Efficient milking systems for pastoral dairy farms

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John Paul Edwards

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ABSTRACT

Factors affecting milking efficiency in pasture-based dairy systems were explored in this thesis. An industry survey was conducted on 61 commercial farms with rotary dairies to benchmark current levels of milking efficiency on-farm. Benchmarks calculated included; cow throughput (cows milked per hour), milk throughput (kg of milk harvested per hour), the operator efficiency values of these benchmarks and cluster utilisation. It was possible to milk more cows per hour in larger rotary dairies, however operator efficiency peaked at 60 bails.

There was a range of performance within a given rotary size and platform speed was identified as one of the determining factors. The second experiment modelled the effect of platform speed and rotary size on throughput using milking duration data collected during the benchmarking study. Faster platform speeds increased the number of cows requiring multiple rotations to complete milking, but this did not decrease throughput.

A further factor that may affect throughput is individual cow milk yield, and consequently cow milking duration. An experiment in late lactation was set up to evaluate strategies to reduce cow milking duration by applying pre-milking stimulation or manipulating end-of-milking criteria. Pre-milking simulation decreased cow milking duration but also decreased milking efficiency. Conversely, changing end-of-milking criteria, by increasing automatic cluster removal (ACR) threshold, reduced cow milking duration by up to 80 s without compromising milk yield or somatic cell count (SCC). This was subsequently validated in peak lactation.

In situations without ACR, milking efficiency must not be achieved at the expense of cow health so an experiment was designed to evaluate the effect of overmilking on teat-end hyperkeratosis. Clusters remained attached for 0, 2, 5 or 9 min after milk flow rate dropped below 0.2 kg/min. Teat-end hyperkeratosis was significantly greater for the 5 and 9 min treatments than 0 and 2 min. The milking efficiency of herringbone dairies was also benchmarked on 19 commercial farms with larger dairies achieving greater throughput (in a linear relationship), due to reduced idle time, but not greater operator efficiency.

Finally, the effect of rotary size, platform speed and end-of-milking criteria were evaluated in a number of scenarios to maximise operator efficiency. These were used to calculate the internal rate of return for different rotary sizes.

DECLARATIONS

This thesis contains no material that has been accepted for a degree or diploma by the University or any other institution. To the best of my knowledge no material previously published or written by another person has been used, except where due acknowledgement has been made in text.

Each chapter is set out in the style of the journal to which it has been submitted. Consequently, there is some repetition in chapter introductions, and differences in formatting and spelling. The submitted manuscripts include supervisors as co-authors. However, for each chapter, I planned the experiment, conducted any fieldwork, and wrote the manuscripts, with guidance from these supervisors.

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CHAPTER 1

GENERAL INTRODUCTION

Introduction

New Zealand and Ireland are both located in the temperate climate zone, having generally adequate rainfall or the ability to irrigate in most areas, thus providing ideal conditions for plant growth. Consequently, agriculture contributes significantly to both economies. In 2010 the agricultural sector contributed 4.8% to New Zealand's gross domestic product, and the dairy industry alone contributed 2.7% (Statistics New Zealand, 2010a); dairy products accounted for 25% of the nation's merchandise exports (Statistics New Zealand, 2010b). The Irish government is turning to agriculture to help rebuild the economy after the 2008 financial crisis and will be drawing on experiences from the expansion of the New Zealand dairy industry.

The strength of pasture-based dairying has been its lower cost of production compared to systems utilising conserved feeds, such as silage or cereal and grain-based concentrates. As a result pasture-based dairy systems have been reported to be more profitable than confined systems of a similar size (Hanson *et al.*, 1998). In order to maintain or increase profitability there is a constant drive to improve on farm productivity (DairyNZ, 2011). In New Zealand this has led to an increase in average herd size from 65 cows in 1960/61 to 393 in 2011/12 (Woolford, 1986; DairyNZ, 2012). The 1960/61 figure is similar to the current average herd size in Ireland. However, after EU milk quotas are removed in 2015 it is anticipated that the Irish dairy industry will go through a rapid expansion phase (DAFF, 2010). Therefore, Irish farmers are looking to learn from the development of the dairy industry in New Zealand over the last 50 years.

As well as utilising pasture as a low cost source of feed, labour efficiency is a key feature influencing the profitability of pastoral dairy systems. Labour accounts for 23% of costs for owner-operator dairies in New Zealand, the second largest cost behind feed but, 33% of costs for 50:50 sharemilkers, which is their largest expense (DairyNZ, 2011). In New Zealand, it is common for a labour unit to manage >160 cows, compared to 100 cows/labour unit in Australia (another pastoral dairy country), 56 cows/labour unit in the UK, 36 cows/labour unit in the USA and 29 cows/labour unit in Ireland (IFCN, 2011). This is partly due to herd size, as globally New Zealand and Australia have some of the largest herds, however, large herds are also common in the American dairy industry while still achieving low labour efficiency. If herd expansion occurs in

Ireland post-2015, Irish farmers need to ensure that they achieve a corresponding increase in labour productivity.

One of the most labour intensive tasks on farm is the process of milk harvesting, which accounts for up to 57% of labour annually in a pastoral dairy farm (Taylor *et al.*, 2009). Therefore, an efficient milking system is critical to achieve improvements in labour and farm productivity. Large advances in milking efficiency have been made in New Zealand since the adoption of machine milking in the early part of the 20th century. Since this time, advances in dairy design and streamlining of milker work routines have led to more than a six fold increase in the number of cows milked per operator per hour (Woolford, 1986). The purpose of the current research was to determine whether there were further advances in milk harvesting efficiency that could be made, primarily through influencing individual cow milking duration and modelling dairy operation, to improve farm productivity in the future.

The objective of this thesis was to determine the components that govern the milking efficiency of common milking systems used in pasture-based dairy farms. Subsequently, to examine each of the components individually and evaluate strategies that may improve their efficiency. Finally, an evaluation of the relative impact of manipulating each component of milking efficiency was required to enable readers to make an informed conclusion on the optimal milking system for a given situation.

To achieve the objectives of the thesis, a study to benchmark the current level of milking efficiency was conducted in rotary dairies in New Zealand. A model was then developed to determine the effect of two key variables identified in the benchmarking study on efficiency. Subsequently, two experimental studies were run to examine strategies aiming to reduce the milking duration of individual cows, another significant factor identified as affecting milking efficiency. Next, an experiment was undertaken to study the negative effects of poor milking efficiency on measures of udder health. The final field study benchmarked milking efficiency in herringbone dairies and examined the potential improvements that could be made by applying a maximum milking time strategy. Finally, a model optimising milking efficiency in rotary dairies was developed.

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CHAPTER 2

A REVIEW OF MILKING SYSTEMS

Introduction

Milk harvesting is a critical component to any dairy industry. At the farm level milk harvesting is also of major importance to the success of the business as it involves all facets of the enterprise from cows, to people and financial performance. The invention of machine milking has allowed cows to be milked in batches, significantly improving milking efficiency over hand milking. Over time different dairy designs have been developed. Similarly, milking routines have evolved to adapt to changing constraints. In pasture-based dairy systems there is a particular focus on minimising costs, thus, labour efficiency is of utmost importance. Therefore, there is a need to ensure that the milk harvesting process continues to evolve as the dairy industry develops in the future.

History and development of milk harvesting facilities

The dairy industry relies on the process of machine milking to harvest milk from cows. Traditionally cows have been milked in facilities designed to milk groups or batches. There have been three major milking facility designs that have played a significant role in the development of dairy farming in New Zealand, namely the walk-through, herringbone and rotary dairies. Each new design has allowed significant gains in labour productivity and improved staff working conditions. The developments in dairy design have occurred alongside changes in milking methods. Early milking routines involved a wash, the removal of foremilk, attachment of clusters, detachment and a machine strip (Phillips, 1987). Routines today generally involve only cluster attachment, detachment and post-milking teat spray (Phillips, 1987).

Prior to 1960, the predominant dairy design was the walk-through dairy (Woolford, 1986). The walk-through dairy (Figure 1) was described by McMeekan (1960) as a New Zealand invention, owing nothing to science and created by the ingenuity of farmers milking large herds on their own. Milking frequently involved the use of leg ropes and the milker was constantly in a physically demanding position (Smith, 1985; Woolford, 1986). Subsequently, major improvements were made to the design by elevating cows and building internal races for cows to exit the dairy. Milking throughput averaged around 9.3 cows per bail per hour which was comparable with modern day herringbones, however, labour productivity was less favourable, with around 30 cows per labour unit per hour being milked (Woolford, 1986).

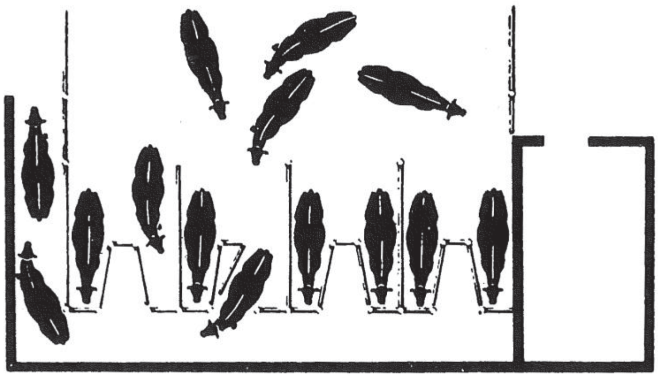

Figure 1. Aerial view of a walk through dairy (Whittleston, 1968).

Today, there are two principal milk harvesting facility designs used in pasture-based dairy production systems; the herringbone and the abreast rotary dairy. The herringbone design (Figure 2) appeared in New Zealand in the late 1950s (Woolford, 1986). The basic principle was that cows lined up either side of a single line of clusters, reducing the walking distance for the operator and allowing more cows to be milked in the same time. Many of the first herringbones were converted from walkthrough dairies, which resulted in tight corners and poor cow flow (Smith, 1985). However, they were rapidly accepted due to higher cow throughput and more efficient labour utilisation. Most herringbone dairies are designed with a single overhead pipeline, with clusters of varying numbers attached that are swung over to serve both sides of a central pit (Figure 2). Additionally, the angle of the cows can vary as well as the distance between the clusters. The use of swing-over herringbone dairies enabled batch preparation and milking, although throughput could be limited by slow milking cows (Woolford, 1986). Woolford (1986) estimated that the minimum time possible for pre-milking preparation, milking and teat spraying was 20 seconds per cow, which gave an overall potential of 180 cows per operator per hour; however, a more common figure was 100 cows per operator per hour. A 1962/63 survey showed that herringbones made up 14% of dairies with an average labour saving of 3.5 man hours per day compared to a walk through system (Woolford, 1986). A decade later in 1973/74 the percentage of herringbone dairies had risen from 14% to 54% (Woolford, 1986). By 2008, herringbone dairies were used on around 75% of New Zealand farms (Cuthbert, 2008).

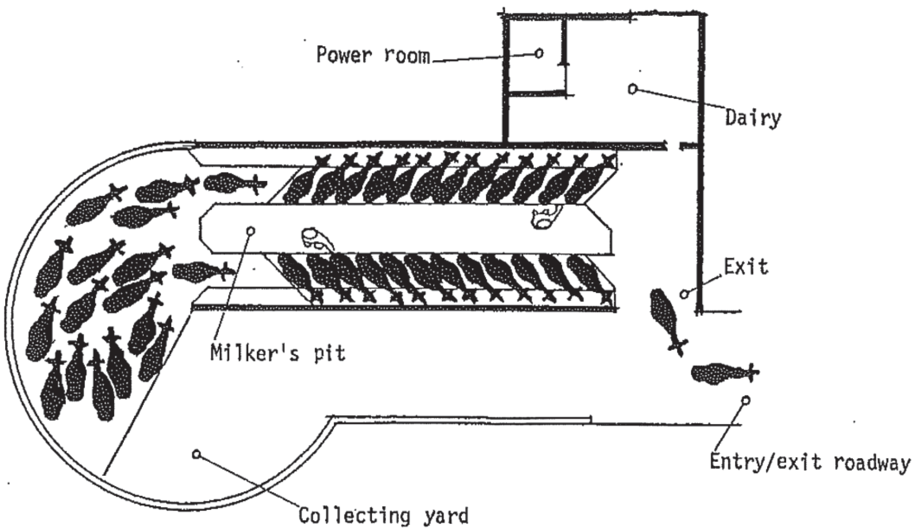

Figure 2. Aerial view of a herringbone dairy (Woolford, 1986).

The swing gate is common in New Zealand herringbone dairies. It is not ideal for fast milking dairies as it is difficult to stop cows at the exit and they frequently can only be closed when the operator is standing next to the gate (Smith, 1985). Another more efficient design is the pendulum gate, which has the ability to be opened and closed from anywhere along the pit. The operator has tight control over cow movement and can intercept any cow in a single file line. As cows are able to follow directly behind those leaving, the time spent by cows moving into the bail area can be reduced (Smith, 1985).

In addition to the more popular swingover herringbone there are several other designs, the double-up herringbone and the rapid exit herringbone. Double-up herringbones have clusters down each side of the pit, compared with the swingover with one set of clusters serving both sides. The advantages of the double-up design are that the pit can be wider, which improves working conditions. Also, a lowline milk delivery pipe can be used instead of the highline as in swingovers. Lowline systems can be used with lower vacuum levels which decreases the chance of teat-end damage. The double-up is also more suited to automatic cluster removers, is easier to install automation such as milk meters and generally slightly higher cow throughput can be achieved. However, there is more cluster idle time and it requires a larger capital investment for the same level of throughput compared with a swingover (CowTime, 2003). The rapid exit design can be used in both the swingover and double-up dairies, although it is more common in the latter (CowTime, 2003). It allows for a faster exit time but requires a wider and higher building, which increases costs. There are also more moving parts and if two exit races are used then two drafting units are required to enable automation (CowTime, 2003).

The trigon (Figure 3) and polygon (Figure 4) were modified designs of the double sided herringbone, containing three and four sides respectively. Multi-sided herringbones have proportionately less units idle at any one time (ADAS, 1982). In the polygon design, generally cows enter from one side, although this then requires bypass lanes. It was designed for large herds of 400 or more cows and could be run with either one or two operators depending on the number of clusters (ADAS, 1982). The advantages of this design are that slow milking cows cause less disruption due to being milked in smaller batches and that the open pit allows the milker to see all the cows in the bail area (Smith, 1985). An increase in milking rate of 25% was claimed over the conventional herringbone (Smith, 1985). The trigon was designed for herds of between 150-350 cows with one operator (ADAS, 1982). The two designs shown differ in the presence of bypass lanes and the number of exits. A disadvantage with both the trigon and polygon is that they cannot be expanded upon once built.

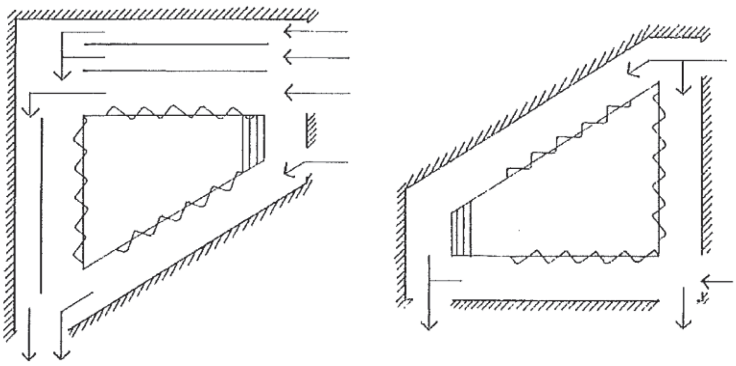

Figure 3. Aerial view of a trigon herringbone (ADAS, 1982).

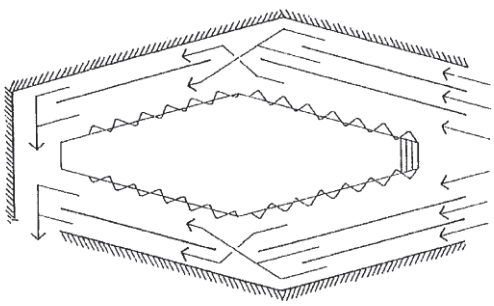

Figure 4. Aerial view of a polygon herringbone (ADAS, 1982).

In the 1970s rotary systems were developed, with two options, the rotary tandem and the rotary abreast. Initially these were ~12-17 bails (Woolford, 1986). The design was based on the philosophy that cows need an easy, simple, entry onto the platform but will exit by themselves. The rotary abreast (Figure 5) quickly became the more popular due to its compact, simple stall design and because it was relatively inexpensive (Woolford, 1986). A modification to the system was trialled at Ruakura whereby cows made two rotations, with the cups being removed on the second rotation (Phillips, 1971). This eliminated the need for the second operator and the additional time spent on the platform could be utilised for in-bail feeding (Phillips, 1971). Other designs included the rotary tandem (Figure 6), rotary herringbone and the internal rotary. The rotary herringbone or ARDCO was the second most popular rotary design in New Zealand. Platforms ranged from 16 to 48 bails, with 24 being the largest suitable for one operator (Smith, 1985). The advantages of the rotary herringbone are that the number of empty bails around the bridge is only one and the operator has a shorter distance to walk between cups on and cups off. For sizes smaller than 32 bails there was a unique cross over entry and exit design, however this did not work in larger sheds due to cows not having sufficient time to enter the platform (Smith, 1985).

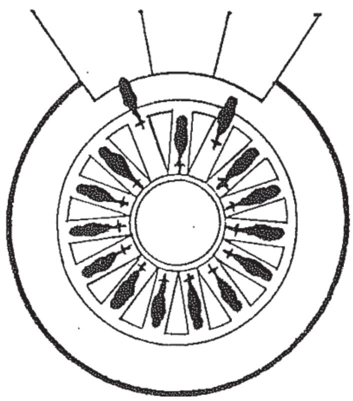

Figure 5. Aerial view of a rotary abreast (Woolford, 1986).

The rotary abreast or rotary turnstile was pioneered in New Zealand by M. Hicks of Taranaki in 1968 (Phillips, 1971). The main feature in this design was that cows face inwards and the operator remained on the outside. Cows entered the platform directly adjacent to the first operator allowing for strict control of cow flow. A second operator was needed to remove cups if automatic cluster removers were not installed. Other advantages included its compact design and few moving parts, which reduced the cost compared with other designs (Phillips, 1971). Plant layout was also simple with everything being contained within the centre of the platform. Rotary tandem sheds (Figure 6) were relatively large for the number of bails compared with other designs making them expensive (Phillips, 1971). Additionally there was limited opportunity to control cow entry as the operator was inside the platform. Cow flow therefore needed to be constant, which could be a problem under New Zealand conditions where in many sheds there was no in-bail feeding to entice cows onto the platform (Phillips, 1971).

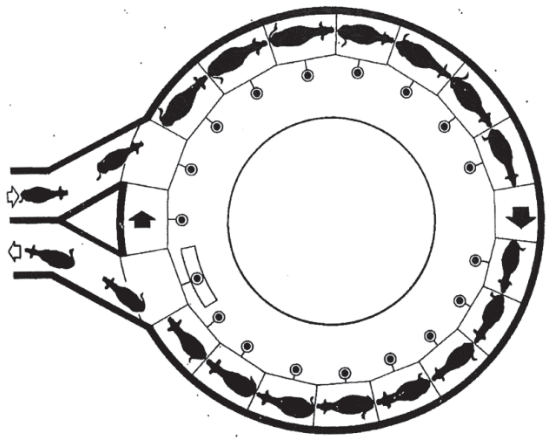

Figure 6. Aerial view of a rotary tandem (Phillips, 1971).

Through the mid-1970s to mid-1980s dairy sizes increased and faster milking routines were introduced to combat growing herd sizes and to satisfy the desire to milk the herd in less than two hours (Smith, 1985). An additional driver was that the larger herds tended to be milked with less labour. This drove changes in milking routines, where pre-milking stimulation and post-milking machine stripping were largely abandoned meaning milkers could spend less time on each cow (Smith, 1985; Phillips, 1987). Milkers could thus handle more clusters and increase the number of cows milked per hour.

Automatic cluster removers (ACR) are a labour-saving device that became available in the 1970s. They automatically remove clusters once the flow rate reaches a certain threshold level, typically 0.2 kg/min. They were of minimal benefit for herringbone designs, except for preventing overmilking, but in the rotary they eliminated the need for the second operator (Phillips, 1971). By 1984, 45% of rotary abreast dairies used ACR (Woolford, 1986).

During this time the popularity of the rotary dairy was limited to Australia and New Zealand. In the USA and Europe the rotary was not favoured because of its higher capital and maintenance costs as well as higher labour costs (Smith, 1985). Smith (1985) reported that one Dutch farmer stated that "a rotary abreast requires three men with ACR and four without it." Reliability was also given as a reason why the rotary was unpopular in Europe. It was more popular in New Zealand due to larger herd sizes which could amortise the capital and labour costs to a level comparable to a herringbone (Smith, 1985). Although the rotary has been around for over 40 years, it has only been in the last 10-15 years that its use has increased. In 1984, 9% of dairies in New Zealand were rotaries (either abreast or herringbone), which by 2008 had risen to 25% (Woolford, 1986; Cuthbert, 2008).

The yard is a fundamental part of any dairy shed design. It can have a significant effect on cow movement onto the dairy platform and on animal health. If cow movement into the platform is poor, this will have detrimental effects on milking speed, and thus milking efficiency. Over time two different designs emerged, the rectangular yard and the circular yard, the former tending to be more popular in Australia and the latter more popular in New Zealand (Smith, 1985). Observations suggest that cow flow is greater in rectangular yards, as cows tend to congregate in a herringbone fashion around the edge of the circular yard, which they have to turn to enter the dairy (Smith, 1985).

When building a new milking facility the decision of which dairy type to choose is complex. Generally, the most important considerations are throughput, which determines total herd milking time, and labour efficiency, which closely relates to the cost of milking and the capital cost of the facility. Other considerations include whether any existing milking facilities can be salvaged. The next decision is how many clusters to install. Therefore, an understanding of how dairies operate is important. In principle the throughput and labour efficiency of swingover herringbone dairies is determined by a combination of the milking routine of the operator, the milk yield of the herd (i.e. milking duration) and the number of clusters (Whipp, 1992). In the rotary dairy, these are determined by the milk yield of the herd, the size of the rotary platform and the speed at which the platform rotates (Copeman, 1985).

Milking routines

The work routine of the operator plays a significant role in determining the amount of time spent milking in both herringbone and rotary dairies. The key factors in achieving a high performance in herringbones are batch milking and in rotary dairies a continuous flow of cows (Mein, 1985). From the walkthrough sheds of the 1960s to the herringbones and rotaries of the 1980s throughput tripled, however, there was still a significant range in performance, leaving room for improvement of the milking routine by eliminating tasks and streamlining those remaining (Mein, 1985). The milking routine can be broken into components and each analysed individually. Traditionally, foremilking was used as a way of identifying mastitis, however, its advantages are outweighed by the disadvantage of teat handling increasing the spread of organisms between cows and the time required to perform the task (Mein, 1985). In-line sensors can also be used to assist with mastitis detection. Udder washing keeps dirt and bacteria out of the milk supply yet cows can be managed in ways so that udders and teats remain sufficiently clean so that udder washing can be abandoned without affecting milk quality (Mein, 1985). Management practices include maintaining clean races and gateways and clipping hairy udders and tails (Mein, 1985). Visibly dirty udders can still be cleaned at the operator's discretion. Stripping at the end of milking was one of the oldest rules in good dairy farm management to ensure udder health (Mein, 1985), however, from the 1970s this practice was largely abandoned too after the continued selection of cows with low stimulus requirements eliminated any production response to stripping (Phillips, 1987). Thus, today, in the herringbone dairy the main components of the operator work routine are cow loading, cluster attachment, cluster detachment, post-milking teat spraying, and cow exiting. The rotary dairy is an efficient design because cow movement is largely automated, where cows enter and exit the platform at a constant rate (Douphrate *et al.*, 2009). Thus, the main components of the operator routine are cluster attachment, detachment and post-milking teat spraying, of which the latter two must be performed by a second operator. However, in both the herringbone and rotary, cluster detachment and post-milking teat spraying can be automated by installing ACR and an automated teat sprayer, thereby removing the requirement of the second operator in rotary dairies.

The operator's stockmanship skills can also significantly impact the efficiency of a routine; if cows fear or mistrust the operator they are less likely to willingly move into the dairy. Where possible cows should be induced to move rather than be forced, for example when an operator enters the yard to push cows in they can quickly become trained to this procedure and await to be pushed in the future (Mein, 1985). Lastly, the time taken to clean the shed and walk cows to and from the paddock should be considered.

Dairy designs have evolved over time to the current herringbone and rotary abreast designs most common today. These changes have largely been driven by increasing herd sizes and labour availability, with these two designs perceived as being the most efficient (Wall, 1995). However there are additional factors other than design that can affect milking efficiency such as management practices on farm and individual cow milking times.

The physiology of milk ejection

The physiology of milk ejection is an important factor in determining the cluster-on time of a cow. Within the mammary gland, milk is stored in two compartments, the cistern and the alveoli (Bruckmaier, 2001). Milk in the cisternal compartment is immediately available for removal by the milking machine, however, much of the milk is held in the alveolar fraction, which must be expelled into the cistern by the process of milk ejection before it can be removed by the milking machine (Sandrucci *et al.*, 2007). International research has shown that without pre-stimulation, the time delay between the complete removal of cisternal milk and the availability of alveolar milk can result in a period of 'blind milking,' where there is no milk available for removal (Bruckmaier, 2001). This can influence the rest of the milking and result in teat damage, potentially increasing the likelihood of mastitis. New Zealand dairy farmers have largely abandoned the practice of pre-stimulation to reduce labour requirements (Phillips, 1987). It is unclear what effect this has had on individual cow milking duration, although there is some indication that the effect of stimulation on milking speed has been bred out of New Zealand cows (Woolford, 1999; Mein & Rheinemann, 2007).

The amount of milk in each compartment varies depending on the milking interval and stage of lactation but with a milking interval of 8-12 hours, around 80% of milk is held in the alveoli leaving 20% in the cistern (Dewhurst & Knight, 1993; Pfeilsticker *et al.*, 1996). Following milking there is little milk present in the cistern, which gradually increases several hours after milking as milk is transferred from the alveoli (Knight *et al.*, 1994). The greatest cisternal yield is seen during peak lactation, although there are conflicting reports as to whether the proportion of total milk held in the cistern increases or decreases with stage of lactation (Dewhurst & Knight, 1993; Pfeilsticker *et al.*, 1996). Cistern size is also correlated with age, with older cows having larger cisterns (Bruckmaier *et al.*, 1994a). Due to the majority of milk being held in the alveoli the process of milk ejection is important to both milk production and milking duration.

The milk ejection reflex occurs in response to tactile stimulation, for example teat washing or the milking machine itself, and acts through a neuroendocrine reflex arc on the myoepithelial cells surrounding the alveoli (Soloff *et al.*, 1980; Crowley & Armstrong, 1992). Once oxytocin reaches a threshold level the myoepithelial cells contract and expel alveolar milk into the cistern (Bruckmaier & Wellnitz, 2008). Consequently there is an increase of pressure within the cistern (Bruckmaier & Blum, 1996). However, the cistern has a limited capacity so not all of the alveolar milk can be shifted to the cistern unless milk removal is occurring at the same time (Bruckmaier *et al.*, 1994b). Milk remaining in the udder after machine milking is referred to generally as residual milk. Typically this residual milk is held in the cistern, and can also be referred to as 'strippings' or strip yield. It is important to distinguish residual milk in the cistern from any milk left remaining in the alveoli, which could have a negative effect on milk production and lactation persistency (Wilde & Peaker, 1990).

There are many forms of stimulation, some eliciting a greater release of oxytocin (stronger response) than others. Attaching the cluster without pulsation is enough to induce milk ejection (Weiss *et al.*, 2003); hand milking induces a stronger response than machine milking (Gorewit *et al.*, 1992) and the response to a suckling calf is stronger again (Lupoli *et al.*, 2001). The strongest stimulant is air blown onto the vagina (Schams *et al.*, 1982). However, it has been shown that the strength of the stimulus does not affect the strength of the milk ejection reflex (Bruckmaier & Blum, 1996), so higher amounts of circulating oxytocin do not equate to greater milk ejection. The time delay from the start of stimulation to the onset of milk ejection normally ranges from 40 seconds to more than 2 minutes (Bruckmaier & Hilger, 2001). In international research this has been reported to be longer than the time taken to remove the readily available cisternal milk, resulting in blind milking. Thus, proper pre-stimulation is important to ensure continuous and rapid milk removal (Sandrucci *et al.*, 2007). Alternatively, if clusters are attached without adequate pre-stimulation a bimodal milk flow curve can be seen (Bruckmaier & Blum, 1996), which has been reported to have negative effects on milking efficiency by increasing cluster-on time and has also been reported to have a significant relationship with somatic cell count (Dodenhoff *et al.*, 1999). A pre-stimulation time of 20 to 30 seconds followed by a delay of 1.3 minutes has been recommended as optimum to ensure a continuous milk flow (Rasmussen *et al.*, 1992). It has been observed that longer delay times reduce cluster-on time by increasing peak or average flow rates (Hogeveen & Ouweltjes, 2003; Weiss & Bruckmaier, 2005). However, recent research has indicated that a short period of stimulation, followed by a short delay, is sufficient to induce milk ejection when the udder is filled at greater than 40% of capacity (Kaskous & Bruckmaier, 2011).

In late lactation, as milk yield declines, the level of udder fill is reduced. This has a negative impact on the time required for milk ejection to occur, and may take as long as 3 minutes from the start of stimulation (Bruckmaier & Wellnitz, 2008). However, recent research has indicated that at low degrees of udder fill (<40%), a short period of stimulation can still be used but a slightly longer delay is required to produce an optimal flow curve (Kaskous & Bruckmaier, 2011). During times of low udder fill oxytocin release is not reduced or delayed (Mayer *et al.*, 1991), which indicates that the delay is due to a slower response at the intramammary level. As there is less milk present, a greater degree of contraction is required by the myoepithelial cells to expel the milk from the alveoli. The amount of cisternal milk at this time will also be lower, further increasing the risk of blind milking (Bruckmaier & Hilger, 2001). The same effect is seen during shorter milking intervals, e.g. four hours, where the degree of udder fill is low. As the intensity of the stimulus does not hasten milk ejection, avoiding the use of a stimulus that simultaneously removes the small quantity of cisternal milk (such as attaching clusters at full vacuum) may have a positive effect on udder health.

The milk ejection reflex can be interrupted under various conditions, either at the site of oxytocin release or at the site of oxytocin action. This is called central inhibition and peripheral inhibition, respectively. Peripheral inhibition can be induced by the administration of an α-adrenergic or an oxytocin receptor blocker (Bruckmaier *et al.*, 1997). This can occur during normal oxytocin release but is limited to experimental use (Bruckmaier *et al.*, 1997). Comparatively, in practice, central inhibition can occur often, particularly during times of stress. Stress can be brought on by milking in unfamiliar surroundings, which can be reversed by administration of oxytocin. As cows acclimatise to a routine, oxytocin release then returns to normal levels. The delivery of oxytocin to the myoepithelial cells can also be disrupted by insufficient blood flow. Cows are also very susceptible to electrical shock due to their low resistance. Low voltages in the shed, known as stray voltage, has been shown to disturb milk removal and increase SCC (Bruckmaier & Blum, 1998). Oxytocin release can also be positively influenced by external factors. For example the feeding of concentrates during milking enhances milking-related oxytocin release (Svennersten *et al.*, 1995). Oxytocin release can also be influenced by light, with greater milking related oxytocin release observed in a well illuminated automatic milking system (Mačuhová & Bruckmaier, 2004). However, these factors would have no effect on milk ejection in cases where the oxytocin release is greater than the threshold level.

In New Zealand, farmers moved to a practice of minimal stimulation due to larger herds and reduced availability of labour, with the goal of achieving maximum production with minimal effort (Phillips, 1987). A trial in 1958 with identical twins showed that there were significant milk production gains from those twins that were exposed to 30 seconds of stimulation (Phillips, 1984). In 1963/64 a trial involving 20 sets of identical twins compared the effects of a short stimulation versus the stimulus to requirement for each individual cow (Phillips, 1986a). Once again those receiving the greater stimulus produced significantly more milk, over 25% when lower producing twin sets were omitted (Phillips, 1986a). It was, however, noted that the response was not uniform and some cows were less affected. This result was attributed to the stimulus environment operating within the New Zealand dairy industry, where hand stripping was routinely practiced. Consequently, many cows that would have had poor production under machine milking alone, and therefore culled, were maintained in herds and contributed to breeding stock (Phillips, 1987). New Zealand cows were thus still highly dependent on stimulation. In 1963 it was recommended that those cows that required a high stimulus should not be bred from, with the aim of removing this requirement from the national herd (Phillips, 1963). It was also shown that the trait was highly heritable and that some artificial breeding bulls sired daughters with a high stimulus requirement. Furthermore, sire proving herds adopted low-stimulus routines so that those with a high stimulus requirement were automatically excluded (Phillips, 1978). In 1977/78 a trial comparing a stepped stimulus, with different stimulation levels over the lactation to a wash only preparation was conducted. No statistically significant differences in milk or fat yield were observed between the two groups whereas 12 years previously the difference had been 18%, indicating that selection pressure over the past decade had had a marked response (Phillips, 1986b). Subsequently, Phillips (1987) concluded that a national herd capable of maximum production under streamlined milking conditions had been successfully developed.

However, the milk ejection reflex is important in determining the milk flow profile of cows. Consequently, it is an important factor in determining the milking time of cows and thus milking efficiency. Inadequate stimulus can cause periods of blind milking, similar to overmilking, which can be detrimental to cow health.

Overmilking

Overmilking is defined as a period when clusters remain attached to teats after the milk flow-rate from an individual cow has fallen below an arbitrary ‘end-point’ of milking e.g. a milk flow rate of 0.2 kg/min. Overmilking occurs in dairies not equipped with ACRs, when cow milking duration is less than the time required for the operator to complete their work routine in herringbone dairies or less than the rotation time in rotary dairies. It is generally accepted that a moderate level of overmilking (up to two minutes) is of relatively minor concern as long as the milking system is functioning correctly (Gleeson *et al.*, 2003). However, overmilking that exceeds two minutes for an extended period of time can result in hyperkeratosis, increased thickening of skin at the external teat orifice and teat congestion and oedema, increasing the risk of infection (Hamann, 1987; Osteras & Lund, 1988; Hamann *et al.*, 1994). Hyperkeratosis of the teat end, in particular, has been reported to be associated with clinical mastitis (Neijenhuis *et al.*, 2001). However, despite the effect on teat morphology, overmilking does not necessarily translate to clinical mastitis (Sieber & Farnsworth, 1981).

One of the earliest studies where the effect of overmilking on udder health was reported was conducted by Dodd *et al.* (1950). Two fixed durations of milking, four and eight minutes, were applied to primiparous pairs of cows at every milking from the first day of milking through to drying off. The treatments resulted in periods of undermilking, and overmilking depending on the treatment and stage of lactation. The bacterial and clinical data indicated that those cows on the eight minute treatment had significantly more mastitis, and the authors concluded this was likely due to being overmilked, however, the exact mechanism was not obvious. Theoretically, during milking, milk within the teat acts as a buffer against the collapse of the teat cup liner, preventing irritation of the epithelial lining. On the other hand, when clusters remain attached after the cessation of milk flow, this cushion no longer exists and teat injury can occur. Peterson (1964) concluded through a series of trials that overmilking was capable of severely injuring internal teat structures and that hyperaemia, haemorrhage and edema of the epithelial lining of the cistern were the most common clinical changes. Teats subjected to shorter amounts of overmilking (5 min) more frequently were less affected than those severely overmilked (20 min) less frequently (Peterson, 1964). Teat colour, feel, and teat ringing have all been reported to worsen with the degree of overmilking (Hillerton *et al.*, 2002). However, it is not clear if this increases the incidence of clinical mastitis. In an experiment where cows were overmilked for 12 min, the number of quarters infected was increased, however, there was no difference in the number of cows infected (Natzke *et al.*, 1982). Natzke *et al*. (1982) hypothesised that the increased number of infections was a result of cross infection, and the negative effect of overmilking was likely associated with the transfer of organisms to non-infected quarters during the time of little or no milk flow. So, overmilking simply increased the at-risk time of little or no milk flow compared with cows not overmilked. This may help to explain the variable results observed from overmilking in commercial herds, as in herds without a mastitis problem the reservoir of bacteria is absent and little effect is apparent. In comparison, herds with a history of mastitis have a reservoir of bacteria and overmilking can result in increased incidence of mastitis (Natzke *et al.*, 1982).

In dairies without ACR the amount of overmilking will depend on a number of factors. In a herringbone parlour, the operator progresses down the row attaching clusters, before returning to the start of the row, and in a swingover herringbone, move the clusters over to the second row of cows (Figure 2). The time from cluster attachment to removal will be dependent upon the number of clusters in the dairy and the work routine of the operator. A similar process occurs in rotary dairies where the speed at which the operator can attach clusters and perform other tasks and the rotary size will determine the time from cluster attachment to exit, when clusters are removed. If the time between cluster attachment to detachment is longer than the milking duration of the cow then overmilking will occur. Thus, the milk yield, and consequently milking duration, for a given work routine and dairy size will also influence overmilking. Cow milking duration is longer when cows are at peak lactation compared to the later stages of lactation. This is particularly relevant in countries with a seasonal calving pattern, resulting in the whole herd being at a similar stage of lactation at any particular time. There is little flexibility in the operator's work routine despite shorter cow milking durations in later lactation, thus potentially increasing the amount of overmilking (O'Brien *et al.*, 2012).

An operator's work routine may be intensive, e.g. involving disinfection/washing of teats, fore-stripping and drying of teats, or minimal, where only parts of this routine are followed. The choice of routine is influenced by regulation. In the EU, legislation (EU, 2004) requires that foremilk be examined and discarded before the milking cluster is attached, so intensive work routines are commonplace. Similarly, in the USA the Pasteurised Milk Ordinance states that teats must be sanitised and dried before clusters are attached (FDA, 2009). Conversely, in New Zealand no such legislation exists and minimal routines are practiced. The intensity of the routine largely determines the number of milking units that can be managed by one operator for a given milk yield, whilst minimising overmilking (i.e. full work routine restricts the number of clusters one operator can manage). However, intensive work routines that include pre-milking preparation of cow teats is a form of stimulation, which can reduce the time to milk let-down and increase milk flow-rate (Bruckmaier & Blum, 1996), thus reducing cluster attachment time. The implications of this are that, in dairies not equipped with ACRs, the duration of overmilking may increase if more clusters are added without additional labour.

Overmilking is thus an important consideration when considering milking efficiency. As herringbone and rotary dairies become larger, and the number of cows and clusters handled by an operator increases, the chance of overmilking is greater. This could result in poorer udder health in these herds.

Industry trends

Changes in herd size and labour availability have been key drivers behind the evolution of the milk harvesting process. Over time there have been large changes in herd size within the New Zealand dairy industry. The average herd in New Zealand for the 2011-12 season was 393 cows (DairyNZ, 2012b). This has increased from 112 cows in the 1974-75 season, whilst simultaneously the number of herds has been declining (Figure 7). The increase in average herd size has partly been driven by an increase in the number of large herds (500+ cows). The 500+ herd size category made up just 4% of herds in the 1998-99 season, which had more than doubled to 9% in 2001-02 and was 25% in 2011-12 (LIC, 1999, 2002; DairyNZ, 2012b). In 2011-12, cows in herds of over 500 cows made up 49% of the national herd.

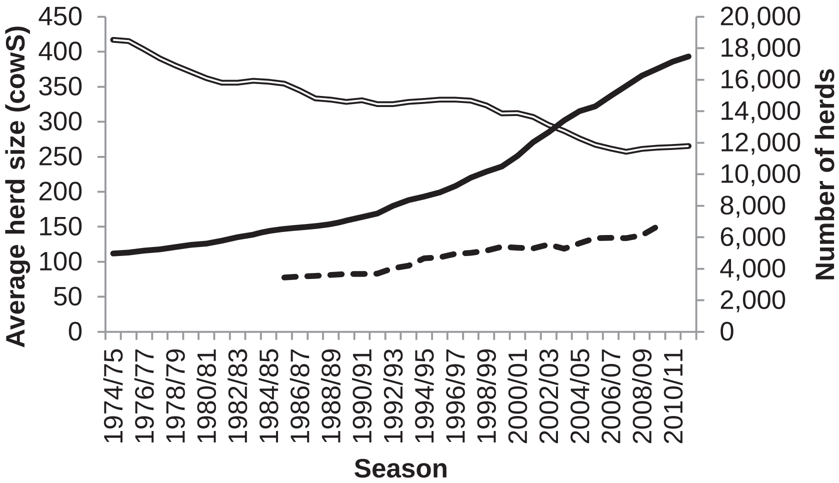

Figure 7. The trend of average herd size (cows; ─), number of herds (═), and labour efficiency (cows/full time equivalent; - -) over time (DairyNZ, 2012a, 2012b).

Herd size influences a farmer's choice of dairy type. The 20 years between 1960 and 1980 saw a marked reduction in the number of walk-through dairies. The majority of walk-through dairies were converted to, or replaced by, herringbone dairies, with a small number of rotary dairies being built (Figure 8b). This change in dairy type enabled the doubling of herd size during that period from 57 to 120 cows, without a corresponding increase in labour input (Phillips, 1987). Figures from 1962/63 suggest a reduction in 3.5 labour hours/day was achieved on farms that converted from a walk-through to a herringbone (Woolford, 1986). Changes in milking routines during this time also improved labour efficiency. From the 1980s to 1990s the percentage of herringbones remained constant at 83% of dairies, with a small increase in the number of rotaries as the remaining walk-through dairies were replaced. Average farm labour efficiency (cows/full time equivalent) increased during this time by about 21% (Figure 7). However, from the mid-1990s the percentage of herringbones declined with a corresponding rise in rotary dairies, likely due to the increase in the number of large herds. Data from Cuthbert (2008) show that herds of more than ~500 cows are more likely to be milked in rotary dairies (Figure 8a). Correspondingly, it follows that in 2008, 40% of the national herd was milked in a rotary dairy, despite representing only 25% of dairies (Cuthbert, 2008). This shift towards rotary dairies and increased herd size resulted in an increase in labour efficiency of 45% during this time, significantly more than the previous decade. Since the 1990s 70% of new-build dairies have been rotaries (Cuthbert, 2008), which have slowly increased in size from the 22-36 bails, described as common by Woolford (1986), to the 50-54 bail and up to 80 bail rotaries of late (Cuthbert, 2008). At $15,000-$17,000 per bail (Lincoln University, 2012) this is a significant increase in capital expenditure, however, few studies have quantified the effect of size on milking efficiency (Armstrong *et al.*, 2001). Generally, herd size and choice of dairy are related and if herd size continues to increase, the rotary dairy is likely to become the dominant dairy type in the future. However, it is appropriate to examine the impact of increase in rotary size from a labour and capital efficiency perspective.

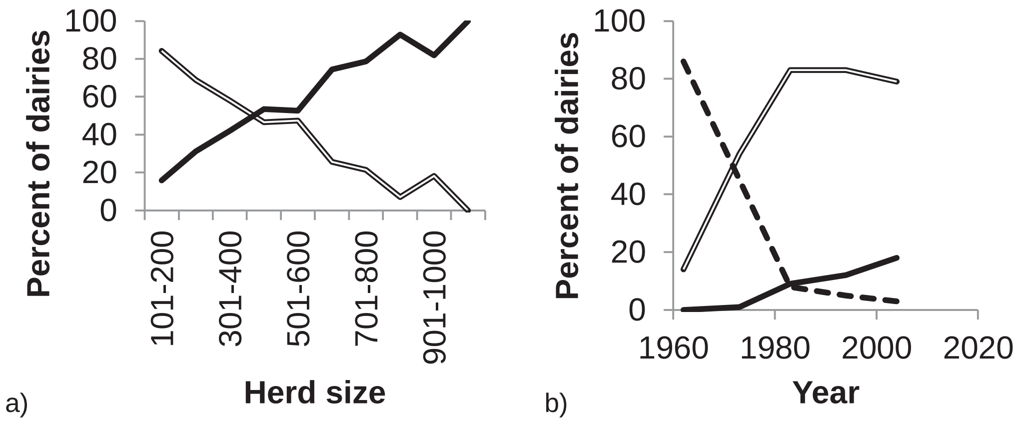

Figure 8. Percentage of herringbone (═), rotary (─), or other (predominantly walk-through; - -) dairies for (a) a range of herd sizes (Cuthbert, 2008), and (b) over time (Ohnstad & Jago, 2006).

Labour efficiency has improved over time with increases in herd size and changes in dairy type. However, labour is still a significant cost to the dairy business and milk harvesting can account for 33 to 57% of annual labour input (O'Brien *et al.*, 2004; O'Donovan *et al.*, 2008; Taylor *et al.*, 2009). As herd size continues to increase it is likely there will be continued pressure to improve the efficiency of the milk harvesting process. Improvements in milking efficiency have been made by new, labour efficient, dairy types and changes to milking routines within the dairy. Recent research has focused on shortening the milking duration of individual cows to improve milking efficiency. Two strategies have emerged, increasing the ACR threshold (Rasmussen, 1993), or applying a maximum milking time (Clarke *et al.*, 2004). The use of ACR in pasture-based dairy systems is limited, with ACR installed in 54% of rotary dairies and

9% of herringbone dairies (Cuthbert, 2008). Alternatively, a maximum milking time strategy can be applied in dairies without ACR, and in some dairies with ACR, depending on the model. In New Zealand, on many systems, the default ACR milk flow rate threshold when the cluster is removed is 0.2 kg/min and recent research has looked at the effect of increasing this to 0.4 kg/min (Jago *et al.*, 2010a; Burke & Jago, 2011). The aim of the maximum milking time strategy is to truncate 20% of the slowest milking cows and is particularly useful in the herringbone dairy where row time is often limited by the slowest milking cow (Jago *et al.*, 2010b). Both strategies have been shown to reduce average cow milking duration without affecting milk production or quality, potentially allowing greater throughput within dairies. However, in New Zealand there is scope to validate the further increase of ACR thresholds to the ~0.8 kg/min tested internationally (Stewart *et al.*, 2002) and the potential benefit to the overall milking system needs to be quantified.

The continued increase in herd size and drive to reduce labour costs means there will likely be continuing pressure to increase milking efficiency. The rotary dairy will likely become the dominant milking parlour type in New Zealand, and possibly Ireland in the future. Therefore, research should focus on determining if there is an optimum rotary size and how to maximise labour efficiency. To maximise labour efficiency, the operation of rotary dairies needs to be examined and current research extended to derive optimal milking strategies.

Conclusions

Over the last 60 years the milk harvesting process has evolved to suit a changing dairy industry. From the start of machine milking in the walk-through dairy, to the invention of the herringbone and rotary dairies, significant improvements in labour efficiency have been made, allowing large herds to be milked through a single facility. Over this time milking routines have also evolved with the abandonment of labour intensive pre-milking routines and post-milking machine stripping. The abandonment of pre-milking stimulation has had unknown effects on the milking characteristics and flow profiles of New Zealand dairy cows. The rotary dairy, which over time has been increasing in size, will likely become the dominant dairy type as herd size increases in the future. The drive to increase the number of clusters per operator can result in overmilking in dairies without ACR, with potential consequences for udder health. To continue the trend of improving labour efficiency in the milk harvesting process the impact of different sizes, and operating principles, of rotary dairies requires examination. Additionally, the further development of strategies to reduce the milking duration of individual cows should be investigated. Furthermore, the effect of these strategies on the overall milking system needs to be quantified and compared in economic terms.

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CHAPTER 3

Large rotary dairies achieve high cow throughput but are not more labour efficient than medium sized rotaries

J. Paul Edwards[A,B], Jenny G. Jago[A] and Nicolas Lopez-Villalobos[B]

[A]DairyNZ, Private Bag 3221,
Hamilton 3240, New Zealand.

[B]Institute of Veterinary, Animal and Biomedical Sciences,
Massey University, Private Bag 11222,
Palmerston North 4442, New Zealand.

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Abstract

It was hypothesised that large rotary dairies (>60 clusters) are not more operator efficient than medium sized rotaries (40-60 clusters). This was tested by collecting and analysing milking data, during peak and late lactation, from block calving herds milked in rotary dairies fitted with electronic milk meters. Data were collected from a total of 61 unique farms around New Zealand, with rotary dairies ranging in size from 28 to 80 clusters, for two five-day periods during spring (September – November 2010; 47 farms; average milk yield 23.1 kg/day) and autumn (February – April 2011; 60 farms; average milk yield 16.4 kg/day). A telephone survey was conducted to collect basic farm details; size, land area, the number of herds managed (including hospital herds), number of operators in the dairy and total labour input. A site visit was conducted to collect data such as the number of bails/stalls over the entrance and exit of the platform. The herd management software on each farm was programmed to record similar fields for each of the six machine manufacturers represented. Variables recorded included cow, date, identification time, bail number, milk yield, milking duration, and average milk flow rate. Calculations were performed to determine the number of cows milked and milk harvested per hour as well as the operator efficiency values for these measures and an estimate of cluster utilisation. Mixed models were used to determine the relationship between the dependent variables, cows milked per hour, milk harvested per hour, cows milked per operator per hour, milk harvested per operator per hour, and cluster utilisation, and the independent variables collected. Cows milked and milk harvested per hour increased linearly with rotary size, during both spring and autumn and there was a quadratic relationship between operator efficiency measures and rotary size, which peaked at approximately 60 clusters. Cluster utilisation, the amount of time clusters were harvesting milk out of the plant running time, was estimated at 46 ± 6%. Larger rotary dairies on average achieved greater throughput, however, they were not more operator efficient than medium sized rotaries. Thus, large rotary dairies are best suited to farms where the additional throughput is required.

Keywords: milking efficiency, rotary dairy, throughput, parlour size

Introduction

Milk harvesting represents the most time consuming task on traditional pastoral dairy farms (Taylor *et al.*, 2009). This important task affects people, cows, milk quality, and capital investment and thus plays an important role in the performance of the farm business. Therefore, careful consideration needs to be given to the design when investing in a milking parlour.

Herd sizes on pastoral dairy farms are increasing and are likely to continue to expand (O'Donnell *et al.*, 2008; DairyNZ, 2011). Farms with larger herds tend to utilise rotary dairies, with 40% of cows in New Zealand being milked through rotaries, despite only representing 25% of dairies (Cuthbert, 2008). Therefore, rotary dairies are likely to become the increasingly dominant milking parlour type.

As herd sizes have increased the number of clusters being installed in new rotary dairies has risen from the 15-30 clusters that were common in early rotaries (Copeman, 1985) to as many as 80-100 clusters today. The operator and throughput efficiency of rotaries has been benchmarked in the USA and Mexico and results indicated that larger dairies (60-116 clusters) achieved higher levels of throughput (cows milked per hour) and could thus milk herds faster than smaller ones. However, larger dairies were less operator efficient than medium sized (48-54 clusters) rotaries (Armstrong *et al.*, 2001).

The process of milk harvesting differs between farm systems. Milking in the USA and Mexico may occur three times a day with the use of labour intensive pre-milking routines, compared with milking twice or even once a day with little to no pre-milking routine in most pasture-based production systems. Additionally, daily milk production per cow is often higher in the USA and Mexico than in countries utilising pasture-based dairy production systems. Furthermore, pasture-based systems tend to have a seasonal calving pattern, whereby the cows calve during a specific season to coincide with pasture growth and thus herd milk yield declines through the season as days in milk increases (Garcia & Holmes, 2001), potentially changing the demands on infrastructure. There is, therefore, a need to benchmark the performance of rotary dairies under these conditions, to assist farmers with making informed decisions on the most appropriate dairy size.

It was hypothesised that large rotary dairies (>60 clusters) are not more operator efficient than medium sized rotaries (40-60 clusters) in pasture-based systems. This was tested by collecting and analysing milking data from spring calving herds milked in rotary dairies fitted with milk meters, ranging in size from 28 to 80 clusters.

Materials and methods

Data collection

Participating farms were selected for their ability to automatically record milking data and all were equipped with electronic identification of cows, electronic milk meters, automatic cluster removers (ACR) and herd management software that recorded individual milking events. Farms were spring calving and were located throughout the dairying regions of New Zealand. Rotary sizes ranged from 28 to 80 clusters and six different milking equipment manufacturers were represented. Data were collected from approximately 10 milking sessions at two time points, in spring, which approximately coincided with peak milk yields between the end of calving and start of mating (September – November 2010; mean daily milk yield 23.1 kg; 47 farms) and in autumn, which coincided with late lactation for the spring calving herds (February – April 2011; mean daily milk yield 16.4 kg; 60 farms). Between the two collections a total of 61 unique farms were represented (<40 clusters, n=1; 40-60 clusters, n=53; > 60 clusters, n=7). Additionally, a telephone survey was conducted to collect basic farm details such as size, the number of herds managed, including hospital herds, number of operators in the dairy and total labour input. The number of bails (stalls) over the entrance and exit of the platform were measured during a site visit.

The herd management software on each farm was programmed to record similar fields for each of the six systems. The variables recorded included cow, date, identification (ID) time, bail number, milk yield (kg), milking duration (s), average flow (kg/min), and maximum flow (kg/min).

Calculations

Cows in the hospital herd were identified and excluded from all calculations. Data were cleaned to exclude values outside the following ranges in a milking session, milk yield between 0.5 and 30 kg, milking duration between 120 s and 1200 s, maximum milk flow between 0.5 and 10 kg/min, and average milk flow between 0.2 and 5 kg/min. If three or more values were excluded for a cow the milk meter was assumed to have failed and the remaining fields for that cow were excluded for that milking session. In systems that did not record average milk flow rate it was estimated by dividing milk yield by milking duration.

Bails not occupied by new cows were calculated by sorting data by ID time at each milking session and counting the number of times bail numbers were not sequential. This was used to calculate the number of rotations during the session by adding the number of cows in the herd and the number of bails not occupied by new cows and dividing this by the number of bails in the rotary.

Average rotation time was calculated by subtracting the last ID time from the first ID time (including any time between herds), and dividing by the number of rotations. The average rotation time was used to estimate the average time spent on the platform by each cow whereby the time taken in the rotation to pass the bails over the entrance and exit was removed. This figure was added to the time between the first ID time and the last ID time to estimate the total milking time of the herd.

Rotary platform speed (s/bail) was calculated by subtracting the last ID time, and the largest time gap(s) between identification of two cows if more than one herd was present, from the first ID time and dividing this by the number of rotations multiplied by the rotary size.

To overcome random ID failure, the number of cows present at each milking session was calculated. At each collection period, if a cow was identified at any of the milking sessions she was assumed to be present at every milking unless in the hospital herd or identified as being part of a herd being milked once-a-day.

Cow throughput was calculated by dividing the number of cows by the total herd milking time. Operator efficiency for this measure was determined by dividing throughput by the number of operators in the dairy. Milk harvesting efficiency was calculated by multiplying the average milk yield per cow by the number of cows then dividing this number by the total herd milking time. This value was further divided by the number of operators in the dairy to determine the operator efficiency for this measure. An estimate of cluster utilisation, defined as the percentage of time clusters were harvesting milk over the time the plant was running, was calculated using Equation 1, where NC is the number of cows, AMD is average cow milking duration (min), HMD is the total herd milking duration (total minutes per cluster) and RS is the rotary size.

Equation 1: Cluster utilisation $= \frac{NC \times AMD}{HMD \times RS}$

Statistical modelling

Data manipulation and statistical analyses were carried out using SAS 9.2 (SAS Institute, Cary, USA). Initially, the differences between milking sessions (AM/PM) and stage of lactation (peak/late) were assessed using a mixed model that included dairy size, session, stage of lactation, the interaction between dairy size and stage of lactation as fixed effects and farm as a random effect. Subsequently, a mixed model analysis was used to determine the relationship between the dependent variables (efficiency measures) and predictor variables, as fixed effects, with farm as a random effect. Predictor variables that were not significant were dropped from the final model. Dependent variables were: cows milked per hour, milk harvested per hour, cows milked per operator per hour, milk harvested per operator per hour, and cluster utilisation. Predictor variables assessed were: dairy size (number of clusters), dairy size squared, cow milk yield (kg/cow), average milk flow rate (kg/min), average rotation time (min). The ability to predict dependent variables was assessed using the relative prediction error (RPE; Equation 2), where A_i is the i^{th} observed actual value and P_i is the i^{th} predicted value using fixed effects only and $\overline{A}$ is the mean of the observed actual values.

Equation 2: $$RPE = \left(\sqrt{\frac{1}{n}\sum_{i=1}^{n}(A_i - P_i)^2} \Big/ \overline{A} \right) \times 100$$

In keeping with Fuentes-Pila *et al.* (1996) an RPE value lower than 10% was considered good prediction, an RPE between 10% and 20 % acceptable prediction, and an RPE greater than 20% poor prediction.

Results

The mean (± standard deviation) size of the 61 farms that participated in the study was 245 ± 97 ha utilisable area, with 4.2 ± 1.6 labour units and an average herd size of 733 ± 328 cows. This equated to 60 ± 15 ha/labour unit and 178 ± 40 cows/labour unit. The descriptive statistics of the milking data at morning and afternoon milkings in spring (peak lactation) and autumn (late lactation) are presented in Table 1. At peak lactation 100% of dairies with fewer than 60 clusters, 100% of dairies with 60 clusters, and 25% of dairies with more than 60 clusters were operated by one person. In late lactation a similar proportion of dairies with fewer than 60 clusters were operated by one person, 95%, whilst the number of 60 clusters dairies with a single operator decreased to 86%. The proportion of dairies with more than 60 clusters being operated by one person fell to 0%. At peak lactation, average time between herds (there were an average of 2.1

herds per farm) was 5.8 ± 4.5 min per milking and it took an average of 15.4 ± 5.3 rotations to milk all cows in a total of 2.7 ± 0.8 hours. During late lactation (average of 2.1 herds per farm) these values had fallen slightly to 5.3 ± 4.5 min, 15.3 ± 5.3 rotations, and 2.4 ± 0.8 hours, respectively. Throughput (cows/h and kg of milk/h), the operator efficiencies of these measures, and cluster utilisation differed by stage of lactation and session (P<0.001) but no interaction was detected between dairy size and stage of lactation.

Cows milked and milk harvested per hour increased linearly with rotary size (Figures 1 and 2). A model including dairy size squared was determined to be the most appropriate for the operator efficiency measures (Figures 3 and 4) and peaked when rotary size was approximately 60 clusters. Cluster utilisation was not associated with rotary size (Figure 5). Predicted values for each rotary size using the models presented in Table 2 and average values for other independent variables at each time point are included in each figure. All models achieved a good or acceptable level of prediction when evaluated by RPE.

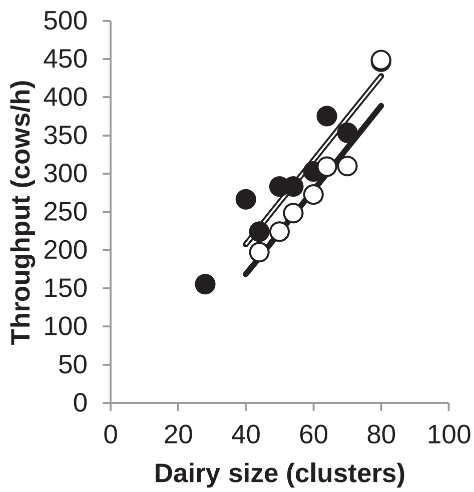

Figure 1. Average throughput (○, peak lactation; ●, late lactation; cows/h) from first cluster on to last cluster off, including time between herds and predicted throughput (─, peak lactation; ═, late lactation) for each rotary size (40-80 clusters) using average values for additional predictor variables.

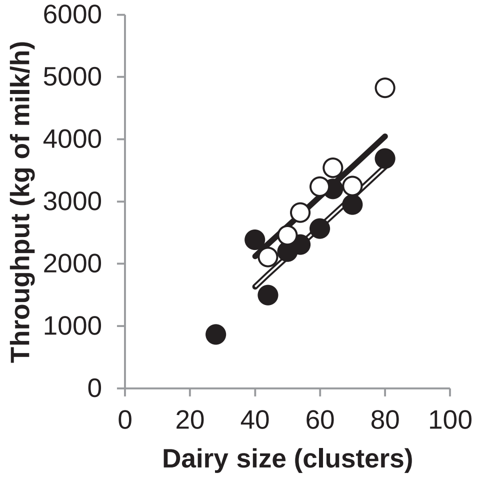

Figure 2. Average throughput (○, peak lactation; ●, late lactation; kg of milk/h) from first cluster on to last cluster off, including time between herds and predicted throughput (─, peak lactation; ═, late lactation) for each rotary size (40-80 clusters) using average values for additional predictor variables.

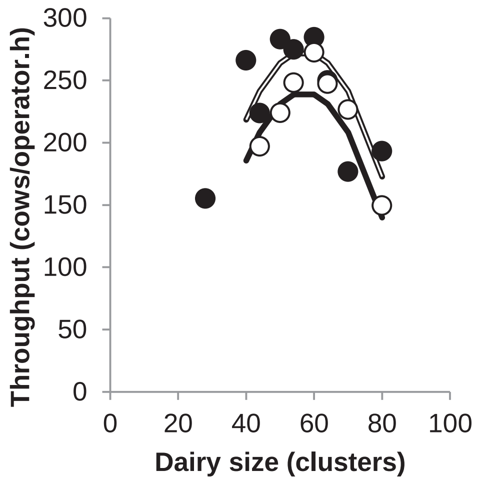

Figure 3. Average operator efficiency (○, peak lactation; ●, late lactation; cows/operator.h) from first cluster on to last cluster off, including time between herds and predicted throughput (─, peak lactation; ═, late lactation) for each rotary size (40-80 clusters) using average values for additional predictor variables.

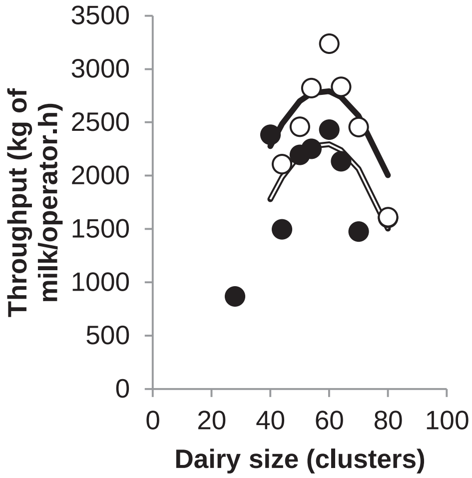

Figure 4. Average operator efficiency (○, peak lactation; ●, late lactation; kg of milk/operator.h) from first cluster on to last cluster off, including time between herds and predicted throughput (─, peak lactation; ═, late lactation) for each rotary size (40-80 clusters) using average values for additional predictor variables.

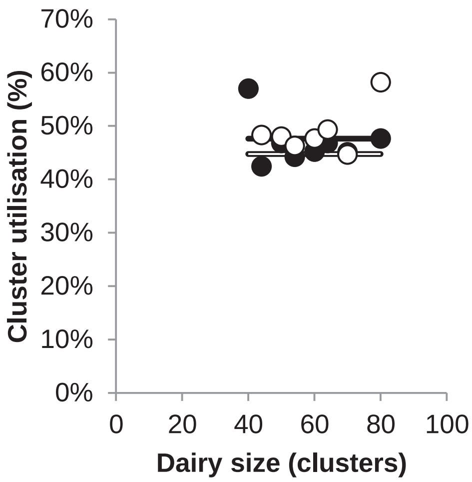

Figure 5. Average cluster utilisation (○, peak lactation; ●, late lactation; %) from first cluster on to last cluster off, including time between herds and predicted throughput (─, peak lactation; ═, late lactation) for each rotary size (40-80 clusters) using average values for additional predictor variables.

Table 1. Descriptive statistics of the 61 benchmark farms for AM and PM milkings in peak and late lactation.

		AM				PM			
Time	Item	Mean	Min	Max	SD	Mean	Min	Max	SD
Peak	Number of cows milked	706	321	1972	275	686	321	1933	263
Lactation	Milk Yield (kg/milking)	13.7	9.9	19.7	1.6	9.4	6.6	12.5	1.2
	Cow milking duration (s)	421	334	498	35	334	209	428	38
	Average milk flow rate (kg/min)	2.0	1.4	2.4	0.2	1.7	1.2	2.2	0.2
	Peak milk flow rate (kg/min)	3.6	2.6	4.2	0.3	3.4	2.5	4.1	0.3
	Dairy size (clusters)	55	44	80	7	55	44	80	7
	Platform rotations	16.0	6.8	36.6	5.7	14.9	6.5	29.4	6.6
	Mean rotation time (min)	10.9	8.8	14.2	1.2	9.6	7.7	12.4	1.0
	Mean platform speed (s/bail)	12	7	17	2	10	6	15	2
	Cows per hour	234	153	403	43	275	178	494	52
	Cows per hour per operator	223	153	305	36	263	165	365	42
	Kilograms per hour	3196	1823	5239	667	2563	1689	4412	513
	Kilograms per hour per operator	3069	1746	5087	647	2456	1429	3360	468
	Cluster utilisation (%)	49%	39%	60%	5%	46%	26%	58%	6%
Late	Number of cows milked	733	255	1989	328	712	208	1989	331
Lactation	Milk Yield (kg/milking)	9.8	5.1	13.5	1.6	6.6	3.7	9.1	1.1
	Cow milking duration (s)	338	253	480	41	278	204	452	35
	Average milk flow rate (kg/min)	1.8	1.1	2.4	0.2	1.5	0.9	2.0	0.2
	Peak milk flow rate (kg/min)	3.5	2.4	4.5	0.4	3.3	2.2	4.1	0.4
	Dairy size (clusters)	56	28	80	9	56	28	80	9
	Platform rotations	15.7	5.6	31.3	5.5	14.9	4.2	30.3	5.2
	Mean rotation time (min)	9.6	6.9	12.4	1.2	8.5	6.0	11.6	1.1
	Mean platform speed (s/bail)	10	6	18	2	9	5	17	2
	Cows per hour	275	140	427	55	318	170	536	71
	Cows per hour per operator	245	104	359	56	282	124	434	63
	Kilograms per hour	2709	886	4704	712	2114	846	4014	597
	Kilograms per hour per operator	2414	886	3668	677	1880	807	3081	549
	Cluster utilisation (%)	46%	35%	59%	6%	44%	31%	65%	7%

Table 2. Coefficients obtained from mixed model analysis.

Independent variable	Predictor variables	Coefficients B	Coefficients SE	F	P-value	RPE-value
Cows per hour	Intercept	215.57	21.44			9%
	Rotary size (clusters)	5.51	0.33	279.6	<0.0001	
	Milk yield (kg/milking)	-4.27	0.63	46.5	<0.0001	
	Rotation time (min)	-21.31	1.50	203.1	<0.0001	
Kilograms per hour	Intercept	-1275.09	248.56			10%
	Rotary size (clusters)	48.09	3.31	211.2	<0.0001	
	Milk yield (kg/milking)	154.40	10.81	203.9	<0.0001	
	Rotation time (min)	-153.59	14.84	107.2	<0.0001	
	Average milk flow rate (kg/min)	677.44	102.49	43.7	<0.0001	
Cows per hour per operator	Intercept	-150.68	105.04			15%
	Rotary size^2 (clusters^2)	-0.19	0.03	39.8	<0.0001	
	Rotary size (clusters)	21.66	3.54	37.4	<0.0001	
	Milk yield (kg/milking)	-3.53	0.98	12.8	0.0004	
	Rotation time (min)	-18.10	2.36	58.9	<0.0001	
Kilograms per hour per operator	Intercept	-4109.57	930.10			14%
	Rotary size^2 (clusters^2)	-1.63	0.25	42.3	<0.0001	
	Rotary size (clusters)	188.74	29.91	39.8	<0.0001	
	Milk yield (kg/milking)	161.67	16.54	95.5	<0.0001	
	Rotation time (min)	-145.09	22.45	41.8	<0.0001	
	Average milk flow rate (kg/min)	570.83	154.64	13.6	0.0003	
Cluster utilisation (%)	Intercept	71.34	3.08			10%
	Milk yield (kg/milking)	2.82	0.21	173.1	<0.0001	
	Rotation time (min)	-2.99	0.29	108.5	<0.0001	
	Average milk flow rate (kg/min)	-13.71	2.02	45.9	<0.0001	

Discussion

The data support the hypothesis that large rotary dairies are not more operator efficient than medium sized rotary dairies, despite throughput increasing as rotary size increased. Rotary size was an important determinant of cows milked per hour and milk harvested per hour. However, other factors such as milk yield, average milk flow rate and the average rotation time were also significant in determining throughput. Empirically, cow milking duration, the speed of the rotary platform and the number of clusters determine cow throughput (Copeman, 1985; Edwards *et al.*, 2012). Therefore, the additional predictor variables chosen are logical, as the average milk flow rate and the milk yield determine cow milking duration, and rotation time is a measure of rotary platform speed. The speed of the rotary platform and cow milking duration will determine the number of cows that require more than one rotation to complete milking, which reduces the amount of clusters available for milking new cows. Much of the variation in throughput not explained by the predictor variables was likely due to unoccupied bails, which due to the way the herd management systems recorded data, were unable to be distinguished from cows on a second rotation in this dataset. Increasing throughput in larger rotary dairies was reported in a group of farms from the USA, Mexico and Australia by Armstrong *et al.* (2001) where throughput increased from 211 cows/hour in rotaries with 22-44 clusters to 284 cows/hour in rotaries with 48-54 clusters and 422 cows/hour in rotaries with 60-116 clusters. These values are slightly higher than reported here (Figure 1), despite a lower average milk yield in the present study. Examining the Australian results only, where conditions are more similar to New Zealand, the average throughput of the 20 farms reported in the study was 325 cows/hour in an average rotary size of 58 clusters during peak lactation, but throughput over a range of sizes was not reported (Armstrong *et al.*, 2001). This result was higher than the 255 cows/hour measured in this study with an average rotary size of 55 clusters during peak lactation. The difference in performance is likely due to the slightly smaller average rotary size and the number of unoccupied bails, possibly occurring between herds, as well as a slightly slower average platform speed of 12 s/bail. Therefore, larger rotary dairies have greater potential throughput, however, the results highlight that individual conditions and operational practices are an important determinant of the actual throughput achieved.

In terms of operators, larger rotary dairies (>60 clusters) were not more efficient than medium sized dairies (40-60 clusters) despite the greater throughput achieved.

Throughput in terms of cows/operator.h and kg of milk/operator.h peaked at around 60 clusters, with most dairies of fewer than 60 clusters being operated by one person, as well as the majority of 60 cluster rotaries. However, many dairies of more than 60 clusters were operated with more than one person in the dairy. Similarly, operator efficiency in a group of American, Mexican and Australian dairies was reported to peak in the 48-54 cluster size range at 130 cows/operator.h, with 22-44 cluster rotaries averaging 105 cows/operator.h and 60-116 cluster rotaries averaging 108 cows/operator.h (Armstrong *et al.*, 2001). The operator efficiency values reported by Smith *et al.* (1999), Armstrong *et al.* (2001) and Smith *et al.* (2003) are considerably less than reported in this study (Figure 3), which is partly due to the prevalence of single operator dairies in this study and minimal milking routines used in pasture-based systems. Greater throughput in larger rotary dairies is achieved by increased platform speed resulting in the amount of operator time available per cow decreasing (Edwards *et al.*, 2012), eventually necessitating an additional operator. Time in motion research indicates that on average 8-12 s is required to attach a cluster (Armstrong & Quick, 1986). Therefore, when consistently operating at platform speeds faster than 8 s/bail more than one operator will likely be required, achieving greater throughput but creating operator idle time and reducing operator efficiency. The time required to attach clusters will be greater on farms applying pre-milking sanitisation and stimulation (e.g. in America and many housed systems) meaning more than one operator will be required at an even lower platform speed. Thus, there is a trade-off between increasing platform speed, and consequently throughput, and the number of operators required in the dairy, and hence operator efficiency. In the present study, a parabolic trend was determined to be the best fit for operator efficiency, peaking at 60 clusters. However, it should be noted that there was a limited number of dairies with more than 60 clusters (n=7), with a maximum size of 80 clusters. Hypothetically, operator efficiency may peak for a second time at 120 clusters where two operators could again be fully occupied (i.e. equivalent to 2 × 60 clusters), creating a polynomial trend. However, in this premise it is assumed that cows could be consistently loaded at a sufficient platform speed, potentially 4-5 s/bail, which may be unrealistic, and also that the platform could physically rotate at this speed. In this scenario, there would be a decreasing advantage to building dairies larger than 120 clusters as the measure cows/h/cluster begins to decline due to the inability to increase platform speed further. Thus, overall, farmers in pasture-based production systems considering larger rotary dairies, that require more than one operator, need to evaluate carefully if the increased throughput potential justifies the increased capital cost and likely poorer operator efficiency in their individual situation.

Differences in throughput between milking session (AM/PM) and stage of lactation were recorded. Greater throughput in terms of cows milked per hour was achieved during the PM milking. Conversely, in terms of kg of milk harvested per hour greater throughput was achieved at the AM milking. The different results can be explained by the milking interval, which is traditionally 14 hours overnight, and 10 hours during the day. The uneven milking interval results in greater milk yield at the AM milking (Table 1), and consequently longer individual cow milking duration despite greater average milk flow rates. Therefore, the longer cow milking duration was likely the reason for reduced cow throughput at the AM milking. The greater amount of milk harvested per hour at the AM milking despite less cow throughput was probably a result of greater milk flow rates due to the greater udder fill (Bruckmaier & Hilger, 2001). Similarly, differences in milk yield and therefore udder fill provide an explanation for the changes in throughput with stage of lactation. As milk yield declined in late lactation cow milking duration also decreased, allowing more cows to be milked per hour. However, the decrease in milk flow rate in late lactation meant less milk was able to be harvested per hour. Thus, in both situations (PM and late lactation) the lower milk yield allowed greater cow throughput but the increase was not sufficient to overcome the lower volume due to lower milk flow rates and consequently less milk was harvested per hour.

Cluster utilisation is a measure of the amount of time the milking plant is harvesting milk during the total time the milking plant is running and values varied greatly between the 61 farms. Cluster utilisation figures averaged under 50% (Table 1; Figure 5), much lower than the 70-80% anticipated and reported by Armstrong *et al.* (2001), although the definition used in that study was based on the difference between average platform speed achieved over the whole milking and the platform speed set by the operator. Low cluster utilisation represents a significant under use of a capital resource, considering that on average dairies were running for 2.4 to 2.7 hours per milking (20 to 23% of a 24 hour period for cows milked twice per day) and were only harvesting milk for ~50% of this time, i.e. only harvesting milk for 10-12% of the day. Improved capital utilisation could be achieved on large farms by building operator efficient rotaries, e.g. 60 clusters instead of 80 clusters, which milk fewer cows per hour, thereby increasing the herd milking time and the hours per day the dairy is operating (a strategy employed in the USA). Farms of this size typically have several herds so the increase in total milking time should not unduly decrease grazing time for individual herds. Additionally, capital use could be improved by increasing cluster utilisation. Factors that may have contributed to the low cluster utilisation include unoccupied bails (including those during the changeover between herds), time the platform is stopped (e.g. for cleaning or loading cows), both of which increase the herd milking time without increasing the number of cows milked, and cows that have finished milking before nearing the platform exit (including those cows requiring more than one rotation which frequently finish milking shortly after the exit). Unoccupied bails or long stoppages between herds (on farms with multiple herds), which were highly variable between farms, was likely a contributor to the lower than expected performance. Additionally, this will have increased average rotation time slightly. However, average rotation time was considerably longer (by 4 min) than the average cow milking duration, indicating that platform speed could be increased (or allowing smaller dairies to be built) to reduce the time cows are occupying bails with clusters removed, waiting to exit the platform (Edwards *et al.*, 2012). Greater numbers of unoccupied bails and/or stoppage time throughout milking may occur due to the greater operator efficiency achieved by the benchmark group, where many dairies were operated by one person, resulting in less time available to monitor the yard backing gate and cow flow onto and off the rotary platform. Furthermore, this could have contributed to the disparity between average rotation time and average cow milking duration, highlighting the need for well-designed dairies and skilled operators to maintain cow flow onto the platform whilst simultaneously attaching clusters. Therefore, it appears there is significant room to improve cluster utilisation, and thus capital utilisation, in some dairies by minimising the number of unoccupied bails or time between herds, whilst better matching rotation time to average cow milking duration. Additionally, capital utilisation could be improved on large farms by building operator efficient dairies rather than larger rotaries that milk the herd in the shortest possible time.

In conclusion, cow throughput varied greatly between farms and was influenced by operator management, though on average larger rotary dairies (>60 clusters) achieved greater throughput in terms of cows milked and milk harvested per hour. However, operator efficiency was reduced where multiple operators attached clusters simultaneously. Farmers in pasture-based production systems considering larger rotary dairies, that require more than one operator, need to evaluate carefully, under their individual conditions, if the increased throughput potential justifies the increased capital cost and likely poorer operator efficiency. Milking efficiency as measured by cluster, or capital, utilisation could be improved by building smaller, operator efficient, rotaries, minimising the number of unoccupied bails or breaks between herds, and ensuring average rotation time is closely matched with average cow milking duration.

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CHAPTER 4

Increasing platform speed and the percentage of cows completing a second rotation improves throughput in rotary dairies

J. Paul Edwards[A,B], Nicolas Lopez-Villalobos[B] and Jenny G. Jago[A]

[A]DairyNZ, Private Bag 3221,
Hamilton 3240, New Zealand.

[B]Institute of Veterinary, Animal and Biomedical Sciences,
Massey University, Private Bag 11222,
Palmerston North 4442, New Zealand.

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Abstract

This study sought to improve milking efficiency in rotary dairies by modelling the effect of increasing platform speed on the percentage of cows requiring multiple rotations to complete milking, i.e. ‘go-around’ cows, and cow throughput. Milking data, including 376,429 milking event records from 44,530 cows, were collected from sixty-two commercial farms with rotary dairies in New Zealand. Average rotation time, a function of platform speed and rotary size, was 10.0 ± 1.5 min, mean milking duration 383 ± 129 s, and mean milk yield 11.9 ± 3.8 kg per milking session. Milking duration data were normalised using a $\log_{10}$ transformation. An estimate of the percentage of ‘go-around’ cows and potential throughput over a range of platform speeds were made using the NORMDIST function of Microsoft Excel 2010. Results indicate that throughput continues to increase with increasing platform speed, despite a greater number of ‘go-around’ cows. If a potential shadow effect (whereby a ‘go-around’ cow may cause the following bail to be unoccupied) is considered, the optimum percentage of ‘go-around’ cows was ~20%. Accordingly, a change of operating practices in many rotary dairies is justified as the current target, of 10% ‘go-around’ cows, may limit throughput. In order to achieve greater cow throughput platform speed should rather be set based on the capability of the operator attaching clusters. The difference between the current average rotation time and milking duration indicates that many dairies can increase platform speed and thus throughput. Furthermore, many work routines can be accelerated so faster platform speeds can be achieved without increasing labour requirements. The increased throughput potential of larger dairies is only realised when operated at fast platform speeds.

Keywords: rotary parlour, cows per hour, milking efficiency, go-around

Introduction

Milking is the most time consuming task on pasture-based dairy farms, accounting for between 33 and 57% of time annually (O'Brien *et al.*, 2004; O'Donovan *et al.*, 2008; Taylor *et al.*, 2009). In the future, milking times will increase due to the continued expansion of herd sizes (DairyNZ, 2011), exerting pressure on labour resources if changes to milking routines and dairy size are not made. Large herds (>500 cows) in New Zealand and Australia tend to be milked through rotary dairies, for example 40% of cows, accounting for only 25% of herds, are milked through rotary dairies in New

Zealand (Cuthbert, 2008). Therefore, the rotary dairy is likely to become the dominant technology for milking cows as herd size increases.

The operating efficiency of rotary dairies is important in determining herd milking times and thus labour requirements for the milking process. Operating efficiency is determined by three factors (Copeman, 1985): (i) the number of bails on the platform, which is determined at the time of construction and cannot be easily changed, (ii) the distribution of individual cow milking times (determined by milk yield, milk flow rate and end-of-milking criteria), and (iii) the speed at which the platform is rotating. The speed of the rotation is the only factor directly controlled by the operator at the time of milking.

Rotation or platform speed (for practical purposes defined as s/bail) is difficult to measure and thus a more common term used on farm is rotation time, defined as the rotation speed multiplied by the number of bails on the platform, or simply the time taken to complete one rotation. Cows with milking durations greater than the rotation time will remain on the platform and complete a further revolution. Thus, rotation time directly affects the number of cows requiring more than one rotation to complete milking (Nitzan *et al.*, 2006). The number of cows requiring a second rotation ('go-around' cows) is obvious to the operator attaching clusters, and is thus the cue most operators use to set platform speed. The effect of platform speed on the efficiency of small rotaries was examined by Copeman (1985), who reported that the maximum throughput (cows milked per hour) was achieved when the speed was set so that 8-16% of cows were sent around on a second rotation. In practice a target of 10% was adopted.

Since the 1980s there has been an increase (~25%) in per cow production (DairyNZ, 2011), potentially altering the distribution of individual cow milking durations. Additionally, rotary sizes have increased from the 17-36 bails examined by Copeman (1985) up to as large as 80-100 bails today and pre-milking routines are no longer common practice (Phillips, 1987). Therefore, setting platform speed using the common target of 10% 'go-around' cows may no longer be appropriate.

It was hypothesised that the highest cow throughput would be achieved with 10% cows 'going-around' on a second rotation. A simple model was developed using data collected from commercial farms. This model was used to determine the effect of varying platform speed on the number of cows requiring a second rotation and cow throughput.

Materials and methods

Data collection

Sixty-two farmers throughout New Zealand participated in a study to provide benchmark data for a range of milking efficiency measures. Farmers were selected for their ability to record milking data automatically and all dairies were equipped with a minimum level of technology including electronic identification, milk meters, automatic cluster removers and herd management software that recorded individual milking events. A range of dairy sizes (40-80 bails), and milking plant manufacturers were included to represent rotary milking systems in use. Milking data were collected from approximately 10 milkings between the end of calving and start of mating (September – November 2010). Additionally, a phone survey was conducted to determine the number of herds being managed and the number of operators attaching clusters in the dairy.

Measurements and calculations

Each herd management system [DairyMaster (Causeway, Ireland), DeLaval (Tumba, Sweden), GEA (Bönen, Germany), Milfos (Hamilton, New Zealand), and Waikato Milking Systems (Hamilton, New Zealand)] was programmed to produce similar reports. Variables recorded included cow number, identification (ID) time, bail number, milk yield, and milking duration.

Bails not occupied by new cows were calculated by sorting data by ID time for each milking session and counting the number of times bail numbers were not sequential. The number of rotations during the session was calculated by adding the number of cows milked and the number of bails not occupied by new cows and dividing by the number of bails in the rotary. An estimate of average platform speed was calculated by subtracting the last ID time from the first ID time and removing the largest time gap(s) during a milking session if more than one herd(s), then dividing this value by the number of rotations and then by the number of bails.

Model development

Milking duration data from the AM and PM session were combined. Data were examined and found to be skewed (Figure 1a) so were normalised using a $\log_{10}$ transformation (Figure 1b). The normalised mean milking duration and standard deviation of the benchmark data were used with the NORMDIST function of Microsoft Excel 2010 (Redmond, WA, USA) to estimate the percentage of cows that would have completed milking in each rotation for a given platform speed and rotary size (rotation time is platform speed multiplied by rotary size, i.e. the number of bails). Subtracting the percentage finished milking from 100 leaves the percentage of cows that would not have finished milking before the end of that rotation. This calculation was repeated for five rotations to account for cows with longer milking durations that may require more than two rotations to complete milking at faster platform speeds (shorter rotation times). For example, a cow with a 20 min milking duration would occupy a bail for four rotations at a 6 min rotation time. The percentage of ‘go-around’ cows at each of the five rotations was summed to give an overall percentage of bails occupied by ‘go-around’ cows on the platform at any given time in a steady state situation. An estimate of throughput for a given platform speed and its corresponding ‘go-around’ percentage was calculated using Equation 1. It was assumed that there were six unutilised bails over the entry and exit to the platform and that there were no unoccupied bails. A second scenario was developed to determine the effect of a potential shadow effect whereby a ‘go-around’ cow may increase the chances the following bail is unoccupied. In this scenario it was assumed that half the bails following a ‘go-around’ cow were unoccupied.

Equation 1: $$\text{Throughput (cows/hour)} = \frac{3600}{\left(\frac{\text{'go-around' \%} + 100}{100}\right) \times \text{platform speed (s/bail)}}$$

Results

Commercial farms

A total of 376,429 milking event records from 44,530 cows were extracted from the 62 commercial farms. The average milking duration was 383 ± 129 s (Figure 1a) and average session yield 11.9 ± 3.8 kg, or a total daily yield of 23.8 kg/cow. The $\log_{10}$ transformed milking duration data had a mean of 2.56 and a standard deviation of 0.14 (Figure 1b).

Single operator dairies (n=57) achieved platform speeds of up to 6.4 s/bail. Mean platform speed was 11.3 ± 2.4 s/bail, and the slowest was 22.0 s/bail. The speed of dairies with two operators (n=2) attaching clusters ranged from a maximum of 5.5 s/bail to as slow as 8.5 s/bail, mean platform speed was 6.8 ± 1.1 s/bail. The remaining dairies operated with between one and two operators (n=3). Smaller dairies tended to operate at slower speeds than larger dairies. Mean rotation time was 10.0 ± 1.5 min, minimum 6.4 min and maximum 16.1 min.

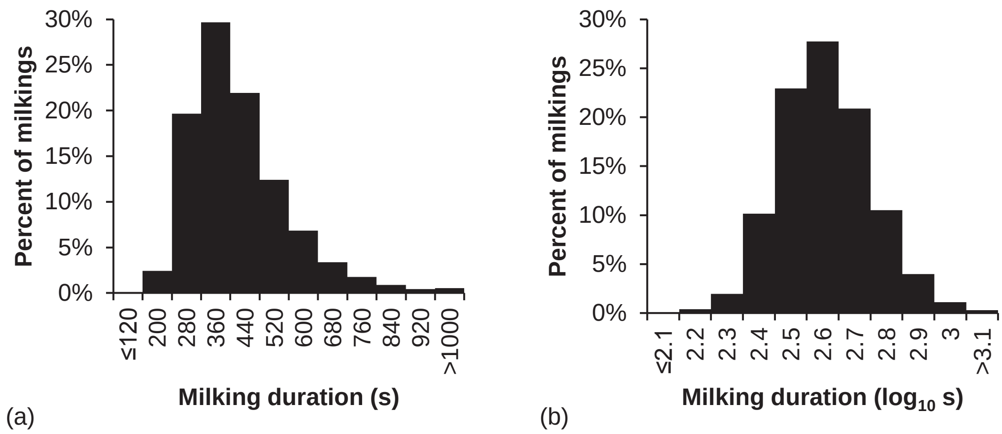

Figure 1. The distribution of milking durations (s) on 62 commercial farms (a) and normalised milking duration data (b).

Modelling

Increasing platform speeds resulted in higher percentages of 'go-around' cows (Figure 2a). A greater number of 'go-around' cows did not result in reduced potential throughput for all dairy sizes. Eighty bail rotary dairies operating at 5 s/bail achieved the highest potential throughput, 484 cows/hour, when an estimated 49% of cows required a second rotation (Figure 2b). Potential throughput was constrained by dairy size. Additionally, potential throughput was reduced when a shadow effect was included and an optimum percentage of go-around cows, ~20% (Figure 2c), was created. Modifying the shadow effect from 50 to 25 or 75% achieved similar results for optimum platform speed at each dairy size. The effect of platform speed on milking performance for a 718 cow herd, the average herd size of the sixty-two farms, milked through a 60 bail rotary, the most common dairy size of the survey farms, is shown in Table 1. Decreasing rotation time from the average 10 min to 8 min could result in a saving of 8.6 min per milking.

Table 1. Effect of four platform speeds on milking performance for a 718 cow herd milked through a 60 bail rotary.

	Platform speed			
Item	8 s/bail	9 s/bail	10 s/bail	11 s/bail
Rotation time (min)	8	9	10	11
Go-around (%)	30	18	11	6
Rotations	15.5	14.2	13.3	12.7
Total milking time (hr)	2.1	2.1	2.2	2.3
Difference[1] (min)	-8.6	-5.3	0	7.2
Throughput (cows/hr)	347	338	325	308

[1]Difference relative to mean rotation time of benchmark farms, 10 min.

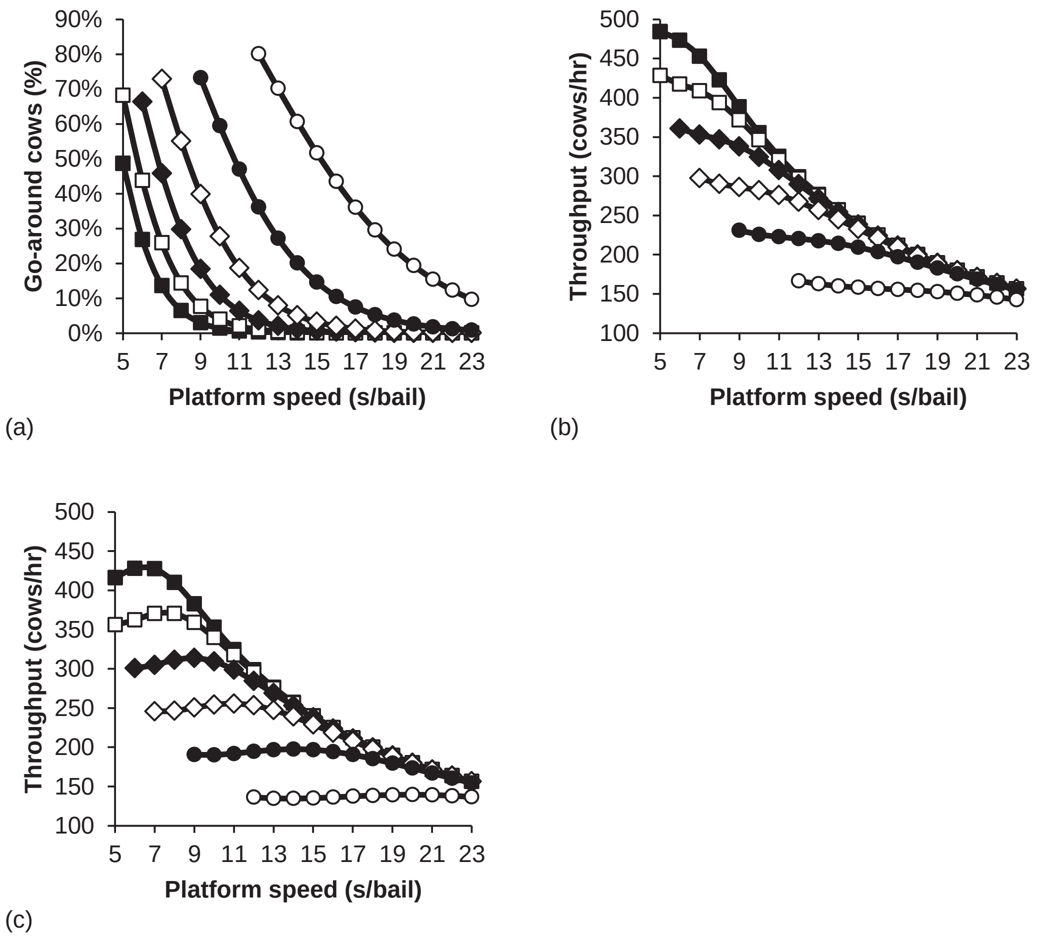

Figure 2. Percentage of go-around cows (a), potential throughput (b) and potential throughput including a theoretical shadow effect whereby half of bails following go-around cows are empty (c) at various platform speeds (s/bail) down to 6 min rotation time for 30 bail (○), 40 bail (●), 50 bail (◇), 60 bail (◆), 70 bail (□), and 80 bail (■) rotaries.

Discussion

The hypothesis that 10% is the optimum percentage of 'go-around' cows to achieve maximum throughput was rejected. The percentage of 'go-around' cows increased with faster platform speeds, however, throughput continued to increase without maxima. This result is consistent with Nitzan *et al.*, (2006) as the combination of a greater number of bails presented per hour and the time saved by cows waiting less time to exit the platform after rotation one is greater than the negative effect of more cows requiring multiple rotations, thus, an increased throughput is achieved. Greater throughput with more 'go-around' cows was not reported by Copeman (1985). However, Copeman (1985) made the assumption that at least 20 s was required to prepare a cow and therefore did not examine faster speeds. Examining the current results in the 20 to 60 s/bail range produces a similar figure to that reported by Copeman (1985). The current results indicate that throughput is highest when platform speeds are set to the maximum physically achievable by each dairy size or, if a potential shadow effect was included, when ~20% of cows were sent on multiple rotations. However, faster platform speeds require good cow flow onto and off the platform and the milking goals of farmers may vary, for example, feeding in bail may be the primary objective in which case a slower speed is appropriate to allow sufficient feeding time. Additionally, increasing the number of 'go-around' cows may result in more cows experiencing extreme overmilking (clusters remaining attached after the cessation of milk flow) when clusters are not removed by the operator normally attaching clusters in dairies not fitted with automatic cup removers, although cows exiting after a single rotation would be less likely to be overmilked. Furthermore, increased speeds and thus rotations may increase maintenance costs, so the increase in throughput should be considered with this in mind. Nevertheless, the current target of 10% 'go-around' cows will limit throughput in many situations. Thus, a major change in philosophy for the operating procedures of rotary dairies is justified.

Increasing platform speed has consequences for work routines and thus labour productivity and sustainability. Surveys in the USA suggest a work routine or platform speed of 8-12 s/bail is a common rate at which to attach clusters (Armstrong & Quick, 1986). The mean platform speed for single operator dairies was 11.3 s/bail, indicating platform speeds could be increased. Furthermore, mean rotation time was 10 min despite an average milking duration of 6.4 min. Rotation times of 10 min or greater will likely result in operator idle time in dairies of 60 bails or less. The dataset provided examples of dairies with a single milking operator attaching clusters at a rate which allowed a platform speed of 6.4 s/bail. Alternatively, dairies were identified where two milking operators attached clusters with a platform speed of 8.5 s/bail. This indicates that at ~7.5 s/bail the platform speed becomes too great for a single operator to attach clusters and two operators are necessary. Therefore, if increasing platform speed beyond the capabilities of one operator, cow throughput should be measured in cows/operator.h. The increase in throughput may not justify the greater labour input. Thus, platform speed should be set based on the abilities of the operator instead of the number of 'go-around' cows, which is used currently.

The rotary dairy is an efficient design because cow movement is largely automated, where cows enter and exit the platform at a constant rate, leaving the operator little time to rest between cows (Douphrate *et al.*, 2009). Additionally, milking tasks are highly repetitive, thus putting the operator at risk of injuries such as carpal tunnel syndrome (Stål *et al.*, 2003). Operators looking to improve throughput by increasing platform speed will reduce the time available to rest the wrists and hands further, potentially increasing the chances of developing injuries (Stål *et al.*, 2003). To reduce repetitiveness and increase rest time Stål *et al.* (2003) advocated the use of job rotation, for example the swapping of operators during the changeover between herds. A task rotation strategy in rotary dairies has been linked with fewer repetitions, and higher opportunities for rest/recovery compared with herringbone dairies (Douphrate *et al.*, 2012). Job rotation has the added benefit of increasing variety, likely leading to greater job satisfaction and improved staff retention. Therefore, on large farms, with considerable herd milking times, operators should be changed after each herd.

The throughput performance of all dairy sizes were similar at slower platform speeds. At these slower speeds, few bails will be occupied by ‘go-around’ cows so the majority of bails presented will be available for new cows. However, the rotation time will be significantly longer than individual cow milking durations in larger dairies and the bail will be occupied for a greater proportion of the rotation without harvesting milk. Conversely, faster platform speeds in larger dairies achieve greater throughput and therefore take less time to milk a herd than smaller dairies. So, if platform speed was limited, for example by a pre-milking routine that required 20 s to apply, then there is little justification for constructing a rotary of more than 40 bails (Figure 1b), unless labour is increased, because at this point routine time is the limiting factor. Similarly, routine time has been reported to limit the number of clusters that should be handled by a single operator in herringbone dairies (O'Brien *et al.*, 2012). Additionally, regardless of pre-milking routine, dairies with more than 60 bails are likely to require more than one operator to achieve the desired speed, thus reducing labour efficiency. This is relevant for very large herds (e.g. >1500 cows) where total time to milk the herd may be of greater importance than labour efficiency. Therefore, larger dairies (>60 bails) are best suited to properties where overall milking time is important and must be operated at fast platform speeds to justify the investment over a smaller rotary.

In conclusion, aiming for 10% ‘go-around’ cows will limit rotary performance in many circumstances. Instead, platform speed should be set to match the abilities of the operator attaching clusters and job rotation strategies should be employed. Larger dairies need to be operated at faster platform speeds to justify the additional investment over a smaller rotary.

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CHAPTER 5

Short-term application of pre-stimulation and increased automatic cluster remover threshold affect milking characteristics of grazing dairy cows in late lactation

J. Paul Edwards,*† Jenny G. Jago,* and Nicolas Lopez-Villalobos†

*DairyNZ, Private Bag 3221,
Hamilton 3240, New Zealand.

†Institute of Veterinary, Animal and Biomedical Sciences,
Massey University, Private Bag 11222,
Palmerston North 4442, New Zealand.

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Abstract

It was hypothesized that reducing cow cluster-on time by increasing automatic cluster remover (ACR) thresholds above 0.4 kg/min required pre-milking stimulation of the mammary gland to maintain milk yield. This was tested by examining the interaction between four ACR thresholds and three pre-milking treatments over an 8 week period with 96 mixed age Friesian-Jersey cross cows being milked twice per day in late lactation (average production 13.9 kg/day). The three pre-milking treatments were: attach cluster immediately (Control), attach cluster 60 s after entering the dairy (Delay), or remove two squirts of foremilk from each quarter and attach cluster 60 s after entering the dairy (Prep). Four ACR thresholds were chosen, where the cluster was removed after the milk flow rate was less than 0.2 kg/min (ACR2), 0.4 kg/min (ACR4), 0.6 kg/min (ACR6), and 0.8 kg/min (ACR8). Measurements included individual cow milk yield, cluster-on time, average milk flow rate, maximum milk flow rate, time from cluster attachment to average milk flow rate, milk yield in the first two min, time from maximum milk flow rate to end of milking, and the milk flow rate at predetermined intervals during each milking session. Composite milk samples were collected weekly at AM and PM milkings to determine composition and somatic cell count (SCC). On three occasions during the experiment, post-milking strip yield was measured. No interactions were detected between pre-milking treatment and ACR threshold in any of the measured variables. Cows receiving the Prep treatment had a 5-9% shorter cluster-on time than the Control treatment. Milk yield, SCC, post-milking strip yield, and maximum flow rate were not different between the three pre-milking treatments. Cluster-on time of the ACR8 cows was 21-29% less than ACR2, but SCC and milk production variables were not different between the four end-of-milking treatments despite higher strip yields as ACR threshold increased. Increasing ACR threshold offers the potential to reduce the duration of milking without detriment to overall productivity. The results of the pre-milking treatments indicate that to achieve the most efficient routine the operator should attach clusters as close as possible to the first bail in rotary dairies to increase bail utilization in pasture-based systems. If cluster attachment can be sped up and ACR threshold lifted there is significant potential to decrease herd milking duration and improve labor productivity.

Keywords: milking duration, stimulation, automatic cluster remover

Introduction

The process of milking cows requires significant labor, accounting for up to 57% of a farm's total annual labor input in pasture-based systems (Taylor *et al.*, 2009). With increasing herd sizes the time required to milk herds may increase, putting even greater pressure on human resource efficiency. The cluster-on time of individual cows is a significant factor in determining herd milking duration and thus labor requirement at a herd level.

International studies have reported that the choice of automatic cluster remover (ACR) milk flow rate threshold influences the cluster-on time of cows, with no effect on production or udder health (Rasmussen, 1993; Stewart *et al.*, 2002). The ACR thresholds tested ranged from 0.2 kg/min to 0.8 kg/min. However, in these studies, cows were milked following pre-milking routines that involved pre-stimulation, which is a legal requirement in the EU and USA (EU, 2004; FDA, 2009). The routine of Rasmussen (1993) included washing teats and the drawing of five squirts of foremilk from each quarter. This is not common practice in pasture-based systems where minimal pre-milking routines are used, for example in rotary dairies clusters are attached, without pre-stimulation, immediately upon entry to the platform or delayed until several bails after the entrance.

The international results led to similar research in New Zealand (Jago *et al.*, 2010a) using a genetic strain of cow on which milking routines with pre-stimulation have not been common practice since the 1970s (Phillips, 1987). Two different ACR thresholds were evaluated, 0.2 kg/min and 0.4 kg/min (Jago *et al.*, 2010a; Burke & Jago, 2011). The authors concluded that, with the higher ACR threshold, the cluster-on time of cows decreased with minimal effects on milk production, clinical mastitis, or SCC (Burke & Jago, 2011). Further decreases in cluster-on time may be possible by increasing ACR thresholds from 0.4 kg/min to the 0.8 kg/min level tested internationally. Possible consequences of increasing ACR thresholds to 0.8 kg/min may be greater SCC and lower milk yield. Studies have indicated that, without adequate pre-stimulation, there might be a significant amount of milk to be harvested after the flow rate falls below 0.8 kg/min near the end of milking (Bruckmaier & Blum, 1996). Pre-milking stimulation has not been common in pasture based systems, after research by Phillips (1987) demonstrated that it was not required to maintain milk production, which has allowed for a greater number of cows per labor unit compared to housed systems. Pre-milking stimulation has been reported to reduce the incidence of bimodal milk flow profiles compared to no pre-milking stimulation (Bruckmaier & Blum, 1996). Bimodal milk flow profiles occur due to the delayed availability of alveolar milk following the removal of the cisternal milk fraction, which can result in collapsed mammary ducts and potentially reduced milk flow rates (Bruckmaier & Blum, 1996), impacting the use of high ACR thresholds. Thus, the adoption of a routine that includes pre-milking stimulation may be necessary to ensure that milk production is not adversely affected by higher ACR thresholds.

Over a lactation, the degree of udder fill is reduced as milk yield declines. At lower degrees of udder fill, moving milk from the alveoli to the cistern requires greater contraction by myoepithelial cells (Bruckmaier & Hilger, 2001), thus delaying milk ejection. Therefore, the response to stimulation is greater in late lactation than early lactation (Bruckmaier *et al.*, 1995; Bruckmaier & Hilger, 2001). For this reason cows in late lactation were chosen for this study. Also, cows in late lactation are more likely to have sufficient cisteral capacity to compensate for early cluster detachment. The objective of this experiment was to evaluate potential strategies of reducing individual cow cluster-on time and the effects on milk yield, and indicators of udder health.

It was hypothesized that reducing cow cluster-on time by increasing ACR thresholds above 0.4 kg/min required pre-stimulation of the mammary gland to maintain milk yield. This was tested by examining the interaction between four ACR thresholds and three pre-milking treatments in late lactation cows.

Materials and methods

Animals

The study was conducted on 96 mixed age Friesian-Jersey cross cows at the DairyNZ Lye Farm (Hamilton, New Zealand) from January to April 2011. The use of animals was approved by the Ruakura Animal Ethics Committee. Prior to and during the experiment, the cows were managed as one herd and rotationally grazed on predominantly perennial ryegrass pasture (Macdonald & Penno, 1998). The herd was milked in the morning between 0700 and 0830 hours and in the afternoon between 1500 and 1630 hours, to maintain a consistent milking interval, through a 30 bail rotary dairy (GEA Farm Technologies, Bönen, Germany) with plant vacuum set at 42 kPa. Post-milking, a commercially available teat sanitizer (Teat-Guard Plus, Ecolab, St. Paul, Minnesota, USA) was applied manually to each cow by pressurized spray.

Experimental design

The experiment was a 3 × 4 factorial arrangement. Three pre-milking treatments were selected to assess the impact of pre-milking stimulation, these treatments were crossed over. The first routine was a control (**Control**), where the clusters were attached at the first bail after cows had walked onto the platform. In the second treatment, tactile stimulation (**Prep**) was applied by removing two squirts of foremilk from each quarter followed by cluster attachment 60 s after entering the dairy. The time taken to remove foremilk was around 15 s, resulting in a 45 s delay before cluster attachment. The third pre-milking treatment was delayed cluster attachment without pre-stimulation (**Delay**). The cows entered the platform and were exposed to the background noises associated with milking before cluster attachment 60 s later, the same point in the dairy as the Prep treatment. Delaying cluster attachment is common practice on Australasian farms, consistent with recommendations for timing of cluster attachment (Brightling *et al.*, 1998). This treatment also allowed for the separation of the effects of delayed cluster attachment and pre-stimulation. An operator was standing at the first bail attaching clusters on Control cows and stimulating Prep cows, and a second operator was attaching clusters on Prep and Delay cows at a position determined by the rotary platform speed.

For each pre-milking strategy four ACR thresholds were imposed by the herd management system: 0.2 kg/min (**ACR2**), 0.4 kg/min (**ACR4**), 0.6 kg/min (**ACR6**) and 0.8 kg/min (**ACR8**). If the cow's milk flow rate remained below the respective threshold level for greater than 4 s, the ACR was activated the cluster was removed within 5 s. All treatments were balanced for days in milk, cluster-on time, yield, SCC, breed and age.

The first week of the experiment was used to gather baseline data to be used as a covariate. All cows were milked as per the Control treatment with clusters attached at entry and the ACR threshold set at 0.35 kg/min, which was standard on this research farm. The second week of the experiment was used to transition the cows to the new ACR threshold. On the first day of the second week ACR2 and ACR4 cows were changed from 0.35 kg/min to their respective thresholds. At the same time cows on the ACR6 and ACR8 treatments were increased to 0.5 kg/min and remained there for three days before changing to their final ACR thresholds of 0.6 and 0.8 kg/min. Cows remained on the allocated ACR treatment for the remainder of the experiment. In week three the pre-milking treatments commenced, and were applied for two weeks (Phase 1).

At week five, the cows on each of the pre-milking treatments were switched to another treatment, half of the cows in each, and this was applied for two weeks (Phase 2). At week seven, the pre-milking treatments were switched to the one remaining treatment, which was applied for a final two weeks (Phase 3).

Measurements

The dairy was fitted with Metatron P21 milk meters (GEA, Bönen, Germany) at each bail. The herd management software was set to record individual cow milk yield, cluster-on time (cluster-on to cluster-off), average milk flow rate (from initiation of milk flow to cluster removal), maximum milk flow rate, time from cluster attachment to average milk flow rate, milk yield in the first two min, time from maximum milk flow rate to end of milking and the average milk flow rate in 15 s intervals up to 4 min, over 30 s intervals between 4-7 min and over 60 s intervals from 7-10 min at each milking session. Milk meter samples were collected weekly to determine composition using a Milko Scan 133B Analyzer (Foss Electric, Hillerød, Denmark) and SCC using an automated cell counter (Fossomatic 5000, Foss Electric, Hillerød, Denmark). At the end of each phase, post-milking strip yield was measured by re-attaching the cluster within two minutes of the end of milking. Downward pressure was applied until no further milk could be removed from the udder. The operator applying the Prep routine was recorded at each session.

Statistical analysis

The milking data from days 6 to 12 of each phase were analyzed using a linear mixed model that included the fixed effects of operator, phase, session, ACR and pre-milking treatment and their interaction and milking characteristics prior to the application of treatments as a covariate and cow and phase within cow as random effects. Somatic cell count data were normalized using a $\log_{10}$ transformation, and strip yield data normalized using a square root transformation. Average milk flow profiles were derived from least square means of the average milk flow rate during each of the recorded time intervals. A milk flow profile was defined as bimodal if during the first 75 s the milk flow rate fell by more than 0.1 kg/min from one time interval to the next, the milk flow rate during the second and third time intervals after either remained the same or increased, and the milk flow rate thereafter was greater than zero. All analyses were undertaken using GenStat 13.2 (VSN International, Hemel Hampstead, UK).

Results

Pre-milking treatment

No interactions were detected between pre-milking treatment and ACR threshold. The main effects are, therefore, presented separately. Cows receiving Prep treatment had a shorter cluster-on time (5-9%; P <0.001) than the Control and Delay treatment, which did not differ from each other (Figure 1, Table 1). The Delay treatment was not significantly different from the Control and on average both had bimodal shaped flow curves, although milk flow profiles were variable between animals. The Prep treatment reduced the number of cows with bimodal shaped milk flow curves (P <0.001). Milk production was not affected by treatment, but there was a small difference in average milk flow rate (P <0.001) and maximum milk flow rate (AM only; P <0.05), this being greater for Prep cows. Time from cluster attachment to average milk flow rate was shorter (P <0.001) and the time from maximum flow rate to end of milking was longer (P <0.05) for the Prep routine. Cows on the Prep treatment had a greater volume of milk harvested in the first two minutes (P <0.001) and greater cumulative yield in the first 195 s (P <0.001), however, there was no difference thereafter. Strip yield and SCC were not different between treatments.

ACR thresholds

Increasing ACR threshold affected cluster-on time (Table 2). In comparison to the ACR2 treatment, the milking time per cow on the ACR8 treatment was 72 and 81 seconds less at AM and PM milkings (21-29%; P <0.001). Time to average milk flow rate decreased and the number of bimodal milk flow profiles increased with increasing ACR threshold at the PM milking only (P <0.05). Average milk flow rate was greater (P <0.001) and decline duration significantly lower (P <0.001) in the higher ACR thresholds. An increase in strip yield was recorded with increasing ACR threshold (P <0.05). Somatic cell count and milk production variables were not affected by treatment.

Table 1. Effect of three pre-milking treatments (Control, Delay and Prep), on milking characteristics, somatic cell count (SCC) and strip yield.

Item	Session	Treatment[1]			SED[2]	P-value
		Control	Delay	Prep		
Average cluster-on time (s)	AM	301	300	284	4.51	<0.001
	PM	237	231	216	2.14	<0.001
Milk yield (kg)	AM	9.5	9.6	9.6	0.08	0.49
	PM	4.3	4.2	4.3	0.04	0.20
Average flow rate (kg/min)	AM	2.2	2.2	2.4	0.04	<0.001
	PM	1.3	1.3	1.5	0.02	<0.001
Maximum flow rate (kg/min)	AM	3.6	3.6	3.7	0.03	<0.05
	PM	2.9	2.9	2.9	0.04	0.83
Time to average flow rate (s)	AM	138	135	107	3.01	<0.001
	PM	109	105	77	1.82	<0.001
Milk yield in first two min (kg)	AM	3.7	3.9	4.9	0.08	<0.001
	PM	2.2	2.3	3.0	0.06	<0.001
Decline duration (s)	AM	74	75	81	2.86	<0.05
	PM	65	62	68	1.91	<0.01
Bimodal milk flow profiles (%)	AM	74	68	43	3.5%	<0.001
	PM	36	37	26	2.7%	<0.001
Daily milk yield (kg)		13.9	13.9	14.0	0.11	0.42
Daily milk fat (kg)		0.69	0.70	0.70	0.01	0.67
Daily milk protein (kg)		0.51	0.51	0.51	0.01	0.83
Daily milk lactose (kg)		0.65	0.65	0.66	0.02	0.90
$Log_{10}SCC$		2.0	2.0	2.0	0.02	0.64
Back-transformed SCC (cells/mL)		96,600	99,400	100,000		
Square root[strip yield] ($kg^{0.5}$)		0.73	0.74	0.72	0.02	0.55
Back-transformed strip yield (kg)		0.53	0.55	0.51		

[1]Treatment: Control: Attach cluster immediately, Delay: Attach cluster after 60 seconds and Prep: Two squirt strip from each quarter and attach cluster after 60 seconds.
[2]Standard error of the difference.

Table 2. Effect of four automatic cluster remover thresholds (ACR2, ACR4, ACR6 and ACR8) on milking characteristics, somatic cell count (SCC) and strip yield.

Variable	Session	Treatment[1]				SED[2]	P-value
		ACR2	ACR4	ACR6	ACR8		
Average cluster-on time (s)	AM	340	299	277	268	6.57	<0.001
	PM	279	227	208	198	4.41	<0.001
Milk yield (kg)	AM	9.6	9.5	9.8	9.5	0.18	0.27
	PM	4.4	4.2	4.3	4.2	0.09	0.32
Average flow rate (kg/min)	AM	2.0	2.2	2.4	2.4	0.06	<0.001
	PM	1.2	1.4	1.4	1.5	0.04	<0.001
Maximum flow rate (kg/min)	AM	3.6	3.6	3.7	3.7	0.06	0.32
	PM	2.8	2.9	2.9	3.0	0.09	0.15
Time to average flow rate (s)	AM	126	127	132	121	5.32	0.29
	PM	101	97	99	90	3.94	<0.05
Milk yield in first two min (kg)	AM	4.1	4.1	4.2	4.3	0.13	0.14
	PM	2.3	2.4	2.6	2.6	0.12	0.07
Decline duration (s)	AM	97	85	65	61	6.40	<0.001
	PM	92	67	52	50	4.42	<0.001
Bimodal milk flow profiles (%)	AM	61	66	61	60	5.0%	0.55
	PM	23	33	38	38	5.1%	<0.01
Daily milk yield (kg)		14.0	13.8	14.1	13.7	0.23	0.25
Daily milk fat (kg)		0.70	0.70	0.70	0.70	0.02	0.99
Daily milk protein (kg)		0.51	0.51	0.52	0.50	0.01	0.65
Daily milk lactose (kg)		0.66	0.64	0.66	0.64	0.02	0.69
Log_{10}SCC		2.0	2.0	2.0	2.0	0.05	0.64
Back-transformed SCC (cells/mL)		92,500	103,700	103,400	95,600		
Square root[strip yield] ($kg^{0.5}$)		0.65	0.65	0.77	0.85	0.07	<0.05
Back-transformed strip yield (kg)		0.42	0.42	0.59	0.72		

[1]Treatment: Cluster was removed after milk flow rate was less than, 0.2 kg/min (ACR2), 0.4 kg/min (ACR4), 0.6 kg/min (ACR6) and 0.8 kg/min (ACR8).

[2]Standard error of the difference.

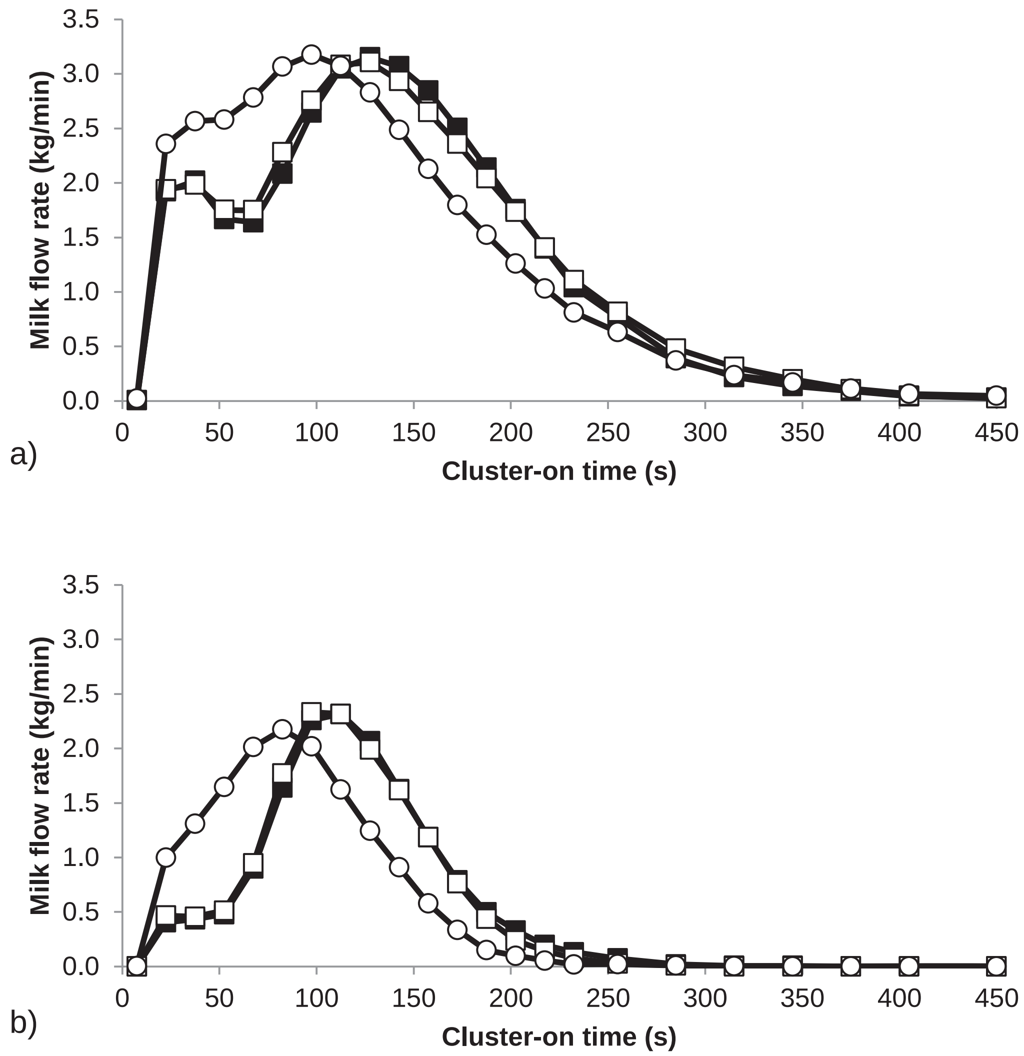

Figure 1. Average milk flow (kg/min) curves for three pre-milking routines, Control (■), Delay (□), and Prep (○), (Control: Attach cluster immediately, Delay: Attach cluster 60 s after entering the dairy and Prep: Two squirt strip from each quarter and attach cluster 60 s after entering the dairy), at AM (a) and PM (b) milking sessions.

Discussion

Milk production variables were not affected by ACR threshold or pre-milking treatment during this short term experiment. None of the pre-milking treatments influenced the effect of changing ACR thresholds for any of the variables measured. Increasing ACR threshold above 0.4 kg/min reduced cow cluster-on time without compromising milk yield. As a result, the hypothesis that increasing ACR thresholds above 0.4 kg/min requires pre-stimulation of the mammary gland to maintain milk yield was rejected. No interaction between pre-milking treatment and ACR threshold was detected, and thus, the results of each are discussed separately.

The Prep treatment decreased cow cluster-on time, while the Delay treatment did not. A decrease in cow cluster-on time in response to the Prep treatment was also reported by Bruckmaier and Blum (1996). A major effect of treatment was the shape of the milk flow curve during the first half of milking (Figure 1). A bimodal milk flow curve was anticipated for the Control treatment due to low milk yield in late lactation and lack of pre-milking stimulation. The average milk flow curve of Prep cows was not bimodal like Control or Delay cows resulting in a shorter time to average milk flow rate and more milk being harvested in the first 195 s. However, in the latter half of milking, from maximum flow rate to the end of milking, the Prep treatment was longer than the Control, negating some of the earlier benefit. The Control and Delay cows had a similar time to average milk flow rate, which was longer than the Prep treatment, indicating that, for most cows, milk ejection is not initiated until the udder is touched by the machine or other means. The shape of the flow curve was similar for the Delay and Control treatments, explaining the lack of difference in cluster-on time and milk yield between the two. All three pre-milking treatments achieved a similar maximum milk flow rate, although the Prep treatment was slightly greater at morning milkings. In contrast, Bruckmaier and Blum (1996) reported larger maximum flow rate increases in response to pre-stimulation by removal of one to two squirts of foremilk and a short manual massage. Maximum flow rate was reached earlier in the Prep treatment but due to the differences in flow curves near the end-of-milking the decline duration was longer, resulting in a net 17 s (AM) or 20 s (PM) reduction in cluster attachment time. However, the time cost of applying stimulation and delaying cluster attachment (60 s) was more than the reduction in cow cluster-on time, meaning the net result was an increase in the time the cow spent in the dairy. This result is supported by Bruckmaier *et al.* (1995). Additionally, there was no benefit in milk yield, nor a change in strip yield or SCC as a result of stimulation. Thus, despite showing a response to pre-stimulation, neither form of pre-milking treatment gave an advantage in reducing overall milking time using cows bred in pasture-based production systems, in which pre-milking routines with pre-stimulation have not been routinely practiced for ~40 years.

The lack of interaction can probably be explained by the flow curves (Figure 1). The slope of the flow curves appears different between treatments before, but not after maximum milk flow, despite maximum flow being reached earlier in the Prep treatment. This is similar to the results of Sandrucci *et al.* (2007), who reported a shorter incline phase but no change in the decline phase following stimulation. The results of the lower ACR thresholds (ACR2 and ACR4) are consistent with Jago *et al.* (2010a) and Rasmussen (1993), which were studies conducted over a longer time period. Use of higher ACR thresholds resulted in greater average milk flow rates, so despite the shorter cluster-on time, there was no decrease in yield. Conversely, strip yield was higher, indicating that more milk remained as a result of the cluster being removed earlier. The strip yields in the lowest ACR threshold were 0.35 kg less than the highest ACR threshold. Such a small difference, of 2.5%, may explain why cows were able to, over the relatively short duration of the trial, maintain daily milk yield with shorter durations of milking. Additionally, this small increase in strip yield did not result in a higher SCC, a finding supported by Burke and Jago (2011) and Clarke *et al.* (2008). However, as this was a short term study in late lactation the effect of ACR thresholds higher than 0.4 kg/min on milk production and SCC requires validation over a whole lactation. The results indicate that in late lactation operators are not restricted to a threshold of 0.4 kg/min when using a minimal pre-milking routine without stimulation and this offers potential to reduce the duration of milking further without detriment to overall productivity.

Pre-milking routine and ACR treatments produced different effects at the AM and PM milkings for some milking characteristics. Variation between AM and PM results was likely due to differences in milk yield as a consequence of a 16 hr milking interval overnight and an 8 hr interval during the day. This possibly resulted in a smaller cisternal milk yield at the PM milking and subsequently fewer bimodal shaped milk flow profiles as initial flow rates remained low (Figure 1b). Similarly shaped milk flow profiles were reported by Bruckmaier and Hilger (2001) for 8 and 12 hr milking intervals at late lactation. Following this theory, that at the PM milking less cisternal milk resulted in fewer bimodal milk flow profiles, the increasing bimodality recorded at PM milkings at higher ACR thresholds is possibly due to a greater cisternal volume as a consequence of greater residual milk, observed as higher strip yields. This is supported by a shorter time to average milk flow rate at the PM milking with higher ACR thresholds. It is likely that this result is unique to situations with low milk yield such as the PM milking during late lactation, as more cisternal milk could be expected to decrease bimodality e.g. during peak lactation (Bruckmaier & Hilger, 2001). The variation between AM and PM may necessitate different rules at each milking such as a longer minimum milking time at the PM milking for cows not pre-stimulated due to their low initial milk flow rates.

The results achieved from pre-stimulation and increased ACR thresholds can be used to devise effective strategies to reduce herd milking duration. In particular the results from the Delay treatment contradict guidelines to stand several bails from the entranceway in rotary dairies (Brightling *et al.*, 1998), which decreases bail utilization. Increasing bail utilization by standing as close as possible to the first bail means clusters can be used for milk harvesting for a greater amount of time in each rotation. In addition, the operator will arguably have better control of cow flow. At the end of milking, an increase in ACR threshold resulted in shorter cow cluster-on time. This result is most applicable to rotary dairies, the majority of which tend to milk larger herds and have ACR installed (Cuthbert, 2008; Mackinnon *et al.*, 2010). In rotary dairies a reduction in cow cluster-on time will result in a decrease in the amount of cows requiring a second rotation at a given platform speed, or allow the same number of 'go-around' cows at a faster platform speed. Alternatively, for farmers building new dairies a smaller size, with fewer bails, may be constructed to achieve the same level of throughput for less capital cost. Increasing platform speed may be limited under some circumstances due to the operator not being able to attach clusters at a fast enough rate (e.g. >60 bail rotaries with one operator attaching clusters). Increasing ACR threshold is less applicable to the herringbone dairy because in some countries it is less common to have ACR installed (Cuthbert, 2008; Mackinnon *et al.*, 2010) and row times are still limited to the slowest milking cow, meaning a reduction in herd milking duration is not assured (Stewart *et al.*, 2002). Accordingly, Clarke *et al.* (2004) concluded that the installation of ACR in herringbone dairies would be an expensive capital investment if only used to shorten cow cluster-on time. However, the authors found merit in the application of a maximum milking time, which has subsequently been supported by the results of Jago *et al.* (2010b). Overall, implementing both strategies of attaching clusters as close as possible to the cow entry and using a higher ACR threshold in rotary dairies will achieve the greatest benefit, as long as the operator work routine is not a constraint.

Large variations in milking speed and flow curves were recorded between individual animals in the present experiment, and as milk flow rate is reported to be heritable (Zwald *et al.*, 2005), there is potential to harness the efficiency benefit of those cows that did not display bimodal flow curves or a delay in milk ejection when milked without a pre-milking stimulation. In the past, the selection of animals on milking characteristics has successfully removed the requirement for a pre-milking stimulus to maximize milk production in New Zealand (Phillips, 1987). Applying pre-milking stimulation to a cross section of the national herd in 1958 resulted in a milkfat response of 33%, which had reduced to zero 20 years later (Phillips, 1987). This result was achieved through a combination of utilizing males that sired progeny with low stimulus requirements, and selection pressure on farm whereby pre-milking stimulation was discontinued and cows that failed to adjust to the change in system were culled due to poor production. Similarly, a minority of cows may be unsuitable if adopting a higher ACR threshold and thus require culling. In the future, if selecting for cows with efficient milk flow curves any associations with detrimental factors, such as clinical mastitis, need to be assessed before selectively breeding for such animals.

Conclusions

Increasing ACR threshold reduced individual cow cluster-on time, and thus can potentially be used to decrease herd milking duration, without negatively affecting milk yield, or SCC over the short term in late lactation. The pre-milking treatments examined did not reduce the amount of time cows spent on the rotary platform. Pre-milking stimulation, in the form of fore-stripping, was not required at higher ACR thresholds to maintain milk yield in New Zealand cows that have not been accustomed to pre-stimulation routines for the past 40 years. Consequently, operators should attach clusters as close as possible to the first bail in rotary dairies to increase bail utilization.

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CHAPTER 6

Milking efficiency for grazing dairy cows can be improved by increasing automatic cluster remover thresholds without applying pre-milking stimulation

J. Paul Edwards,*† Jenny G. Jago,* and Nicolas Lopez-Villalobos†

*DairyNZ, Private Bag 3221,
Hamilton 3240, New Zealand.

†Institute of Veterinary, Animal and Biomedical Sciences,
Massey University, Private Bag 11222,
Palmerston North 4442, New Zealand.

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Abstract

It was hypothesized that streamlined pre-milking stimulation routines are effective at reducing cow cluster-on time but are not required to maintain milk yield or quality when increasing automatic cluster remover (ACR) threshold above 0.4 kg/min. This was tested by examining the effect of three pre-milking treatments and four ACR thresholds over an 11 week period with 96 mixed age New Zealand Friesian-Jersey cross cows during peak lactation. Three pre-milking treatments were chosen: attach cluster immediately (Control), attach cluster immediately and apply 30 s of mechanical stimulation (Stim), and remove two squirts of milk from each quarter and attach cluster (Strip). Four ACR milk flow rate thresholds were imposed: 0.2 kg/min (ACR2), 0.4 kg/min (ACR4), 0.6 kg/min (ACR6), and 0.8 kg/min (ACR8). Measurements included individual cow milk yield, cluster-on time, average milk flow rate, maximum milk flow rate, time to average milk flow rate, time from maximum milk flow rate to end of milking, and the milk flow rate and cumulative yield at predetermined intervals during each milking session. Milk composition and somatic cell count (SCC) were determined on composite milk samples, collected weekly. Post-milking strip yield was measured at the end of each treatment period. Cows receiving the Strip treatment had a 3-4% shorter cluster-on time than the Control treatment, but cows receiving Stim were not different to the Control. Milk yield, SCC, and post-milking strip yield were not different between the three pre-milking treatments. Cluster-on time of ACR8 cows was 18-26% less than ACR2, but SCC and milk production variables were not different between the four end-of-milking treatments despite higher strip yields as ACR threshold increased. Increasing the ACR threshold is an effective strategy to improve milking efficiency (cows milked per operator per hour) in situations where the work routine times of dairy operators can be accelerated. To achieve the greatest milking efficiency clusters should be attached immediately without pre-milking manual or mechanical stimulation.

Keywords: milking duration, stimulation, automatic cluster remover

Introduction

Herd sizes in pasture-based dairy farms have increased dramatically in recent decades, a trend that is likely to continue (O'Donovan *et al.*, 2008; DAFF, 2010; DairyNZ, 2012). Herd expansion requires additional labor and often exerts pressure on existing resources. Annually, 33 to 57% of labor resources on pasture-based dairy farms are required for the milk harvesting process (O'Brien *et al.*, 2004; Taylor *et al.*, 2009). An efficient milk harvesting process is, therefore, important to successful expansion and management of large herds.

The cluster-on time of individual cows is an important factor determining herd milking times and thus labor requirements. Reducing the cluster-on time of cows, without impacting milk yield and udder health indicators, by increasing automatic cluster remover (ACR) threshold from 0.2 to 0.4 kg/min, has been reported previously (Rasmussen, 1993; Burke & Jago, 2011). A recent study with dairy cows in late lactation reported ACR thresholds up to 0.8 kg/min further reduced individual cluster-on times without impacting milk yield or indicators of udder health when using a milking routine with no pre-milking stimulation, as is common practice on pasture-based dairy farms (Edwards *et al.*, 2013). However, higher post-milking milk residuals were reported with increasing ACR threshold, therefore, the consequences of applying these ACR thresholds in peak lactation, when milk yields are greater, requires examination.

Pre-milking stimulation has been reported to reduce cluster-on time despite using a genetic strain of cow where pre-stimulation has not been commonplace since the 1970s (Phillips, 1987; Edwards *et al.*, 2013). However, the time taken to apply the pre-milking stimulation was greater than the reduction in cluster-on time, resulting in cows remaining in the dairy longer and additional labor being required. The requirement for additional labor could be eliminated and the pre-stimulation routine shortened if the latency period between stimulation and cluster attachment was removed from the routine. Recent research has indicated that a latency period between stimulation and cluster attachment provided no benefit to milk yield or cluster-on time when udder fill was greater than 40% (Kaskous & Bruckmaier, 2011). Thus, if the time to cluster attachment can be reduced using pre-milking stimulation without a latency period a net benefit to milking efficiency (cows milked per operator per hour) may be achieved without increasing labor requirements in some dairies.

Maximum throughput is achieved in many larger rotary dairies (>50 bails) when rotation speeds are faster than 10 s/bail (Edwards *et al.*, 2012). This speed does not allow sufficient time for a single operator to apply manual stimulation and attach clusters (Armstrong & Quick, 1986). Therefore, additional labor would be required to maintain this speed, even with the removal of the latency period, unless a form of mechanical stimulation was introduced. Likewise, in larger herringbone dairies (>18 units) the addition of ~10 s/cow for stimulation during spring would reduce throughput unless labor was increased (O'Brien *et al.*, 2012).

It was hypothesized that streamlined pre-milking stimulation routines are effective at reducing cow cluster-on time but are not required to maintain milk yield or quality when increasing the ACR threshold above 0.4 kg/min. This was tested by examining the effect of three pre-milking treatments and four ACR thresholds on peak lactation dairy cows yielding an average 22.3 kg/day.

Materials and methods

Animals

The study was conducted using 96 mixed age New Zealand Friesian-Jersey cross cows at the DairyNZ Lye Farm (Hamilton, New Zealand) from September to December 2011. Cows were representative of those present in pasture-based production systems and, therefore, had relatively low daily milk yields in comparison to those achieved by cows managed in mixed ration systems typical in North America and continental Europe. The use of animals was approved by the Ruakura Animal Ethics Committee. Cows were managed as one herd and rotationally grazed on predominantly perennial ryegrass pasture following the decision rules of Macdonald and Penno (1998). Milking of the herd occurred in the morning between 0700 and 0830 hours and in the afternoon between 1500 and 1630 hours, through a 30-bail rotary dairy (GEA Farm Technologies, Bönen, Germany) with plant vacuum set at 42 kPa. Post-milking, a commercially available teat sanitizer (Teat-Guard Plus, Ecolab, St. Paul, Minnesota, USA) was applied manually to each cow by pressurized spray on exit from the rotary platform.

Experimental design

The experiment was arranged as a 3 × 4 factorial; three pre-milking treatments were applied across four ACR thresholds. Pre-milking treatments were: clusters attached at the first bail after cows had walked onto the rotary platform (**Control**); tactile stimulation applied by removing two squirts of foremilk from each quarter, requiring ~10 s, followed by immediate cluster attachment (**Strip**); and mechanical stimulation applied using StimoPuls Apex M (GEA, Bönen, Germany) equipped clusters (**Stim**). The pulsator ratio during stimulation was 70:30 with 300 cycles/min (at half vacuum) and during normal milking 60:40 with 60 cycles/min. Stimulation time set at 30 s was considered appropriate for cows with a high degree of udder fill as expected during peak lactation (Weiss & Bruckmaier, 2005).

For each pre-milking strategy four ACR thresholds were imposed by the herd management system: 0.2 kg/min (**ACR2**), 0.4 kg/min (**ACR4**), 0.6 kg/min (**ACR6**) and 0.8 kg/min (**ACR8**). If the cow's milk flow rate remained below the respective threshold level for longer than 4 s, the ACR was activated and the cluster was removed within 5 s. Clusters remained attached for a minimum of 120 s. All treatment groups were balanced for days in milk, cluster-on time, yield, SCC, breed and age.

Covariate data were collected in week one, when cows were milked using the Control treatment with clusters attached at entry and the ACR threshold set at 0.35 kg/min. In the second week, cows were transitioned to the new ACR threshold and remained on the allocated ACR threshold for the remainder of the experiment (nine weeks). On the first day of the second week ACR2 and ACR4 cows were changed from 0.35 kg/min to their respective thresholds. At the same time cows on the ACR6 and ACR8 treatments were increased to 0.5 kg/min and remained there for three days before changing to their final ACR thresholds of 0.6 and 0.8 kg/min. At the beginning of week three the pre-milking treatments commenced, and were applied for three weeks (Period 1). At the start of week six, cows in each of the pre-milking treatment groups were randomized and split evenly into each of the other two treatments, which were applied for a further three weeks (Period 2). At the start of week nine, cows switched pre-milking treatments to the remaining treatment, which was applied for a final three weeks (Period 3), so each cow was exposed to all three treatments.

Measurements

The dairy was fitted with Metatron P21 milk meters (GEA, Bönen, Germany) at each bail. The herd management software, DairyPlan (GEA, Bönen, Germany) was set to record individual cow milk yield, cluster-on time (vacuum on to cluster off), average milk flow rate (from initiation of milk flow to cluster removal), maximum milk flow rate, time to average milk flow rate, and time from maximum milk flow rate to end of milking (decline duration). Additionally, average milk flow rate and cumulative yield were recorded in 15 s intervals up to 4 min, over 30 s intervals between 4-7 min and over 60 s intervals from 7-10 min for each cow at each milking session. Milk meter samples were collected weekly to determine composition (Milko Scan 133B Analyzer, Foss Electric, Hillerød, Denmark) and SCC using an automated cell counter (Fossomatic 5000, Foss Electric, Hillerød, Denmark). At the end of each period, post-milking strip yield was measured by re-attaching the cluster within two minutes of the end of milking. Downward pressure was applied until no further milk could be removed from the udder. Milk weight was recorded prior to and following cluster re-attachment. Teat-end hyperkeratosis was assessed using the field evaluation method (Mein *et al.*, 2001) during week one and week eleven. Teat-ends were scored using a 1-4 scale, whereby teats classed as Normal (N), Smooth (S), Rough (R) and Very Rough (VR) were assigned the scores 1, 2, 3 and 4, respectively. At the last AM milking of week two and on the last AM milking of each period foremilk samples were collected aseptically from each quarter of all cows. Bacteria in the milk were identified using recommended procedures (NMC, 1999). A 10 µL subsample from each quarter was streaked across 1 quadrant of agar plate containing 5% sheep blood and 0.1% esculin (Fort Richard Laboratories, Otahuhu, Auckland, New Zealand) and incubated at 37°C for 48 hours. Identification of isolates was made on the basis of colony morphology, catalase test, patterns of hemolysis, esculin reaction, inulin fermentation, sodium hippurate reaction, Gram stain, growth in BHI broth with 6.5% salt, and Christie, Atkins, Munch-Petersen (CAMP) test. Gram-negative isolates were identified by lactose reaction, citrate utilization, motility development, oxidase reaction, and triple sugar iron slant reaction.

Statistical analysis

Somatic cell count data were normalized using a $\log_{10}$ transformation, and strip yield data were normalized using a square root transformation. The milking data from days 6 to 19, normalized SCC and strip yield data were analyzed using a mixed model that included the fixed effects of period, session (AM/PM), ACR threshold, pre-milking treatment, interaction between ACR threshold and pre-milking treatment, and initial milking characteristics as covariables plus the random effect of cow within each period. Average milk flow profiles were derived from least square means of the average milk flow rate during each of the recorded time intervals. A milk flow curve was defined as bimodal if during the first 75 s the milk flow rate fell by more than 0.1 kg/min from one 15 s time interval to the next, the milk flow rate during the second and third time intervals after this interval either remained the same or increased, and the milk flow rate thereafter was greater than zero. All analyses were undertaken using GenStat 14.1 (VSN International, Hemel Hampstead, UK).

Results

Pre-milking treatment

Milk yield and composition were not affected by pre-milking treatment and no interaction with ACR threshold was detected for any milk production variable. The average herd milk yield was 22.3 kg/day, comprised of 0.9 kg fat/day, 0.8 kg protein/day and 1.1 kg lactose/day. The statistical significance of milking characteristics were similar at AM and PM milkings. Cows receiving the Strip treatment had a shorter cluster-on time than the Control treatment (P <0.001; Table 1), with the scale of the reduction similar at the AM and PM sessions, 13 and 11 s respectively (3-4%). In contrast, mechanical stimulation (Stim) provided no benefit in reducing cluster-on time compared to the Control at both AM and PM milkings. Cows on the Strip treatment had a greater average milk flow rate (P <0.001), shorter time from cluster attachment to average milk flow rate (P <0.001) and greater maximum milk flow rate (P <0.001). However, no differences in decline duration were detected between pre-milking treatments. Differences and similarities in the daily average milk flow curves of the three treatments can be observed in Figure 1. Examining the average milk flow curve, no pre-milking treatment, including the control, had a bimodal shaped milk flow curve (Figure 1), although a percentage of cows at any given milking had bimodal curves (Table 1). Furthermore, no differences in SCC, strip yield, or interaction between these measures and ACR threshold were detected.

ACR thresholds

Cluster-on time decreased by 18-26% with increasing ACR threshold, for ACR2 and ACR8 treatments (P <0.001; Table 2). No differences were detected in milk yield, milk composition, SCC, or teat hyperkeratosis score. Only five cows developed a new infection by *Corynebacterium bovis* or a coagulase-negative staphylococcus during the experiment. Average milk flow rate increased with higher ACR threshold (P <0.001). However, there was no difference in time to average flow, maximum milk flow rate (AM only), or milk harvested in the first two min (AM only). Decline duration, the time from maximum milk flow rate to the end of milking, decreased with increasing ACR threshold (P <0.001). The statistical significance of milking characteristics and shape of the average milk flow curves were similar at AM and PM milkings, therefore daily averages were used to produce Figure 2. Cumulative yield was greater (P <0.05) between 135 and 240 s of milking for higher ACR thresholds (Figure 2). Average milk flow rate during early milking, 30 to 45 s, and near peak milk flow, 120 to 135 s, was greater (P <0.05) for higher ACR thresholds (Figure 2). Strip yield increased with higher ACR threshold (Table 2).

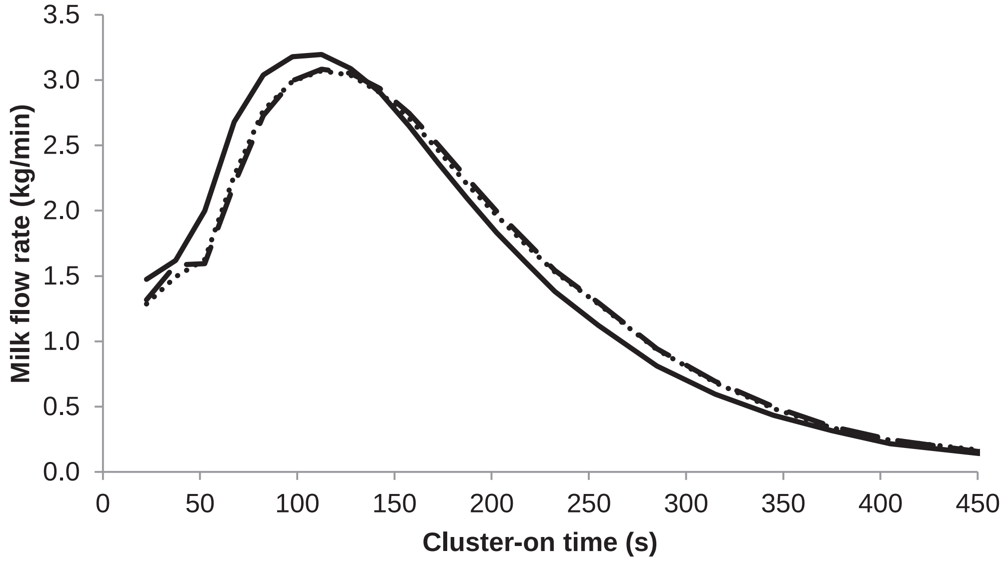

Figure 1. Average daily milk flow (kg/min) curves (average of AM and PM) for three pre-milking treatments, Control (···; attach cluster immediately), Stim (– –; attach cluster immediately and apply 30 s of mechanical stimulation), and Strip (—; two squirt strip from each quarter and attach cluster).

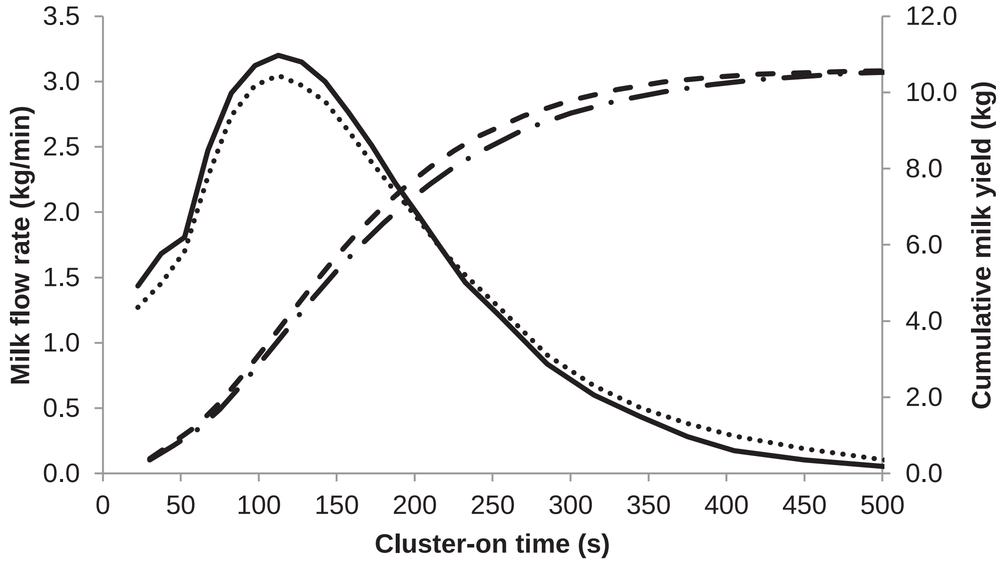

Figure 2. Average daily milk flow (kg/min) curves (average of AM and PM) for two automatic cluster remover thresholds ACR2 (···; cluster removed at 0.2 kg/min) and ACR8 (—; cluster removed at 0.8 kg/min) and average cumulative yield (kg) curves for ACR2 (– ·) and ACR8 (– –).

Table 1. Effect of three pre-milking treatments (Control, Stim and Strip), on milking characteristics, SCC and strip yield.

Item	Session	Treatment[1] Control	Stim	Strip	SED[2]	P-value
Average cluster-on time (s)	AM	398	395	385	2.15	<0.001
	PM	270	270	259	1.63	<0.001
Milk yield (kg)	AM	14.9	14.9	14.9	0.07	0.70
	PM	7.4	7.5	7.4	0.05	0.19
Average flow rate (kg/min)	AM	2.6	2.6	2.7	0.02	<0.001
	PM	2.0	2.0	2.1	0.02	<0.001
Maximum flow rate (kg/min)	AM	3.7	3.7	3.8	0.02	<0.001
	PM	3.3	3.4	3.4	0.02	<0.001
Time to average flow rate (s)	AM	171	163	155	2.84	<0.001
	PM	124	126	114	1.64	<0.001
Milk yield in first two min (kg)	AM	4.6	4.6	5.0	0.04	<0.001
	PM	3.2	3.2	3.6	0.04	<0.001
Decline duration (s)	AM	101	100	100	2.36	0.80
	PM	60	60	61	1.34	0.78
Bimodal milk flow profiles (%)	AM	43%	51%	40%	2.1%	<0.001
	PM	34%	37%	31%	2.1%	<0.01
Daily milk yield (kg)		22.3	22.4	22.3	0.11	0.46
Daily milk fat (kg)		0.94	0.94	0.94	0.01	0.77
Daily milk protein (kg)		0.80	0.80	0.80	0.00	0.60
Daily milk lactose (kg)		1.06	1.07	1.06	0.01	0.62
$Log_{10}SCC$		1.57	1.55	1.53	0.03	0.47
Back-transformed SCC (cells/mL)		36,700	35,400	33,800		
Square root[strip yield] ($kg^{0.5}$)		0.63	0.59	0.61	0.04	0.43
Back-transformed strip yield (kg)		0.40	0.34	0.37		
Proportion of quarters with CB[3]		1.8%	2.1%	1.8%	0.2%	0.37
Proportion of quarters with CNS[4]		1.6%	1.3%	1.6%	0.2%	0.37

[1]Treatments: Control: attach cluster immediately, Stim: attach cluster, 30 s of mechanical stimulation applied and Strip: two squirt strip from each quarter and attach cluster.

[2]Standard error of the difference.

[3]*Coryne-bacterium bovis.*

[4]Coagulase-negative staphylococci.

Table 2. Effect of four automatic cluster remover thresholds (ACR2, ACR4, ACR6 and ACR8) on milking characteristics, SCC, strip yield and teat-end hyperkeratosis score.

Variable	Session	Treatment[1]				SED[2]	P-value
		ACR2	ACR4	ACR6	ACR8		
Average cluster-on time (s)	AM	434	394	386	356	10.51	<0.001
	PM	315	265	252	233	7.82	<0.001
Milk yield (kg)	AM	15.0	14.9	14.8	14.9	0.26	0.83
	PM	7.4	7.6	7.4	7.3	0.20	0.63
Average flow rate (kg/min)	AM	2.5	2.6	2.6	2.8	0.07	<0.001
	PM	1.8	2.0	2.1	2.2	0.06	<0.001
Maximum flow rate (kg/min)	AM	3.7	3.7	3.7	3.8	0.09	0.76
	PM	3.2	3.4	3.4	3.4	0.08	<0.05
Time to average flow rate (s)	AM	171	161	162	159	9.30	0.60
	PM	122	123	122	119	4.38	0.81
Milk yield in first two min (kg)	AM	4.7	4.7	4.7	4.9	0.14	0.33
	PM	3.1	3.3	3.4	3.4	0.13	<0.05
Decline duration (s)	AM	121	106	97	78	7.85	<0.001
	PM	85	60	51	45	5.48	<0.001
Bimodal milk flow profiles (%)	AM	44%	49%	41%	44%	6.1%	0.59
	PM	33%	33%	32%	37%	5.8%	0.80
Daily milk yield (kg)		22.3	22.5	22.2	22.2	0.34	0.88
Daily milk fat (kg)		0.93	0.98	0.93	0.93	0.03	0.19
Daily milk protein (kg)		0.80	0.81	0.80	0.80	0.01	0.88
Daily milk lactose (kg)		1.05	1.07	1.06	1.05	0.02	0.69
$Log_{10}SCC$		1.59	1.52	1.54	1.55	0.05	0.55
Back-transformed SCC (cells/mL)		38,600	33,000	34,200	35,600		
Square root[strip yield] ($kg^{0.5}$)		0.52	0.52	0.64	0.75	0.08	<0.05
Back-transformed strip yield (kg)		0.27	0.27	0.41	0.57		
Proportion of quarters with CB[3]		2.1%	1.4%	4.2%	0.0%	2.4%	0.38
Proportion of quarters with CNS[4]		1.0%	1.7%	3.1%	0.0%	1.7%	0.30
Teat-end hyperkeratosis score[5]		2.4	2.3	2.3	2.2	0.14	0.81

[1]Treatments: Cluster was removed after milk flow rate was less than, 0.2 kg/min (ACR2), 0.4 kg/min (ACR4), 0.6 kg/min (ACR6) and 0.8 kg/min (ACR8).

[2]Standard error of the difference.

[3]*Coryne-bacterium bovis.*

[4]Coagulase-negative staphylococci.

[5]Assessed using the field evaluation method (Mein *et al.* 2001).

Discussion

Data from the present study support the hypothesis that pre-milking stimulation is not required to maintain milk production when utilizing ACR thresholds greater than 0.4 kg/min, as no interaction was detected between pre-milking treatment and ACR threshold for any milk production variable or indicator of udder health using cows typical of a pasture-based production system. Furthermore, a higher ACR threshold reduced cluster-on time without compromising milk production, a result consistent with that reported for cows in late lactation (Edwards *et al.*, 2013).

The streamlined pre-milking treatment, without a latency period (Strip), was effective at reducing cluster-on time during peak lactation. In comparison to the Strip treatment, mechanical stimulation in the form of the Stim treatment provided no advantage to milking efficiency over attaching clusters with no pre-milking preparation. Similarly, Weiss and Bruckmaier (2005) reported no decrease in total milking time using between zero and 90 s of mechanical stimulation. Neither form of stimulation provided an advantage to milk yield, composition, or milk quality/udder health. The Strip treatment reduced the time clusters were attached on average by 12 s, slightly less than the average 19 s reported by Edwards *et al.* (2013) using dairy cows in late lactation. However, the effect of stimulation was expected to be less in peak lactation (Bruckmaier & Hilger, 2001). The similar reduction in cluster-on time recorded between peak and late lactation, the former without a latency period, lends support to the results of Kaskous and Bruckmaier (2011) who reported no effect of latency period when udder fill was greater than 40%. The reduction in cluster-on time of cows on the Strip treatment was achieved through greater average milk flow rates, particularly prior to maximum milk flow rate, where time to average milk flow rate was less and a greater amount of milk was harvested in the first two minutes. Additionally, a greater maximum milk flow rate was recorded for Strip cows, a result also reported by Bruckmaier and Blum (1996) using cows at mixed stages of lactation, though the same effect was not reported by Edwards *et al.* (2013) using cows in late lactation. Post peak milk flow, the decline duration was not different between pre-milking treatments, and thus, overall, Strip cows achieved a greater average milk flow rate and a shorter cluster-on time.

The Strip treatment provided little advantage to milking efficiency despite the reduction in cluster-on time. Cluster-on time was reduced by 12 s, and the removal of a latency period from the routine allowed it to be applied without increasing labor requirements, however, ~10 s was required for stimulation so it provided little net benefit to the time from the cow entering the dairy to cluster removal. Thus, the Strip treatment was an improvement from the routine used by Edwards *et al.* (2013) and could comply with EU legislation that requires milk from each animal to be checked for organoleptic or physico-chemical abnormalities by the milker (EU, 2004), however, would not comply with the Pasteurized Milk Ordinance (FDA, 2009), which requires teats to be treated with a sanitizing solution and wiped dry. Furthermore, adding 10 s to the work routine of the operator attaching clusters reduces the maximum amount of cows able to be milked per hour unless additional labor is added (Edwards *et al.*, 2012; O'Brien *et al.*, 2012). This result may be in contrast to that experienced in the USA, where there is conflicting evidence as to the effect of pre-milking preparation on overall dairy performance (Eicker *et al.*, 2000; Armstrong *et al.*, 2001). Differences may exist due to a greater response to stimulation, reportedly around 60 s (Sagi *et al.*, 1980), or greater average milk flow rates compared to those reported here (Watters *et al.*, 2012). Additionally, in housed systems, which are common in the USA, pre-milking routines are of greater importance to comply with milk hygiene regulations (FDA, 2009). In the present scenario, if no labor is added, increasing the work routine time would increase the rotation time in rotary dairies or row time in herringbone dairies, thereby reducing potential throughput but also increasing overmilking (clusters remaining attached after the cessation of milk flow) in dairies not fitted with ACR. In these dairies overmilking would be exacerbated by the pre-milking stimulation increasing average milk flow rate, and thus reducing the time required to harvest milk, whilst increasing cluster-on time through the longer rotation or row times. Ideally, decreasing cluster-on time without increasing work routine time would have been achieved using mechanical stimulation, however, cluster-on time was not significantly shorter for the Stim treatment compared to the Control. Thus, neither pre-milking treatment appears effective at improving milking efficiency in herds typically found in pasture-based production systems and to achieve maximum efficiency, clusters should be attached immediately after entering the bail to improve utilization, a conclusion supported by Edwards *et al.* (2013).

In comparison to strategies involving pre-milking stimulation, increasing ACR threshold above 0.4 kg/min appeared to provide significant benefits to milking efficiency, without requiring pre-milking stimulation. Increasing ACR threshold to 0.4, 0.6 and 0.8 kg/min provided a daily average 12, 15 and 21% reduction in cluster-on time compared to the New Zealand standard of 0.2 kg/min, without negatively impacting milk production, composition or indicators of udder health. Correspondingly, the recorded increase in average milk flow rate with increasing ACR threshold was logical, in part due to the cluster being removed earlier and thereby reducing the time of low milk flow rate near the end of milking and mathematically increasing average milk flow rate. The reduction in the duration of low milk flow rate at the end of milking is confirmed by the decreasing decline duration with increasing ACR threshold. However, milk flow rate must have also physically increased in order to maintain milk production with reduced cluster-on times, as the shortening of the decline duration accounted for only 39 to 55% of the total reduction in cluster-on time. The physical increase in average milk flow rate could be explained by small differences in milk flow curve and cumulative yield curve between the treatments (Figure 2). The greater average cumulative yield of ACR8 cows compared to ACR2 cows from 135 s through to 240 s of milking indicates greater average milk flow between these points. The milk flow curves and cluster-on times of individual cows varied greatly, however, examining the average flow curves of the ACR2 and ACR8 cows indicated small but significant differences. The ACR8 cows reached a statistically greater average milk flow rate in early milking for the period 30-45 s and near the peak period of 120-135 s, however, it should be noted that unlike pre-milking treatments cows did not crossover ACR treatments. The greater average milk flow recorded in early milking may be the result of greater cisternal milk volume, which can be rapidly evacuated from the udder after cluster attachment (Bruckmaier, 2001). Greater cisternal milk could be present due to residual milk from the previous milking, which increased with increasing ACR threshold due to the cluster being removed earlier (Edwards *et al.*, 2013). Residual milk is reabsorbed by the alveolar compartment immediately post milking (Knight *et al.*, 1994; Caja *et al.*, 2004), however, a small amount of newly secreted milk moves back to the cistern within the first six hours post milking (Stelwagen *et al.*, 1996). Additionally, Knight *et al.* (1994) reported that the movement of milk to the cistern occurs in two distinct stages, the first being soon after milking. Greater residual milk in the alveolar compartment could increase the availability of milk to be transferred during this time and may therefore increase the rate of movement back to the cistern, potentially resulting in greater cisternal volume at the next milking (Pfeilsticker *et al.*, 1996). It is likely that greater cisternal milk will generate a higher baseline intramammary pressure (Pfeilsticker *et al.*, 1995), resulting in an increased milk flow rate. Thus, a potential explanation is provided for the greater average milk flow rate recorded with higher ACR thresholds.

Increasing ACR threshold had no impact on indicators of udder health despite greater residual milk due to earlier removal of the cluster. Residual strip yield increased by 0.3 kg from ACR2 to ACR8, whilst SCC remained unchanged. Interestingly, the strip yield of the ACR2 and ACR4 treatments were similar, a result also reported by Edwards *et al.* (2013) but not reported during peak lactation in previous studies (Jago *et al.*, 2010a; Burke & Jago, 2011). The presence of residual milk is thought by many farmers to be linked with mastitis, however, there is increasing evidence from the current and previous studies, some longer term, that an increase in residual milk does not adversely affect SCC or rates of clinical mastitis (Clarke *et al.*, 2008; Jago *et al.*, 2010b; Burke & Jago, 2011; Edwards *et al.*, 2013). Thus, increasing ACR threshold does not appear to affect udder health adversely.

Increasing ACR threshold can be implemented on many farms to improve milking efficiency and decrease herd milking times. Decreasing individual cow cluster-on time allows more cows to be milked and milk harvested per hour (Edwards *et al.*, 2012). However, to take the greatest advantage of this reduction a decrease in rotation time for rotary or row time for herringbone dairies is required, although it should be noted that row time in the herringbone is limited by the slowest milking cow so increasing ACR threshold may not result in decreased row times (Stewart *et al.*, 2002). To facilitate the decrease in row or rotation time a corresponding decrease in the work routine time of the operator attaching clusters must occur. For example, if moving from ACR2 to ACR8 in a 60 bail rotary work routine time needs to be reduced, and thus platform speed increased, by 1.3 s/bail, or in a 20 unit herringbone dairy, by 4 s/cow to achieve the ~80 s decrease in rotation or row time. A change of this magnitude should be achievable on many farms, particularly those with rotary dairies fewer than 60 bails (Edwards *et al.*, 2012), or herringbone dairies with fewer than 26 units during peak lactation (O'Brien *et al.*, 2012). Thus, increasing ACR threshold to improve milking efficiency is a strategy that can be implemented on many farms.

Conclusions

Increasing ACR threshold is an effective strategy to improve milking efficiency in situations where work routine times can be accelerated. The increased average milk flow rate recorded with higher ACR thresholds may be a result of a greater volume of cisternal milk. The mechanical stimulation treatment chosen was not effective at replacing manual stimulation and neither appears to provide an advantage to milking efficiency in pasture-based systems. Manual stimulation decreases the number of cows able to be milked per hour unless labor is added and it may cause increased overmilking in dairies not fitted with ACR. Consequently, to achieve the greatest milking efficiency in pasture-based systems clusters should be attached immediately without pre-milking preparation.

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CHAPTER 7

Overmilking causes deterioration in teat-end condition of dairy cows in late lactation

J. Paul Edwards,[1,3] Bernadette O'Brien,[2] Nicolas Lopez-Villalobos[3] and Jenny G. Jago[1]

[1]DairyNZ, Private Bag 3221,
Hamilton 3240, New Zealand.

[2]Teagasc Animal and Grassland Research and Innovation Centre,
Moorepark, Fermoy, Co. Cork, Ireland.

[3]Institute of Veterinary, Animal and Biomedical Sciences,
Massey University, Private Bag 11222,
Palmerston North 4442, New Zealand.

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Abstract

The objective of the present study was to determine the effect of varying degrees of overmilking on teat-end hyperkeratosis, milk production variables and indicators of udder health during late lactation. This was examined by assessing the effect of four end-of-milking criteria on 181 spring calving, mixed age Holstein-Friesian cows, at an average 217 ± 24 day in milk, over a six week period. The four treatments were: remove cluster once milk flow rate fell to 0.2 kg/min plus 5 s (Ovr0), plus 120 s (Ovr2), plus 300 s (Ovr5), and plus 540 s (Ovr9). Daily measurements included individual cow milk yield, milking duration, overmilking duration, maximum milk flow rate, milk flow rate at cluster removal and the number of cluster re-attachments. Individual cow bulk milk samples were collected weekly at AM and PM milkings to determine composition (fat, protein and lactose) and somatic cell count (SCC; AM only). Teat-end hyperkeratosis score was assessed at week 0, 3, 5 and 6. At week 6 mean teat-end hyperkeratosis score of the Ovr2 treatment was not greater than Ovr0, whilst Ovr5 was greater than Ovr2 and Ovr9 was greater than Ovr5 and Ovr2. Milk production, milking characteristics and SCC were not different between treatments, except milking duration and milk flow rate at cluster removal. However, higher teat-end hyperkeratosis scores may have a longer term impact on indicators of udder health if teat-end condition reaches severe levels. Results indicate that to minimise changes in teat-end condition, overmilking should be limited to 2 min, which has implications for milking management in large parlours not fitted with automatic cluster removers.

Keywords: overmilking, teat-end hyperkeratosis, milking management

Introduction

Milk harvesting on pastoral dairy farms accounts for a significant portion of labour input, between 33 and 57% annually (O'Brien *et al.*, 2004; O'Donovan *et al.*, 2008; Taylor *et al.*, 2009). Furthermore, herd sizes on pastoral dairy farms are increasing and are likely to continue to expand in the future (O'Donnell *et al.*, 2008; DairyNZ, 2011), exerting pressure on scarce labour resources.

To minimise the effect of increasing herd size on labour resources, larger dairies with more units, that are capable of greater throughput (Edwards *et al.*, 2012; O'Brien *et al.*, 2012), are being installed in an attempt to maintain total herd milking times. However, this can increase the number of clusters handled per operator, often resulting in an increase in row (herringbone parlour) or rotation (rotary parlour) time due to the inability to reduce per unit work routine times appreciably (O'Brien *et al.*, 2012). Thus, cluster-on time could increase in dairies not fitted with automatic cluster removers (ACR), estimated to represent 95% of swingover parlours in Ireland (Kelly, 2009), and 91% of swingover and 46% of rotary parlours in New Zealand (Cuthbert, 2008), potentially resulting in clusters remaining attached after the cessation of milk flow, resulting in overmilking.

Most pasture-based production systems involve a seasonal calving pattern, which results in a lactation curve where herd yield declines as the season progresses. The decline in yield results in shorter milking durations for cows whilst per unit work routine times for the operator remain constant, resulting in greater potential for overmilking in late lactation (O'Brien *et al.*, 2012).

The reported effects of overmilking on udder health are variable. Overmilking has been linked with an increased incidence of infected quarters, incidence of clinical mastitis and higher somatic cell count (SCC) in some studies (Natzke *et al.*, 1982; Osteras & Lund, 1988), although other studies have reported no such relationship (Neave *et al.*, 1962; Natzke *et al.*, 1978; Olney & Mitchell, 1983). Similarly, some studies have reported an effect of overmilking on teat condition (Peterson, 1964; Hillerton *et al.*, 2002), whilst others have not (Natzke *et al.*, 1982; O'Callaghan *et al.*, 1998; Gleeson *et al.*, 2003b). These conflicting results could be in part due to the varying lengths of treatments, clusters and liners, degrees of overmilking applied and the scale of the experiments. Additionally, Natzke *et al.* (1982) concluded that overmilking is likely associated with the transfer of organisms to non-infected quarters during the time of little or no milk flow so an increase in the incidence of mastitis may only be seen in herds with a reservoir of bacteria.

Within the dairy industry it is generally acknowledged that 2 min of overmilking is acceptable, a level supported by O'Callaghan *et al.* (1998), Hillerton *et al.* (2002) and Gleeson *et al.* (2003b). However, few studies have compared more than one level of overmilking in the same experiment, with the exception of Hillerton *et al.* (2002), who noted the limited number of cows used in their study (n=6), short time period (12 days out of three weeks) and uncertainty about the practical implications of the induced changes. Overmilking of greater than 2 min is regularly occurring on commercial farms without ACR (Hillerton *et al.*, 2000; Jago *et al.*, 2012). Thus, the objective of the experiment was to examine the effect of four different levels of overmilking on the teat-end hyperkeratosis score, milking characteristics and indicators of udder health of dairy cows in late lactation.

Materials and methods

Animals

The study was conducted on 181 spring calving mixed age Friesian cows on two research farms (Curtins Research Farm, n=92, Moorepark Research Farm, n=89; Fermoy, Co. Cork, Ireland), from October to November 2011. Average lactation number was 2.5 ± 1.5 and cows were 217 ± 24 days in milk. The use of animals was approved by the Moorepark Animal Ethics Committee. Treatments for the present experiment were balanced across each of the existing management herds on each farm. The herds were milked in the morning between 0700 and 0830 hours and in the afternoon between 1500 and 1630 hours, ensuring a consistent milking interval. At Curtins Research Farm, cows were milked through a 14 unit high level swingover side by side parlour (DairyMaster, Causeway, Ireland) fitted with ACR and DairyMaster 916S liners using 4×0 pulsation. Plant vacuum was set at 48 kPa. Post milking, a commercially available teat sanitizer (Teatcare Plus AG206, Deosan, Northampton, UK) was applied manually to each cow by pressurized spray. At Moorepark Research Farm, cows were milked through a 30 unit high level swingover side by side parlour (DairyMaster, Causeway, Ireland) fitted with ACR and DairyMaster 916S liners using 4×0 pulsation. Plant vacuum was set at 50 kPa. Post milking, a commercially available teat sanitizer (Super Iodip AG205, Deosan, Northampton, UK) was applied manually to each cow by pressurised spray.

Experimental design

The experiment used a randomised design with repeated measures. Four treatments were selected to assess the impact of overmilking on teat-end condition, milking characteristics and indicators of udder health. All treatments were balanced for pre-trial teat-end hyperkeratosis score, herd, lactation number, milking duration, yield, and SCC. Clusters were attached to cows in all treatment groups without pre-milking preparation. Clusters were removed automatically by ACR 5 s after milk flow rate reached 0.2 kg/min, this treatment was considered the control (**Ovr0**). The remaining three treatments (**Ovr2**, **Ovr5**, and **Ovr9**) had identical pre-milking procedures to the control, whilst clusters were removed at 120 s, 300 s and 540 s after milk flow rate reached 0.2 kg/min. Cows remained on their allocated treatment for the duration of the six week experiment. Following the experimental period ACR threshold was returned to 0.2 kg/min + 5 s and cows were dried off an average of 3 weeks later.

Measurements

Weighall individual milk meters (DairyMaster, Causeway, Ireland) were used to record individual cow milk yield, milking duration (cluster-on to cluster-off), maximum milk flow rate, overmilking time (time cluster was attached after milk flow rate reached 0.2 kg/min), milk flow rate at cluster removal, and the number of times the cluster was re-attached at each milking (an indicator of the number of times clusters were kicked off). Individual cow milk samples were collected weekly and analysed for composition using a Milko Scan 203 Analyzer (Foss Electric, Hillerød, Denmark) and SCC (AM sample only) using a flow-cytometer (Bentley 3000, Bentley Instruments Incorporated, Chaska, Minnesota, USA).

Teat-end hyperkeratosis score was assessed using the field evaluation method described by Mein *et al.* (2001), using a 1-4 scale, whereby teats classed as normal (N), smooth (S), rough (R) and very rough (VR) were assigned the scores 1, 2, 3 and 4, respectively. Measurements were taken at four time points, at week 0, week 3, week 5 and week 6. On each occasion all four teats were scored twice by the same assessor, at an AM and PM milking, after cluster removal (within 60 s) and prior to the application of teat sanitizer. The AM and PM scores were then averaged. Overmilking treatments were not marked visually. Cows with clinical mastitis were identified and recorded by farm staff and treated according to farm guidelines. The foremilk of suspect cows was inspected and clinical mastitis was defined as one quarter displaying any of the following signs: flakes or clots in the milk, watery or discoloured milk, or hot or swollen mammary tissue. Following the detection of clinical mastitis, treatments were stopped and further data was not collected.

Statistical analysis

Somatic cell count data were normalized using a $\log_{10}$ transformation. The milking data were analysed using mixed models, including the fixed effects of farm, session (AM/PM), overmilking treatment, the interaction of session with overmilking treatment and initial milking characteristics as covariables plus cow within farm, session and week within cow as random effects. Teat-end condition data were analysed using mixed models including the fixed effects of farm, overmilking treatment, the interaction of week and overmilking treatment and initial teat-end score as a covariable plus cow as a random effect. The residuals provided no evidence that a transformation was required. Percentages of score 4 teats were analysed for treatment differences at each measurement week using generalised linear models with logit link and binomial error distribution. All analyses were undertaken using GenStat 14.1 (VSN International, Hemel Hampstead, UK).

Results

Teat condition

Teat-end hyperkeratosis score increased with increasing duration of overmilking at each measurement week (Table 1). The greatest change occurred from week 0 to 3 (P<0.001), changes from week 3 to 5 and from weeks 5 to 6 were not significant (P>0.05). However, there was an interaction between overmilking treatment and week (P<0.05). Mean teat score of the Ovr2 treatment was significantly higher than Ovr0 only at week 5 (Table 1). In comparison, mean teat score of the Ovr5 and Ovr9 treatments were greater than the Ovr0 treatment at week 3, 5 and 6 (P<0.001). However, mean teat score of the Ovr9 treatment only increased significantly beyond the Ovr5 treatment at week 6 (P<0.001). At week 6 mean teat scores were 0.1, 0.2, 0.4 and 0.6 units higher than week 0 for the Ovr0, Ovr2, Ovr5 and Ovr9 treatments, respectively. The percentage of score 4 (VR) teats increased with level of overmilking (Table 3).

Milking performance

Overmilking time recorded by the milking parlour confirmed that treatments had been applied correctly and cluster-on time increased accordingly (P<0.001; Table 2). Milk production variables (milk yield, fat yield, protein yield, and lactose yield) were unaffected by overmilking treatment. Furthermore, the number of cluster re-attachments and maximum milk flow rate were not different between treatments. However, milk flow rate at cluster removal declined from Ovr0 to Ovr5. The $\log_{10}$ transformed SCC did not differ between treatments and no interaction was detected between overmilking treatment and measurement week (P=0.6). During the experiment, one cow on the Ovr5 treatment developed clinical mastitis.

Table 1. Effect of four overmilking treatments (Ovr0, Ovr2, Ovr5 and Ovr9) on mean teat-end hyperkeratosis score (1-4 scale).

Time	Treatment†				SED‡	P-value
	Ovr0	Ovr2	Ovr5	Ovr9		
Number of cows	45	46	45	45		
Week 0	1.7	1.7	1.7	1.7		
Week 3	1.8	1.9	2.1	2.1	0.07	< 0.001
Week 5	1.7	1.9	2.0	2.1	0.06	< 0.001
Week 6	1.8	1.9	2.1	2.3	0.07	< 0.001

†Treatment: Cluster was removed 5 s (Ovr0), 120 s (Ovr2), 300 s (Ovr5) and 540 s (Ovr9) after milk flow rate reached 0.2 kg/min.
‡Standard error of the difference.

Table 2. Effect of four overmilking treatments (Ovr0, Ovr2, Ovr5 and Ovr9) on milking characteristics, yield and somatic cell count (SCC).

Variable	Treatment†				SED‡	P-value
	Ovr0	Ovr2	Ovr5	Ovr9		
Number of cows	45	46	45	45		
Overmilking time (s)	14	129	307	535	1.79	< 0.001
Milking duration (s)	299	416	598	828	3.91	< 0.001
Max flow (kg/min)	2.8	2.7	2.7	2.7	0.05	0.400
Flow rate at removal (kg/min)	0.15	0.06	0.03	0.03	0.01	< 0.001
Mean number of re-attachments	0.04	0.04	0.04	0.03	0.01	0.655
Session milk yield (kg)	5.8	5.8	5.8	5.9	0.12	0.541
Fat yield (kg)	0.29	0.29	0.29	0.30	0.01	0.418
Protein yield (kg)	0.23	0.23	0.23	0.24	0.01	0.745
Lactose yield (kg)	0.26	0.26	0.26	0.26	0.01	0.963
Log_{10}SCC	5.1	5.2	5.1	5.1	0.06	0.550
Back transformed SCC (cells/mL)	126,000	143,000	137,000	119,000		

†Treatment: Cluster was removed 5 s (Ovr0), 120 s (Ovr2), 300 s (Ovr5) and 540 s (Ovr9) after milk flow rate reached 0.2 kg/min.
‡Standard error of the difference.

Table 3. Effect of four overmilking treatments (Ovr0, Ovr2, Ovr5 and Ovr9) on the percentage of score 4 teats.

Time	Treatment†				SED‡	P-value
	Ovr0	Ovr2	Ovr5	Ovr9		
Number of cows	45	46	45	45		
Week 0	0.7%	0.7%	0.7%	0.7%		
Week 3	0.8%	0.8%	3.6%	4.7%	1.6%	< 0.05
Week 5	0.4%	0.6%	2.4%	4.4%	1.4%	< 0.05
Week 6	0.0%	0.9%	1.3%	7.7%	1.5%	< 0.001

†Treatment: Cluster was removed 5 s (Ovr0), 120 s (Ovr2), 300 s (Ovr5) and 540 s (Ovr9) after milk flow rate reached 0.2 kg/min.
‡Average standard error of the difference.

Discussion

The average teat-end hyperkeratosis score for cows on the Ovr2 treatment was not significantly higher than those receiving no overmilking in all weeks, except week 5. In comparison, cows on the Ovr5 treatment had a greater teat-end hyperkeratosis score during each of the three measurement weeks. The degradation in teat health is consistent with Gleeson *et al.* (2003a), who reported increased teat sinus injury after 5 min overmilking and Hillerton *et al.* (2002), who reported differences in teat ringing at 5 min but not 2 min of overmilking. Similarly, O'Callaghan *et al.* (1998) and Gleeson *et al.* (2003b) reported no difference in teat-end hyperkeratosis score with 2 min of overmilking. Thus, farmers should seek to limit overmilking to 2 min to minimise changes in teat-end condition.

An interaction between overmilking treatment and measurement week was detected for teat-end score indicating that the rate of increase in teat score was not uniform between overmilking levels. The mean teat score of the Ovr2 and Ovr5 treatments had increased from 1.7 to 1.9 and 2.1 units by week 3 and remained at this level for the remainder of the experiment, and thus, appeared to have reached an upper limit. Similarly, the mean teat score of the Ovr9 treatment had increased from 1.7 to 2.1 units by week 3, and remained at this level for week 5 before increasing to 2.3 units in week 6. Thus, there was no difference between overmilking by 5 or 9 min until week 6, indicating that the maximum rate of teat-end degradation may have been reached. Additionally, the stepped increase in mean teat-end score of the Ovr9 treatment may be a reflection of requiring several weeks for the teat-end score to move from one classification band to the next. It is unclear whether presence of an apparent maximum rate of teat-end degradation and upper limit to teat-end hyperkeratosis score (Ovr5) reported in this short term experiment could apply long-term or whether teat-end condition score would continue to increase to its maximum value if these levels of overmilking had been imposed for a full lactation.

Indicators of udder health were not compromised despite the increase in teat-end condition score over the 6 week experiment. The absence of an effect on SCC despite higher teat-end hyperkeratosis is consistent with the results of Shearn and Hillerton (1996), Gleeson *et al.* (2004) and Breen *et al.* (2009a) who reported no association between increased teat-end hyperkeratosis score and SCC on commercial farms. Mild teat-end hyperkeratosis has been reported to reduce the chances of invasion by bacteria through entrapment in the keratin, which is subsequently flushed from the teat canal during milking (Mein *et al.*, 1986). Furthermore, using another indicator of udder health, Sieber and Farnsworth (1981) reported no association between teat-end condition and the prevalence of clinical mastitis in 22 commercial herds. However, several studies have reported relationships between udder health and teat-end condition. Neijenhuis *et al.* (2001) reported clinical mastitis was associated with higher teat-end callosity up to three months prior to the mastitis occurring. Similarly, Breen *et al.* (2009b) reported quarters with moderate to severe hyperkeratosis, which were more prevalent in the longer overmilking treatments of this study, were more likely to develop clinical mastitis, in the same herds where no association between teat-end hyperkeratosis score and SCC had been detected (Breen *et al.*, 2009a). Thus, changes in udder health caused by overmilking may not be apparent in the short term, however, may develop over a period of time after an increase in teat-end callosity or when teat-end hyperkeratosis becomes severe.

Cows did not appear in discomfort despite the longer cluster attachment time. Clusters remained attached for nearly twice the normal amount of time for Ovr5 cows, and more than 2.5 times for Ovr9 cows, resulting in a period of milking with low milk flow as evidenced by the lower milk flow rate at cluster removal (Table 2). Milking during a period of low milk flow causes the cluster to climb, collapsing teats (Bruckmaier, 2001). However, despite this there was no recorded increase in the number of times clusters required re-attachment (after being kicked off by cows), which is an indicator of discomfort and source of potential frustration to the operator should it occur often. The absence of a difference in cluster re-attachment supports the conclusion by Natzke *et al.* (1982) that extended milking has little or no traumatizing effect on the mammary gland. Thus, due to the lack of interruption to the routine of the milking operator, through having to re-attach clusters, manage SCC or treat clinical mastitis, many operators may be unaware of overmilking until teat condition reaches a critical point.

The results of this overmilking study have implications for milking management in dairy parlours. The effect of overmilking on teat-end hyperkeratosis can be rapid, with changes detected in three weeks, although it may take a period of time for hyperkeratosis to reach a severe level. Overmilking of greater than 2 min is likely to occur in single operator swingover parlours (14 – 30 units) utilising a full pre-milking routine (spray, strip, wipe, and cluster attachment) without the use of ACR, during any stage of lactation (O'Brien *et al.*, 2012). Additionally, greater than 2 min of overmilking is likely to occur in single operator parlours without ACR when applying no pre-milking routine (i.e. immediate cluster attachment) if parlour size is greater than 26 units and 22 units at peak and late lactation (O'Brien *et al.*, 2012). Thus, to minimise changes in teat-end condition, care is required when sizing milking parlours. When constructing a new swingover parlour the ideal number of units should be determined based on the anticipated cow milking duration and operator work routine time to ensure maximum utilisation of clusters and minimal operator idle time. In existing parlours, if overmilking is likely to occur then either the work routine may be streamlined by removal of components such as pre-spray and wipe, an additional operator employed in the parlour, ACR installed, or an appropriate number of units deactivated.

In conclusion, overmilking of greater than 2 min resulted in an increase in teat-end hyperkeratosis score of dairy cows in late lactation. However, overmilking did not affect indicators of udder health in this six week experiment or appear to cause cow discomfort and overmilking may therefore go unidentified by operators until hyperkeratosis reaches a critical point. To limit overmilking to 2 min in parlours not fitted with ACR the row time in swingover parlours should be appropriately matched to cow milking duration by manipulating operator work routine time through streamlining pre-milking routines, adding an additional operator, installing ACR or deactivating an appropriate number of clusters.

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CHAPTER 8

Milking efficiency of swingover herringbone parlours in pasture-based dairy systems

J. Paul Edwards,[1,3] Bernadette O'Brien,[2] Nicolas Lopez-Villalobos[3] and Jenny G. Jago[1]

[1]DairyNZ, Private Bag 3221,
Hamilton 3240, New Zealand.

[2]Teagasc Animal and Grassland Research and Innovation Centre,
Moorepark, Fermoy, Co. Cork, Ireland.

[3]Institute of Veterinary, Animal and Biomedical Sciences,
Massey University, Private Bag 11222,
Palmerston North 4442, New Zealand.

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Abstract

The objective of this study was to collect and analyse milking data from a sample of commercial farms with swingover herringbone parlours to evaluate milking efficiency over a range of parlour sizes (12-32 milking units). Data were collected from 19 farms around the Republic of Ireland equipped with electronic milk meters and herd management software that recorded data at individual milking sessions. The herd management software on each farm was programmed to record similar data for each milking plant type. Variables recorded included cow identification, milking date, identification time, cluster attachment time, cluster/unit number, milk yield, milking duration, and average milk flow rate. Calculations were performed to identify efficiency benchmarks such as cow throughput (cows milked per hour), milk harvesting efficiency (kg of milk harvested per hour) and operator efficiency (cows milked per operator per hour). Additionally, the work routine was investigated and used to explain differences in the benchmark values. Data were analysed using a linear mixed model that included the fixed effects of season-session (e.g. spring-AM), parlour size and their interaction, and the random effect of farm. Additionally, a mathematical model was developed to illustrate the potential efficiency gains that could be achieved by implementing a maximum milking time (i.e. removing the clusters at a pre-set time regardless of whether the cow had finished milking or not). Cow throughput and milk harvesting efficiency increased with increasing parlour size (12 to 32 units), with throughput ranging from 42 to 129 cows per hour and milk harvesting efficiency from 497 to 1430 kg per hour (1-2 operators). Greater throughput in larger parlours was associated with a decrease in operator idle time. Operator efficiency was variable across farms and likely dependent on milking routines in use. Both of these require consideration when sizing parlours so high levels of operator efficiency as well as cow throughput can be achieved simultaneously. The mathematical model indicated that application of a maximum milking time within the milking process could improve cow throughput (66% increase in an 18 unit parlour when truncating the milking time of 20% of cows). This could allow current herd milking durations to be maintained as herd size increases.

Keywords: milking efficiency, parlour, dairy, overmilking

Introduction

The average herd size in pasture-based production systems, such as New Zealand and Ireland, has been increasing through time (DairyNZ, 2011; ICBF, 2011). This trend is likely to continue and in some countries, such as Ireland, the removal of milk production quotas imposed by the European Union (EU) is expected to lead to a further increase in dairy herd expansion (O'Donnell *et al.*, 2011). Milking the herd is the most time consuming task on pasture-based dairy farms using batch milking, and thus requires significant labour input (O'Donovan *et al.*, 2008; Taylor *et al.*, 2009). As herd sizes expand, efficient milking parlour performance is critical to permit increased farm labour efficiency. Yet, to date there has been limited field evaluation of parlour efficiency.

The most common type of milking parlour in pasture-based systems is the swingover herringbone, accounting for 75% of the milking parlours in New Zealand and 91% in Ireland (Cuthbert, 2008; Kelly, 2009). The swingover herringbone is popular due to its lower investment costs relative to other parlour types (double-up herringbone, rotary) and potential for expansion of the parlour. The high cluster utilisation of this parlour type is supported by relatively uniform cow milking durations due to cows within a herd normally being at a similar stage of lactation in pasture-based systems. However, all milking parlours represent a significant capital investment, and therefore, careful consideration is required when selecting the appropriate number of milking units.

Milking parlour performance can be assessed in a number of ways using data extracted from parlours with electronic milk meters installed (Edwards *et al.*, 2013a). Data such as first and last cluster attachment time, the number of cows milked and milk yield can be used to calculate benchmarks such as cow throughput, harvesting efficiency and the operator efficiencies associated with these measures. These values are affected by the number of units in the parlour, the work routine time of the operator (including idle time), and individual cow milking duration. As herd sizes have grown the number of units in parlours has increased accordingly in an attempt to limit the number of rows and, therefore, time required to milk the herd. A potential consequence of increasing the number of units in parlours not equipped with automatic cluster removers (ACR) is overmilking, where the operator has insufficient time to remove the cluster at the desired point, which is exacerbated by a long work routine time and low milk yields (O'Brien *et al.*, 2012). In pastoral dairying it is common for swingover parlours not to have ACR installed, in Ireland this figure has been estimated to be 95% (Kelly, 2009), with a similar estimate of 91% in New Zealand (Cuthbert, 2008). Thus, there is a need to benchmark the performance of swingover herringbone dairies on commercial farms to determine if increased throughput is being realised in larger parlours, and if so, estimate whether this increase is potentially affecting herd health through overmilking in those parlours without ACR.

The performance of milking parlours can be influenced by the milking duration of individual cows (Jago *et al.*, 2010b; Edwards *et al.*, 2012), where shorter cow milking durations can allow greater throughput. In herringbone parlours some operators choose to wait for slow-milking cows to milk out, hence creating longer row times and reducing throughput. For example, in a survey of 280 operators of herringbone parlours in New Zealand 56% answered that they always or sometimes wait for cows to milk out (Cuthbert, 2008). Research has indicated that an effective strategy to reduce cow milking duration is to apply a maximum milking time, thereby truncating the milking of cows with milking durations longer than this selected time (Clarke *et al.*, 2004; Jago *et al.*, 2010b). Furthermore, minimal effects on overall production or indicators of udder health were reported in studies where a maximum milking time was applied (Clarke *et al.*, 2008; Jago *et al.*, 2010a). Applying a maximum milking time is straightforward to implement in herringbone parlours (DairyNZ, 2013).

The objective of this study was, firstly to investigate the current level of milking efficiency and the influence of parlour size and work routine time on milking efficiency for a sample of Irish dairy farms with swingover herringbone parlours fitted with ACR, ranging in size from 12 to 32 units. Secondly, a model was developed to illustrate the effect of parlour size and implementation of a maximum milking time strategy on cow throughput, operator work routine time and overmilking (if no ACR installed) in swingover herringbone parlours. This information can potentially be used to advance knowledge for the design and operation of herringbone parlours.

Materials and Methods

Data collection

Participating farms were selected for their ability to record milking data and all were equipped with a minimum level of technology including electronic identification of cows, electronic milk meters, automatic cluster removers (ACR) and herd management software that recorded individual milking events. Herringbone parlour sizes ranged from 12 to 32 units (12 units, n=2; 16 units, n=1; 18 units, n=3; 20 units, n=6; 22 units, n=2; 24 units, n=3; 30 units, n=1; 32 units, n=1) and two different parlour manufacturers (DairyMaster, Causeway, Ireland; DeLaval, Tumba, Sweden) were represented. Thirty and 50 degree parlours were included. Data were collected from 22 milking sessions at each of two time points, autumn (October – December 2011; 16 farms) and spring (April – May 2012; 19 farms). Cows were milked twice per day with an average milking interval of 14/10 h. A telephone survey was conducted to collect basic farm details such as herd size, the number of operators in the parlour and the presence of a hospital herd.

The herd management software on each farm was programmed to record similar data fields for each of the two systems. The variables recorded at each milking, according to manufacturer definitions, included cow identification (ID) number, milking date, ID time, cluster attachment time (vacuum-on; timestamp hh:mm:ss), row number, unit number, milk yield (kg), milking duration (s; vacuum-on to cluster-off), average milk flow rate (kg/min), and maximum milk flow rate (kg/min).

Calculations

Data were cleaned to exclude values outside the following ranges in a milking session: milk yield between 0.5 and 30 kg, milking duration between 120 s and 1200 s, maximum milk flow rate between 0.5 and 10 kg/min, and average milk flow rate between 0.2 and 5 kg/min (Edwards *et al.*, 2013a). In DairyMaster systems average milk flow rate was calculated by dividing milk yield by milking duration. Cluster removal time was calculated by adding the cow milking duration to the cluster attachment time. Conservative limits were also placed on cow ID times, whereby within a row any ID times outside a given range (the median ID time ± 6 s × the number of units in the parlour) were removed. Cluster attachment times occurring before the ID time for a given unit within a row were also removed. Furthermore, it was assumed that the last cluster attachment time in a row must occur before the first ID time of the next row, except row one because rows one and two could be loaded simultaneously.

Cow throughput (cows milked per hour) was calculated using the formula $(id_{r=n} - id_{r=1}) / \sum_{r=n-2}^{r=1} x_r$, where *id* was the first ID time of a given row, *r* was the row number, *n* was the total number of rows in the milking session (excluding any sick cows treated differently at the end of milking), and *x* was the number of cows in the row. The first ID time of the nth row was assumed to be the end of row n – 2, as the systems did not record exit times and so the end point of the n^{th} row could not be determined. Operator efficiency was determined by dividing cow throughput by the number of operators in the parlour. Milk harvesting efficiency and operator harvesting efficiency were calculated by multiplying cow throughput and operator efficiency respectively with the average cow milk yield at that session. The average amount of operator time per cow (average work routine time; s/cow) was calculated by dividing 3600 (the number of seconds in one hour) by cow throughput. Work routine time per operator was calculated by multiplying this average work routine time by the number of operators. For farms where cluster attachment times were recorded, work routine time was broken into five components, loading time, waiting time, time required to attach clusters, exit and post-milking teat spray time, and finish time. Loading time was calculated as the time between the first ID time and last ID time of a row. Waiting time was defined as the time between the last ID time of a row, at which point the row was assumed to be loaded, and the first cluster attachment time. Negative values were possible for waiting time if the operator began attaching clusters before the row was fully loaded. The time required to attach clusters was calculated as the time between the first cluster attachment and the last cluster attachment. Exit and post-spray time was defined as the time between the last cluster attachment time and the first ID time of the next row. Each of these components were summed for row one to row n – 2 and divided by the number of cows milked in these rows to give a time per cow. Finally, finish time was the loading time, waiting time, time required to attach clusters and exit and post-spray time for row n – 1 divided by the number of cows milked in rows one to n – 2. All five components sum to give average work routine time. A subsequent measure, waiting and attachment time, was created by adding waiting time and time required to attach clusters. Average row time (min) was calculated using the formula $60u/t$, where u was the number of units in the parlour, and t was cow throughput.

Statistical analysis

The milking data were combined to produce average values for each farm for each time point (season; spring/autumn) and milking session (AM/PM). Initially, data were analysed using a linear mixed model that included the fixed effects of season-session (e.g. spring-AM), parlour size and their interaction, and the random effect of farm. Linear and quadratic contrasts of parlour size were also tested in the model to aid interpretation of parlour size differences. All analyses were undertaken using GenStat 14.1 (VSN International, Hemel Hampstead, UK).

Model development

A model was created to estimate the effect of applying a maximum milking time. Milking duration data from AM and PM sessions of the 19 herringbone benchmark farms were combined. Data were examined and found to be skewed so were normalised using a log_{10} transformation. The normalised mean milking duration and standard deviation were inputted in the NORM.INV function of Microsoft Excel 2010 (Redmond, WA, USA) to estimate the time, where if clusters were removed in order of unit, then 1, 10, 20 and 30% of cows would have their milking truncated (for parlour sizes 12 – 44 units). This range of sizes was chosen to cover common parlour sizes in use in pasture-based systems. Row loading time was assumed to take four seconds per cow and 23 seconds per cow to apply any milking routine, attach clusters and post-milking teat spray, based off the figures in Table 1. The operator routine used was that recommended by DairyNZ MilkSmart (2013) as the most efficient routine, where the operator moves along the parlour detaching/attaching clusters in order, instead of changing them as individual cows finish milking. Additionally, exiting occurs simultaneously while post-spraying the cows in this routine so time to exit is minimal and was not included in the work routine time. Initially, it was assumed only one operator was present, so in larger parlours there was no reason to truncate milkings due to absence of idle time.

The row times for the four levels of truncation were divided by the number of units to determine an average work routine time. Operator idle time was calculated as the average work routine time minus the cow loading and the time required to attach clusters. Cow throughput was calculated by dividing 3600 seconds by the average work routine time. For each of the truncation levels used, overmilking occurred when the row time was greater than the milking duration of a cow, assuming ACRs were not installed. However, if there was operator idle time this was used to detach a cluster to prevent overmilking. Walking between units and detaching a cluster was assumed to require four seconds per cow, and thus, the number of clusters that could be detached in a given parlour size and level of truncation was calculated. The milking duration of cows was simulated using the log_{10} transformed distribution, described above. Overmilking time was then determined by subtracting the row time of the given level of truncation from the simulated cow milking durations. Average overmilking time was calculated by summing the duration of those cows that were over milked (positive values) and dividing this value by the number of cows in the row. Subsequently, if work routine time was insufficient to reach the desired row time, additional operators were added to the model, which allowed 30% of milkings to be truncated for all parlour sizes. Identical calculations were then performed to determine work routine time, operator idle time, throughput and average overmilking time.

Results

Benchmarking

The milking efficiency characteristics of parlour sizes ranging from 12 to 32 units are presented in Table 1. No interactions were detected between season-session and parlour size. Cow throughput and milk harvesting efficiency (cows milked and kg of milk harvested per hour) increased linearly with parlour size (Table 1; Figure 1a). Conversely, work routine time decreased linearly with parlour size but the non-linear effect was also significant. There were no differences in row loading time between parlour sizes. However, operator idle time waiting for a cluster decreased with increasing parlour size. No trend was detected between the time required to attach clusters and number of units. The combination of operator idle time waiting for a cluster and the time required to attach clusters decreased with increasing numbers of units. Likewise, exit and post-milking spray time decreased with increasing parlour size. No trend was detected between the last row time and number of units.

Cluster idle time was variable and no differences were detected between parlour sizes. Average row time, cows milked per operator per hour, and the work routine times per operator were not different between the various parlours. Furthermore, milking characteristics, milk yield, average milk flow rate and maximum milk flow rate were not different between the parlour sizes. Harvesting efficiency increased with parlour size but operator harvesting efficiency was not different between parlour sizes (Table 1; Figure 2).

Table 1: Milking efficiency benchmark values, components of milking routine and milking characteristics of 19 farms with swingover herringbone parlours of different sizes.

Item	Parlour size (units)						Pooled SED†	Linear P-value‡	Quadratic P-value§
	12	16-18	20	22	24	30-32			
Average herd size	45	91	115	86	237	169			
Cow throughput (cows/h)	42	82	94	88	106	129	9.38	<0.001	0.218
Total work routine time (s/cow)	92	46	40	43	34	29	7.90	0.001	0.003
Row loading time (s/cow)	3.9	2.9	3.6	3.6	4.3	3.4	0.47	0.375	0.752
Idle waiting for cluster (s/cow)	3.7	6.6	4.8	2.7	-0.2	-	1.32	0.060	0.001
Cluster attachment time (s/cow)	23.8	16.3	17.2	17.1	17.4	-	2.50	0.172	0.080
Waiting + attachment time (s/cow)	27.5	22.9	22.0	19.8	17.1	-	2.86	0.006	0.688
Exit and spray time (s/cow)	18.0	6.9	5.1	3.6	6.2	-	3.19	0.026	0.096
Last row time (s/cow)	20.3	10.2	8.9	15.6	8.6	-	3.95	0.315	0.122
Cluster idle time (s/cluster/row)	260	176	206	192	198	-	73.8	0.871	0.634
Average row time (min/row)	18.5	13.5	13.3	15.6	13.7	14.9	2.01	0.477	0.090
Operator efficiency (cows/operator.hr)	43	72	71	88	76	95	23.4	0.087	0.515
Work routine time per operator (s)	91	59	60	43	51	42	19.8	0.055	0.219
Milk yield (kg)	12.1	12.0	11.8	13.3	11.6	11.0	1.14	0.510	0.567
Average flow (kg/min)	2.2	1.8	1.8	1.9	1.7	2.0	0.15	0.838	0.019
Maximum flow rate (kg/min)	3.5	3.5	3.6	3.8	3.3	3.4	0.28	0.544	0.682
Harvesting efficiency (kg/h)	497	950	1098	1187	1231	1430	145.6	<0.001	0.099
Operator harvesting efficiency (kg/operator.hr)	521	833	810	1187	880	1031	268.7	0.132	0.390

†Average standard error of the difference.

‡Testing for a linear trend.

§Testing for a non-linear trend.

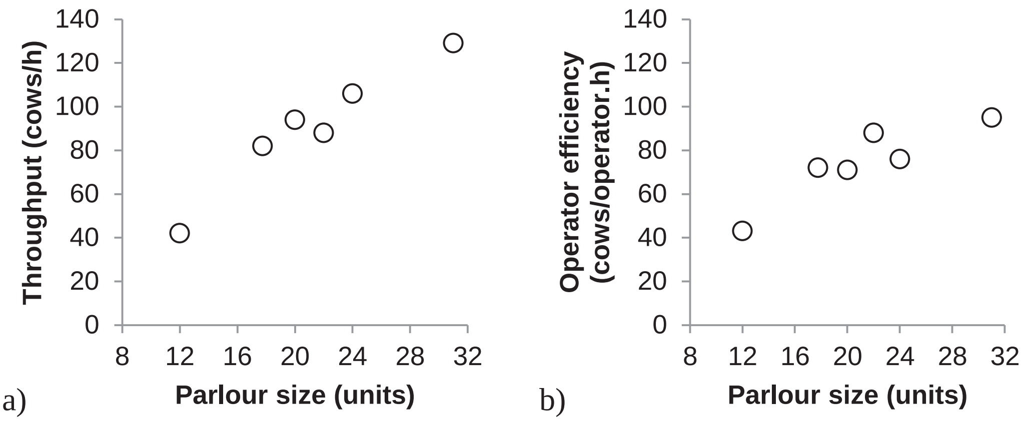

Figure 1. Average throughput (cows/hr; a) and operator efficiency (cows/operator.hr; b) from first cluster on to last cluster off, excluding hospital herds for each parlour size (12-32 units).

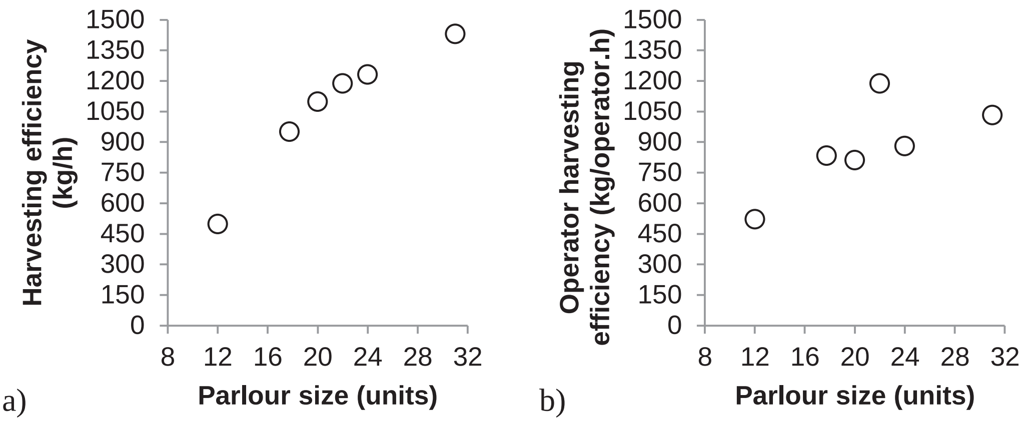

Figure 2. Average harvesting efficiency (kg milk/hr; a) and operator harvesting efficiency (kg milk/operator.hr ;b) from first cluster on to last cluster off, excluding hospital herds for each parlour size (12-32 units).

Modelling

Transformed mean cluster-on time was 2.587 (386 s) with a standard deviation of 0.150 (1.4 s). Increasing parlour size and the percentage of cows with truncated milkings resulted in less operator idle time and improved cow throughput (Figure 3a). However, higher levels of truncation were not achievable in parlours ≥18 units due to insufficient operator time for the routine applied, and thus maximum throughput (133 cows/hour) was reached at this point. As the level of truncation decreased, larger parlours were required to reach this level of cow throughput. Subsequently, when an additional operator was added to ensure the desired level of truncation was achieved in all parlour sizes, throughput continued to increase up to the maximum parlour size examined (44 units). The highest throughput estimated was 342 cows/hour by the 44 unit parlour with 30% of milking truncated (Figure 4a), when three operators were required. However, operator efficiency in terms of cows milked per operator per hour peaked at different parlour sizes depending on the level of truncation (Figure 4b). When it was assumed that operator idle time (Figure 3b) in the core routine was allocated to the removal of clusters from cows that had finished milking (if no ACR installed), overmilking occurred in small parlours with greater levels of truncation but as the level of truncation decreased more units could be handled before cows were overmilked (Figure 3c). With the addition of an operator(s) overmilking did not continue to increase as the greater operator idle time allowed time for cluster detachment (Figure 4c; Figure 4d).

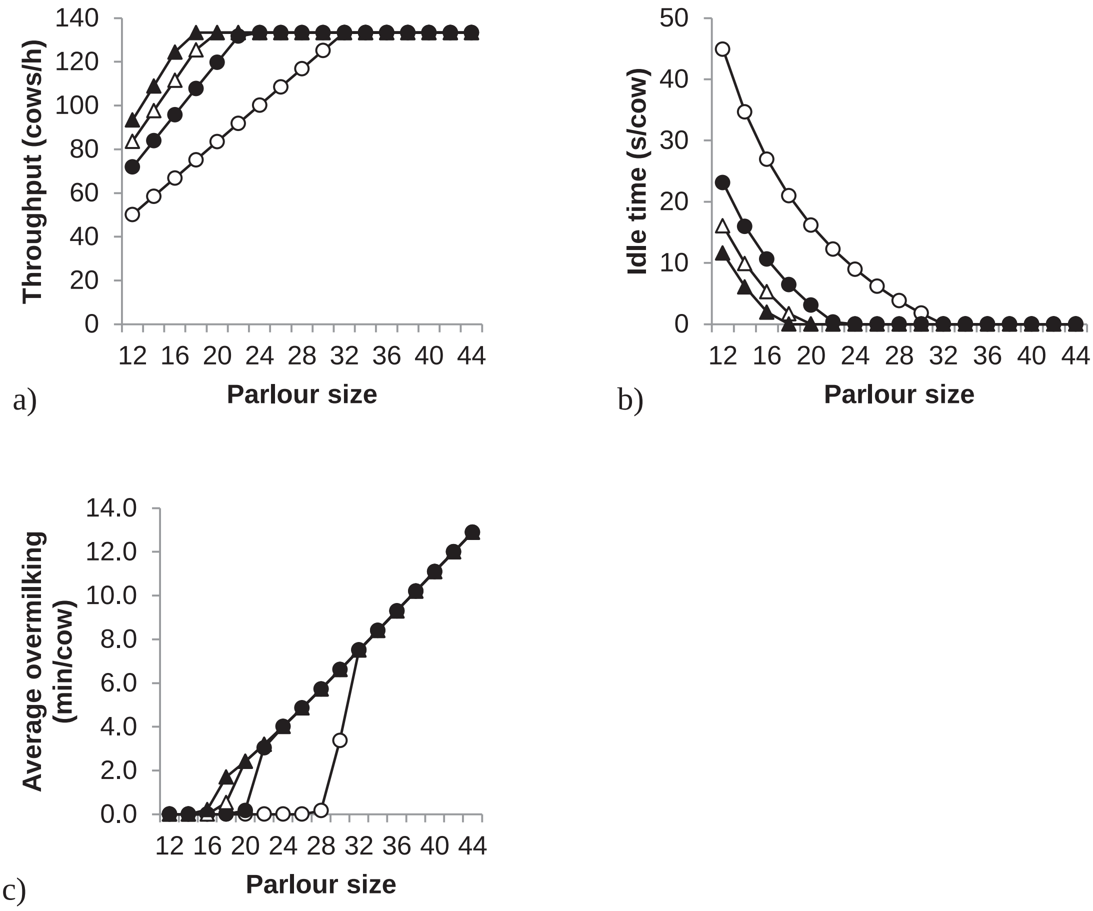

Figure 3. Predicted throughput (cows/hr; a), operator idle time (s/cow; b) and average overmilking (min/cow; c) over a range of parlours sizes (12-44 units) with a single operator while truncating the milking duration of a percentage of cows (1%, ○; 10%, ●; 20%, △; 30%, ▲).

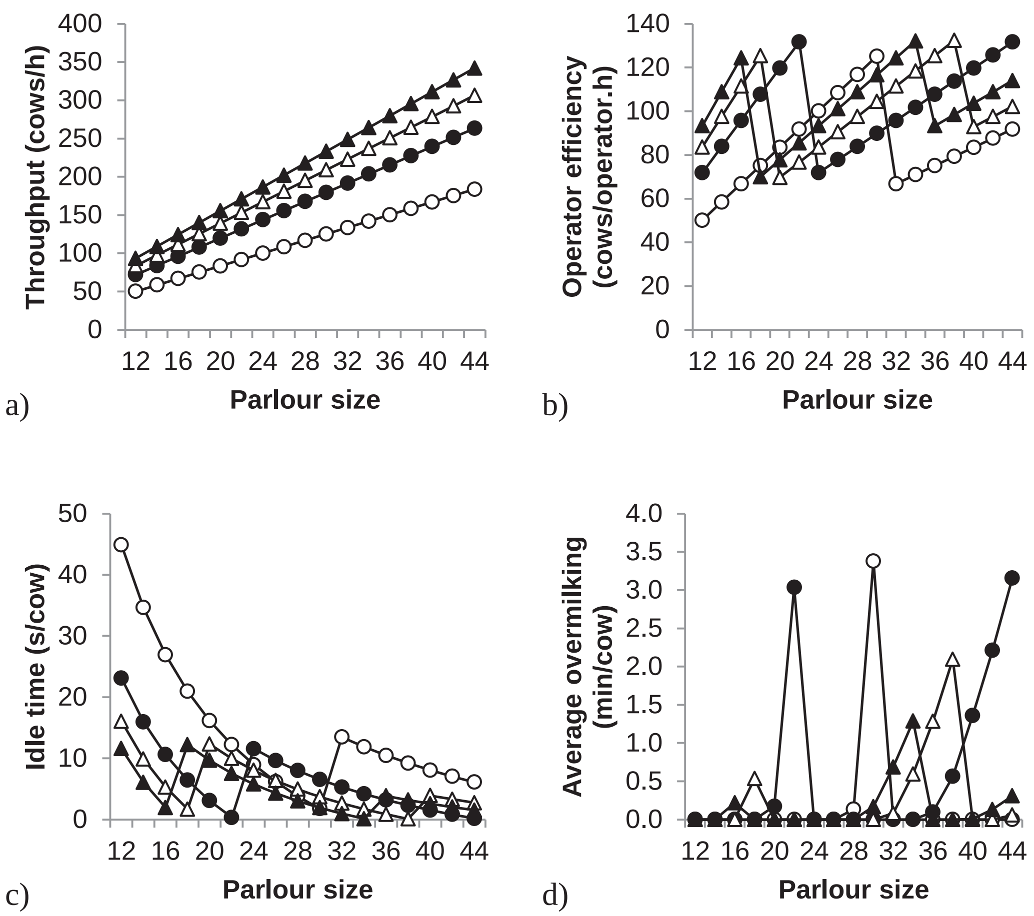

Figure 4. Predicted throughput (cows/hr; a), operator efficiency (cows/operator.hr; b) operator idle time (s/cow; c) and average overmilking (min/cow; d) over a range of parlours sizes (12-44 units) with multiple operators (if required) while truncating the milking duration of a percentage of cows (1%, ○; 10%, ●; 20%, △; 30%, ▲).

Discussion

There was a linear association between parlour size and throughput whereby larger parlours achieved greater throughput. However, empirically, parlour throughput is determined only by the operator work routine time, which may include time where the operator is idle. In theory, the time taken to complete the core components of the work routine should remain constant at a per cow level regardless of parlour size, which is supported by the results of the present study as no differences were detected for either cow loading time or cluster attachment time in different parlour sizes (Table 1). Conversely, significant differences were detected in operator idle time, where the row was loaded and the operator was waiting for a cluster to become available to swing over from the previous row. However, there were low values recorded by 12 unit parlours. It is possible that the farmers with 12 unit parlours operated their routines differently and the milker only completed the filling of the row as the last cows of the previous row were finishing milking, meaning that idle time may have been occurring between attaching clusters. Therefore, the variable ‘waiting + attachment time’ (Table 1) was created, which had a linear trend. Consequently, if it is assumed that cluster attachment time was constant between parlours then it could be ventured that the idle time component of the operator work routine decreased with increasing parlour size, allowing greater throughput. This hypothesis is supported by the results of O'Brien *et al.* (2012), who reported less operator idle time in larger parlours. Additionally, the exit and post-milking spray time was significantly different between parlour sizes, with a linear association. Hypothetically, the time required to post-milking teat spray and exit should not be related to parlour size on a per cow basis. However, in practice, this difference was likely due to variances in when the operator opened the gate to release the row of cows, as in larger parlours the total time to exit is greater, therefore encouraging the operator to release the head gate earlier so cows are exiting while completing post-milking teat spraying of the last few cows. In comparison, operators in smaller parlours are more accustomed to idle time waiting for cows to finish milking, and are more likely to be milking a smaller herd, and therefore are less motivated to release the head gate before finishing the row. Thus, it appears that parlour size has an influence on two components of the operator work routine, reducing the time spent on both, consequently allowing greater throughput.

Larger parlours were not necessarily more operator efficient (cows milked and kg of milk harvester per operator per hour) despite achieving greater throughput (Figure 1b). A similar result was reported by Edwards *et al.* (2013a) in rotary dairies, where larger dairies achieved greater throughput but were not more operator efficient. However, unlike the results reported by Edwards *et al.* (2013a) there was no quadratic trend of parlour size with operator efficiency. Operator work routine time, as discussed, decreased with increasing parlour size in a non-linear trend (an inverse relationship), likely through a reduction in operator idle time. In principle, what was operator idle time in smaller parlours was replaced by core components of the work routine, such as attaching clusters and post-milking teat spraying, as cluster number increased. This can continue until the routine contains no operator idle time, at which point if cluster number is increased there will be no throughput advantage and cluster idle time will begin to increase, as observed by O'Brien *et al.* (2012). Thus, there is a trade-off between operator idle time and cluster idle time. At this point another operator can be added, effectively doubling the work routine time available. Initially, the majority of this additional work routine time will be operator idle time so there will only be a small improvement in throughput with a reduction in operator efficiency, but this will improve as clusters are added, consequently reducing operator idle time. Therefore, the relationship between operator efficiency and parlour size will have multiple repeating peaks and troughs, as illustrated in Figure 3b. However, in practice there appeared to be variable operating practices between farms regarding the use of a second operator. These farm specific differences are likely dependent on the work routine in use and cow milk yield. Milk yield and stage of lactation will influence the milking duration of the cows, and thus will determine the parlour size at which point operator idle time is exhausted and throughput is constrained if another operator is not added. Additionally, the number of fixed components of the work routine will influence operator efficiency, for example if performing foremilk inspection, as per EU regulation (EU, 2004), or pre-milking sanitisation. The inclusion of these components will increase the core work routine time and change the parlour size at which operator idle time will be exhausted and throughput constrained if another operator is not added. Furthermore, the inclusion of additional components to the core work routine time will reduce maximum potential throughput regardless of parlour size unless another operator is added. However, the operators work routine must be sustainable and accordingly can only be minimised so far. Thus, the individual farm situation will influence operator efficiency, and the parlour size when further operators are required, which is likely why no clear trend was recorded. Furthermore, when planning a new parlour, consideration should be given to the proposed milking routine and milk yield to ensure the parlour is correctly sized to achieve high levels of both throughput and operator efficiency, whilst minimising overmilking.

Larger parlours, without ACR, have a greater risk of overmilking because in some cases it results in more clusters being handled per operator (O'Brien *et al.*, 2012). Overmilking has been reported to increase teat-end hyperkeratosis (Edwards *et al.*, 2013d), potentially increasing the risk of mastitis (Neijenhuis *et al.*, 2001). Overmilking was not directly measured in the present study because all parlours were equipped with ACR. However, the level of overmilking that may have occurred, assuming ACR had not been installed, could be estimated by examining cluster idle time. Cluster idle time was the time between the cluster being removed by the ACR and being swung over and re-attached to a cow in the following row. In a swingover parlour without ACR this would have effectively been overmilking unless operator idle time (if available) was available and being used to detach and hang up clusters between rows. Row times in the present study were not significantly different across all parlour sizes, as anticipated, and there were no differences in cluster idle time as would be expected based on similar row times. This result indicates that on these farms a second operator was being added as required to maximise cluster utilisation and throughput, not operator efficiency. Therefore, overmilking would not have increased in larger parlours if ACR had not been installed on these farms. However, cluster idle time was ~200 s for all parlour sizes which, in the absence of ACR, would have been greater than the recommended overmilking limit of 120 s (Gleeson *et al.*, 2003).

The modelling results indicate that large increases in cow throughput could be achieved by applying a maximum milking time and, furthermore, illustrate the principles discussed. The throughput estimates of the 1% truncation level produced similar figures to that reported in the benchmarking part of the study (Figure 3a). The results indicated that operator idle time existed in small parlours (≤16 units) regardless of the level of truncation (Figure 3b) and thus were less operator efficient. Moreover, it indicated with current milking practices, that, in a well-managed parlour, one operator can handle up to 30 clusters, which was recorded in this study, although ACR was required to limit overmilking (Figure 3c). However, using a maximum milk out time aiming to truncate 20% of cows, a similar level of throughput was estimated in an 18 unit parlour (Figure 3a), saving significantly on capital expenditure. Additionally, at this level of truncation maximum throughput in a single operator parlour was estimated with 20 clusters. Alternatively, within a given parlour size it highlights that large improvements in throughput were estimated by applying a maximum milking time. For example, expected throughput in an 18 unit parlour using current standard milking practices would be about 75 cows/hour, but by truncating the milking duration of 20% of the herd throughput could be expected to increase to 125 cows/hour (66% increase), while still only requiring one operator. In that scenario, if ACR were not installed overmilking would average 0.5 min/cow. Thus, the use of a maximum milking time can be used to improve the throughput in existing parlours allowing herd milking duration to be maintained as herd size increases, or when constructing a new parlour, enables the same level of throughput to be achieved in a smaller parlour, saving on capital expenditure.

Implementation of a maximum milking time strategy may result in an increase in residual milk. The presence of residual milk is considered by many to be linked with increased mastitis. However, studies done in Australasia examining the use of a maximum milking time (Clarke *et al.*, 2004; Jago *et al.*, 2010a; Jago *et al.*, 2010b) have reported no effect of setting a maximum milking time on SCC, the incidence of clinical mastitis, number of infected quarters or milk production, even when truncating 30% of cows (Jago *et al.*, 2010b). Similar results have been reported by other studies examining the use of increased ACR thresholds to shorten cow milking duration (Edwards *et al.*, 2013c, 2013b). This outcome is supported by historic advice by Thiel and Dodd (1979), who stated that contrary to popular belief there is little evidence to suggest incomplete milking results in lost production or increased infections. The modelling results demonstrate that large improvements can be made to milking efficiency through the application of a maximum milking time and, therefore, validation of experiments in local environments are justified.

In conclusion, larger parlours were able to achieve greater throughput, likely through a decrease in operator idle time due to sufficient numbers of clusters to keep the operator fully occupied and efficient gate release of the row resulting in the operator beginning to attach clusters before the row is fully loaded. Operator efficiency was variable between farms and likely dependent on milking routines in use and cow milk yields, and thus no clear trend with parlour size was detected. Estimated overmilking was not associated with parlour size, likely because additional operators were added as required, though it was greater than 120 s for all parlour sizes. Modelling indicated that through the use of a maximum milking time large improvements in throughput were possible, allowing herd milking duration to be maintained as herd sizes increase, or capital expenditure minimised.

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CHAPTER 9

Principles for maximising operator efficiency and return on investment in rotary dairies

J. Paul Edwards[A,B], Jenny G. Jago[A] and Nicolas Lopez-Villalobos[B]

[A]DairyNZ, Private Bag 3221,
Hamilton 3240, New Zealand.

[B]Institute of Veterinary, Animal and Biomedical Sciences,
Massey University, Private Bag 11222,
Palmerston North 4442, New Zealand.

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Abstract

This study quantified the effect of rotary size, platform speed, cluster attachment time, milk yield and end-of-milking criteria on cow throughput, operator efficiency and return on investment. A model was developed to predict the mean and standard deviation of cow milking duration for a given milk yield using milking data collected from commercial dairy farms in New Zealand. After accounting for the effect of end-of-milking criteria, this estimate was used to calculate the expected cow throughput and operator efficiency for a given platform speed, rotary size and cluster attachment time. The economic return of investing in rotaries of 44-80 bails, relative to a 40 bail rotary, was evaluated using a 25-year internal rate of return (IRR). The economic return of installing automatic cluster removers (ACR) was also evaluated. Estimated cow throughput increased with increasing platform speed and ACR threshold for a 50 bail rotary (a common rotary size) and the largest single gain in cow throughput came from changing the ACR threshold from 0.2 to 0.4 kg/min. Further increases had less impact, especially at lower platform speeds. However, for larger rotaries maximum operator efficiency could be achieved using a variety of platform speeds and end-of-milking criteria. A larger rotary was required to achieve maximum potential operator efficiency, for a given cluster attachment time, as milk yield was increased. Increasing the minimum cluster attachment time decreased maximum potential operator efficiency. Consequently, operator ability and anticipated milk yield are key parameters when selecting the number of bails in a new-build rotary. Seventy and 80 bail rotaries were generally not more operator efficient than 60 bail rotaries. Economically, the 50 bail rotary allowed the greatest labour saving per dollar invested for a typical farm conversion in Canterbury, New Zealand, although the ultimate choice of rotary size depends on the individual farm situation. The IRR for installing ACR decreased with increasing rotary size, but was always positive. Farmers should carefully evaluate their options before investing in a new rotary.

Keywords: rotary, milking efficiency, labour efficiency, investment

Introduction

The process of milk harvesting is fundamental to the dairy enterprise and affects all parts of the business from cows to people and financial performance. Milking requires up to 57% of farm labour in grazing dairy systems using batch milking (Taylor *et al.*, 2009). Furthermore, the milking facility is a large capital investment. Therefore, selecting the optimum milking facility and operating it in an efficient manner are key components to a profitable dairy business.

With the continued growth in New Zealand herd size (DairyNZ, 2012), there has been heightened interest in milking efficiency (Jago *et al.*, 2010a; Jago *et al.*, 2010b). Larger herds tend to be milked through rotary dairies, which are thus likely to become the dominant milking facility in terms of total cows milked. In 2008, 40% of the national herd in New Zealand were milked through a rotary dairy (Cuthbert, 2008). Consequently, Edwards *et al.* (2013a) focussed on the rotary dairy when benchmarking milking performance on commercial farms and Edwards *et al.* (2012) examined operating procedures for rotary dairies. These studies highlighted the importance of individual cow milking duration in determining cow throughput, and thus herd milking duration. An attempt to reduce individual cow milking duration, without compromising milk yield and udder health, by manipulating end-of-milking criteria, was first evaluated by Rasmussen (1993) in an environment where pre-milking stimulation was common practice. Subsequently, more recent studies (Clarke *et al.*, 2004; Jago *et al.*, 2010a; Edwards *et al.*, 2013b, 2013c) have considered this further under grazing conditions where pre-milking stimulation has not been common practice for ~40 years (Phillips, 1987).

Previous studies relating to milking efficiency have made suggestions on how improvements could be made to the various factors affecting efficiency. The results of the rotary benchmarking study (Edwards *et al.*, 2013a) indicated that some farms probably had larger rotaries than necessary, and were thus overcapitalised. Modelling the operation of rotary dairies demonstrated that, contrary to popular belief, increasing the number of cows requiring multiple rotations to complete milking did not of itself negatively affect cow throughput, and that platform speed should be set as fast as is comfortable for the operator attaching clusters (Edwards *et al.*, 2012). Experiments manipulating end-of-milking criteria demonstrated that the milking duration of individual cows could be significantly reduced, without negatively affecting milk yield or SCC, through the use of higher automatic cluster remover (ACR) flow thresholds than previously examined in a pasture-based system, but that pre-milking stimulation was not effective at improving milking efficiency (Edwards *et al.*, 2013b, 2013c). However, to date there has been no analysis to quantify the net improvement to milking efficiency that could be achieved using these strategies, or combinations of them, from either a labour or capital efficiency perspective.

The objective of this study was to evaluate the effect of rotary size, platform speed, and end-of-milking criteria on cow throughput, operator efficiency and return on investment.

Materials and Methods

Estimating cow throughput

Evaluation of milking efficiency using different rotary sizes, platform speeds and end-of-milking criteria required the estimation of cow throughput. Cow throughput was estimated using the model described by Edwards *et al.* (2012), which required the rotary size, platform speed or rotation time and cow milking duration (mean and standard deviation). However, on farms without in-line milk sensors, knowledge of cow milking duration and variability is rare, although average milk yield is generally well known from milk collection receipts. Therefore, a prediction equation using average milk yield was developed to estimate cow milking duration and its variability. Milk yield and $\log_{10}$ transformed milking duration data collected in the study of Edwards *et al.* (2013a) were used to develop a linear regression using the PROC REG function of SAS 9.2 (SAS Institute, Cary, NC). Mean cow milking duration was estimated using the regression equation and an estimate of its variability was made using the root mean square error.

Five end-of-milking criteria were considered; ACR thresholds of 0.2 kg/min, 0.4 kg/min, 0.6 kg/min and 0.8 kg/min and a maximum milk out time (MaxT). When using the MaxT criterion it was assumed no cows could 'go-around' on a second rotation and consequently these cows had their milking truncated. Guidelines recommend to truncate the milking of the slowest 20% of cows (DairyNZ, 2013) but the percentage of cows with truncated milkings was allowed to range from 12 to 32%, as determined by the rotation time and milking duration (from the prediction equation). The estimate of cow milking duration from the prediction equation was assumed to be applicable to an ACR threshold of 0.2 kg/min, as the industry standard threshold in New Zealand. An ACR threshold of 0.4 kg/min was assumed to reduce mean milking duration by 46 s, 0.6 kg/min by 61 s and 0.8 kg/min by 78 s, based on average values reported by Edwards *et al.* (2013b) and Edwards *et al.* (2013c), with no change in milk production. It was assumed that variability remained constant, irrespective of end-of-milking criteria. This enabled the estimation of cow throughput for a given milk yield, rotary size, platform speed and end-of-milking criteria using the formula 3600/(g × platform speed), where g was ('go-around %' + 100)/100 and platform speed was measured in seconds per bail (Edwards *et al.*, 2012).

Estimating operator efficiency

Automatic cluster removers, bail retention arms, automatic teat spraying (post-milking) and automatic drafting were included in the simulation, and thus rotaries were assumed to be operated by a single operator, if there was sufficient time for the operator to attach clusters. The time available for the operator to attach clusters was calculated by adding the platform speed (s/bail) and operator idle time generated by not having to attach clusters to 'go-around' cows for a given rotation time and end-of-milking criteria. If the time available to attach clusters was less than that specified in the scenario (range of 8-10 s/cow) it was assumed a second operator was required to attach clusters. This range of cluster attachment times was chosen because Edwards *et al.* (2012) estimated a second operator was required at ~7.5 s/bail and Armstrong and Quick (1986) reported 8-12 s was required to attach a cluster.

Economic evaluation

Internal rate of return (IRR) was used to benchmark the investment performance of different rotary sizes relative to a base situation, which varied depending on the scenario. Investment performance was evaluated over 25 years, which was the assumed life of the rotary building, while the rotary plant required replacement in year 13. The initial investment (year 0) was calculated as the difference in building and plant costs between the base situation and the rotary size under evaluation, and the difference in plant costs were again considered as an additional investment in year 13. It was assumed there was no residual value after 25 years. Estimated maximum operator efficiency for the rotary size under evaluation was used to calculate the total labour cost to milk the herd for a given cluster attachment time, milk yield, labour cost (NZ$/h) and herd size. It was assumed cows were milked twice daily (milking interval 14/10 h) over a lactation of 275 days (DairyNZ, 2012). The difference in total labour costs (i.e. labour saving) between the base scenario and rotary size under evaluation was considered the net revenue for each of the 25 years. All other revenue and expenses were assumed to be the same. Net cash flow was then determined for each year after purchase (y) by adding the investment (negative) and the labour saving (positive). A discount factor was applied to each year using the formula $1/(1+d)^y$, where d was the discount rate and y

Table 1. Breakdown of capital costs (NZ$) for a range of sizes of rotary dairies.

Item	Rotary size (bails)							
	40	44	50	54	60	64	70	80
Basic milking plant	117,000	129,000	140,000	149,000	162,000	170,000	183,000	211,000
Rotary platform	104,000	114,000	126,000	135,000	148,000	157,000	175,000	194,000
Automatic cluster removers[1]	61,000	66,000	76,000	81,400	91,000	97,600	106,300	120,800
Automatic teat sprayer and drafting	58,000	58,400	59,000	59,400	60,000	60,400	61,000	62,000
Total plant and technology costs	**340,000**	**367,400**	**401,000**	**424,800**	**461,000**	**485,000**	**525,300**	**587,800**
Estimate of building construction[2]	550,000	580,000	600,000	650,000	680,000	700,000	750,000	800,000
Total shed costs	**890,000**	**947,400**	**1,001,000**	**1,074,800**	**1,141,000**	**1,185,000**	**1,275,300**	**1,387,800**

[1]Including bail retention arms.

[2]Estimate includes building, site works, effluent system, electrical and refrigeration costs.

was the number of years. The discounted cash flows were summed over the 25 years to generate a net present value. Internal rate of return was defined as the discount rate that generated a net present value of zero.

Scenarios

Initially, maximum cow throughput was determined for each of the five end-of-milking criteria in a 50 bail rotary. It was assumed that milk yield was 12 kg/cow.milking. At maximum throughput the rotation time, cow loading time, cluster attachment time, and the percentage of 'go-around' cows were recorded. Then, cow throughput over a range of platform speeds was calculated for the five end-of-milking criteria. One operator could cope with all combinations of platform speed and end-of-milking criteria so cow throughput and operator efficiency were identical. The 50-bail rotary was chosen as an example for optimisation as each end-of-milking criterion could be maximised with a single operator and it was a common rotary size (Cuthbert, 2008).

Subsequently, this evaluation was expanded to estimate the operator efficiency of combinations of platform speed and end-of-milking criteria for 40, 50, 60, 70 and 80 bail rotaries. Milk yield was again assumed to be 12 kg/cow.milking and that an average cluster attachment time of less than 8 s/cow required a second operator. Operator efficiency was calculated as cow throughput divided by the number of operators. The maximum operator efficiency was then recorded for each rotary size (40-80 bails, including common intermediate sizes) using milk yields of 8, 12, and 16 kg/cow.milking, and cluster attachment times of 8, 9 and 10 s/cow.

Internal rate of return was evaluated under five scenarios. The base scenario was typical of a Canterbury dairy farm and was chosen because many new dairy farm conversions have occurred in this region (DairyNZ, 2012). The capital costs used in the model are shown in Table 1, which were collected from Milfos Ltd on 28/03/2013 (GEA Farm Technologies, Bönen, Germany). Assumptions were: a herd size of 770 cows, production of 20 kg/cow.day (12 kg AM, 8 kg PM), NZ$30/h labour cost and an 8 s/cow cluster attachment time. The IRR of investing in each rotary size was calculated relative to a 40 bail rotary, which was considered to be the base size where operator efficiency was generally constrained. It was assumed that operator efficiency was the maximum achievable in each rotary size (Figure 3). The remaining scenarios tested the effect of modifying each of the assumptions individually i.e. a sensitivity analysis. Herd size was increased to 1540 cows, milk yield increased to 28 kg/cow.day (16 kg AM, 12 kg PM), labour cost increased to NZ$40/h and cluster attachment time increased to 9 s/cow.

The final analysis examined the return on investing in ACR for each rotary size. The difference in the capital cost of installing ACR, and accompanying technology (automatic drafting, teat spraying and bail retention arms) to allow the removal of an operator was accounted for at year zero and year 13, when the plant required replacement. Total herd milking time was estimated assuming the herd was 770 cows, milk yield was 20 kg/cow.day (12 kg AM, 8 kg PM) and the rotary without ACR was using a MaxT routine (no 'go-around' cows; 20% of cows truncated). The labour saving of installing this technology, used in conjunction with MaxT, was considered the value of one operator, i.e. the herd milking duration multiplied by NZ$30/h labour cost. The capital cost, including breakdown of building and plant costs, for each rotary size is presented in Table 1.

Results

Cow throughput

The prediction equation for $\log_{10}$ milking duration was determined to be $0.02 \times$ milk yield + 2.31 with a standard deviation 0.11. The estimated maximum throughput of five different end-of-milking criteria were determined for a 50-bail rotary (Table 2).

Throughput ranged from 305 cows/h for the 0.2 kg/min ACR threshold to 391 cows/h for the 0.8 kg/min ACR threshold. The rotation time required to achieve these results varied from 8.1 min to 6.2 min, respectively. However, the percentage of 'go-around' cows was similar, 21-24%, except for MaxT where the slowest 20% of cows had their milkings truncated, resulting in a modelled throughput of 365 cows/h. The effect of different platform speeds is shown in Figure 1. For each of the ACR thresholds throughput increased with increasing platform speed, though the rate of increase declined.

Table 2. The modeled effect of different end-of-milking decision criteria (milk flow rate or maximum milking time, MaxT) optimised to achieve maximum cow throughput in a 50 bail rotary harvesting 12 kg/cow.milking.

Item	End-of-milking criteria				
	0.2 kg/min	0.4 kg/min	0.6 kg/min	0.8 kg/min	MaxT
Rotation time (min)	8.1	7.0	6.7	6.2	8.2
Cow loading time (s/bail)	9.7	8.4	8.0	7.4	9.9
Cluster attachment time (s/bail)	11.9	10.3	9.8	9.2	9.9
Go-around (%)	22%	23%	22%	24%	0%[1]
Throughput (cows/h)	305	350	367	391	365

[1]20% of cows with milkings truncated.

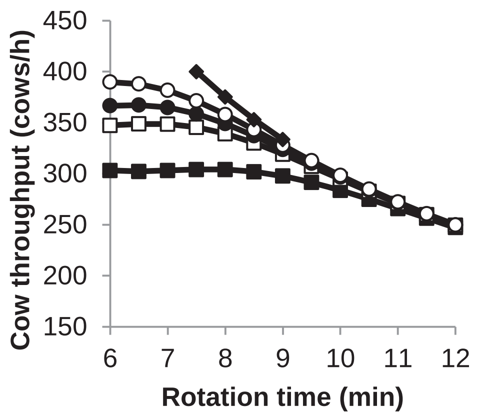

Figure 1. The effect of different rotation times on cow throughput for five end-of-milking criteria (0.2 kg/min, ■; 0.4 kg/min, □; 0.6 kg/min, ●; 0.8 kg/min, ○; MaxT, ◆) when harvesting 12 kg/cow.milking, MaxT shown between 7.5 min (32% of cows truncated) and 9 min (12% of cows truncated).

Operator efficiency

The effect of rotary size, platform speed and end-of-milking criteria on operator efficiency is shown in Figure 2, assuming a milk yield of 12 kg/cow.milking and minimum cluster attachment time of 8 s/cow. Operator efficiency reached the maximum 450 cows/operator.h in 60, 70 and 80 bail rotaries but was constrained in 40 and 50 bail rotaries to 305 and 391 cows/operator.h, respectively (Figure 2). In rotaries ≥60 bails, maximum operator efficiency was reached using multiple combinations of platform speed and end-of-milking criteria. The effect of changing average herd milk yield and the cluster attachment time is presented in Figure 3. Increasing the minimum cluster attachment time reduced maximum operator efficiency; 9 s/cow resulted in 400 cows/operator.h and 10 s/cow in 360 cows/operator.h. Increasing the average milk yield increased the rotary size needed to achieve maximum operator efficiency for a given cluster attachment time (Figure 3). To harvest 16 kg of milk at a cluster attachment time of 8 s/cow, meant maximum operator efficiency was not reached in rotaries of less than 70 bails. When attaching clusters at 10 s/cow, maximum operator efficiency was reached in rotaries ≥60 bails. At a lower milk yield of 8 kg/cow and cluster attachment time of 8 s/cow, maximum operator efficiency was reached in rotaries ≥50 bails, but could be reached in all rotary sizes examined at a cluster attachment time of 10 s/cow.

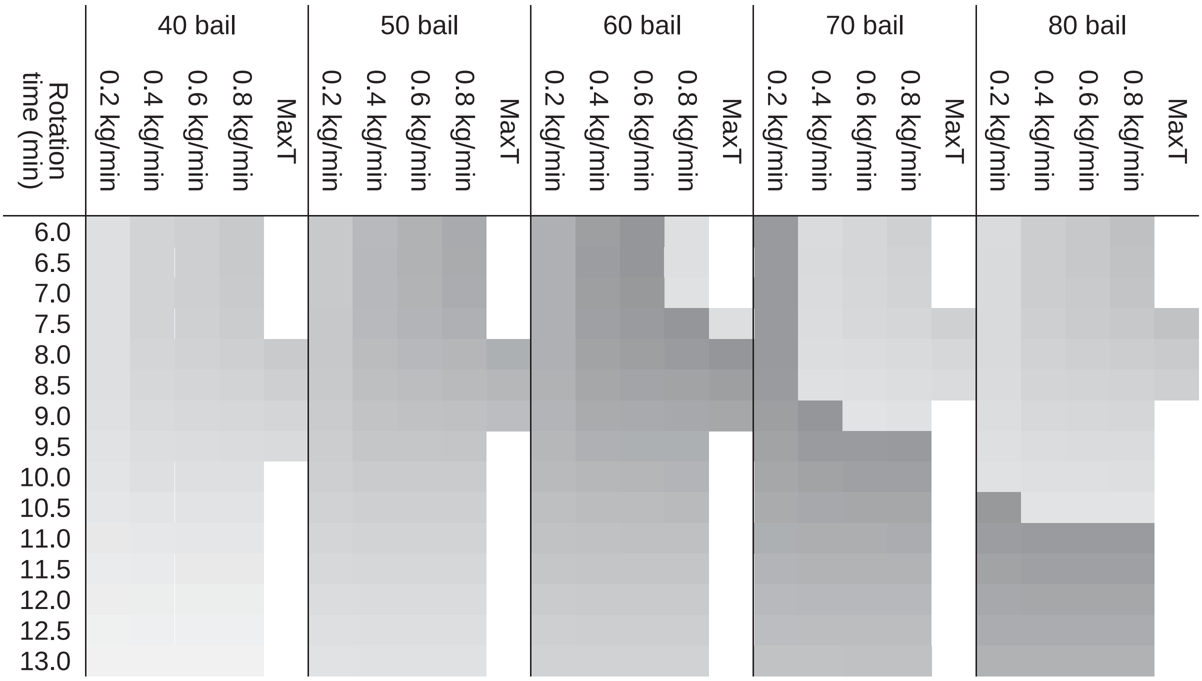

Figure 2. Potential operator efficiency ranging from dark grey (450 cows/operator.h) to light grey (185 cows/operator.h) using different end-of-milking criteria (ACR thresholds of 0.2 to 0.8 kg/min and MaxT, i.e. no 'go-around' cows) and different rotation times for five rotary sizes assuming a milk yield of 12 kg/cow.milking and a minimum cluster attachment time of 8 s/cow.

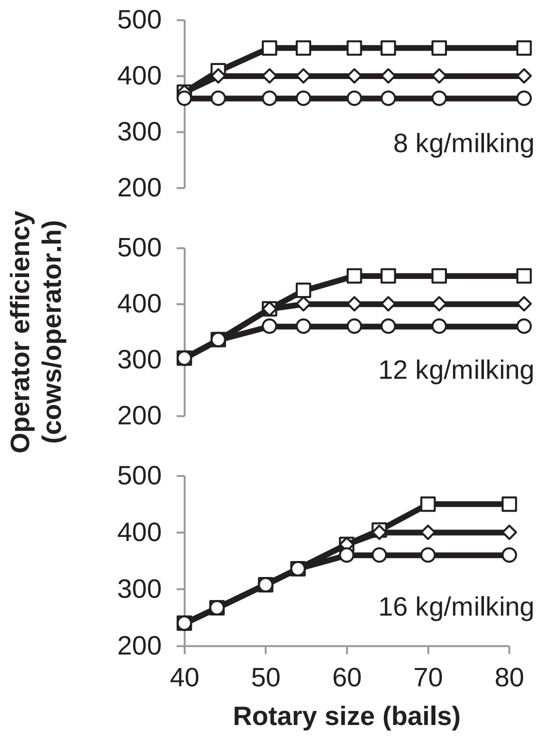

Figure 3. Maximum potential operator efficiency (cows/operator.h) of a range of rotary sizes for different minimum cluster attachment times (8 s, □; 9 s, ◇; 10 s, ○) and three milk yields (8, 12, 16 kg/cow.milking).

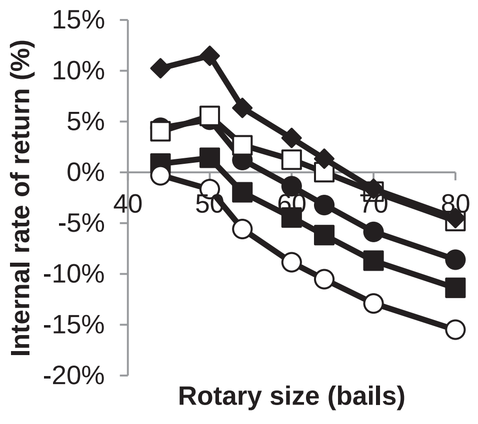

Figure 4. Internal rate of return of a range of rotary sizes relative to investing in a 40 bail rotary for five farm scenarios (20 kg/cow.day, 8 s cluster attachment, 770 cow herd, $30/h labour cost, ■; 20 kg/cow.day, 8 s cluster attachment, 770 cow herd, $40/h labour cost, ●; 20 kg/cow.day, 8 s cluster attachment, 1540 cow herd, $30/h labour cost, ◆; 28 kg/cow.day, 8 s cluster attachment, 770 cow herd, $30/h labour cost, □; 20 kg/cow.day, 9 s cluster attachment, 770 cow herd, $30/h labour cost, ○).

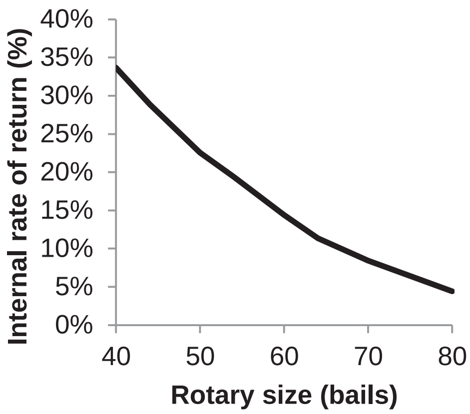

Figure 5. Internal rate of return for investing in automatic cluster removers over a range of rotary sizes.

Economic efficiency

The IRR for a typical farm conversion in Canterbury (20 kg/cow.day, 8 s cluster attachment time, 770 cow herd, $30/h labour cost) was highest for a 50 bail rotary at 1.4% (Figure 4). Rotary sizes greater than 50 bails had negative IRRs. Increasing the value of labour to NZ$40/h resulted in higher IRRs; however, the optimum was still the 50 bail rotary at 5.2%. The IRR of rotaries 44-64 bails were positive when the herd size was increased to 1540 cows, although the 50 bail returned the greatest rate of 11.5%. Increasing milk yield to 28 kg/cow resulted in positive IRRs for rotaries 44-60 bails but the 50 bail rotary had the greatest IRR at 5.5%. Increasing the cluster attachment time to 9 s/cow resulted in negative IRRs for all rotary sizes 44-80 bails. In all scenarios evaluated, the IRRs of 70 and 80 bail rotaries were negative (Figure 4). The IRR of installing ACR was positive for all rotary sizes and was greatest for small rotaries: ranging from 4% in 80 bail rotaries to 34% in 40 bail rotaries (Figure 5).

Discussion

The choice of platform speed and end-of-milking criterion had a large impact on rotary performance and some important operating principles were highlighted during the optimisation of milking efficiency in the 50-bail rotary (Table 2; Figure 1). The first principle was that the rotation time corresponding to the maximum estimated throughput, for each ACR threshold, resulted in 22-24% of cows requiring multiple rotations to complete milking (i.e. ‘going-around’). This supports the conclusion of Edwards *et al.* (2012) that the industry target of 10% ‘go-around’ cows may limit throughput. However, the benefit of increasing platform speed reduced near maximum throughput (Figure 1), thus allowing operators to choose a slightly lower, more comfortable, platform speed while still achieving a relatively efficient milking. The presence of 'go-around' cows meant the operator did not have to attach clusters to every cow in a rotation, highlighting that despite fast rotation times (<7 min; <8 s/bail) the average amount of time available to attach clusters did not decrease below 9 s/cow. Consequently, all of the scenarios evaluated only required one operator. However, the time per bail available for cow loading decreased, highlighting the need for good dairy design and stockmanship to maintain cow flow onto the rotary. The second concept illustrated was, when using ACR thresholds >0.2 kg/min to improve milking efficiency, the platform must be operated at a sufficient speed to achieve additional throughput, i.e. to realise the higher potential throughput when increasing ACR threshold, the platform speed must be increased simultaneously (Figure 1). The largest gain in efficiency came in the first step from moving ACR threshold from 0.2 to 0.4 kg/min, with further increases having less impact, particularly at slower platform speeds. Overall, the greatest efficiency was predicted with the highest ACR threshold (0.8 kg/min) and a fast rotation time (6.2 min). However, rotaries >50 bails may require multiple operators (Edwards *et al.*, 2013a), due to less time being available per bail for a given rotation time. Therefore, each rotary size may require a different milking strategy to maximise operator efficiency.

Achieving high operator/labour efficiency is important in rotary dairies due to their higher capital cost relative to herringbone dairies. When attempting to maximise operator efficiency the optimal combination of platform speed and end-of-milking criterion was not consistent across rotary sizes and was achieved by multiple combinations within a given rotary size (Figure 2). Maximum operator efficiency was realised in 60, 70 and 80 bail rotaries with a single operator using combinations of platform speed and end-of-milking criterion that allowed average cluster attachment time to reach the minimum 8 s/cow, which equated to 450 cows/operator.h (3600 s/h divided by 8 s/cow). Seventy and 80 bail rotaries are often run with two operators attaching clusters (Edwards *et al.*, 2013a) but maximum operator efficiency was not achieved with two operators in this evaluation. The use of two operators meant that an average cluster attachment time of 4 s/cow would have needed to be achieved to maximise operator efficiency. However, average cluster attachment time with two operators did not fall below 5.5 s/cow due to cows 'going-around,' despite using a fast platform speed and high ACR threshold. Considering the additional investment required to build 70 and 80 bail rotaries, operators of these sizes often sacrifice operator efficiency to achieve greater cow throughput. Therefore, in scenarios where maximum operator efficiency was no greater than for a 60-bail rotary, only a requirement for additional cow throughput (i.e. shorter total milking time) could potentially justify the construction of a new rotary >60 bails. In this situation the slightly reduced cow throughput of the 60 bail rotary could be mitigated through the use of job rotation strategies (Edwards *et al.*, 2012), whereby one staff member is responsible for bringing a herd to the dairy, milking and returning the herd to grazing. Consequently, the grazing time of individual herds within a farm, the time spent in the collecting yard, and the time operators are in the dairy may not be unduly affected, although management complexity would likely be increased. Thus, a farmer considering a 70 or 80 bail rotary should instead evaluate if a 60 bail rotary would result in less milking labour and minimise capital investment.

Cluster attachment time determined maximum operator efficiency, which could be reached using a combination of platform speed and end-of-milking criterion, provided the rotary was large enough for a given milk yield (Figure 3). This highlights the importance of teaching staff techniques to enable sustainable and fast cluster attachment. However, in some rotary sizes it was not possible to attain maximum operator efficiency due to 'go-around' cows creating operator idle time, regardless of platform speed or end-of-milking criteria. For example, 9 s/bail equates to a 6 min rotation in a 40 bail rotary, but at this rotation time many cows will require a second rotation thus creating idle time for the operator and mean that cluster attachment time will average >9 s/cow. In comparison, 9 s/bail equates to a 12 min rotation in an 80 bail rotary, where few cows will require a second rotation and therefore average cluster attachment time will approach 9 s/cow. This relationship exists because platform speed is faster (fewer s/bail) in a larger rotary for a given rotation time. Consequently, the rotary size where maximum potential operator efficiency can be reached for a given cluster attachment time depends on the amount of milk to harvest (i.e. cow milking duration). For example, if an operator could attach clusters at 8 s/cow and there was 16 kg of milk to harvest then maximum cow throughput for a single operator was not realised in rotaries with fewer than 70 bails. Therefore, farmers with higher yielding herds and efficient operators may be able to justify rotaries >60 bails. However, at this milk yield, if the operator was only able to attach clusters at 10 s/cow then maximum operator efficiency was achieved in a 60-bail rotary, albeit a lower value than if clusters were attached at 8 s/cow. Conversely, with a milk yield of 8 kg, and a cluster attachment time of 8 s/cow, the maximum potential operator efficiency was reached with a 50-bail rotary. It is interesting to note that, for the range of cluster attachment times (8-10 s/cow) and milk yields (8-16 kg) examined, the maximum potential operator efficiency was reached only once in the 40 bail rotary. Therefore, operator ability and anticipated milk yield should be key parameters in selecting the size of a new-build rotary.

The trade-off between capital investment and operator efficiency (labour saving) is important in the evaluation of the most economic rotary size. This relationship was evaluated using IRR, where the IRR of investing additional capital above a 40 bail rotary was compared under various scenarios (Figure 4). The first scenario represented a typical farm conversion in Canterbury. The optimal rotary size was 50 bails; indicating the marginal increase in labour saving relative to the marginal increase in capital cost was greatest for this size. For rotary sizes >50 bails the marginal increase in labour efficiency was less favourable, i.e. the present value savings in operator efficiency per additional dollar invested was lower. Negative IRRs were reported for ≥60 bail rotaries, which was the result of only small increases in operator efficiency compared to the previous size (54 bail; Figure 3), despite their higher capital cost. When the cost of labour was increased from NZ$30 to NZ$40/h, total labour saving increased whilst capital cost remained unchanged, resulting in higher IRRs. However, the shape of the curve remained the same as the first scenario because the operator efficiency remained unchanged for each rotary size. The results were similar when herd size was increased from 770 to 1540 cows, where the greater total labour saving gave a higher return on capital; the main difference was that the IRRs were positive for all rotaries ≤64 bails. The trend was slightly different when the milk yield was changed from 20 to 28 kg/cow as the relative operator efficiencies between rotary sizes were different, i.e. maximum operator efficiency was not reached until 70 bails (Figure 3). Consequently, the IRRs remained positive for rotaries ≤64 bails, although the 50 bail rotary still provided the greatest labour saving per dollar invested.

The final scenario examined the impact of increasing the minimum cluster attachment time from 8 to 9 s, which reduced maximum operator efficiency (Figure 3) and resulted in negative IRRs for all rotary sizes (44-80 bails). This outcome further reinforces the importance of teaching operators efficient cluster attachment methods, especially as operators must also have sufficient time to monitor animal health. There was an economic optimum at 50 bails for a typical Canterbury farm, however, on larger farms a less capital efficient rotary size may be justified to minimise total herd milking time. This is particularly important if sub-optimal milking strategies are being used. For example, the results of Edwards *et al.* (2013a) indicate a milking time of 3.9 h for an 80 bail would increase to 6.7 h in a 50 bail rotary for 1500 cows, which may not allow sufficient time between milkings for maintenance. Conversely, the 3.9 h could also potentially be achieved by the 50 bail rotary if using optimal routines (Figure 1), although this would likely by slightly longer due to time the rotary is stopped and empty bails. Alternatively, depending on farm layout, the use of one milking facility may result in long walking distances for cows, and the use of two smaller rotaries could be considered, although may result in additional management complexities. Thus, while the choice of rotary size will vary depending on the individual farm situation, economically the 50 bail rotary appears the optimum size in general.

Typically most new-build rotaries have ACR installed to increase operator efficiency and reduce labour costs. The IRR for installing ACR and associated labour saving technology, allowing the elimination of one operator from a given rotary size, is shown in Figure 5. The negative trend in IRR was due to operator efficiency being constrained in smaller rotaries (i.e. less operator efficient), which consequently required more time and labour to milk the herd. Thus, labour costs were higher, resulting in a greater labour saving relative to the cost of installing ACR compared with larger rotaries.

Conclusions

Estimated cow throughput increased with increasing platform speed and ACR threshold for a 50 bail rotary. The largest gain in cow throughput came from an initial move of ACR threshold from 0.2 to 0.4 kg/min, with further increases having less impact, especially at slower platform speeds. However, for larger rotaries, maximum cow throughput was achieved using a range of platform speeds and end-of-milking criteria. The rotary size where maximum potential operator efficiency could be achieved for a given cluster attachment time increased with increasing milk yield. Increasing the minimum cluster attachment time decreased maximum potential operator efficiency. Consequently, operator ability and anticipated milk yield are key parameters when selecting the number of bails in new-build rotaries. Economically, the 50 bail rotary allowed the greatest labour saving per dollar invested for a typical farm conversion in

Canterbury, New Zealand. The IRR for installing ACR decreased with increasing rotary size, but was always positive.

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CHAPTER 10

GENERAL DISCUSSION

Introduction

Studies pertaining to the improvement of milking efficiency in pastoral dairy systems were reported in this thesis. Predominantly the studies focussed on the rotary dairy as it will likely become the dominant dairy type in the future if average herd size continues to increase. However, some analysis of herringbone dairies was undertaken. Two industry surveys (herringbone/rotary) were completed to determine the current level of milking efficiency being achieved on farm. Operational procedures within the dairy were examined and strategies to reduce the milking duration of individual cows evaluated. The effect of overmilking on teat-end condition, a consequence of poor milking efficiency, was quantified. Lastly, a model was developed to estimate the effect of the strategies developed in earlier experiments on operator efficiency and return on investment over a range of rotary sizes. This chapter discusses limitations and questions that arose as a result of the experimental studies to guide the direction of future research in milking efficiency. Finally, general conclusions from this collection of research are presented.

Limitations

A limitation of the benchmarking studies was the small numbers of dairies at both the small and large end of the size spectrum from which to collect data. Industry benchmarking of this magnitude would be logistically challenging to do manually, thus forcing the use of dairies with a high level of technology installed. As this level of technology is rare in pasture based production systems (Cuthbert, 2008), only limited numbers of dairies were available for inclusion in the study. For future benchmarking studies, it would be preferable to include at least two farms from each dairy size to help separate the effect of farm and dairy size. It would also be useful to be able to distinguish between ‘go-around’ cows and empty bails in rotary dairies to examine if relationships between yard design and cow flow into the dairy exist.

This body of research focussed on milking efficiency within the dairy. However, the process of moving cows from the paddock and into the dairy, subsequent cleaning of yards and return of animals to the paddock is also important. For example, the use of technology such as automatic gate latches and construction of cow races of sufficient width and surface quality, without sharp corners, can save time (Eden & Jago, 2009). Cow flow is reportedly better in a rectangular yard than a circular yard, similarly, exits from the dairy to cow race should be as short as possible. The importance of moving cows from the collecting yard into the dairy cannot be ignored. The results of Chapter 9 have highlighted the need for rotary dairies to be operating at fast platform speeds to maximise efficiency. The reason the rotary dairy can be more operator efficient than the herringbone is due to automated loading and unloading of cows. However, maximum operator efficiency cannot be realised if bails are not occupied due to poor cow flow. Thus, in larger rotaries it is of particular importance to ensure the entry and exits are well designed and operators milk in a calm and relaxed atmosphere. Guidance on dairy design is available at www.milksmart.co.nz.

Experiments in this thesis were completed either in New Zealand or Ireland; both under grazing conditions. The use of New Zealand genetics is also widespread in the Irish dairy industry. Therefore, the results of each experiment are applicable in both countries. However, there are significant differences between the dairy industries of each country, which means that the relevance of individual studies may vary, particularly relating to rotary dairies. In particular, the average herd size in New Zealand is 386 compared with 66 in Ireland (DairyNZ, 2011; ICBF, 2011) and farmers in Ireland must comply with EU legislation that requires the foremilk of each quarter to be inspected before milking (EU, 2004). The small herd size means that around 91% of the dairies in Ireland are herringbones, of which 95% don't have ACR (Kelly, 2009). Thus, the results of Chapters 7 and 8 are more likely to be of interest to Irish farmers currently. However, the removal of European Union milk quotas in 2015 is expected to lead to a period of rapid herd expansion (DAFF, 2010) and hence the number of rotary dairies is likely to rise in the future. In rotary dairies the requirement to inspect foremilk has implications for the time required by an operator to attach clusters. The removal of foremilk from each quarter takes ~10 s/cow, halving the potential operator efficiency (Chapter 9). This would reduce the rotary size where maximum operator efficiency can be achieved for a given milk yield (Figure 1). It is also likely that labour costs differ between countries, and thus, in the future it would be worthwhile to repeat the investment analysis using Irish data.

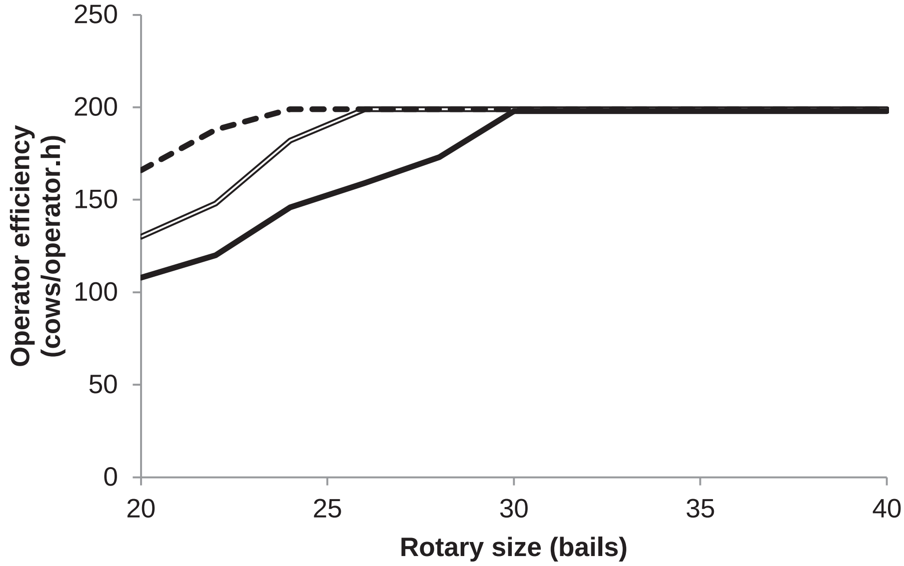

Figure 1. Maximum potential operator efficiency (cows/operator.hr) of a range of rotary sizes (cows/operator.h) for three milk yields (8 kg/cow.milking, ---; 12 kg/cow.milking, ═; 16 kg/cow.milking, ─), assuming a preparation and cluster attachment time of 18 s/cow.

Future research questions

Increasing automatic cluster remover (ACR) threshold and the application of a maximum milking time have been shown to be useful strategies to reduce the milking duration of individual cows in a number of studies (Clarke *et al.*, 2004; Jago *et al.*, 2010a; Jago *et al.*, 2010b; Burke & Jago, 2011). Experiments conducted during the present study indicated that ACR thresholds could be increased further, above those previously tested in a pastoral environment, without compromising milk yield and udder health (Edwards *et al.*, 2013a, 2013b). However, to date no experiment has determined how milk yield was maintained when increasing ACR threshold, despite an increase in strip yield. A mechanism was proposed in Chapter 6 where, in short, the hypothesis was that the remaining milk results in a greater proportion of milk held in the cistern at the next milking, which is then removed at a greater milk flow rate (Edwards *et al.*, 2013a). In order to test this hypothesis a new experiment needs to be conducted. Treatments would need to include at least two ACR thresholds, e.g. 0.2 and 0.8 kg/min, and measurements could be similar to those described by Knight *et al.* (1994) and Stelwagen *et al.* (1996). These measurements involve the catheterising of each quarter, thus allowing the rate of milk accumulation in the cistern to be quantified, or the milking of cows in unfamiliar surroundings to prevent oxytocin release and milk ejection, enabling the measurement of cisternal milk volume. Alternatively, a more practical method to measure total cisternal volume may be to block the milk ejection reflex by the administration of an α-adrenergic or an oxytocin receptor blocker (Bruckmaier *et al.*, 1997). The use of identical twins in this study should be considered, with one twin assigned to each ACR treatment. The use of identical twins in research on milking characteristics has been used previously in New Zealand and was shown to have much less variation between identical twins than fraternal twin pairs (Brumby, 1956). Alternatively, large numbers of animals would be required in the study, which may prove difficult if udder quarters are catheterised, or animals would need to cross over treatments, which is difficult as the stage of lactation is no longer consistent and would make comparison problematic. Therefore, the merits of this experiment to help explain the mechanism allowing cows to maintain production with shorter milking durations and higher ACR thresholds should be considered in the near future while identical twin sets are available.

The results of Chapters 5 and 6 demonstrated that higher ACR thresholds than previously tested could be used during peak and late lactation to reduce cow milking duration without compromising milk yield or udder health (Edwards *et al.*, 2013a, 2013b). However, these experiments were nine and six weeks for peak and late lactation, which are relatively short term in comparison to the length of a lactation. Therefore, a full lactation trial, similar to that done by Jago *et al.* (2010a), should be undertaken to validate the results of using ACR thresholds of 0.6 and 0.8 kg/min before recommending these thresholds for longer periods. There is also interest from farmers wanting to apply this strategy to cows being milked once-a-day. Under these conditions it is likely that udder capacity is constrained in peak lactation, so increasing strip yield may result in decreased production. Similarly, it is of interest to examine the effect of increased ACR thresholds using cows with high SCC. To date experiments in New Zealand have used cows with average SCC <150,000 cells/ml. There is a long held belief within the dairy industry that leaving residual cisternal milk, by increasing ACR threshold, will result in increased SCC and/or mastitis despite evidence to the contrary being available for a long time (Dodd *et al.*, 1950; Thiel & Dodd, 1979). Evidence provided by Clarke *et al.* (2008), where high and low SCC cows were milked with two different ACR thresholds, suggest that incomplete milking, i.e. greater strip yield, did not result in increased SCC. However, SCC was positively related to strip yield indicating that high SCC causes high strip yield and that strip yield does not cause high SCC. However, the belief remains strongly held, and farmers continue to be sceptical that the results of recent ACR experiments can be applied to farms with average SCC >150,000 cells/ml. Therefore, the most effective way of increasing adoption of this concept may be to perform a full lactation experiment using multiple herds of cows with SCC >200,000 cells/ml.

The experiments in Chapters 5 and 6 also highlighted that there was large variation between the milk flow profiles of individual cows. Some cows had bimodal milk flow profiles under normal milking methods but responded to pre-milking stimulation and maintained a high milk flow rate over the course of milking. However, some cows displayed this type of flow curve in the absence of pre-milking stimulation. Therefore, it may be useful to collect detailed milk flow curves for large numbers of animals milked on commercial farms and determine what a 'normal' milk flow curve is for a pasture-based dairy cow and ascertain if this trait is heritable. These data could be used to determine the distribution of milking durations within a herd, or for a given milk yield. This information is useful when implementing a maximum milking time strategy (Jago *et al.*, 2010a). The key criteria of this strategy is to set a time whereby any cows not finished milking by this point have their clusters removed. The time is chosen with the aim to truncate the slowest 20% of cows, i.e. 20% of cows have their clusters removed before finishing milking. However, selecting the maximum milking time, thus truncating the correct number of cows, requires knowledge of the distribution of cow milking durations within a herd. Current guidelines for setting a maximum milking time have been adapted from Australian data and evidence from Jago *et al.* (2010a) has suggested that these guidelines result in >20% of New Zealand cows having their milking truncated. Therefore, there is a need to develop recommendations based on data collected in New Zealand.

Chapter 9 highlighted the importance of efficient cluster attachment techniques to achieve maximise operator efficiency and achieve positive returns on investing in larger rotary dairies. Ideally, operators should be able to attach clusters at 8 s/cow, with a significant reduction in operator efficiency anticipated at a rate of 9 s/cow (Chapter 9; Figure 3, Figure 4). International time and motion research has indicated that it takes approximately 8-12 s to attach clusters (Armstrong & Quick, 1986), indicating operators need to be working at the upper range of performance. This is likely one of the reasons rotary dairies are less popular in the USA where regulations requiring pre-milking sanitisation (FDA, 2009) mean preparation and attachment can take >20 s/cow. The results of Chapter 4 suggest that efficient operators in New Zealand can attach clusters at a rate of 6.4 s/cow, however, a more common figure may be 7.5 s/bail (Edwards *et al.*, 2012). It is also important that when working at this high level of performance the cluster attachment method is sustainable for the operator. The ability of individual operators will vary, likely depending on the technique used and experience. In general there is little emphasis on training of new farm workers in cluster attachment techniques. To address this the DairyNZ MilkSmart programme have developed videos of efficient and sustainable attachment techniques for use in training new staff (DairyNZ MilkSmart, 2013). However, additional research may be required, similar to Douphrate *et al.* (2012), looking at the effect of different cluster attachment speeds. In addition, the issue of fast and sustainable cluster attachment opens the door for the development of automatic cluster attachment (ACA) technologies. A feasibility study indicated that there would be limited economic benefit to ACA technology (Ohnstad & Jago, 2006). However, a local New Zealand company has developed a robot that can attach clusters to cows at a rate of 12-15 s/cow, which can be retrofitted to existing rotaries (Scott Milktech, 2013). Currently, the company advises that it can be used to replace one worker in a rotary that requires two operators to attach clusters. Therefore, depending on the cost, the economics of large rotary dairies may be improved as operator efficiency would be increased. In the future the likely continued development of this technology may enable cluster attachment times of ≤8 s/cow possibly making this technology the next evolution in batch milking systems.

The model to estimate milking efficiency in rotary dairies developed in Chapter 9 could be developed further into a useful tool for farmers and professionals working near-farm. This would require a graphical interface to be overlaid on the model, and the layout set in a way that allows intuitive use as some concepts can be initially hard to grasp. Additionally, more robustness could be added to the model by validating some of the assumptions in the field. This model, or milking efficiency calculator, could sit on a website and/or be a standalone application on a flash drive making it portable when offline. The model could be expanded further to include herringbone dairies, potentially allowing for the economic comparison between a herringbone and rotary dairy. However, in order for this to occur, more research needs to be conducted to determine the differences in maintenance and operating costs between the two dairy types.

General conclusions

The main conclusions of this thesis were the following:

- Large rotary diaries (>60 bails) achieve greater cow throughput (cows milked per hour) but are not more operator efficient (cows milked per operator per hour) than medium sized rotaries (40-60 bails). However, actual efficiency achieved on farm varied greatly.
- In rotary dairies, platform speed explained much of the farm-to-farm variation in milking efficiency. Modelling results indicated that aiming for the current industry target of 10% 'go-around' cows could limit efficiency and instead, platform speed should be set to match the abilities of the operator attaching clusters.
- Increasing ACR threshold reduced individual cow cluster-on time, and thus can potentially be used to decrease herd milking duration, without negatively affecting milk yield, or SCC over the short term in peak and late lactation.
- The pre-milking treatments examined (including mechanical stimulation) decreased milking efficiency and pre-milking stimulation was not required at higher ACR thresholds to maintain milk yield. Consequently, operators should attach clusters as close as possible to the first bail in rotary dairies to increase bail utilisation.
- Overmilking of greater than 2 min resulted in an increase in the teat-end hyperkeratosis score of dairy cows in late lactation. However, overmilking did not affect indicators of udder health within six weeks. To limit overmilking in parlours not fitted with ACR the row time in swingover parlours should be appropriately matched to cow milking duration by manipulating operator work routine time through streamlining pre-milking routines, adding an additional operator, installing ACR, deactivating an appropriate number of clusters or applying a maximum milking time.
- Larger herringbone dairies were able to achieve greater throughput, likely through a decrease in operator idle time due to sufficient numbers of clusters to keep the operator fully occupied and efficient gate release of the row resulting in the operator beginning to attach clusters before the row is fully loaded. Operator efficiency was variable between farms and likely dependent on milking routines

in use. Modelling indicated that the use of a maximum milking time could lead to large improvements in cow throughput.

- Using the results of the ACR experiments, the largest estimated gain in cow throughput came from moving the ACR threshold from 0.2 to 0.4 kg/min, with further increases having less impact, especially at slower platform speeds (>10 min rotation). In small rotaries (≤50 bails) cow throughput increased with increasing platform speed and ACR threshold. However, for larger rotaries, maximum cow throughput was achieved using a range of platform speeds and end-of-milking criteria.
- The rotary size where maximum potential operator efficiency could be achieved for a given cluster attachment time increased with increasing milk yield. Increasing the minimum cluster attachment time decreased maximum potential operator efficiency. Consequently, operator ability and anticipated milk yield are key parameters when selecting the number of bails in new-build rotaries.
- Economically, the 50 bail rotary allowed the greatest labour saving per dollar invested for a typical farm conversion in Canterbury, New Zealand and the IRR for installing ACR decreased with increasing rotary size but was positive for all rotary sizes.

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APPENDICES

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STATEMENT OF CONTRIBUTION TO DOCTORAL THESIS CONTAINING PUBLICATIONS

(To appear at the end of each thesis chapter/section/appendix submitted as an article/paper or collected as an appendix at the end of the thesis)

We, the candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of Candidate: John Paul Edwards

Name/Title of Principal Supervisor: A/Prof Nicolas Lopez-Villalobos

Name of Published Research Output and full reference:

Edwards, J. P., J. G. Jago and N. Lopez-Villalobos. 2013. Large rotary dairies achieve high cow throughput but are not more labour efficient than medium sized rotaries. Anim. Prod. Sci. 53:573–579. doi:10.1071/AN12312

In which Chapter is the Published Work: 3

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate: 70%

  and / or

- Describe the contribution that the candidate has made to the Published Work:

  The candidate:
  - designed the survey and identified relevant data fields for collection
  - visited 80 farms throughout NZ to collect data, with the assistance of a summer student
  - processed all data, calculated benchmarks, and performed analysis in SAS
  - identified main discussion points and wrote the chapter
  - was corresponding author for the submitted paper, dealing with revisions

Paul Edwards — Digitally signed by Paul Edwards DN: cn=Paul Edwards, o=DairyNZ, ou, email=paul.edwards@dairynz.co.nz, c=NZ Date: 2013.07.29 16:40:26 +12'00'

Candidate's Signature

29/7/2013

Date

Nicolas Lopez-Villalobos — Digitally signed by Nicolas Lopez-Villalobos DN: cn=Nicolas Lopez-Villalobos, o=Massey University, ou=Institute of Veterinary, Animal and Biomedical Sciences, email=N.Lopez-Villalobos@massey.ac.nz, c=NZ Date: 2013.07.30 14:09:07 +12'00'

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In which Chapter is the Published Work: 4

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate: 70%

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- Describe the contribution that the candidate has made to the Published Work:

  The candidate:
  - identified the study area and how to address the research question
  - extracted relevant data from previous study (chapter 3)
  - processed all data, and performed analysis
  - identified main discussion points and wrote the chapter
  - was corresponding author for the submitted paper, dealing with revision

Paul Edwards
Digitally signed by Paul Edwards
DN: cn=Paul Edwards, o=DairyNZ, ou, email=paul.edwards@dairynz.co.nz, c=NZ
Date: 2013.07.29 16:40:26 +12'00'

Candidate's Signature

29/7/2013

Date

Nicolas Lopez-Villalobos
Digitally signed by Nicolas Lopez-Villalobos
DN: cn=Nicolas Lopez-Villalobos, o=Massey University, ou=Institute of Veterinary, Animal and Biomedical Sciences, email=N.Lopez-Villalobos@massey.ac.nz, c=NZ
Date: 2013.07.30 14:10:32 +12'00'

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Please indicate either:

- The percentage of the Published Work that was contributed by the candidate 80%

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- Describe the contribution that the candidate has made to the Published Work:

The candidate:
- designed the experiment in consultation with statistician and supervisors and presented at experimental planning meeting
- prepared animal ethics submission
- was technician in charge, organising rosters and attending all samplings (strip yields, bacto samples etc)
- processed all data, and collated results
- identified main discussion points and wrote the chapter
- was corresponding author for the submitted paper, dealing with revisions

Paul Edwards
Digitally signed by Paul Edwards
DN: cn=Paul Edwards, o=DairyNZ, ou, email=paul.edwards@dairynz.co.nz, c=NZ
Date: 2013.07.29 16:40:26 +12'00'

Candidate's Signature

29/7/2013

Date

Nicolas Lopez-Villalobos
Digitally signed by Nicolas Lopez-Villalobos
DN: cn=Nicolas Lopez-Villalobos, o=Massey University, ou=Institute of Veterinary, Animal and Biomedical Sciences, email=N.Lopez-Villalobos@massey.ac.nz, c=NZ
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Please indicate either:

- The percentage of the Published Work that was contributed by the candidate 65%

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- Describe the contribution that the candidate has made to the Published Work:

  The candidate:
  - identified outstanding questions from previous experiment (chapter 5) and adjusted experimental design in consultation with statistician and supervisors and presented ideas at experimental planning meeting
  - processed all data, and collated results
  - identified main discussion points and wrote the chapter
  - was corresponding author for the submitted paper, dealing with revisions

Paul Edwards Digitally signed by Paul Edwards DN: cn=Paul Edwards, o=DairyNZ, ou, email=paul.edwards@dairynz.co.nz, c=NZ Date: 2013.07.29 16:40:26 +12'00'

Candidate's Signature

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Name/Title of Principal Supervisor: A/Prof Nicolas Lopez-Villalobos

Name of Published Research Output and full reference:

Edwards, J. P., B. O'Brien, N. Lopez-Villalobos and J. G. Jago. 2013. Overmilking causes deterioration in teat-end condition of dairy cows in late lactation. J. Dairy Res. 80:344-348. doi:10.1017/S0022029913000307

In which Chapter is the Published Work: 7

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate: 75%

  and / or

- Describe the contribution that the candidate has made to the Published Work:

  The candidate:
  - designed the experiment in consultation with statistician and supervisors
  - was technician in charge, organising rosters and scored all teat-ends for hyperkeratosis at each sampling
  - processed all data, and collated results
  - identified main discussion points and wrote the chapter
  - was corresponding author for the submitted paper, dealing with revisions

Paul Edwards
Digitally signed by Paul Edwards
DN: cn=Paul Edwards, o=DairyNZ, ou, email=paul.edwards@dairynz.co.nz, c=NZ
Date: 2013.07.29 16:40:26 +12'00'

Candidate's Signature

29/7/2013

Date

Nicolas Lopez-Villalobos
Digitally signed by Nicolas Lopez-Villalobos
DN: cn=Nicolas Lopez-Villalobos, o=Massey University, ou=Institute of Veterinary, Animal and Biomedical Sciences, email=N.Lopez-Villalobos@massey.ac.nz, c=NZ
Date: 2013.07.30 14.15.05 +12'00'

Principal Supervisor's signature

30/7/2013

Date

MASSEY UNIVERSITY
GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION TO DOCTORAL THESIS CONTAINING PUBLICATIONS

(To appear at the end of each thesis chapter/section/appendix submitted as an article/paper or collected as an appendix at the end of the thesis)

We, the candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of Candidate: John Paul Edwards

Name/Title of Principal Supervisor: A/Prof Nicolas Lopez-Villalobos

Name of Published Research Output and full reference:

Edwards, J. P., B. O'Brien, N. Lopez-Villalobos and J. G. Jago. Milking efficiency of swingover herringbone parlours in pasture-based dairy systems. J. Dairy Res. 80:467-474. doi:10.1017/S0022029913000393

In which Chapter is the Published Work: 8

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate: 75%

  and / or

- Describe the contribution that the candidate has made to the Published Work:

The candidate:
- liaised with equipment manufacturers to identify study farmers and contacted farmers get their support
- designed the survey and identified relevant data fields for collection
- visited 20 farms throughout Ireland to collect data
- processed all data, calculated benchmarks
- identified main discussion points and wrote the chapter
- was corresponding author for the submitted paper, dealing with revisions

Paul Edwards Digitally signed by Paul Edwards DN: cn=Paul Edwards, o=DairyNZ, ou, email=paul.edwards@dairynz.co.nz, c=NZ Date: 2013.07.29 16:40:26 +12'00'

Candidate's Signature

29/7/2013

Date

Nicolas Lopez-Villalobos Digitally signed by Nicolas Lopez-Villalobos DN: cn=Nicolas Lopez-Villalobos, o=Massey University, ou=Institute of Veterinary, Animal and Biomedical Sciences, email=N.Lopez-Villalobos@massey.ac.nz, c=NZ Date: 2013.07.30 14:18:15 +12'00'

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Date

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Name of Candidate: John Paul Edwards

Name/Title of Principal Supervisor: A/Prof Nicolas Lopez-Villalobos

Name of Published Research Output and full reference:

Edwards, J. P., J. G. Jago and N. Lopez-Villalobos. Principles for maximising operator efficiency and return on investment in rotary dairies. Anim. Prod. Sci. doi:10.1071/AN13200

In which Chapter is the Published Work: 9

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate 80%

  and / or

- Describe the contribution that the candidate has made to the Published Work:

  The candidate:
  - identified the study area and how to address the research question
  - extracted relevant data from previous studies (chapter 4, 5, 6)
  - processed all data, and performed analysis
  - identified main discussion points and wrote the chapter
  - was corresponding author for the submitted paper, dealing with revisions

Paul Edwards Digitally signed by Paul Edwards DN: cn=Paul Edwards, o=DairyNZ, ou, email=paul.edwards@dairynz.co.nz, c=NZ Date: 2013.07.29 16:40:26 +12'00'

Candidate's Signature

29/7/2013

Date

Nicolas Lopez-Villalobos Digitally signed by Nicolas Lopez-Villalobos DN: cn=Nicolas Lopez-Villalobos, o=Massey University, ou=Institute of Veterinary, Animal and Biomedical Sciences, email=N.Lopez-Villalobos@massey.ac.nz, c=NZ Date: 2013.07.30 14:20:47 +12'00'

Principal Supervisor's signature

30/7/2013

Date