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Production and economic comparison of milking F_1 Holstein × Gir cows with and without the stimulus of the calf

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Abstract

F1 Holstein × Gir cows were allocated to two treatments as they calved: C− (53) were milked without their calves (bucket-fed four kg milk/day) and C+ (52) were milked with the stimulus of the calf for approximately 60 days and without the calf thereafter. Milk yield, composition, somatic cell count and milk sucked by the calf were recorded monthly and cow body weight and condition bimonthly. Times spent in milking and related activities were periodically recorded. Analyses of (co)variance were performed by least squares or maximum likelihood (repeated observations) and discrete variables were analysed by chi-square. The milked out milk means in C+ and C− were, respectively, 2383 ± 176 and 2184 ± 176 kg and the milk consumed by the calves 268 ± 75 and 195 ± 88 kg. The concentrations of protein, fat, lactose and solids in the milked out milk were not significantly different between treatments ($P > 0.05$) but C+ cows had longer lactations than C− cows (251 ± 12 and 216 ± 12 days). No significant differences were found between treatments in somatic cell count, calf mortality and morbidity, 2-month calf weight, cow weight and body condition score, calving to first oestrus and calving to conception intervals. The additional time needed to milk with the calf in C+ was similar to the time spent on artificial feeding in C− (3.8 and 3.6 min/calf/day). Saleable milk was 410 kg higher in C+ than in C−, resulting in a US$33.5/lactation/cow superiority in gross margin.

Keywords: Milking systems; Milking time; Restricted suckling; Tropical dairy production

1. Introduction

Making use of the calf to stimulate milking is a popular practice in tropical countries. As an example, Madalena et al. (1997) reported that this system was adopted by 95% of 289 farms surveyed in the State of Minas Gerais, Brazil.

In the usual practice in Latin-America, the calves are kept in or brought to a pen adjacent to the milking parlour and when a cow is about to be milked, her calf is brought to her, allowed to suckle a few milk jets and then tied up in front of her or to her front leg, during

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milking, after which both dam and calf remain together in another pen/paddock until milking of the whole herd is completed, when cows and calves are then separated and moved to their own pastures/paddocks/pens until the next milking. Although it is now well established that the restricted suckling system, coupled with early weaning, results in higher milk production than milking without the calf (e.g. Preston and Vaccaro, 1989; Caldas and Madalena, 2001; Combellas and Tesorero, 2003), it is often considered a backward practice, on the grounds that milking with the calf present is cumbersome and it would cause poor milk hygiene. On the other hand, the labour involved in bucket feeding/cleaning for artificial calf rearing is generally disregarded. However, to our knowledge, no economic comparison between these systems has been published.

Dairy F_1 *Bos taurus* × *Bos indicus* females are currently very popular in Brazil and other tropical countries (Madalena, 1998; Guimarães et al., in press) and systems to capitalise on the important heterosis in this cross were suggested (Madalena, 1993; Madalena and Junqueira, 2004) based in crossbreeding trials where milking was performed with the calf stimulus (Madalena et al., 1990). However, the suitability of the F_1 cross for machine milking without the calf is not well documented and farmers diverge widely in their perception of the proportion of F_1s going dry in that case.

The objective of this research was to assess the biological and economic differences between milking with and without the calf in F_1 Holstein × Gir cows.

2. Material and methods

2.1. Animals and treatments

The experiment was conducted at the private Calciolândia Farm, located in the Municipality of Arcos, State of Minas Gerais, S 20°14′88″ W 45°39′00″. This farm focuses mainly on breeding registered purebred dairy Gir and Guzerá cattle but a dairy unit based on crossbred Holstein/zebu cows is also in operation, mainly to provide recipient females for Gir and Guzerá embryos. A part of those cows, 105 F_1 Holstein × Gir crosses of first (93), second (10) and third (2) parity, were utilized for the present experiment, being alternatively assigned to each of two treatments as they calved, from 06/26/2002 to 07/30/2003, also balancing treatments for cow parity. Multiparous cows had previously been milked with the calf.

The treatments were: C−, with 53 cows milked without the stimulus of the calves and C+, with 52 cows milked with the stimulus of the calf for approximately 60 days of lactation and without the calf thereafter. C− included four cows with stillborn calves, but otherwise normal gestation and one cow whose calf died in the first day of life. Out of the 101 calves born alive, 77 were by Holstein sires (i.e. 3/4 Holstein: 1/4 Gir) and 24 were straight-bred Gir by embryo-transfer. C+ and C− cows were kept and milked together with other non-experimental cows, totalling a herd of approximately 120 animals.

2.2. Management and health

Milking started at 03.00 and 15.00 h. All cows initiated their lactation in a bucket machine-milking parlour but 32 cows (16 of each treatment, at 1 to 42 days of lactation) were transferred for management reasons to another unit, where they were manually milked for the remaining lactation. The cows were dried-off at 60 days from next expected calving, or, else, if milk yield dropped below three kg/day. Forty-seven cows were artificially inseminated to Holstein semen as from 45 days post-calving and the remaining 58 were allocated to embryo transfer and inovulated whenever a suitable embryo was available, so blank oestrus occurred in this group.

The suckled calves were kept on Bermudagrass (*Cynodon dactylon* (L.) Pers. cv Tifton 85) paddocks and were brought at each milking to a small corral adjacent to the milking parlour. Just before the dam was to be milked, its calf was set loose, allowed to suck a few jets and then tied up to the dam's foot during milking, after which they remained together until completion of milking of the whole batch, for subjectively estimated average times of 30 and 50 min in machine and manual milking. Both in the morning and afternoon milking, calves in this group sucked a few jets before milking plus one quarter left unmilked and the residual milk in the other three quarters, after milking.

During the rainy season (November to March) the cows rotationally grazed Green panic (*Panicum maximum* Jacq. cv Tanzania), Tifton and elephant grass

(*Pennisetum purpureum* Schum. cv Napier) and during the dry season (April to October) they were kept on small paddocks with maize silage as practically the only roughage available. Cows were fed farm-made concentrate mixtures at a ratio of approximately 1 kg ration per 4 kg milk. The mean concentrate mixture composition during the experimental period was (g/kg): ground maize, 500, soybean meal, 324, cottonseed 42, citrus pulp pellets, 82, and minerals, 52.

The artificially reared calves were kept in mobile huts that were periodically moved to avoid mud. They were bottle-fed for 5 days and then bucket-fed 4 l/day of whole, non-heated, milk, in two daily meals. The calves of both C− and C+ treatments had available ad libitum concentrate and Tifton hay.

All cows had been vaccinated against brucellosis as calves and tested free of it by the 2-mercaptoetanol test. They were also vaccinated against leptospirosis, infectious bovine rhinotracheitis, foot and mouth disease and rabies. Tick (*Boophilus microplus*) burdens were kept low by chemical control when necessary.

2.3. Data collection

Milk yield was recorded monthly, when a 20 ml sample was collected from the bucket for each cow, both in the morning and afternoon milking, added together to form one composite sample per cow and sent (conserved with bronopol, 2 bromo-2-nitropropane-1.3-diol) for assessment of protein, fat, lactose, total solids and somatic cell count (SCC), to the Federal Research Organization (EMBRAPA-Dairy Cattle) Laboratory. Milk component concentration was assessed with an electronic infra-red analyser (Bentley 2000) and SCC with a flow cytometer (Somacount 300) of the Bentley Combi 2300 equipment. The cows were individually weighed after calving and at approximately 60-day intervals thereafter, when body condition score (BCS) was also assessed, on a one to five scale. Heat detection was performed twice a day by trained personnel with the assistance of teaser bulls equipped with a chin-ball devise (ratio 1 to 40 cows).

The calves were weighed at birth (average age 2.1 days) and at weaning (average age 61.3 days). In addition milk consumed by the C+ calves was assessed twice for each calf, at approximately 1 and 2 months of age, by the weight–suckle–weight procedure (Neidhardt et al., 1979), at both daily milkings. The average of both monthly assessments was taken as the calf's daily milk consumption, which, divided by the average daily gain from birth to weaning, was considered as the efficiency of milk utilization.

The time spent in the various activities associated with milking was recorded over the whole lactation as described in Table 1.

2.4. Statistical

Lactation milk and component yields were estimated by the test day interval method. Factors to adjust for the calving to first test interval (Everett and Carter, 1968) were obtained by the within treatment linear regression of yield on days on milk. The cows were dried off within 2 days of the last recording, so there was no need for an adjustment for that last interval.

Traits expressed once per cow (lactation milk and component yields, lactation length, lactation component percentages, calving to first oestrus interval and service period) were separately analysed by least-squares procedures using Proc GLM of the SAS package (SAS, 2000) with a model including the fixed effects of milking system (C− and C+) and calving period (June to October 2002, November 2002 to March 2003 and April to July 2003). The

Table 1
Records of times spent on activities required for milking

Activity	Nature and number of observations
–Moving C+ calves from paddocks to milking parlour and back.	Time recorded on 13 occasions, for groups of 12 to 41 calves each.
–Bringing calf from pen to its dam.	Individual times spent for 52 calves on 86 occasions.
–Tying up dam's legs (both in C− and C+), putting calf to suck a few jets and tying it up to the dam's foot (in C+ only).	Individual times for all 105 cows, in 301 occasions (86 with and 215 without the calf).
–Actual milking (time from placing to retiring teat cup or from beginning to end of manual milking).	As above.
–Bucket feeding of C− calves and cleaning buckets.	Time recorded on 9 occasions, for groups of 12 to 34 calves.

effect of mechanical vs. manual milking and the interactions between the main factors were not significant in preliminary analyses and were excluded from the model (Junqueira, 2004). Repeated cow traits (live weights, BCS and SCC) were analysed by restricted maximum likelihood procedures using Proc Mixed of the SAS package (Littell et al., 1996). The models were as above plus the effects of record number and cow (random) within milking system. The autoregressive order one covariance structure was adopted because it fitted the data better than the compound symmetry structure (Junqueira, 2004). Following Ali and Shook (1980), SCC was transformed to ln (SCC + 10) for analysis. The model for this variable included also the mechanical vs. manual milking effects and its interaction with milking system.

Calf traits (live weight, daily weight gain, milk consumed and milk efficiency) were analysed by Proc GLM with a model including milking system, calf genotype (3/4 Holstein or Gir), sex and the interactions of genotype × milking system and genotype × sex.

The data on individual animal activity times (Table 1) were analysed by Proc Mixed. The model for these variables included the fixed effects of milking system (C− and C+), milking type (mechanical or manual), milking hour (morning or afternoon), the interactions of milking system × milking type and milking system × milking hour and the random effect of cow within milking system.

The time spent moving groups of calves between the paddocks and the milking parlour was regressed on group size to predict the time to handle a group of 15 calves, similar to the average group size in this experiment. This predicted value divided by 15 provided an estimate of the time spent per calf. A similar procedure was followed to estimate the time spent per calf for bucket feeding.

Differences between the two milking systems in the frequencies of classification variables (causes terminating lactation, calf morbidity and mortality) were assessed by the χ^2 test.

2.5. Economic evaluation

Differences in gross margin between the C+ and C− systems were calculated from the difference between receipts and expenditures based on the mean performance of C+ and C− cows for relevant variables.

To estimate roughage consumption (assumed to have 1.35 Mcal NE_L/kg DM), the NE_L provided by concentrates (assuming 1.46 Mcal NE_L/kg DM) was subtracted from the total NE_L requirements (NRC, 2001) for milk, fat, protein and lactose yield, maintenance, growth and gestation. However, the NRC (2001) maintenance requirement of 0.08 Mcal/body weight$^{0.75}$ was multiplied by 0.756, to acknowledge the lower requirement of F_1 Holstein/zebu cows (Solis et al., 1988).

In the C+ system, saleable milk was the milk actually milked out, whereas in the C− system it was the milked out milk minus the milk fed to calves. Total milk production was the sum of milked out plus suckled milk in C+ and equalled milked out milk in C−.

3. Results

Three calves in C+ died before 45 days of age (at 26, 30 and 33 days), and four after that age (at 45, 50, 56 and 63 days), and the average age at weaning was 59 days (range 57 to 67). Two cows were dried off because of mastitis, both in C+, at 114 and 232 days of lactation (the calf of the first one died at 26 days). Similarly, 10 C− calves 1 to 47 days old died, so the average artificial rearing period was 50 days. Because these events might have been caused by the milking systems, all data were included in the results presented, unless otherwise specifically stated.

3.1. Milk yield and composition

Neither the effect of machine vs. manual milking nor its interaction with C+/C− were significant for any of the milk yield and composition variables studied ($P > 0.21$).

As it may be seen in Table 2, the total lactation milk production per cow in C+ was 468 kg higher than in C−. This 21% superiority (468/2184) was due to the milk consumed by the calf (12%) and to the milked out milk (9%), which in turn was higher because of the 35-day longer lactation in C+, rather than because of a higher daily yield, which was similar in both milking systems (Fig. 1).

Table 2
Milk and component yield and mastitis in two milking systems (LSM = least squares mean, S.E. = standard error)

	Milking system				P > difference
	With the calf[a]		Without the calf		
	LSM	S.E.	LSM	S.E.	
Milk yield					
Milked out, kg	2383	176	2184	176	0.41
Consumed by the calf, kg	268	–	210	–	–
Total production, kg	2652[b]	184	2184	176	0.07
Saleable, kg	2383[c]	176	1974[d]	177	0.11
Lactation length, day	251	12	216	12	0.04
Components of milked out milk					
Fat, %	4.28	0.10	4.14	0.10	0.29
kg	102	8	91	8	0.32
Protein, %	3.58	0.03	3.57	0.03	0.87
kg	85	6	77	6	0.35
Lactose, %	4.56	0.04	4.45	0.04	0.04
kg	109	8	99	8	0.34
Total solids, %	13.4	0.13	13.2	0.13	0.15
kg	320	24	289	23	0.33
Mastitis					
Clinical cases	4	–	4	–	–
Days treated/days on milk, %	0.18	–	0.13	–	–
Somatic cell count, 1000	262	21	203	15	–
Log somatic cell count	10.6	0.33	10.7	0.32	0.71
Number of cows	52	–	53	–	–

[a] During the first 60 days of lactation.
[b] Total production in this system = milked out + consumed by the calf.
[c] In this system saleable = milked out.
[d] In this system saleable = milked out minus consumed by the calf.

In spite of C+ calves consuming 73 kg more milk than C− calves, the saleable milk per lactation per cow was 410 kg (20%) higher in C+ than in C−, as 4 kg milk/day had to be fed to calves in the latter system.

Deleting from C+ the four observations of cows with calves dead before 45 days of age or dried off because of mastitis did not alter much the Table 2 means of this group, which remained within 1.5% of the original value. For example, the milked out milk mean changed from 2383 to 2363 kg/lactation.

The differences between C+ and C− in the components of the milked out milk were not statistically significant, except for lactose, which was slightly higher in C+ (Table 2).

Udder health was very reasonable (Table 2). There were no differences between C+ and C− in the number of cows showing clinical mastitis neither in log SCC.

3.2. Lactation length

A trend for shorter lactations in C− than in C was apparent (Table 3). However, the proportions of causes for drying off were very similar in both systems.

3.3. Live weight and body condition

The cows weighed 405 kg after calving and gained weight steadily thereafter. There were no differences between the C+ and C− systems in live weight gain or body condition score (P = 0.78). The gain from calving to end of lactation of an average C+ cow (251

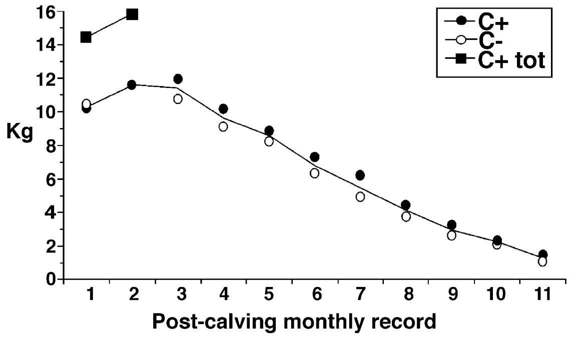

Fig. 1. Milked out and total milk production (tot = milked out + consumed by the calf) of cows milked with (C+) or without (C−) the presence of the calf during the first 60 days of lactation.

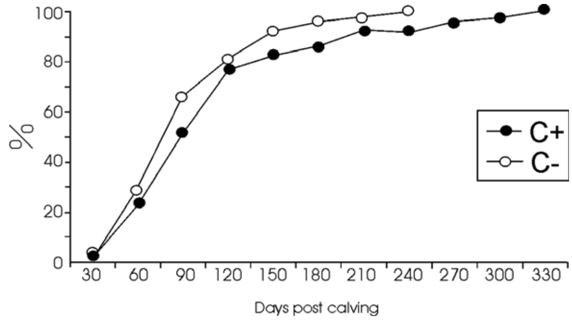

Fig. 2. Cumulative percentage of first post-calving oestrus in cows milked with (C+) or without (C−) the presence of the calf during the first 60 days of lactation.

days) was 61 kg. Body condition score increased from 3.0 at calving to 3.4 at 10 months after calving.

3.4. Reproductive traits

The cumulative distribution of the calving to first oestrus interval is shown in Fig. 2. The slower rate of cycling in C+ was mostly due to four late-cycling cows and the difference between the distributions in C+ and C− was not significant ($P > \chi^2 = 0.49$). The means of the calving to first oestrus and calving to conception intervals are shown in Table 4. The C+ cows showed their first heat after calving 18.5 days later than the C− cows and this difference approached significance ($P = 0.07$). If only cows in the artificial insemination programme were considered, the difference was even larger, but not significant, as the number of observations was not large. If all animals were considered, i.e. including also those in the embryo transfer programme, then the difference practically vanished.

3.5. Calf performance

Six Gir calves had to be bottle-fed as they refused bucket-feeding. The milking system did not significantly affect birth and 2 month weight, daily gain or the efficiency of milk utilization. However the interaction of milking system × calf genotype was significant for all four variables ($P < 0.04$).

As it may be seen in Table 5, the C+ calves consumed significantly more than the 4 kg of milk/day fed to C− calves. The mean milk consumption of

Table 3
Distributions (%) of lactation length and cause of drying off in cows milked with (C+) or without (C−) the presence of the calf during the first 60 days of lactation[a]

	Lactation length class (days)[b]							
	≤60	61–120	121–180	181–240	241–300	301–360	>360	Total
C+	0	5.8	9.6	32.7	21.1	23.1	7.7	100.0
C−	9.4	5.7	17.0	20.8	26.4	17.0	3.7	100.0

	Cause of drying off[c]			
	Gestation	Low yield	Mastitis	Total
C+	19.2	76.9	3.9	100.0
C−	22.6	77.4	0	100.0

[a] 52 cows in C+ and 53 in C−.
[b] $P(>\chi^2$ heterogeneity = 0.12).
[c] $P(>\chi^2$ heterogeneity = 0.96).

Table 4
Intervals (days) from calving to first oestrus and calving to conception in two milking systems (LSM = least squares mean, S.E. = standard error)

Interval from calving to	Milking system						P > difference
	With the calf (C+)[a]			Without the calf (C−)			
	N	LSM	S.E.	N	LSM	S.E.	
First oestrus[b]	52	108	8	53	90	8	0.07
Conception[b]	45	143	11	46	139	11	0.80
Conception[c]	26	143	16	19	120	19	0.14

[a] During the first 60 days of lactation.
[b] All animals considered.
[c] Excluding cows on embryo transfer programme.

straight-bred Gir C+ calves was 0.76 kg/day higher than for the 3/4 Holstein C+ ($P=0.11$). The daily gain and 2 month weight of 3/4 Holstein and straight-bred Gir was similar in C+, but the 3/4 grew faster and were 19 kg heavier than the Gir when artificially raised (C−). The efficiency of milk utilization was higher in 3/4 Holstein calves in C−, followed by 3/4 in C+, Gir in C+ and Gir in C−.

The incidences of calf diseases and mortality were rather high and not significantly different between both milking systems (Table 6). Five 3/4 Holstein and two Gir calves died in C+ and six and three, respectively, in C−. Excluding diseased calves caused little change in the Table 5 means for efficiency of milk utilization except in the C− Gir calves (−0.02, +0,02, −0.06 and +0.21 kg gain/10 kg milk for the C+ 3/4 Holstein, C+ Gir, C− 3/4 Holstein and C− Gir groups, respectively).

3.6. Milking times

The regressions of group handling time on number of calves in the group (n) were:

$$\text{moving C+ calves from/to paddocks /milking parlour (min)} = 8.518 + 0.418n,$$

$$\text{bucket-feeding C − calves and cleaning buckets (min)} = 12.046 + 1.010n.$$

The times spent per calf per day estimated for these activities for $n=15$ calves in the group handled are shown in Table 7 along with times for the other activities, estimated from individual animal records.

Table 5
Calf performance (only for 2-month-old survivors) in two milking systems (LSM = least squares mean, S.E. = standard error)

Calf genotype	Milking system							
	With the calf (C+)[1]				Without the calf (C−)			
	3/4 H:1/4 Gir[2]		Gir		3/4 H:1/4 Gir[2]		Gir	
	LSM	S.E.	LSM	S.E.	LSM	S.E.	LSM	S.E.
Birth weight, kg[3]	31.1[a,b]	0.7	27.3[a,c]	1.4	32.2[b]	0.8	23.9[c]	1.3
Two month weight, kg[4]	58.0[a]	1.3	56.9[a,b]	2.7	66.6[c]	1.4	47.4[b]	2.53
Daily gain, g/day	476[a]	23	492[a,b,c]	59	602[c]	27	269[b]	65
Milk consumption, kg/day	4.38[a]	0.19	5.14[a]	0.44	4.00[b]	–	4.00[b]	–
Weight gain/milk consumed, kg/10 kg	1.16[a]	0.06	0.88[a]	0.16	1.53[b]	0.08	0.67[a]	0.18
Number of calves	35	–	10	–	30	–	9	–

[a,b,c] Means without common superscript differ at $P<0.05$.
[1] During the first 60 days of lactation.
[2] H = Holstein.
[3] Average age 2 days.
[4] Average age 61 days.

Table 6
Incidence of diseases and mortality from birth to 2 months of age in calves in two milking systems

	Milking system				$P>\chi^2$
	With the calf (C+)[a]		Without the calf (C−)		
	N	%	*N*	%	
Diarrhoea	16	30.8	10	20.8	0.26
Respiratory problem	8	15.4	5	10.4	0.46
Death	7	13.5	9	18.8	0.47
Number of calves	52	100.0	48	100.0	–

[a] During the first 60 days of lactation.

The time spent in the milking parlour was 1.84 min/cow/day higher for the C+ than for the C− animals (Table 7), which added to the 1.97 min/calf/day required to move the C+ calves back and forth from their paddocks yielded a difference of 3.81 min/cow/day more time spent on milking related activities in C+ than in C−, which was very similar to the 3.63 min/day spent on bucket-feeding the C− calves, so the total time was practically the same in both systems.

3.7. Economic performance

The consumption of concentrates in C+ and C− was 610 and 507 kg/lactation/cow or 2.38 and 2.09 kg/cow/day of lactation, corresponding to 1 kg concentrate per 4.58 and 4.42 kg milk yield, so the C+ cows received more concentrate just because of their higher lactation yield. The estimated consumptions of roughages were, respectively, 2885 and 2694 kg dry matter in 251 days (the lactation length of C+ cows) and another 107 kg were needed to maintain a 475 kg dry C+ cow during 18 days (the difference over C− in calving to first heat interval Table 4).

The extra 35 days lactation in C+ demanded more labour, power and repairs than in C−, which were calculated as the weighted mean of machine and manually milked cows. All other expenses were considered equal for both C+ and C−, since there were no differences in cow and calf health and mortality, calf weight and daily labour.

The milk receipts in C+ above C− (65.94 US$/lactation/cow) were only partially offset by the US$32.43 extra expenditures, so that the net difference favoured the C+ system by 33.51 US$/lactation/cow.

4. Discussion

Several authors previously reported higher total milk production and higher saleable milk per cow in restricted suckling compared to artificial rearing systems, as found in the present experiment (e.g. Chandler and Robinson, 1974; Ugarte and Preston, 1975;

Table 7
Times spent (minutes per animal per day) on activities related to milking in two systems (LSM = least squares mean, S.E. = standard error)

Activity	Milking system			
	With the calf (C+)[1]		Without the calf (C−)	
	LSM	S.E.	LSM	S.E.
1. Moving calves from/to paddocks/milking parlour[2]	1.97	0.08	–	–
2. Bringing calf from pen to its dam	1.52	0.09	–	–
3. Tying up cow legs (both in C− and C+), putting calf to suck a few jets and tying it up to the dam's foot (in C+ only).	2.96	0.18	2.60	0.16
4. Actual milking[3]	12.08	0.44	12.12	0.36
5. Time spent in milking parlour[4]	16.56[a]	0.54	14.72[b]	0.44
6. Bucket-feeding and cleaning buckets[1]	–	–	3.63	0.07
Total time[5]	18.53	0.56	18.35	0.45

[a,b,c] Means without common superscript differ at $P<0.05$.
[1] During the first 60 days of lactation.
[2] Considering a group of 15 calves.
[3] Time from placing to retiring teat cup or from beginning to end of manual milking.
[4] In C+ = 2+3+4, in C− = 3+4.
[5] In C+ total = 5+1, in C− total = 5+6.

Fulkerson et al., 1978; Thomas et al., 1981; Alvarez and Saucedo, 1982; Silva et al., 1988; Campos et al., 1993a; Monforte et al., 1996; Sanh et al., 1997; Tesorero et al., 2001; Margerison et al., 2002; Combellas et al., 2003).

A high incidence of short lactations was observed in the present results (Tables 2 and 3), particularly in C−. However, the animals in this experiment, bought as heifers, were extremely wild, even after calving, which may have contributed to enhance the stressful nature of weaning. This stress may perhaps have been less for the C+ cows because they had 60 more days to get accustomed to handling and temperament notoriously improved as lactation proceeded. The hypothesis that in the C− system machine milking would cause higher losses than manual milking was not warranted, as the interaction of these factors (manual/machine milking × C+/C−) was not significant for any of the dairy traits studied ($P > 0.67$). Longer lactations due to restricted suckling were also found by some authors (e.g. Chandler and Robinson, 1974; Alvarez and Saucedo, 1982; Silva et al., 1988; Margerison et al., 2002; Brandão, 2004) but not by others (Ugarte and Preston, 1975; Fulkerson et al., 1978; González et al., 1984; Campos et al., 1993a; Das et al., 1999; Msanga and Bryant, 2003).

Except for lactose, milked out milk composition was not significantly affected by the milking systems, which is in agreement with some previous reports (Campos et al., 1993a; Ferreira et al., 1996) although others reported higher fat content in cows milked without the calf (Boden and Leaver, 1994; Tesorero et al., 2001; Margerison et al., 2002). The first authors also found lower protein and higher lactose milk contents in suckled cows. The lower fat content in the milked out portion may be explained by the much higher content of the suckled portion (Sandoval-Castro et al., 1999, 2000; Margerison et al., 2002). However, in the present experiment, the procedure of leaving a whole quarter for the calf may have caused similarity of both portions, and of C+ and C− milked out milk composition.

The incidence of clinical mastitis and somatic cell counts was not affected by the milking system, as would perhaps be expected since those indicators of udder health were very reasonable (Table 2). With higher incidence of mastitis, a reduction due to restricted suckling was reported by several authors (Ugarte and Preston, 1975; Rigby and Ugarte, 1976; Campos et al., 1993a; Preston et al., 1995; Monforte et al., 1996; Sanh et al., 1997; Mejia et al., 1998) but no differences between restricted suckling and artificial rearing were found by Fulkerson et al. (1978) and Ferreira et al. (1996) in herds with low incidence of mastitis. However, Margerison et al. (2002) reported a reduction in somatic cell count due to restricted suckled cows in a low level of mastitis.

It is not clear from the present results whether restricted suckling affected the length of the postpartum interval to oestrus or to conception. Literature results are rather contradictory, but then several reports were based on rather few observations. A weighted mean (by the inverse of the variance) of the difference in calving to first oestrus intervals yielded 7.89 ± 11.7 days, so the average difference is within one standard error of zero (Ugarte and Preston, 1975; Carruthers and Hafs, 1980; Hippen and Escobar, 1984; Campos et al., 1993a; Ferreira et al., 1996; Monforte et al., 1996; Mejia et al., 1998; Margerison et al., 2002). Adding to those the present results yielded 8.45 ± 11.62 days. From a review of results on zebu and crosses, Galina et al. (2001) concluded that restricted suckling for a few weeks did not have practical consequences on cow reproductive efficiency. It should be noted that in the present experiment nutrition was sufficient to sustain growth and good body condition in both the C+ and C− cows, in spite of the higher milk production of the former.

The growth rate and efficiency of milk utilization of artificially reared 3/4 Holstein calves was very reasonable but Gir calves did not perform well, which may have been caused by the lower inherent growth rate of Gir compared to Holstein in crosses (Martins et al., 2004) and to the effect of diseases. The well known difficulty of *B. indicus* and high grade *B. indicus* crosses to adapt to bucket feeding (Black, 1982; Ward et al., 1983) required that some calves be bottle fed, but there was no refusal to drink the 4 l milk offered daily. C+ calves of both genotypes showed reasonable weight gains. However, it is unlikely that leaving a whole quarter to suckle would be justifiable for commercial calves, as similar growth rates may be attained with lower milk consumption (Campos et al., 1993b; Combellas and Tesorero, 2003). The optimal growth rate of calves is extremely variable in Brazil, both geographically, depending on regional peculiarities, and temporally, due to large fluctuations in the relative milk and beef prices (Madalena, 2001), so, as pointed out by Sandoval-Castro et al. (2000), the details of the milking procedure with the calf may be manipulated to regulate the proportions of milk suckled and sold, to tailor systems according to particular circumstances (Combellas and Tesorero, 2003).

The incidence of calf diarrhoea/respiratory diseases and the mortality rate were rather high. Deficiencies in the disinfection of the calf pen in C+ were detected and corrected by moving the calves to open paddocks. Lack of experience of farm personnel with the hut artificial rearing system may have influenced the high mortality rate in C−. Thus, the comparison of calf morbidity and mortality in restricted suckling or artificial rearing is very much related to the peculiar circumstances of each experiment; and data from many farms seem necessary to generalize on this respect. Ugarte (1992) reported 6.5% mortality for 3,820 calves reared in restricted suckling in Cuba and 9.9% for 75,937 artificially reared calves.

The total time spent in milking and handling cows and calves was similar in both C+ and C− systems, as previously reported by Caldas and Madalena (2001) for a small sample of different farms in either system. Thus, the extra saleable milk in C+ compensated for the extra costs, so this system was economically preferable to C−. This conclusion might perhaps not apply to large scale milking facilities for several hundred cows, where it may be preferable to optimise milking time in detriment of milk production, although some Brazilian farmers are improvising ways to adapt such facilities to milking with the calf.

The milk consumption in C+ was likely to have been underestimated because the actual amount of milk consumed by the calf in which it was based is expected to have been biased downwards, due to urination and defecation between both weightings. This bias was estimated by Neidhardt et al. (1979) in 7% of the suckled milk. Nonetheless, increasing in this proportion the amount of milk consumed by the calf and considering it to have 6.34% fat content (Sandoval-Castro et al., 2000), rather than 4.28% as in Table 2, had a negligible effect on the economic superiority of C+ over C−, which was reduced only by US$0.36/cow. Disregarding the difference of 18.5 more days dry in C+ had also a small effect, increasing by US$1.94/cow the superiority of this system over C−.

5. Conclusion

For herd size and facilities as in the present experiment, milking with the stimulus of the calf for the first 60 days of lactation proved to be more economical than artificial rearing, as more milk and equal calf live weights were obtained, while the labour involved was similar in both systems.

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