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

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ABSTRACT

It was hypothesized that streamlined premilking stimulation routines are effective at reducing cow cluster-on time but are not required to maintain milk yield or quality when increasing the automatic cluster remover (ACR) threshold above 0.4 kg/min. This was tested by examining the effect of 3 premilking treatments and 4 ACR thresholds over an 11-wk period with 96 mixed-age New Zealand Friesian-Jersey cross cows during peak lactation. Three premilking treatments were chosen: attach cluster immediately (control), attach cluster immediately and apply 30 s of mechanical stimulation (Stim), and remove 2 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. Postmilking strip yield was measured at the end of each treatment period. Cows receiving the Strip treatment had a 3 to 4% shorter cluster-on time than did cows on the control treatment, but cows receiving Stim were not different from the control cows. Milk yield, SCC, and postmilking strip yield were not different between the 3 premilking treatments. Cluster-on time of the ACR8 cows was 18 to 26% less than that of the ACR2 cows, but SCC and milk production variables did not differ between the 4 end-of-milking treatments, despite higher strip yields as the 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 premilking manual or mechanical stimulation.

Key words: 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 and LIC, 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. It has been reported (Rasmussen, 1993; Burke and Jago, 2011) that the cluster-on time of cows can be reduced, without affecting milk yield and udder health indicators, by increasing the automatic cluster remover (ACR) threshold from 0.2 to 0.4 kg/min. A recent study with dairy cows in late lactation reported that ACR thresholds up to 0.8 kg/min further reduced individual cluster-on times without affecting milk yield or indicators of udder health when using a milking routine with no premilking stimulation, as is common practice on pasture-based dairy farms (Edwards et al., 2013). However, higher postmilking 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.

Premilking stimulation has been reported to reduce cluster-on time despite using a genetic strain of cow in which prestimulation has not been commonplace since the 1970s (Phillips, 1987; Edwards et al., 2013). However, the time taken to apply premilking stimulation was greater than the reduction in cluster-on time, resulting

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in cows remaining in the dairy longer and additional labor being required. The requirement for additional labor could be eliminated and the prestimulation 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 and Bruckmaier, 2011). Thus, if the time to cluster attachment can be reduced using premilking 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 greater 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 and 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).

We hypothesized that streamlined premilking 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 3 premilking treatments and 4 ACR thresholds on peak-lactation dairy cows yielding, on average, 22.3 kg/d.

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 compared with 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 h and in the afternoon between 1500 and 1630 h, through a

30-bail rotary dairy (GEA Farm Technologies GmbH, Bönen, Germany) with plant vacuum set at 42 kPa. Postmilking, a commercially available teat sanitizer (Teat-Guard Plus, Ecolab, St. Paul, MN) was applied manually to each cow by pressurized spray upon exit from the rotary platform.

Experimental Design

The experiment was arranged as a 3×4 factorial: 3 premilking treatments were applied across 4 ACR thresholds. Premilking treatments were as follows: clusters attached at the first bail after cows had walked onto the rotary platform (control); tactile stimulation applied by removing 2 squirts of foremilk from each quarter, requiring ~10 s, followed by immediate cluster attachment (**Strip**); and mechanical stimulation applied using StimoPuls Apex M (GEA) equipped clusters (**Stim**). The pulsator ratio was 70:30 with 300 cycles/min (at half vacuum) during stimulation and 60:40 with 60 cycles/min during normal milking. Stimulation time set at 30 s was considered appropriate for cows with a high degree of udder fill, as expected during peak lactation (Weiss and Bruckmaier, 2005).

For each premilking strategy, 4 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 wk 1, when cows were milked using the control treatment with clusters attached at entry and the ACR threshold set at 0.35 kg/min. In wk 2, cows were transitioned to the new ACR threshold and remained on the allocated ACR threshold for the remainder of the experiment (9 wk). On the first day of wk 2, 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 3 d before changing to their final ACR thresholds of 0.6 and 0.8 kg/min. At the beginning of wk 3, the premilking treatments commenced and were applied for 3 wk (period 1). At the start of wk 6, cows in each of the premilking treatment groups were randomized and split evenly into each of the other 2 treatments, which were applied for a further 3 wk (period 2). At the start of wk 9, cows switched premilking treatments to the remaining treatment, which was applied for a final 3 wk (period 3), so each cow was exposed to all 3 treatments.

Measurements

The dairy was fitted with Metatron P21 milk meters (GEA) at each bail. The herd management software, DairyPlan (GEA), 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 and 7 min, and over 60-s intervals from 7 to 10 min for each cow at each milking session. Milk meter samples were collected weekly to determine composition (MilkoScan 133B Analyzer, Foss Electric, Hillerød, Denmark) and SCC using an automated cell counter (Fossomatic 5000, Foss Electric). At the end of each period, postmilking strip yield was measured by reattaching the cluster within 2 min of the end of milking. Downward pressure was applied until no further milk could be removed from the udder. Milk weight was recorded before and following cluster reattachment. Teat-end hyperkeratosis was assessed using the field evaluation method (Mein et al., 2001) during wk 1 and 11. Teat-ends were scored using a 1–4 scale, whereby teats classed as normal, smooth, rough, and very rough were assigned the scores 1, 2, 3, and 4, respectively. At the last a.m. milking of wk 2 and on the last a.m. 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- μ L subsample from each quarter was streaked across 1 quadrant of an agar plate containing 5% sheep blood and 0.1% esculin (Fort Richard Laboratories, Otahuhu, Auckland, New Zealand) and incubated at 37°C for 48 h. 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 brain-heart infusion broth with 6.5% salt, and the 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 d 6 to 19, normalized SCC, and strip yield data were analyzed using a mixed model that included the fixed effects of period, session (a.m./p.m.), ACR thresh-

old, premilking treatment, interaction between ACR threshold and premilking treatment, and initial milking characteristics as covariables plus the random effect of cow within each period. Average milk flow profiles were derived from least squares 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 decreased 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 Hempstead, UK).

RESULTS

Premilking Treatment

Milk yield and composition were not affected by premilking treatment and no interaction with ACR threshold was detected for any milk production variable. The average herd milk yield was 22.3 kg/d, composed of 0.9 kg of fat/d, 0.8 kg of protein/d, and 1.1 kg of lactose/d. The statistical significance of milking characteristics was similar at a.m. and p.m. milkings. Cows receiving the Strip treatment had a shorter cluster-on time than those on the control treatment ($P < 0.001$; Table 1), with the scale of the reduction similar at the a.m. and p.m. sessions, at 13 and 11 s, respectively (3–4%). In contrast, mechanical stimulation (Stim) provided no benefit in reducing cluster-on time compared with the control at both a.m. and p.m. 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 premilking treatments. Differences and similarities in the daily average milk flow curves of the 3 treatments can be observed in Figure 1. Examining the average milk flow curves, no premilking treatment, including the control, had a bimodal 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 to 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

Figure 1. Average daily milk flow curves (average of a.m. and p.m. sessions) for 3 premilking treatments: control (···; attach cluster immediately), Stim (---; attach cluster immediately and apply 30 s of mechanical stimulation), and Strip (—; 2-squirt strip from each quarter and attach cluster).

score. Only 5 cows developed a new infection by *Corynebacterium bovis* or CNS during the experiment. Average milk flow rate increased with higher ACR threshold ($P < 0.001$). However, time to average flow, maximum milk flow rate (a.m. only), or milk harvested did not differ in the first 2 min (a.m. 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 a.m. and p.m. 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).

DISCUSSION

Our data support the hypothesis that premilking stimulation is not required to maintain milk production when utilizing ACR thresholds greater than 0.4 kg/min because no interaction was detected between premilking 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

Table 1. Effect of 3 premilking treatments (control, Stim, and Strip) on milking characteristics, SCC, and strip yield

Item	Session	Treatment ¹			SED ²	P-value
		Control	Stim	Strip		
Average cluster-on time (s)	a.m.	398	395	385	2.15	<0.001
	p.m.	270	270	259	1.63	<0.001
Milk yield (kg)	a.m.	14.9	14.9	14.9	0.07	0.70
	p.m.	7.4	7.5	7.4	0.05	0.19
Average flow rate (kg/min)	a.m.	2.6	2.6	2.7	0.02	<0.001
	p.m.	2.0	2.0	2.1	0.02	<0.001
Maximum flow rate (kg/min)	a.m.	3.7	3.7	3.8	0.02	<0.001
	p.m.	3.3	3.4	3.4	0.02	<0.001
Time to average flow rate (s)	a.m.	171	163	155	2.84	<0.001
	p.m.	124	126	114	1.64	<0.001
Milk yield in first 2 min (kg)	a.m.	4.6	4.6	5.0	0.04	<0.001
	p.m.	3.2	3.2	3.6	0.04	<0.001
Decline duration (s)	a.m.	101	100	100	2.36	0.80
	p.m.	60	60	61	1.34	0.78
Bimodal milk flow profiles (%)	a.m.	43	51	40	2.1	<0.001
	p.m.	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 <i>Corynebacterium bovis</i> (%)		1.8	2.1	1.8	0.2	0.37
Proportion of quarters with CNS (%)		1.6	1.3	1.6	0.2	0.37

¹Control = attach cluster immediately, Stim = attach cluster, 30 s of mechanical stimulation applied, and Strip = 2-squirt strip from each quarter and attach cluster.

²Standard error of the difference.

Figure 2. Average daily milk flow curves (average of a.m. and p.m. sessions) for 2 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 curves for ACR2 (— ·) and ACR8 (— · —).

consistent with that reported for cows in late lactation (Edwards et al., 2013).

The streamlined premilking treatment, without a latency period (Strip), was effective at reducing cluster-on time during peak lactation. Compared with the

Strip treatment, mechanical stimulation in the form of the Stim treatment provided no advantage to milking efficiency over attaching clusters with no premilking 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 that 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 and 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 before maximum milk flow rate, where time to average milk flow rate was less and a greater amount of milk was harvested in the

Table 2. Effect of 4 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)	a.m.	434	394	386	356	10.51	<0.001
	p.m.	315	265	252	233	7.82	<0.001
Milk yield (kg)	a.m.	15.0	14.9	14.8	14.9	0.26	0.83
	p.m.	7.4	7.6	7.4	7.3	0.20	0.63
Average flow rate (kg/min)	a.m.	2.5	2.6	2.6	2.8	0.07	<0.001
	p.m.	1.8	2.0	2.1	2.2	0.06	<0.001
Maximum flow rate (kg/min)	a.m.	3.7	3.7	3.7	3.8	0.09	0.76
	p.m.	3.2	3.4	3.4	3.4	0.08	<0.05
Time to average flow rate (s)	a.m.	171	161	162	159	9.30	0.60
	p.m.	122	123	122	119	4.38	0.81
Milk yield in first 2 min (kg)	a.m.	4.7	4.7	4.7	4.9	0.14	0.33
	p.m.	3.1	3.3	3.4	3.4	0.13	<0.05
Decline duration (s)	a.m.	121	106	97	78	7.85	<0.001
	p.m.	85	60	51	45	5.48	<0.001
Bimodal milk flow profiles (%)	a.m.	44	49	41	44	6.1	0.59
	p.m.	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 <i>Corynebacterium bovis</i> (%)		2.1	1.4	4.2	0.0	2.4	0.38
Proportion of quarters with CNS (%)		1.0	1.7	3.1	0.0	1.7	0.30
Teat-end hyperkeratosis score ³		2.4	2.3	2.3	2.2	0.14	0.81

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

²Standard error of the difference.

³Assessed using the field evaluation method (Mein et al., 2001).

first 2 min. 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, although 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 premilking 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 European Union legislation that requires milk from each animal to be checked for organoleptic or physicochemical abnormalities by the milker (European Union, 2004). However, the Strip treatment would not comply with the Pasteurized Milk Ordinance (DHHS-PHS-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 number of cows that can 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 United States, where conflicting evidence has been reported as to the effect of premilking 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 with those reported here (Watters et al., 2012). Additionally, in housed systems, such as are common in the United States, premilking routines are of greater importance to comply with milk hygiene regulations (DHHS-PHS-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 premilking stimulation increasing average milk flow rate, and thus reducing the time required to harvest milk, while 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 with the control. Thus, neither premilking treatment appears effective at improving milking efficiency in herds typically found in pasture-based production systems; to achieve maximum efficiency, clusters should be attached immediately after entering the bail to improve utilization, a conclusion supported by Edwards et al. (2013).

Compared with strategies involving premilking stimulation, increasing the ACR threshold above 0.4 kg/min appeared to provide significant benefits to milking efficiency without the need for premilking stimulation. Increasing the 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 with the New Zealand standard of 0.2 kg/min, without negatively affecting milk production or 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, 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 to maintain milk production with reduced cluster-on times, because 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 with ACR2 cows from 135 s through 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, 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 to 45 s and near the peak period of 120 to 135 s; however, it should be noted that, unlike with the premilking treatments, ACR treatments were not applied in a crossover design. 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 after 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 6 h postmilking (Stelwagen et al., 1996). Additionally, Knight et al. (1994) reported that the movement of milk to the cistern occurs in 2 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 would 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 effect 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, whereas SCC remained unchanged. Interestingly, the strip yields 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 and Jago, 2011). The presence of residual milk is thought by many farmers to be linked with mastitis; however, increasing evidence from the current and previous studies (some longer term) indicates 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 and Jago, 2011; Edwards et al., 2013). Thus, increasing the ACR threshold does not appear to adversely affect udder health.

Increasing the 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. It should be noted, however, that row time in the herringbone is limited by the slowest milking cow, so increasing the 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 approximately 80-s decrease in rotation or row time. A change of this magnitude should be achievable on many farms, particularly those with rotary dairies having <60 bails

(Edwards et al., 2012), or herringbone dairies with <26 units during peak lactation (O'Brien et al., 2012). Thus, increasing the ACR threshold to improve milking efficiency is a strategy that can be implemented on many farms.

CONCLUSIONS

Increasing the 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 premilking treatment appeared 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 premilking preparation.

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