P	0.051	-15.3	**0.016**	-3.0
Total P	0.076	-15.1	**0.027**	-1.2
E. coli	405 (9697)	-6.8	**178 (4198)**	7.9
Suspended Sediments	3.85	-11.4	**1.70**	-2.9
Waiokura				
Nitrate-Nitrite-N	2.820	-0.5	3.087	2.5
Ammoniacal-N	0.025	-2.0	**0.019**	-7.8
Dissolved Reactive P	0.029	-4.3	**0.032**	1.6
Total P	0.104	-4.4	**0.091**	-2.8
E. coli	989 (5410)	-9.2	**740 (4465)**	-3.6
Suspended Sediments	18.00	-5.4	**15.00**	-3.2
Toenepi				
Nitrate-Nitrite-N	1.115	1.9	0.883	-0.2
Ammoniacal N	0.022	0.0	0.019	-2.5
Dissolved Reactive P	0.097	2.8	**0.062**	-11.0
Total P	0.164	-1.1	**0.097**	-9.3
E. coli	354 (4394)	1.5	**451 (4444)**	-0.2
Suspended Sediments	3.30	0.0	2.70	7.4

[1] All concentrations are in mg L^{-1}, except for *E. coli* which is in cfu $100mL^{-1}$. The numbers in parentheses refer to the 95^{th} percentile of *E. coli* concentrations.

DISCUSSION AND CONCLUSIONS

During a 10-year extension advice period to farmers on strategies to mitigate contaminant losses, water quality monitoring indicated a range of contaminants had decreasing concentrations in the five catchments. These reductions can be attributed to farmer changes in best management practice in better effluent management (land application, storage, including the capture of effluent from off paddock infrastructure), a shift from flood to spray irrigation, and less P fertiliser. These data indicate that changes in best management practice were still having an effect although other farm actions such as stock exclusion and riparian restoration may have also influenced in-stream concentrations (Wilcock, et al., 2013), as part of the Dairy Clean Streams Accord (MPI, 2013). Farmers should continue to champion best management practices and engage with the freshwater farm planning approach (Macintosh et al, 2021) as an effective mechanism to influence the up-take of mitigations for maintaining and improving water quality in Aotearoa New Zealand.

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Improving pasture growth assessment using machine vision

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ABSTRACT

Frequent pasture dry matter and quality assessments are vital for determining grazing schedules and managing the feed base, and ultimately profitability. Dry matter is typically assessed from manual observations or tools such as a rising plate meter that are labour-intensive and can be prone to subjective variability. Spatial dry matter assessment can be automated using satellite imagery which may be limited by cloud cover, and on-the-go height or multispectral sensors which require manual operation to traverse the field. There is potential for infield machine vision cameras to provide pasture quality and quantity features at a daily time scale, while also significantly reducing labour and increasing accuracy and repeatability in feed base assessments. This system could also detect grazing events which could be used to automate record keeping and improve pasture management. Field and image datasets have been collected over two irrigated pasture seasons at a field within Tasmanian Institute of Agriculture's Dairy Research Farm at Elliott where perennial ryegrass is dominant (90-95%). Daily images were collected from cameras, analysed and compared with estimates of dry matter quantity from weekly-fortnightly C-Dax measurements. A machine vision system was developed that detected pasture dry matter amount with $r = 0.715$ and RMSE = 381.5 kg DM/ha. The camera system used trends of assessed dry matter quantity to accurately detect grazing date. The system could monitor daily pasture growth rate and assist in making grazing and management decisions in pasture production systems. Further work includes evaluating other machine vision properties and different pasture compositions.

Keywords: Dry matter biomass, image analysis, colour indices, texture

INTRODUCTION

Pasture quantity is typically assessed to determine grazing schedules and manage feed in dairy production systems, via labour-intensive visual inspections or a calibrated rising plate meter. Automated sensors that are installed in multiple paddocks or mounted on ground or aerial vehicles can reduce labour in spatial data collection. Commercially available sensors that are towed around fields include standalone height sensors calibrated with rising plate meter measurements (e.g. C-Dax, Agricultural Solutions, Ltd, Palmerston North, New Zealand) with RMSE=437-515 kg/ha, Rennie *et al.* 2009), or height sensors calibrated with satellite imagery (Farmote Stationary Pasture with R^2=0.93, Milsom *et al.* 2019).

Dry matter (DM) has also been assessed using vegetation indices from on-the-go multispectral point sensors (e.g. Greenseeker, Holland Scientific CropCircle, Soil Adjusted Vegetation Index with RMSE=288 kg/ha, Trotter *et al.* 2010), and UAV imagery with plant segmentation to extract indices from plant pixels (R^2=0.75 using Green Normalised Difference Vegetation Index (NDVI), Théau *et al.* 2021). Satellite-based pasture monitoring systems assess dry matter using NDVI or normalised difference red edge index (NDRE) in both commercial systems (i.e. Pasture.io) and systems developed in research (R^2=0.85 and standard error=315 kg/ha using NDVI, Edirisinghe *et al.* 2011).

The availability of satellite imagery could be limited by cloud cover, and on-the-go sensors require significant labour for data collection. An alternative approach is to install sensors at discrete field locations for continuous data collection, which is commercially feasible if at low cost. An infield sensing system can assess pasture at a daily time scale with no labour (e.g.

McCarthy & Raine 2022) but has not previously been reported for grazed pasture. In addition, NDVI is a measure of green cover that could be assessed using infield colour cameras (Elshikha *et al*. 2008). A consideration for the image analysis is variation in lighting throughout the day that can change the plant appearance. Existing approaches to extract daily information from images have been achieved using moving averages, medians, means and filtering over values obtained at different times of day (Hufkens *et al.* 2012, Cao *et al.* 2018).

An infield automated DM sensor could also be used for automated grazing detection from DM trends on consecutive days. Manual record keeping of grazing events can be labour-intensive across multiple paddocks and machine vision could be an alternative for cattle tags (e.g. IDS Australasia's GFarm tracker which require battery replacements).

The sensor reporting DM and grazing dates could be linked to data acquisition technologies (e.g. FarmPulse). This would enable reporting of the sensor data next to other data streams (e.g. soil moisture, pump flow rates) for improved management.

This paper describes the development and evaluation of a low-cost machine vision system for automated pasture DM and grazing assessment. This was conducted using field data collection and pasture assessments over two seasons.

MATERIALS AND METHODS

Field site selection and data collection

A predominantly perennial ryegrass field (90-95%) was selected for image and field data collection in Elliott, Tasmania, Australia. The field was irrigated using a five-span centre pivot irrigator, and comprised 21 fenced paddocks with each paddock grazed approximately monthly. The field was monitored for two seasons between 1 November 2020 and 25 May 2021, and 1 November 2021 and 30 April 2022.

Two locations were monitored for DM in a paddock, using machine vision cameras (Figure 1) and a C-Dax height sensor. The cameras captured oblique images throughout the season for image analysis. The selected camera was a low-cost solar powered smartphone (<AU$100) running an App to capture and upload images to a server every four hours between 05:00 and 19:00. Each camera was surrounded by an electric fence to protect it from grazing cows. Grazing dates were recorded from visual inspection of images from the infield cameras.

(a)

(b)

Figure 1. Infield cameras for assessment of pasture dry matter and grazing dates over two seasons: (a) camera installation; and (b) camera image before grazing. An electric fence line and marker post was installed near each camera.

Pasture DM was measured weekly using a C-Dax height sensor pulled by a quad bike. The C-Dax is commonly used to assess DM in commercial paddocks and as an alternative to pasture biomass assessment using cuts and plate meters (e.g. Chen et al., 2021). A linear calibration equation provided by TIA farm staff was used to convert pasture height from the C-Dax to DM.

Image processing

Canopy cover from multispectral sensors was a machine vision parameter selected to indicate DM, as it is equivalent to NDVI as reported in the literature. Canopy cover was calculated from the ratio between detected plant pixels using segmentation and all pixels. The plant pixels were detected using a segmentation algorithm that detected green plant pixels. A moving average was applied to the machine vision-assessed canopy cover. The canopy cover was converted to DM through a linear interpolation of the machine vision result to the minimum and maximum DM for the paddocks (1500-4000 kg/ha). Grazing events were detected if there were periods of reducing DM.

Performance evaluation

The correlation between the canopy cover using machine vision and DM measured using the C-Dax was evaluated using the Pearson correlation coefficient (*r*) and root mean square error (RMSE). The performance of the algorithms was evaluated on images collected at different times: early morning (<08:00), late morning (08:00-11:00), midday (11:00-14:00), early afternoon (14:00-17:00) and late afternoon (>17:00). This would help identify the optimal time of day for image collection or whether averaging values over the day is suitable. The absolute error in grazing date detection was calculated.

RESULTS

Table 1 shows the performance of the machine vision system for estimating DM at different times of day. After 08:00, DM was assessed with *r*=0.688-0.715 and RMSE=381.5-449.7 kg DM/ha, with the highest correlation in the late afternoon. The late afternoon potentially provides most uniform lighting because of a lack of shadows. This is comparable with the reported performance of automated systems (300-400 kg DM/ha). There is potential to improve the performance by exploring other machine vision properties(characteristics).

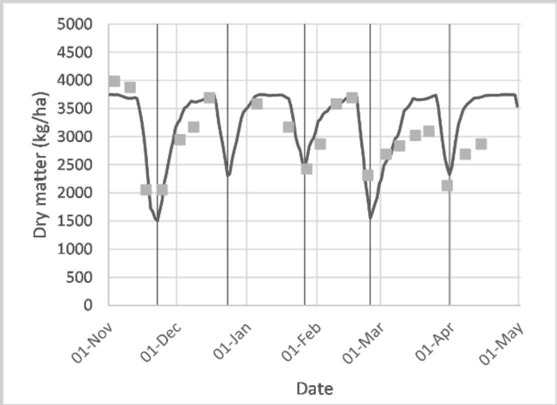
Figure 2 shows the detected DM and grazing dates using machine vision for the two cameras. The machine vision system had good overall performance for DM estimation, with some over and under-estimations. These may be caused by slight differences in location between the C-Dax measurements and the camera. In addition, canopy cover was saturated before grazing, so other colour-based machine vision properties should be explored. The grazing date was assessed using this machine vision system with 100% accuracy.

Table 1. Correlation (*r*) and RMSE (kg DM/ha) between measured and estimated dry matter with noted sample sizes (*n*) at different times of day.

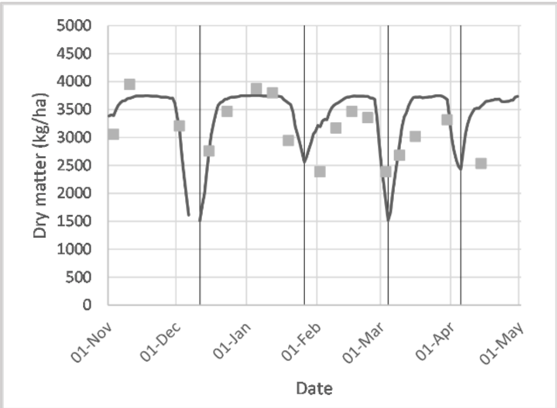
Time of day	*n*	*r*	RMSE
Early morning	11	0.448	597.1
Late morning	23	0.700	416.5
Midday	20	0.714	433.8
Early afternoon	22	0.688	449.7
Late afternoon	15	0.715	381.5
All	91	0.663	448.6

DISCUSSION AND CONCLUSIONS

A novel infield low-cost machine vision system was developed and evaluated for assessing daily perennial ryegrass production. Dry matter assessed using machine vision had accuracy levels comparable with existing approaches, and better temporal resolution (e.g. satellite imagery) and lower labour requirement for field measurement (e.g. C-Dax or rising plate meter). The system has potential to monitor daily pasture growth rate, and assist in making grazing and management decisions in pasture production systems. Grazing date was accurately assessed using machine vision, which would reduce record keeping in pasture production systems. Further work includes evaluating other machine vision properties, and different pasture compositions.



(a)



(b)

Figure 2. Measured and estimated dry matter from one camera in: (a) 2020/21; and (b) 2021/22. Square markers are C-Dax measurements, black lines are camera dry matter estimates, and vertical lines are estimated grazing dates.

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Climate trends account for dairy farm yields in Australia science 1975

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ABSTRACT

Australia's climate has changed over the last century with increasing temperatures, carbon dioxide concentrations, heat waves, droughts, and in southern Australia, a reduction in winter and spring rainfall. These climate change trends have affected south-eastern Australian dairy farms – where most of the milk is produced – challenging both farmers and the dairy industry to remain profitable in the short and long term. This research investigated the extent to which hotter and drier climate trends, and extreme climate events, have impacted on the productive and economic performance of south-eastern Australian dairy farms. Two rainfed dairy farms located in Gippsland and Fleurieu Peninsula were studied. Whole farm simulation models and profit budgets were developed to estimate pasture harvested and economic performance between 1975 and 2019, using historical climate data and farm inputs. The data analysed was first arranged in 44 financial years and then divided into four groups, each comprising a period of 11-Financial Years. Pasture growth rates decreased during late spring until the following autumn but increased during the winter and early spring across time periods. Profits declined by 32 and 25 % in Gippsland and Fleurieu Peninsula, respectively, in the driest period 1998/08 due to an increasing reliance on purchased feed, compared to the wettest period 1987/97 when profits were highest. This research has demonstrated that climate change has had a direct impact on dairy farm profits and highlights the need for the industry to adapt to changing climatic conditions.

Keywords: climate change, pasture harvested, return of assets, biophysical simulations.

INTRODUCTION

The Australian dairy industry has developed as an important part of the country's sustained development and economic growth, generating in excess of $13M in revenue and comprising 40,000 employees across the total supply chain (Dairy Australia, 2018). South-eastern Australia is the major milk production region. However, past climate change trends and climate variability (in the form of extreme weather events) affecting this region have impacted and challenged farmers and the dairy industry to remain profitable on a year-to-year basis and in the long term (Daly et al., 2015).

Rising temperatures and dry periods have been previously attributed to reducing pasture harvested and agricultural economic outputs of demanding water farms of south-eastern Australia. Disregarding changes in average climate trends, climate variability demands attention, since fewer and more intense events (such as heatwaves, extreme rainfall, and droughts) in comparison to gradual climate changes, can increase damage to pasture production and economic performance in dairy (Harrison et al., 2016).

To date, climate change research on south-eastern Australian dairy has addressed the impact that past climate trends have had on different components of the production system. In addition, research has forecasted the economic performance and adaptation capacity of south-eastern Australian dairy farms in the long term under varying future climate scenarios and extreme weather events (Harrison et al., 2017, Armstrong et al., 2010). Overall, importance should be placed on the extent to which climate trends and climate variability have previously impacted on dairy profitability at the whole-farm level rather than single components. Therefore, the objective of this research is to identify, using a modelling approach, the extent to which hotter and drier climate trends and extreme climate events since 1975 have impacted on the pasture harvested and profitability of two representative south-eastern Australian dairy farms located in Gippsland, and Fleurieu Peninsula.

MATERIALS AND METHODS

Overview

The farms' dataset to be analysed in this research was previously described by Harrison et al. (2017). Here, farm inputs and 38 years of regional historical climate data (from 1975 to 2013) were combined to run whole-farm simulation models. Their aim was to relate past pasture and milk production with the expected production of 38 years of projected climate data and compare between farm adaptive measures. In this research, this data was amended up to the last financial year (2018/19) by running the simulations again using updated climate data.

Farms' characteristics and climate data

A group of locally based experts determined the inputs criteria when selecting the most representative case study dairy farm for each region. Table 1 summarises the Gippsland and Fleurieu Peninsula's farm inputs. Each farm accounted for a milking area (MA) for the dairy cows, and a runoff area (RA) where calves and heifers were grown in addition to supplementary forage (hay/silage).

Table 1. Summary of modelling inputs and assumptions for each farm. Adapted from Harrison et al. (2017).

	Gippsland	Fleurieu Peninsula
Milking cows	352	350
Milking area (ha)	110	208
Stocking rate (cows/ha of milking area)	3.2	1.7
Runoff area (ha)	83	44
Calves 5-12 months	100	97
Heifers 12-20 months	100	86
Mature cow live weight (kg)	475	550
Average milk production (kg MS cow/year)	401	523
Replacements reared per year	100	97
Calving time	Aug-Sep	May-July
Grain (tonne DM/cow/year)	1.1	1.6
Wastage of hay/silage during feeding (%)	15	10
Irrigation applied (mm/year ha)	0	0
Total assets managed ($,000,000)	4.47	5.35

Historical daily weather data for each site was retrieved from meteorological archives (http://www.longpaddock.qld.gov.au/silo: Silo database), recorded from 1 January 1975 to 31 December 2019.

Table 2. Summary of average rainfall and min/max temperature for each of the 11-Financial year periods. Values in parenthesis are percentage coefficient of variation (CVs).

	1976/86	1987/97	1998/08	2009/19
Gippsland, VIC				
Rainfall (mm)	928 (16)	1,072 (12)	801 (15)	875 (21)
Tmax (°C)	18.2 (2)	18.4 (3)	19.2 (3)	19.6 (3)
Tmin (°C)	8.7 (4)	8.4 (5)	8.6 (3)	8.7 (4)
Fleurieu Peninsula, SA				
Rainfall (mm)	941 (12)	954 (11)	907 (7)	925 (15)
Tmax (°C)	17.9 (2)	17.7 (2)	17.9 (3)	18.5 (3)
Tmin (°C)	10.4 (3)	10.3 (3)	10.5 (3)	10.9 (3)

Whole farm simulations and regression models

Two whole-farm simulation models were used to generate the farm outputs for each site. DairyMod software – developed by IMJ Consultants in collaboration with Dairy Australia - was used to model the milking area and SGS - developed as an integral part of the Sustainable Grazing Systems National Experiment - for the runoff area. By selecting both climate and farm management inputs, DairyMod and SGS are capable of simulating photosynthesis, sward growth and composition, soil biophysics, and animal pasture intake from both grazing and supplementary feed sources. In addition, DairyMod also simulates milk production based on plant growth, pasture status and diet composition. Rainfall, CO_2 atmospheric concentration, wind speed, daily radiation, vapour pressure and maximum and minimum temperature were sourced from the Silo database, while farm inputs such as fertiliser use, herd size and supplementary feeding were obtained by interviewing local farmers and detailed by Harrison et al. (2017) (Table 1).

RESULTS

Influence of climate change on the seasonal growth rate

In comparing the first and last two 11-year periods of the timeframe analysed, pasture growth rates decreased during late spring until the next autumn but increased during the winter and early spring. In addition, the last two periods also accounted for increased warming and drying conditions compared to the first two in both regions. Within the two regions, Gippsland's pasture growth rate shifted the most among the two farms when comparing between the first and the last 11-year periods.

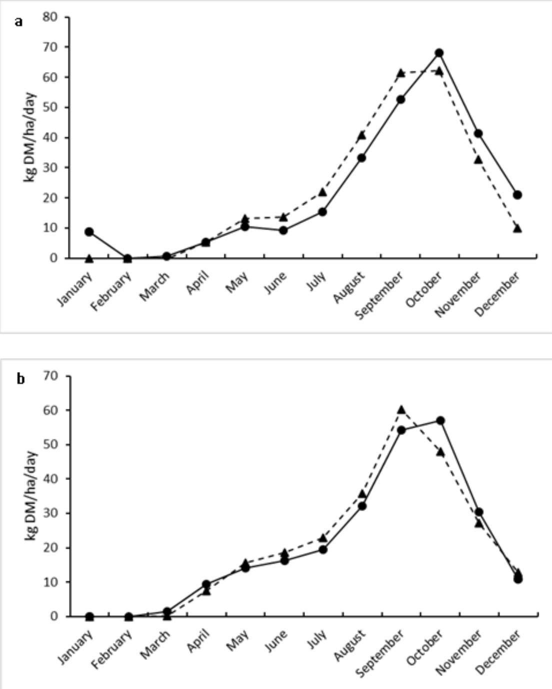

Figure 1. Comparison of simulated monthly average pasture growth rates between 1976/97 ●▬● and 1998/19 ▲- -▲for (a) Gippsland and (b) Fleurieu Peninsula.

Effect of climate change on milk production and pasture harvested

The Gippsland farm had the largest whole-farm pasture harvested (t DM. ha-1) among the two regions, but it also had the most variability throughout the four 11-year periods for most of the Dairymod generated outputs (pasture intake, forage intake, pasture harvested, and nitrogen fertiliser applied) (Table 3). In addition, the annual average pasture harvested decreased over periods, but the increasing pasture growth rate during the growing season allowed more fodder to be conserved. In comparison, the Fleurieu Peninsula's pasture harvested ranged less than Gippsland's, but large variabilities were observed especially during the last two periods. Additionally, the Fleurieu Peninsula outputs remained more constant and achieved similar average values across the four periods.

Table 3. Average farm outputs for each case study site for each 11-year period (percentage coefficient of variation in parentheses).

Farm outputs	1976/86	1987/97	1998/08	2009/19
Gippsland, VIC				
Milk produced (kg MS/cow)	407 (4)	410 (5)	396 (2)	393 (3)
Total milk produced (t MS/farm)	143 (4)	144 (5)	139 (2)	138 (3)
Pasture intake (kg DM/cow)	2856 (14)	3024 (16)	2722 (17)	2593 (23)
Forage intake (kg DM/cow)	1141 (31)	1051 (37)	1237 (29)	1317 (34)
Cut yield (t DM/ha)	3.2 (9)	2.9 (6)	3.5 (8)	3.5 (9)
Total fodder purchased (t DM)	265 (58)	239 (73)	261 (68)	308 (62)
Nitrogen fertiliser applied (kg N/ha)	99 (15)	101 (14)	102 (15)	104 (18)
Milking area pasture harvested (t DM/ha)	9.1 (13)	9.7 (15)	8.7 (17)	8.3 (22)
Runoff pasture harvested (t DM/ha)	6.6 (8)	6.6 (10)	7.0 (18)	6.7 (14)
Whole farm pasture harvested (t DM/ha)	8.0 (11)	8.4 (13)	8.0 (16)	7.6 (19)
Fleurie Peninsula, SA				
Milk produced (kg MS/cow)	517 (3)	520 (3)	525 (3)	528 (2)
Total milk produced (t MS/farm)	181 (3)	182 (3)	184 (3)	185 (2)
Pasture intake (kg DM/cow)	3474 (9)	3206 (14)	3281 (13)	3282 (19)
Forage intake (kg DM/cow)	2262 (10)	2509 (15)	2446 (14)	2466 (20)
Cut yield (t DM/ha)	2.0 (11)	2.0 (9)	2.0 (10)	2.0 (9)
Total fodder purchased (t DM)	474 (25)	568 (31)	521 (37)	554 (42)
Nitrogen fertilizer applied (kg N/ha)	108 (0)	108 (0)	108 (0)	108 (0)
Milking area pasture harvested (t DM/ha)	7.8 (7)	7.4 (9)	7.6 (11)	7.5 (14)
Runoff pasture harvested (t DM/ha)	7.2 (9)	6.8 (14)	6.9 (12)	6.8 (16)
Whole farm pasture harvested (t DM/ha)	7.7 (7)	7.3 (10)	7.5 (11)	7.4 (14)

Effect of climate change on the return of assets

Table 4 summarises the cashflow and the average economic results for the two farms.

Table 4. Average economic results for each case study site and each 11-year Financial Period. (Coefficient of variation in parentheses).

Economic farm outputs	1976/86	1987/87	1998/08	2009/19
Gippsland, VIC				
Total milk produced (t MS/farm)	143 (4)	144 (5)	139 (2)	138 (3)
Milk receipts ($000)	752 (4)	757 (5)	732 (2)	726 (3)
Total gross income ($000)	782 (4)	787 (5)	762 (2)	756 (4)
Concentrate purchased ($000)	110 (0)	110 (0)	112 (0)	110 (0)
Fodder purchased ($000)	66 (58)	60 (73)	65 (68)	77 (62)
Hay and silage making ($000)	34 (0)	31 (6)	37 (9)	37 (9)
Nitrogen fertiliser ($000)	32 (19)	34 (12)	30 (11)	30 (14)
Total Costs (Variable and Overhead) ($000)	609 (6)	601 (7)	609 (7)	620 (8)
Total cost per kg MS	4.3 (5)	4.2 (6)	4.4 (8)	4.5 (8)
Earnings before interest and taxes ($000)	173 (19)	186 (21)	153 (32)	136 (38)
EBIT per kg Milk Solids	1.2 (19)	1.3 (20)	1.1 (32)	1.0 (38)
Return on assets (%)	3.9 (19)	4.2 (21)	3.4 (32)	3.0 (38)
Fleurieu Peninsula, SA				
Total milk produced (t MS/farm)	181 (3)	182 (3)	184 (3)	185 (2)
Milk receipts ($000)	978 (3)	983 (3)	992 (4)	997 (2)
Total gross income ($000)	1,033 (3)	1,038 (3)	1,047 (3)	1,053 (2)
Concentrate purchased ($000)	165 (0)	165 (0)	165 (0)	165 (0)
Fodder purchased (000$)	99 (25)	119 (31)	109 (37)	116 (42)
Hay and silage making ($000)	62 (12)	62 (12)	66 (10)	63 (10)
Total Costs (Variable and Overhead) ($000)	915 (2)	936 (4)	929 (4)	933 (5)
Total cost per kg MS	5.05 (3)	5.14 (4)	5.06 (4)	5.0 (5)
Earnings before interest and taxes ($000)	118 (28)	102 (35)	119 (39)	120 (41)
EBIT per kg Milk Solids	0.65 (26)	0.56 (35)	0.64 (38)	0.65 (41)
Return on assets (%)	2.2 (27.5)	1.9 (35)	2.2 (39)	2.2 (41)

The following can be noticed from Table 4:

- The Gippsland farm return on assets (ROA) decreased during the last two periods compared to the first two, due to less average annual rainfall and pasture harvested.
- The Fleurieu Peninsula's farm had the

smallest average ROA and the greatest variability in each period and accounted for the largest expenses in concentrate and fodder purchased. Here, the lowest ROA compared to Gippsland was due to increased costs associated with external feed reliance.

DISCUSSION AND CONCLUSION

Growing season and pasture growth rate

In comparing the first and last two 11-year periods of the timeframe analysed, pasture growth rates decreased during late spring until the next autumn but increased during the winter and early spring in both farms (Fig 1). These trends are expected to continue up to 2040 (Harrison et al., 2017).

Within the two regions, Gippsland's pasture growth rate shifted the most when comparing between the first and last 11-year periods. This is due to having undergone the most significant variation in temperature and interannual rainfall (Vivès and Jones, 2005), whereas Fleurieu Peninsula has warmed up just slightly.

Pasture harvested and profitability

A greater warming rate in Gippsland increased grass production in winter and early spring. At the runoff area, this shift of pasture growth rate led to 3.1 t DM. ha-1 cut yield during the first two 11- year periods increasing by around 15% up to 3.5 t DM. ha-1 in the last two periods. Increased grass production due to higher warming in winter allowed for more fodder to be conserved as hay in Gippsland, ameliorating the need to purchase external feed.

The Fleurieu Peninsula had a short but reliable growing season. Despite the growing season shifting the same as Gippsland, the Fleurieu Peninsula pasture intake and cut yield have not been impacted as much as the Gippsland farm due to climate change (cut yield remained at 2.0 t DM. ha-1 across the four periods while pasture intake remained reliable).

The salient rate of climate change impact on Gippsland's dairy profits is due to decreasing average rainfall and steep drought to flood years within a decade. In comparison, despite the potential for Gippsland's rainfall to vary on a yearly basis, the farming system of the Fleurieu Peninsula is increasingly exposed to extreme below-than-average rainfall years. This influences the need to rely on external feed purchase (reflected in the highest ROA variability), which increases business and financial risks associated with feed supply and price variability (Malcolm et al., 2005).

In evaluating development options in a very similar rainfed farm in Gippsland, Armstrong et al. (2010) determined that increasing the stocking rate to 3.5 cows/ha (harvesting 8.5 t DM. ha-1) without expanding the MA or RA decreased the average annual operating profits by 48%, due to increasing reliance on external feed purchase. However, increasing pasture harvested by 24% can increase said profits by 12%.

These results support the tenet that improvements in pasture growth and consumption are essential for the ongoing profitability within rainfed dairy farm businesses. In conclusion, this research has demonstrated that climate change has had a direct impact on farm outputs and profitability and the magnitude of that impact varies within region and farm system.

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Early establishment of tropical pastures species being evaluated for use in sub-tropical dairy systems

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ABSTRACT

In sub-tropical dairy systems in Australia, pastures play an important role in contributing to the nutritional requirements of dairy animals. Besides utilising popular grasses such as kikuyu (*Pennisetum clandestinum*) and annual ryegrass (*Lolium multiflorum*), a long-term trial has been implemented at the Gatton Research Dairy (Queensland, Australia) to determine whether newer or alternative tropical grass cultivars could provide a cost-effective source of feed for various classes of dairy animals. In December 2019, a replicated plot trial was established to compare the growth and nutritional value of Whittet kikuyu (WK), Splenda setaria (SS - *Setaria sphacelata*), Reclaimer Rhodes (RR - *Chloris gayana*), Gatton panic (GP - *Megathyrsus maximus*), Floren bluegrass (FB - *Dicanthium aristatum*) and Brachiaria mulato II (BM - *Brachiaria ruziziensis* × *B. brizantha* × *B. decumbens*). The aim of this study was to assess seed quality, germination rate, plant density and canopy cover during the establishment phase of the trial. FB was excluded from the study, as it became apparent that the seed lot contained a proportion of Rhodes grass seed which influenced the seed testing and field trial results. At the time of planting, RR, GP and BM all exhibited moderate seed viability (57-64%). However, seeds of RR displayed high germinability of viable seeds (100%) compared to GP and BM, which exhibited 40 and 11%, respectively. SS and WK had high viability (83–100%), but only moderate germinability (46–49%). The high germination of RR coincided with it also having the greatest density (75 plants m^{-2}) and canopy cover (48%) eight weeks after planting. Consequently, the proportion of other grasses and broadleaf weeds was low. All other grasses displayed similar early establishment responses, characterised by lower plant densities (2.3 – 19.5 m^{-2}) and canopy cover (1-10%) and the plots were dominated by other summer grasses and broadleaf weeds. The results highlight the significant variability associated with establishing pasture grasses and that for some species, more time and management interventions (e.g. weed control, irrigation, mulching and light grazing) may be needed to facilitate successful establishment.

Keywords: Brachiaria mulato, kikuyu, green panic, Rhodes grass, setaria, weed

INTRODUCTION

Dairy farming is Australia's third major rural industry with over 5,700 dairy farmers producing around 9 billion litres of milk per year for human consumption (Dairy Australia 2017). However, meeting the nutrient requirement of dairy cows effectively and economically is a major challenge to the industry (Chapman et al. 2008; Rusdy 2016). Pasture is vital in dairy farming when considering the cost of feeding and sustainability (Fulkerson et al. 2007). However, there has been immense dependence on concentrate feed as pasture production declined due to a series of droughts and dry seasons or seasonality of rainfall (Doyle and Stockdale 2011; Fulkerson et al. (2007)). Consequently, increasing the use of pasture grass as the main feed with concentrates or legumes as supplements gives the opportunity to maximise productivity while maintaining nutrient requirements of dairy animals (Ball et al. 2001; Chapman et al. 2008).

Presently, in sub-tropical and tropical dairy systems, the dominant pasture grasses used as feed are ryegrass *(Lolium perenne/ Lolium multiflorum)* and Kikuyu grass *(Pennisetum clandestinum)*. However, previous study by Fulkerson et al. (2007) have confirmed that ryegrass and kikuyu cannot be successfully established in all areas of dairy regions of Australia as both grasses are constrained to temperate regions both in sub-tropical and tropical regions. Hence, the main objective of this study was to compare the growth and nutritional value of six tropical pasture species grown under supplementary irrigation conditions.

MATERIALS AND METHODS

Study Species

The six pasture species designated for the study were Reclaimer Rhodes grass (*Chloris gayana),* Splenda setaria (*Setaria sphacelata),* Bracharia mulato II (*Brachiaria ruziziensis x B. decumbens x B. brizantha),* Gatton panic (*Megathyrsus maximus),* Floren bluegrass (*Dicanthium aristatum*) and Whittet kikuyu (*Pennisetum clandestinum*).

Seed Characteristics

Prior to planting in December 2019, the percentage of filled seeds and the germinability and viability status of seed lots of all pasture grasses was determined at the Plant Science laboratory, University of Queensland, Gatton Campus.

In November 2019, five replicates of 30 seeds were randomly selected from seed lots of the six pasture species and x-rayed to determine the proportion of filled seeds using a Faxitron™ X-ray machine. Subsequently, the seed lots were subjected to germination testing, by placing them into 9 cm Petri dishes inserted with a single layer of filter paper. Deionised water was added for moisture, and the Petri dishes were then randomly placed in an incubator set at a 30/20°C day/night temperature regime. Newly germinated seeds were recorded daily for 21 days and subsequently removed. After 21 days, there was no further germination, and viability testing was then undertaken through a physical inspection of the seed.

Field trials

In December 2019, a field experiment was implemented on a section of land at the joint UQ/QDAF Gatton Research Dairy facility located on the University of Queensland, Gatton Campus (27°32'04.5"S, 152°20'12.2"E). The trial was undertaken under supplementary irrigation conditions to mitigate the effects of prolonged dry periods on plant establishment and growth. Two irrigation events were necessary during the eight-week study period. A randomised complete block design was established with six treatments (i.e. pasture species) and four replicate blocks making a total of 24 plots (c.a. 0.04 ha in size 13 x 31m). On the 9 January 2020, seeds were broadcast by hand and the soil then gently scarified to maximise soil seed contact. The plots were fertilised with urea at a rate of 100 kg/ha.

Measurement

Eight weeks after planting, early establishment and growth of the pasture species was assessed by estimating plant cover (i.e. of pasture species, other grasses and broadleaf weeds), pasture density counts, and growth (height, basal diameter, number of tillers, reproductive status) and dry matter measurements. These measurements were undertaken from four 50 cm × 50 cm permanent quadrats located within each plot. Growth parameters were recorded on two of the designated pasture grass plants located within each quadrat.

Statistical analysis

All data was subjected to Analysis of Variance (ANOVA) to determine if there were significant differences between the pasture species. If there were, Fishers Protected Least Significant Difference test (LSD) was used to determine which treatments were significantly difference from each other at $P<0.05$. Afterwards, Microsoft excel was used to generate graphs and tables.

RESULTS

During the seed testing and field trial it became apparent that there was a proportion of Rhodes grass within the Floren bluegrass seed sample, which resulted in establishment of a dense Rhodes grass pasture. Consequently, Floren bluegrass was removed from the study and results recorded for the remaining five pasture species.

Seed characteristics

There were significant differences ($P < 0.05$) in % filled seed, germination and viability between the pasture seeds. WK had the most filled seed at 93% and BM the least at 45% and the rest were in between (61-71%) (Table 1). Likewise for viability, WK had the highest at (100%) followed by SS (83%), with the rest not significantly different (P > 0.05) from each other (57-64%). RR had the highest germinability (100%), BM the lowest (11%) and the rest were in between (40-49%), and not significantly different (P > 0.05) to each other.

There was very large variation in the pattern of germination of the five pasture species (Figure 1). RR started germinating after one day and very rapidly, compared to BM which didn't start until day 6 and had low germination thereafter. The other three species took 3 to 4 days to commence germination.

Table 1. Seed characteristics of five sub-tropical and tropical pasture species. Values within rows followed by the same letter are not significantly different at P<0.05.

Seed characteristics (%)	Species				
	WK	SS	GP	RR	BM
Filled seed	93a	71b	69b	61bc	45c
Germination	49ab	38bc	25c	57a	7d
Dormancy	51ab	45ab	39b	0c	56a
Viability	100a	83b	64c	57c	63c
Germinability	49b	46b	40b	100a	11c

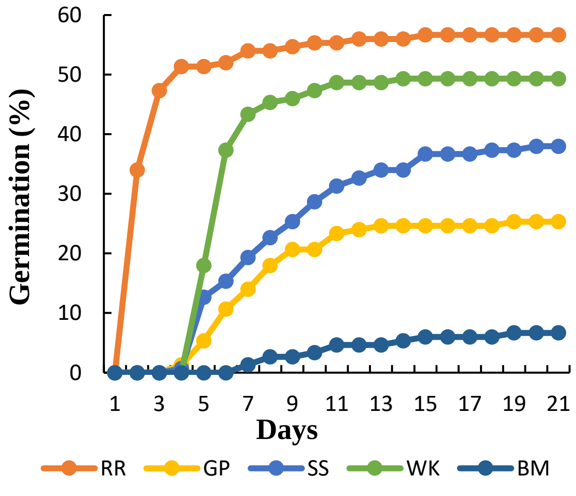

Figure 1. Cumulative germination curves for five subtropical and tropical pasture species.

Field trials

Eight weeks after planting, total plant cover ranged between 63-74%, with SS plots significantly (P<0.05) lower than the other pasture treatments. Plots of RR had the greatest pasture cover (48%) and least broadleaf weeds (only 13%). Others had < 10% of the intended pasture and more weeds (>30%) (Table 2).

A significant difference occurred in the density and height of the pasture grasses (P<0.05), but not the number of tillers or average basal diameter of plants (P>0.05) (Table 2). RR recorded the greatest density in plots (74.9 plants/m^2) and tallest plants (Table 2). Plant density averaged less than 19.5 plants/m^2 for all other pasture grasses.

In terms of plant biomass, there was a significant difference (P<0.05) between the five pasture grasses for leaf, stem and total plant biomass, as well as the leaf/stem ratio (Table 2). RR, SS and GP plants had higher leaf, stem and total biomass than WK and BM. In contrast, the smaller WK and BM plants had a greater proportion of leaf material eight weeks after planting.

DISCUSSION AND CONCLUSIONS

This study confirmed that tropical pasture grass seeds vary greatly in terms of their viability and germinability, with many having a physical constraint that impacts on the rate of germination and seedling emergence (Usberti & Martins 2007).The findings of this study also demonstrate that some species require more time and management interventions such as weed control, irrigation and fertilisation to facilitate successful establishment and overcome harsh environmental impacts (Cook 2007).

There are a few restrictions related with the study. Due to the situation during the period of the experiment, the duration of monitoring and data collection was reduced to 8 weeks, therefore other measurements such as reproductive maturity and plant nutrient analysis were not taken. These measurements could be included in future trials to further assess the performance of the five sub-tropical and tropical pasture grasses.

ACKNOWLEDGEMENTS

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CONFLICT OF INTEREST DECLARATION

There are no real or perceived conflicts of interests.

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Table 2. The plant cover (%), density and growth and plant biomass of five sub-tropical and tropical pasture species eight weeks after planting. Values within rows followed by the same letter are not significantly different at $P<0.05$.

Plant measurements	Species				
	RR	WK	SS	GP	BM
Plant cover (%)					
Designated Pasture grass	48a	1b	3b	4b	10b
Other grasses	9b	34a	27 a	33a	28a
Broadleaf weeds	13b	41a	34a	42a	37a
Total cover	70ab	76a	63b	79a	74a
Density and growth					
Density of Pasture/m^2	74.9a	3.1bc	5.5bc	2.3bc	19.5ab
Plant height (normal)	72.7a	23.8c	35.9bc	46.8b	34.8bc
Plant height (cm) (stretched)	111.6a	37.6c	72.7b	75.4b	53.4c
Tillers per plant (cm)	9.2	5.4	8.4	11.5	3.7
Average Basal diameter (mm)	19.2	15.7	23.5	27.3	15.6
Plant biomass					
Total leaf (kg DM/ha)	8.25a	0.18b	10.47a	9.95a	1.70b
Total stem (kg DM/ha)	10.59a	0.09b	14.58a	11.47a	1.05b
Total plant (kg DM/ha)	18.84a	0.27b	25.05a	21.42a	2.75b
Leaf/stem ratio	0.775b	2.760a	0.91b	0.96b	1.78ab

An extended suckling system for pasture-based dairies

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ABSTRACT

Agricultural productivity and sustainability are central issues for maintaining food production in the new global context. Dairy systems where animals can be produced to high welfare standards can help improve long-term herd productivity while also addressing societal concerns to ensure the future sustainability of the industry. While animal welfare benefits from extended suckling have been explored internationally in indoor dairy systems, research on pasture-based systems are lacking. The objective of this study was to examine the effect of a pasture-based extended suckling system on milk production and udder health of dairy cows. Thirty cows (Friesian x Holstein, Jersey) were used in the study. Sixteen cows were managed in a pasture-based cow-calf suckling system. The cow-calf herd was kept together for 10 weeks from calving to weaning. They grazed together during the day and were separated with fence-line contact overnight. Dams were milked once per day in the morning before being reunited with their calves. The remaining 14 cow were separated from their calves at birth and commercially managed with twice-a-day milking. Cow milk production was recorded daily until 10 weeks post-weaning. Milk somatic cell count (SCC) was collected at one-month pre-weaning and one-month post-weaning. Mastitis risk (SCC >200,000) did not differ between treatments during pre-weaning ($X_2(1, n=30)=0.02$, $p=0.9$, phi=-0.13) or post-weaning periods ($X_2(1, n=30)=0.02$, $p=0.9$, phi=-0.13). Suckled-cow's milk yield was lower than commercial cows during the 10-week suckling period (mean±SD 16.3±2.9 Vs 25.2±3.0 litres, $p<0.001$), but daily milk production in the 10-weeks post-weaning was comparable between the treatments (25.7±2.0 and 24.5±2.7 litres respectively, $p=0.16$). Total lactation milk yield was lower on suckled than commercial cows (6213±495 and 6730±557 litres; $p=0.015$). Suckling calves were consuming an estimated 9.9 L milk/day at 10 weeks of age. The extended suckling system did not increase the risk of mastitis or compromise suckled-cows productive performance after weaning. A dam rearing system with half-day contact and once-a-day milking may be a feasible option in developing alternative dairy industry practices that are aligned with public expectations for improved animal welfare.

Keywords: cow/calf contact, dam rearing, seasonal calving, pastoral systems.

INTRODUCTION

Future livestock systems require novel production strategies to meet the growing demand for animal products without increasing risks to environmental, social (including animal welfare), and financial pillars of sustainability (Harrison *et al.* 2017). There is increasing public concern over the removal of dairy calves from their dams soon after birth (Beaver *et al.* 2019).

The development of alternative systems that enable cows and calves to stay together may address these societal concerns for animal welfare. A dairy system that milks cows once-per-day and allows calves to suckle directly from the dam is an example of a system that could deliver to the aforementioned pillars of sustainability. We have designed a cow-calf suckling system for pastoral dairies based on once-a-day (OAD) milking in the morning and half-day contact with temporary separation of cows and calves overnight (Plate 1). Reducing milking frequency addresses labour shortages in the industry and supports a lifestyle change (Kennedy *et al.* 2021). It can also improve cow body condition, with further benefits for reproduction and immune function, reduce the risk of lameness and improve natural grazing patterns (McNamara *et al.* 2008). However, there may be an increased risk of udder discomfort and mastitis in OAD milking systems, particularly around peak lactation (O'Driscoll *et al.* 2012). Calf suckling could mediate this risk. Our system is designed with half-day cow-calf contact. There is evidence that cows give more milk in the morning after overnight separation than do cows with full-time contact with calves (Johnsen *et al.* 2016). This management may provide the benefits of increased milk intakes and calf weight gains seen in full-day contact systems, while also simplifying the collection of cows for milking, yielding more saleable milk, providing opportunities for physical assessment of the calves, accustoming calves to handling and encouraging independence from the cow (Verdon 2022). The latter may ease the transition at weaning. Extended suckling systems have been explored in indoor systems. However, studies of pasture-based cow-calf systems are lacking. This study aimed to examine the effects of our pasture-based extended suckling system on cow udder health and saleable milk production.

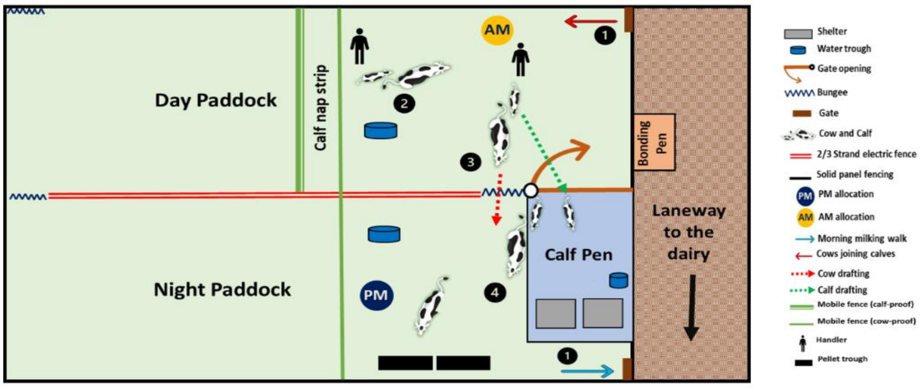

Plate 1. Pasture-based cow-calf suckling system paddock layout and the daily cow-calf pairs separation (not at scale). **1.** Cows were collected from the night paddock and milked in the morning, after spending the night separated from the calves. They were returned to the day paddock after milking. **2.** Cows and calves spent day-time hours together in the paddock with a fresh pasture allocation. **3.** Calves were drafted into their pen in the evening, providing overnight fence-line contact with the dam. **4.** Cows spent the night in the night paddock where they were provided concentrate, silage and fresh pasture. Up to 3 handlers performed the separation as animals adjusted to the system (i.e., 7 days post-calving), but a single handler managed the separation beyond that (~10 minutes).

MATERIALS AND METHODS

This research was performed under the approval of the University of Tasmania Animal Ethics committee (A0024805) and carried out at the Tasmanian Institute of Agriculture Dairy Research Facility (TDRF) located at Elliot (41°08'S, 145°77'E; 155.0 m a.m.s.l) in North West Tasmania.

Study design

Thirty dairy cows (*Bos taurus*, *Friesian x Holstein, Jersey*) balanced for parity (mean parities 2.2±1.3), body condition score (4.2± 0.2) and live weight (510.7±54.9 Kg) were assigned to one of two experimental groups, from here called 'suckling' (managed in our cow-calf system, Plate 1) and 'commercial' group (separated from calves at birth and managed in the commercial herd). The suckling treatment consisted of 16 cow-calf pairs that were managed together until weaning at 10 weeks. Cows and calves remained together during the day, allowing ~8 hours of unrestricted contact. The pairs were separated overnight (~05:00 PM) with fence-line contact. Suckled cows were milked once per day in the morning (~08:00 AM) and then reunited with the calves at the day paddock (~9:00 AM).

A two-stage weaning of suckled calves was followed. Calves were fitted with nose flaps that prevented suckling for 3 days (nutritional separation) and during this time milking increased to twice daily for suckled cows. After this, cows were moved to a different paddock away from their calves following their morning milking (physical separation). The cows re-joined the milking herd 5 days after weaning and continued their lactation cycle under commercial farm management. Cows in the commercial treatment (n=14) were separated from their calves at birth as per commercial practice. Commercial cows were managed in the 300-cow herd and milked twice daily. Cows in both treatments were provided with a fresh pasture allocation each day (*Lolium perenne L.*) that was supplemented with silage and pellets (~5 Kg/day/cow), allowing for a daily energy intake of 21.4 Kg DM/day/cow.

Measures recorded

Data were collected from cows during the 10-week suckling period until 10-weeks post-weaning. Total lactation milk yield was obtained from daily records. Milk somatic cell count (SCC) was collected one-month before weaning and one-month after weaning. Cows were considered at risk of mastitis if their cell >200,000 cells/ uL. The estimated milk intake of suckling calves at 10 weeks of age (EMI) was calculated by subtracting the suckled cows average milk yield (litres/cow.day) during the last week pre-weaning from their average milk yield in the first week post-weaning.

Statistical Analysis

All analyses were carried out using SPSS software, version 28.0.1.0. The data distribution data was assessed visually and through a normality test (Kolmogorov-Smirnov statistic). Lactation was divided into pre-weaning (10 weeks from birth to weaning) and post-weaning (10 weeks after calves were weaned from milk) periods for analysis. Daily milk yield data were summed for each lactation period and then averaged over days. The effects of treatment, lactation stage (pre/post-weaning) and their interaction on milk yield were assessed using linear mixed models (LMM) which accounted for repeated observations of cows. An independent-samples t-test was conducted to compare the total lactation milk. The proportion of cows in the two treatments classified at risk of mastitis (i.e., SCC> 200,000 cells/uL) were analysed with Chi-Square tests for independence with Yate's continuity correction.

RESULTS

The number of cows in each treatment with SCC values exceeding 200,00 cell/uL were the same for the pre- and post-weaning periods: 14.3% of commercial cows and 6.3% of suckled cows. There was no difference between groups in the risk of mastitis (pre-weaning, X_2(1, n=30)=0.02, p=0.9, phi=-0.13; post-weaning, X_2(1, n=30)=0.02, p=0.9, phi=-0.13). Suckled cows yielded 8.9 L less milk than commercial cows during the pre-weaning lactation stage (mean±SD 16.3±2.9 vs 25.2±3.0 L respectively, $F_{1,28}$=69.3, p<0.001), but average milk production did not differ post-weaning (25.7±2.0 Vs 24.5±2.7 L respectively, $F_{1,28}$=2.05, p=0.16, Figure 1). Total lactation milk yield was lower on suckled than commercial cows (6214±495 Vs 6731±557 L respectively; t(26)=2.60, p=0.015, two-tailed). Suckling calves consumed an estimated 9.9 L milk/day at 10 weeks of age.

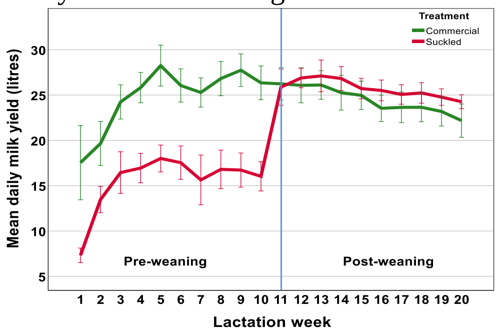

Figure 1. The mean daily milk yield per week (litres) produced for commercial and suckled cows across the 10 weeks pre-weaning and 10 weeks post-weaning. Error bars are +/- 95% confidence interval. The blue line indicates the start of post-weaning lactation period.

DISCUSSION AND CONCLUSIONS

Our cow-calf suckling system, featuring once-a-day milking and half-day contact, did not negatively affect cow health or milk yield post-weaning. In accordance with previous studies, suckled cows presented lower saleable milk during the suckling period (Meagher *et al.* 2019). However, the reduction in milk production of suckled cows did not persist post-weaning. Similar results were reported when cows had 9h contact with calves in an indoor dairy system (Nicolao *et al.* 2022). These cows yielded 42% less milk during suckling, whereas a 35% reduction in the milk yield is reported in our study. This discrepancy could be attributed to differences in cow genetics (Holstein, Montbéliarde vs. Friesian×Holstein, Jersey), feeding regime (mixed-ration vs. pasture-based) and calf sex (36% vs 100% female) between the study by Nicolao *et al.* (2022) and the present research.

There was no evidence of an increased risk of mastitis in our suckling system. Reduced SCC is frequently reported in calf suckling systems (Beaver *et al.* 2019). Calf saliva and the act of frequent suckling may remove bacteria from the teat skin, reduce the risk of infection and improve the function of the mammary gland (Bar-Pelled *et al.* 1995). Feeding increased milk volumes to calves is now recommended (i.e., 20% BW) (Verdon 2022). Other reported benefits of dam suckling include improved calf health and growth, reduction in mastitis, reduction in labour required to feed suckling calves, and improved farmer satisfaction. Economising suckling systems based on milk sales alone may provide a reductive comparison to conventional systems. Further research needs to determine the long-term effects of pasture-based cow-calf suckling systems on heifer growth and development, 1st lactation milk production and cow health. An economic analysis of the costs and benefits of these systems is also recommended.

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CONFLICT OF INTEREST DECLARATION

The authors declare no conflicts of interest.

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Investigating the use of livestock to manage Californian thistle

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ABSTRACT

A preliminary study was established in perennial ryegrass (*Lolium perenne*)-based pastures to determine the effect of molasses application on the extent to which trained dairy-beef cross heifers grazed Californian thistle (*Cirsium arvense*). Treatments comprised no (nil), thistle only (spot) or whole plot (full) application of a 50:50 molasses:water solution prior to grazing, on eleven occasions between March 2020 and July 2021. Heifers were familiarised with novel feeds over 12 days prior to the treatment period in each year, with increasing amounts of chopped Californian thistle and molasses. Herbage mass, thistle height and the percentage of ungrazed thistles were lower in the full and/or spot treatments than the nil treatment on some occasions. In June 2020, thistle stem density before grazing averaged 29,100 stems/ha, reducing to zero after grazing for all treatments. Similarly, in July 2021, few thistles remained after grazing. Further research is required to determine if cattle grazing management can be used to achieve a long-term reduction in thistle abundance in New Zealand farming systems.

Keywords: weed control, thistle control, weed management, pasture management.

INTRODUCTION

Californian thistle (*Cirsium arvense*) is widespread throughout New Zealand. It is avoided by livestock, proliferates rapidly and severely reduces pasture productivity (Bourdôt et al. 2007). Alternatives to herbicides to manage this weed are required, given increasing global consumer demand for food produced with fewer agrichemicals.

Thistles are readily grazed when stems are cut and leaves wilted (Tiley 2010), but grazing of uncut thistles is a more thorny problem.

Using livestock for weed management is practiced in the USA (e.g., Launchbaugh 2006; Bauman 2022). One approach involves training livestock to eat the target weed through a weed familiarisation process. After training, the livestock consume rather than avoid the weed when grazing pasture (Frost et al. 2012; Voth 2010). Grazing attractants, such as molasses, have also been used to encourage cattle to consume weedy pasture (e.g., Tozer & Cameron 2009; Grange 2016).

Preliminary research was conducted to determine if the addition of molasses increased trained dairy-beef cross heifer consumption of Californian thistle, in perennial ryegrass (*Lolium perenne*)-based pastures.

MATERIALS AND METHODS

Site and treatments

The site comprised two 0.9 ha Californian thistle-infested perennial ryegrass-based paddocks, at Ruakura Research Centre, Hamilton, New Zealand.

Treatments comprised application of a 50:50 molasses:water solution to the whole plot (full), thistle plants within the plot (spot) or no molasses solution application (nil). Plots were 4 m x 4 m, arranged in a randomised complete block design with three replicates per paddock.

Treatments were applied to the same plots throughout the study, immediately before cattle entered the study paddocks. In 2020, the site was grazed over 4 days beginning 16 March and 13 May (first paddock), and 20 May and 23 June (second paddock). In March and May, cattle had access to the whole paddock while in June, the paddock was strip-grazed over 4 days. In 2021, the site was grazed 16 February, 26 April and 2 June (first paddock), and 10 February, 6 April, 24 May and 6 July (second paddock). Cattle had access to the whole paddock on 6 April, 24 May and 6 July; otherwise paddocks were strip-grazed. Grazing management decisions were at the discretion of the farm manager and based on availability of pasture and supplement.

Livestock and training

Table 1. Training diet (total kg) prior to the treatment period in 2020 and 2021. Thistle plants were coarsely chopped.

Day	Time	Food
1	AM	50 kg lucerne grass silage
	PM	25 kg lucerne grass silage + 25 kg kibbled maize
2	AM	50 kg ‘50:50’: kibbled maize, crushed barley and molasses
	PM	50 kg ‘Collins brew’ kibbled maize, crushed peas and molasses
3	AM	2 (≈20 kg) bales red clover hay
	PM	50 kg multi-feed pellets: barley, wheat, maize, peas, molasses, dicalcium phosphate, salt, vegetable oil, soya meal, lime
4	AM	50 kg palm kernel expeller
	PM	2 (≈15 kg) bales barley straw
5	PM	1 (≈20 kg) bale red clover hay + 2 kg thistle + 0.7 kg molasses
6	PM	½ (≈20 kg) bale red clover hay + 4 kg thistle + 0.3 kg molasses
7	PM	½ (≈20 kg) bale red clover hay + 5 kg thistle + 0.3 kg molasses
8-11	PM	5 kg thistle + 0.3 kg molasses
12	PM	5 kg thistle, no molasses

Two herds of rising 2-year-old dairy-cross heifers were trained; the first had 48 heifers (March – June 2020) and the second had 80 (February – July 2021). Only trained heifers were used in this preliminary study.

Herds were trained in March 2020 and February 2021 by feeding unfamiliar forages, immediately prior to the first treatment application in each year, based on Voth (2009) (Table 1). The forages were made available to the cattle in two troughs for approximately 30 minutes for each session, with *ad libitum* access to surrounding pasture.

Measurements

In each plot, damaged and undamaged thistle stem density (in four, 1 m^2 quadrats), thistle height (n=10 stems per quadrat) and herbage mass of the pasture between thistles (rising plate meter (RPM), n=20 placements), were randomly assessed before and after each grazing. Botanical composition, and nutritive values of pasture and thistles, were randomly assessed immediately before molasses treatment application. Ten pasture snip samples were cut to ground level and bulked for each plot, a sub-sample removed and the remainder dissected into perennial ryegrass, other grasses, broadleaf weeds, dead vegetation and legumes. The pasture sub-sample, and 15 thistle leaves were each bulked for each plot, stored at -20°C, freeze dried, and ground to a fine powder. Nutritive values were determined using near infrared reflectance spectroscopy for pasture, and wet chemistry for thistle digestible organic dry matter (DOMD) and metabolisable energy (ME), by Hill Laboratories, Hamilton. Data were analysed using Genstat 20th edition (VSN International) by a randomised block ANOVA. Baseline data are not reported given there were no treatment effects (P>0.05).

RESULTS

Thistle stem density

There was no treatment effect on thistle stem density on any of the 11 measurement occasions (P>0.05).

In June 2020, the density of thistle stems before grazing was similar in all treatments (29,100 stems/ha, P>0.05). After grazing, no thistles were present in any of the treatments.

Similarly, in July 2021 stem density before grazing was similar in all treatments, averaging 18,300 stems/ha (P>0.05). After grazing, stem density averaged 2400 stems/ha (only 13% of thistles remained), with no difference between treatments (P>0.05). All stems showed signs of grazing damage to leaves or stems. On no other dates were all/nearly all the thistles removed.

Thistle height and ungrazed stem percentage

The average stem height before or after grazing was higher in the nil and/or spot treatments than the full treatment on three occasions (P<0.5, Table 2).

The percentage of ungrazed thistle stems was higher in the nil than full treatment, with the spot treatment being intermediate, on three occasions (P<0.5, Table 2).

Table 2. Effect of molasses application on thistle height, and the percentage of ungrazed thistle stems measured after grazing. *P<0.05, **P<0.01.

Date	Nil	Spot	Full	sed
Pre-grazing thistle height (cm)				
13 May-20	26	32	11	6.7**
6 Apr-21	25	29	23	5.6
26 April-21	24	25	21	5
2 Jun-21	21	15	12	3.5*
Post-grazing thistle height (cm)				
13 May-20	17	16	10	1.1
6 Apr-21	24	20	16	2.6
26 April-21	22	16	11	2.1**
2 Jun-21	15	11	8	3.3
Ungrazed stems (% of total stems)				
13 May-20	43	10	7	6.7**
6 Apr-21	69	48	38	4.7**
26 April-21	72	26	21	12.4*
2 Jun-21	33	19	34	12.1

Thistle nutritive values

There was no effect of treatment on thistle ME or DOMD on any occasion (P>0.05). The average ME and DOMD were 10.5 MJ/kg DM and 65% respectively in February/March, and 11.7 MJ.kg DM and 72% respectively in May/June.

Herbage mass, botanical composition and nutritive values of pasture

Herbage mass averaged over all treatments and years was 3050±391 kg DM/ha before grazing and 1600±146 (±sem) kg DM/ha after grazing. Herbage mass before or after grazing was highest in the nil and lowest in the full treatment on three occasions (P<0.05, Table 3).

There were negligible treatment effects on botanical composition. The pastures comprised an average of 44% perennial ryegrass (*Lolium perenne*), 15% other grasses, 14% broadleaf weeds, 19% dead and 8% legume (% of total DM, averaged over all paddocks and dates).

The content of soluble sugars was higher in the full than nil treatment on two occasions only and crude protein on one occasion (Table 3, P<0.05). There were no treatment effects on DOMD, ME, acid detergent fibre or neutral detergent fibre (data not shown, P>0.05).

Table 3. Effect of molasses application on pre- and post-grazing herbage mass and the soluble sugars and crude protein contents. *P<0.05.

Date	Nil	Spot	Full	sed
Pre-grazing herbage mass (kg DM/ha)				
16 Mar-20	1630	1510	1560	87
6 Apr-21	3570	3450	2960	330
2 Jun-21	3530	2500	2640	315*
Post-grazing herbage mass (kg DM/ha)				
16 Mar-20	1810	1710	1460	100*
6 Apr-21	2140	2020	1640	190*
2 Jun-21	1530	1290	1320	156
Soluble sugars (% of total DM)				
13 May-20	12.3	11.8	12.9	0.26*
16 Feb-21	9.7	10.6	12.1	0.82*
Crude protein (% of total DM)				
6-Jul-21	20	21	23	0.6*

DISCUSSION AND CONCLUSIONS

Californian thistle provided a high-quality component of a pasture-based diet in this study. Values were similar to those reported by Tiley (2010) for digestibility (64-79%).

Cattle intensively grazed Californian thistle, regardless of molasses application, in June and July, when thistle shoots were young, leafy and visually less spiny than in late spring-summer. This is consistent with Daines (2006), who advised that livestock most effectively graze Californian thistle when ‘rosettes are green and begin to sprout’, from the seedling stage to the late vegetative stage.

In June 2020, pastures were also strip-grazed. Strip-grazing increases localised stocking density, reduces per day feed allocation and increases competition between animals for feed from the first day of grazing, which may increase the consumption and trampling of thistle stems. Californian thistle abundance was also reduced by high density low frequency stocking when compared to low density high frequency stocking in Canadian pastures grazed by cattle (De Bruijn & Bork 2006). This was attributed to less selective grazing, greater total pasture utilisation and increased trampling damage of thistle stems.

Research is required to determine the effect of grazing intensity on Californian thistle throughout its growth cycle in New Zealand pastures.

As expected, molasses application increased thistle defoliation. This was demonstrated by greater reductions in thistle height, the number of ungrazed thistle stems, and pasture cover in the whole plot than spot or nil application treatments, between April and early June. However, molasses is expensive and labour-intensive to apply. Voth (2009) also found that molasses application alone was insufficient to train cattle to graze a target weed. Given that molasses application only increased thistle grazing occasionally, future research needs to focus on livestock training and grazing management.

This preliminary trial demonstrated that (i) molasses could be used to increase grazing defoliation of Californian thistle by trained cattle, and that (ii) contrary to expectations, cattle can intensively graze thistles irrespective of molasses application. Further research is required to determine if (i) the training process is necessary, (ii) high stocking rates for short durations (without training) increase grazing defoliation of thistle plants, and (iii) grazing Californian thistle can lead to a long-term reduction in its abundance in New Zealand farming systems.

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CONFLICT OF INTEREST

There are no conflicts of interests.

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Pasture management strategies to mitigate summer stresses: protecting and enhancing plant energy reserves

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ABSTRACT

Pastures are subject to increasing drought stress over summer in Australasia which reduces perennial grass tiller populations. Based on published literature and recent experimental data, we discuss the strengths and weaknesses of four management approaches to enable tiller populations to avoid, better tolerate and/or recover from drought stress. We propose that the following factors will enable tiller populations to be maintained as the level of stress increases: (i) increased leaf regrowth stage prior to grazing (reflecting increased accumulation of carbohydrate and root growth), (ii) enforcing dormancy and delaying tillering until after the stress period (i.e. deferred grazing), (iii) appropriate endophyte selection and (iv) selection of earlier-heading cultivars. We present empirical evidence that increased leaf regrowth and deferred grazing can enhance carbohydrate reserves and help maintain tiller populations. Research is required to determine to what extent endophyte and heading date effects can be utilised to protect and enhance carbohydrate reserves and maintain tiller populations.

Keywords: Perennial ryegrass, *Lolium perenne*, *Epichloë* endophyte, persistence

INTRODUCTION

Pastures in Australasia are subject to increasing abiotic and biotic stresses, such as drought and invertebrate pests, which compromises the resilience of perennial grass tiller populations (e.g. Lee et al. 2017).

To increase the resilience of perennial ryegrass to summer drought, greater focus is required on strategies that protect and enhance reserves of water-soluble carbohydrate prior to and/or over summer. This can be achieved by (i) extending the grazing interval to enable greater leaf development prior to grazing, and/or (ii) deferred grazing. The use of (iii) endophytes specifically to enhance grazing deterrence, and (iv) earlier-heading cultivars to avoid negative impacts of heat and soil moisture stress on carbohydrate reserves and tiller development, may provide alternative strategies, although these require investigation.

STRATEGIES FOR SUMMER SURVIVAL

Leaf regrowth stage

Leaf regrowth stage (leaf stage) is a proxy for carbohydrate replenishment. After defoliation, carbohydrate reserves (stored in the base of the tiller) are prioritised for leaf regrowth to enable photosynthesis and replenishment of carbohydrate, and root growth temporarily ceases (Donaghy & Fulkerson 1998). Depletion and replenishment of ryegrass plant reserves follows a typical U-shaped curve, with a minimum around the 1-leaf stage, with adequate levels around the 2-leaf stage and a plateau around the 3-leaf stage or slightly later. Therefore, it is recommended that perennial ryegrass-based pastures should not be grazed until there are at least 2 new leaves present, with the target window for grazing being between the 2- and 3-leaf stages (Fulkerson & Donaghy 2001).

As temperature increases (e.g. over summer months), there is a concomitant exponential increase in respiration that uses carbohydrate reserves, and a decrease in photosynthesis that supplies the carbohydrate, resulting in fewer reserves available for regrowth. In these situations, withholding grazing until there are three new leaves present increases persistence, especially in warmer subtropical environments (Donaghy et al. 1997; Donaghy & Fulkerson 2002).

Recently, a decline in the content of perennial ryegrass was recorded over four years when grazing decisions were based on a minimum of two new leaves and an average of 2.5 new leaves prior to grazing. These pastures were grazed by mixed age dairy heifers and data were averaged over 11 different cultivar-endophyte combinations (Samson, Bronsyn, One50 and Rohan, infected with NEA2, wildtype and AR37). A regression of ryegrass content in spring showed a significant decline (regression of ryegrass content in spring 2018-2022, R^2=0.92, P<0.002, Figure 1). Based on the research in subtropical pastures (Donaghy et al. 1997; Donaghy & Fulkerson 2002), delaying grazing to the 3-leaf stage may have improved persistence.

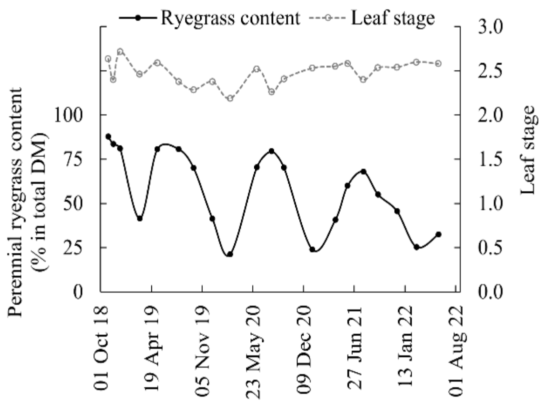

Figure 1. Perennial ryegrass content (% of total DM) and leaf stage prior to grazing, averaged over four perennial ryegrass cultivars each infected with up to three endophytes (AR37, NEA2 and wildtype).

In the upper North Island or other areas where persistence is an issue (e.g. Lee et al. 2017), it is therefore recommended that grazing be delayed until the 3-leaf stage to enable greater protection and replenishment of carbohydrate reserves.

Deferred grazing

Maintaining an adequate post-grazing residual herbage mass and preventing overgrazing of tiller base (below 4 cm) will protect reserves and enhance resilience. This can be difficult to implement in practice, given high stocking densities and operational complexities, especially in times of high temperature and/or moisture deficit, when pasture growth is reduced and animal demand remains high.

An alternative approach to prevent overgrazing is to exclude livestock from late spring until the end of summer from pastures which require rejuvenation (Tozer et al., 2021). This enables reserves to be replenished and enhances regrowth and tillering in the autumn once the deferred pasture is grazed.

Simulating this deferred grazing approach using 1 m-deep root tubes in a glasshouse study demonstrated that water soluble carbohydrate (WSC) content increased by 1.8 – 4.8-fold depending on the plant part, compared to the WSC content in the simulated rotationally grazed control treatment (Table 1). Plants were defoliated at the 3-leaf stage for the 25-week study duration for the control treatment and before and after the 16-week deferred period extending from late spring until the end of summer in the ‘deferred’ treatment (Table 1). These accumulated reserves fuel the prolific tillering and increased pasture growth rates typically observed after deferring pastures (Tozer et al. 2021).

Table 1. Water soluble carbohydrate content (%WSC in total DM) in perennial ryegrass plants subjected to a simulated rotationally grazed or a deferred defoliation regime in a glasshouse study. Data are from the end of the simulated deferred period. **: P<0.01, ***: P<0.001. sed: standard error of difference.

Plant part	WSC content (% in total DM)		sed
	Rotation	Deferred	
Leaf	4	7	0.7 **
Stubble	9	30	3.9 ***
Crown	4	19	3.0 ***
Roots	4	8	1.1 **

Implementation of this strategy requires a spring surplus and having appropriate stock to graze the typically poor-quality pasture at the end of the deferred period. The use of deferred grazing on dairy farms can be profitable despite the poor-quality feed. In Taranaki, New Zealand, milk produced from a farmlet on which 13% of pastures were deferred had a similar fat content but higher protein content than milk produced from a farmlet with mechanically conserved feed (e.g. silage and hay). The extra income from milk solids and the savings in feed conservation increased farm profitability (McCallum et al. 1991). Given looming biosecurity concerns (e.g. foot and mouth disease), practices such as deferred grazing that are not reliant on external contractors or imported supplements such as palm kernel expeller, should be re-evaluated with respect to their impact on feed value, profitability and risk.

Potential heading date impacts

An alternative strategy to avoid depletion of reserves over summer involves choice of grass heading (flowering) date. Later heading perennial ryegrass cultivars grow more high-quality feed in spring, which increases milk production (Gowen et al. 2003). However, later heading cultivars may not be suited to areas where spring rainfall is compromised (Leddin 2017). Later heading cultivars may be at greater risk of undergoing a peak in tillering post-heading when temperatures are increasing and soil moisture decreasing. We propose that this combination of factors may lead to rapid depletion of reserves with negative consequences for the maintenance of tiller populations. This has yet to be tested, as there are no published studies that compare the effects of heading date on the persistence of perennial ryegrass, without confounding the effects of heading date, cultivar and timing of defoliation. For example, the New Zealand Forage Value Index provides a rich source of data on the comparative performance of many cultivars, but rankings are based on field sites where swards are defoliated under standard management. The timing of grazing will interact with the phenological development stage and could affect tillering patterns. To determine the impact of heading date on persistence, research is required in which cultivars are defoliated at similar phenological development stages which will occur on different dates, rather than applying standard grazing principles.

Choice of endophyte

Epichloë fungal endophytes are widely found in many old ryegrass pastures where they produce an array of bioactive secondary metabolites that can impart anti-herbivore properties to the endophyte-grass association, along with a number of less well-studied benefits to the ryegrass under various stresses. This is also the case for novel endophytes which have been selected for secondary metabolite expression that provides insect resistance but with few animal welfare issues (Caradus et al. 2021). The anti-herbivore effects on invertebrates provides key protective properties to the grass host from a number of insect pests in Australasia, through deterrence and/or toxicity. What is much less known, are the anti-feeding properties on livestock and how these may influence grazing residuals in the warm seasons of the year. This effect has been well-recognised for tall fescue containing the toxic endophyte producing ergovaline in the USA which can prevent overgrazing and ensure persistence compared with selected, non-toxic endophyte strains (or endophyte-free) (Aiken & Strickland 2013). This effect in grazed ryegrass pasture is much less evident and/or been rarely studied. For ryegrass, the endophyte focus for livestock has typically been on detrimental clinical (e.g. ryegrass staggers) and subclinical (e.g. reduced milk production) effects.

In New Zealand, sheep studies with standard (toxic to livestock) endophyte-infected ryegrass have shown reduced pasture intakes, greater pasture residuals and preference for non-endophytic ryegrass relative to endophyte-free ryegrass (Edwards et al. 1993; Watson et al. 1999; Cosgrove et al. 2002). There is no information as to how selected endophytes, which have very low or reduced toxicity to livestock, can impact grazing residuals, and how this may affect pasture persistence. If an experimentally observed grazing preference occurs on-farm, mammalian toxic endophytes are likely to increase over time and diminish the positive attributes of ryegrass pastures sown to selected endophytes. This warrants further investigations.

CONCLUSIONS

There is evidence to recommend delaying grazing until the 3-leaf stage in the upper North Island and other environments where there are multiple stresses over summer, and for the use of deferred grazing to enhance carbohydrate reserves and improve pasture resilience. However, there are significant knowledge gaps regarding the effects of standard and selected endophyte on grazing deterrence and the survival of tiller populations, and also the effects of heading date on the survival of tiller populations over summer. Research is required to determine to what extent, if any, endophyte and heading date effects can be utilised to protect and enhance carbohydrate reserves over summer and maintain tiller populations.

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