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Abstract
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Disciplines
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Comments
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Sources of Variation in Quarter Milk Flow Measures[1,2]

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ABSTRACT

An individual quarter milker was used to measure milk yields at staggered 20-s intervals from 198 Holstein cows in the Beltsville Agricultural Research Center herd. Several flow rate variables were calculated. The 2792 quarter samples of milk yield were taken during afternoon milkings. Yields and rates of individual quarters were examined as were effects of lactation, stage of lactation, machine, and cow. Differences between rear and front quarters were .78 kg for yield and .12 kg/min for maximum rate. Differences between left and right quarters were .02 kg/min for maximum rate and .10 kg for yield during the period of maximum rate. Yields departed from front-rear and left-right side patterns. This lack of symmetry, interactions of front-rear by side, for the yield traits may have been from permanent environmental causes such as developmental error, mastitis, or injury. Cow effects were important for all traits as were the effects of lactation, stage of lactation, and machine for many of the traits. Repeatabilities were .63 for maximum rate and .60 for average rate. Designers of milking machines may wish to account for differences between quarters in newer milking machines.

INTRODUCTION

Measures of rates of milk flow have economic value (2, 8, 9, 10). Measures (traits) of primary importance were total milking time and maximum (peak) rate of flow. These traits generally have been investigated for the whole udder (9, 10). Progeny are tested for rate of milking in Holland (8), and progeny testing for total milking time adjusted for milk yield and herd average milking time has been recommended (2). Variation in total milking time may be an important labor factor in some milking parlors. Rate of flow declines throughout lactation for the whole udder (1, 3, 10). Smith et al. (10) investigated milk flow traits for whole udder and found maximum rate, duration of maximum rate, time to strip, strip time, total time, and average rate were affected by lactation, machine, and interaction of stage of lactation by machine. Milk flow differed between AM and PM milkings. Differences for machine were reported by Smith and Peterson (11), Baxter et al. (1), and Schmidt and Van Vleck (9). Schmidt and Van Vleck (9) suggested adjustments of milking rates for pulsation rates, pulsation ratio, and vacuum.

Examinations of milk flow on individual quarters have been less extensive. Matthews et al. (7) examined differences among quarters for yield per quarter, proportion per quarter, and milk flow. Right front (RF) and left front (LF) quarters produced 21.6 and 20.2% of the total yield, whereas right rear (RR) and left rear (LR) quarters produced 29.0% and 29.2%. Marx and Pursel (6) found that front quarters produced 39.1% and left quarters produced 49.5% of total yield. Differences in rates of milking have been reported (6, 7). Marx and

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Pursel (6) found rates on RF, LF, RR, and LR were .51, .46, .74, and .72 kg/min. Differences in stage of lactation (6, 7) and in lactation for quarter flow traits (7) have been reported.

Advances in milking machine engineering have produced automatic take-off units that remove the milking machine from all quarters simultaneously or each individually. Interest also has focused on proper time for removal of the milking machine and its relationship to incidence of mastitis. To design machines that might adjust for yields and flow rates of individual quarters, the engineer needs to know factors that affect quarter yields and flow rates and their relative patterns. Objectives were to describe variation of measures of quarter flow and to determine what factors affect flow traits of quarters.

MATERIALS AND METHODS

Yields of individual quarters (2792) were recorded at 20-s intervals from 198 registered Holstein cows in the Beltsville Agricultural Center herd between 1962 and 1965. Two milking systems were used.

System 1 was the old style De Laval[6] with operating vacuum 30 to 33 cm Hg, 48 pulsations/min, and a 1:1 pulsation ratio of milking to rest alternating from side to side. System 2 was a De Laval Model 100 with operating vacuum of 38 to 41 cm Hg, 60 pulsations/min, and a 2.5:1 pulsation ratio of milking to rest, milking all quarters simultaneously. The claw was modified so milk from individual quarters remained separated. Milk from each quarter was collected in graduated cylinders attached to a vacuum system (Figure 1). The cumulative yield in each cylinder was recorded to the nearest .045 kg at staggered 20-s intervals. All recordings were during the PM milking. Three stages of lactation were defined: 1 to 100 days, 101 to 200 days, and 201 to 300 days. Originally, all cows were to be sampled once during each stage of lactation, but some cows were sampled for more than one lactation. Strip point was defined for each quarter as the point at which the quarter had produced greater than 85% of its total yield and at which milk yield in the 20-s periods before and after that point was less than .045 kg. Similarly, the period of maximum rate was defined as the consecutive 20-s periods within .045 kg of the period with highest yield. Duration (of maximum yield) was defined as the period at which maximum rate was maintained, and maximum yield was the yield during the period of maximum rate. Average rate was defined as the yield to strip point divided by the time to strip point.

Two data sets were formed. Data set 1 contained yield per quarter and proportion of a cow's total yield per quarter for all cows. Data set 2 contained measures of flow rates and time for all milkings where yield from each quarter was greater than 1.13 kg. Estimates of flow rates for quarters yielding less than 1.13 kg were erratic because of the discrete readings at 20-s intervals; they were discarded, leaving 1790 observations from 168 cows. The dis-

Figure 1. Quarter milker.

[6] Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the United States Department of Agriculture and does not imply its approval to the exclusion of other products that may be suitable.

carding of smaller yields disproportionately affected the number of samples from lactation stage 3. This discarding shows in the distribution of samples by lactation and stage of lactation in Table 1. Milk yield and flow rate traits of the observations from data set 2 were analyzed then by the mixed model:

$$\mathbf{y} = \mathbf{X}\beta + \mathbf{Z}\mathbf{u} + \mathbf{e}$$

where

- $\mathbf{y}$ is the measure for a quarter flow trait,
- β includes fixed effects of lactation, stage of lactation, side, front-rear, machine, and interactions of side by front-rear, side by machine, stage by side, stage by front-rear, stage by machine, front-rear by machine, side by front-rear by machine,
- $\mathbf{u}$ includes random effects of cows,
- $\mathbf{e}$ includes random error, and
- $\mathbf{X}$ and $\mathbf{Z}$ are known fixed incidence matrices.

The expectations of E(u) and E(e) are null and

$$\text{Var}\begin{bmatrix}\mathbf{u}\\ \mathbf{e}\end{bmatrix} = \begin{bmatrix}\mathbf{I}\sigma_c^2 & \mathbf{O}\\ \mathbf{O} & \mathbf{I}\sigma_e^2\end{bmatrix}.$$

Cow and error variances were computed by Henderson's Method 3 (4) and were used for repeatabilities of flow rate traits.

RESULTS AND DISCUSSION

Means, standard deviations, and ranges for milk yield and proportion of milk yield per quarter from data set 1 are in Table 2. The LR and RR quarters produced 2.47 and 2.35 kg while LF and RF quarters produced 1.67 and 1.68 kg. Front quarters produced 40.6% of the total yield, and left quarters produced 50.8%. Similar proportions for front quarters of 41.8% have been reported by Matthews et al. (7), 41.2% by Johansson and Korkman (5), and 39.1% by Marx and Pursel (6). Left quarter proportions of 49.9%, 49.5%, and 49.4% have been reported (5, 6, 7) and are less than our 50.8%. Because primary interest was in examining flow rate traits, no further analysis concerns yield and proportion per quarter from data set 1.

TABLE 1. Number of observations by lactation and stage of lactation for quarter milk flow rate (data set 2).

Lactation no.	Stage 1	2	3	Total
1	304	316	171	791
2	252	212	64	528
⩾3	244	151	76	471
Total	800	679	311	1790

Arithmetic means, standard deviations, and ranges for measures of milk flow rate are in Table 3. All yields less than 1.13 kg were removed from data set 1 to form data set 2. As expected with removal of smaller yields, average yields per quarter in data set 2 were larger than in data set 1. Maximum rates (kg/min) (Table 3) for RF, LF, RR, and LR of .58, .59, .68, and .70 are close to those by Marx and Pursel (6) of .51, .46, .74, and .72. Since the machine system of Marx and Pursel (6) is unknown, a comparison is difficult to interpret. Front quarters produced less milk from initiation of milking to strip point (yield to strip), required more strip time, and yielded more milk (strip yield) during the strip period.

Analysis of variance is in Table 4. All lines for main effects for all quarter traits represent main effects averaged equally over their interactions and so affect discussion of results. Effects of lactations were significant for all traits except for strip yield and strip time. Average yield per quarter increased from 1.95 kg for first lactation to 2.58 kg per quarter for third and later lactations. Average maximum rate declined .14 kg/min and average rate also declined .06 kg/min during the same period. These results were similar to those by Matthews et al. (7). Stage of lactation was important for all quarter traits except strip time. Yields and rates both declined through lactation. Other researchers (1, 3, 9) have reported that peak and average rates on a whole udder basis declined throughout lactation.

Sides differed only in maximum rate, yield during period of maximum rate, and average rate. Quarters on the left side (Table 5) had a maximum rate of .02 kg/min more than quarters on the right side and yielded .1 kg more during the period of maximum rate. Equal bilateral

TABLE 2. Means, standard deviations, and ranges for milk yield and proportion per quarter for all cows.

Trait	Quarter			
	Left front	Right front	Left rear	Right rear
	(698)[a]	(698)	(698)	(698)
Yield/quarter (kg)				
Mean	1.67	1.68	2.47	2.35
Standard deviation	.82	.84	1.06	1.02
Maximum value	4.49	5.53	6.39	6.53
Minimum value	.05	.09	.09	.09
Proportion/quarter (%)				
Mean	20.37	20.19	30.44	29.01
Standard deviation	5.31	5.34	5.52	6.14
Maximum value	42.90	50.00	50.50	54.30
Minimum value	1.60	1.80	11.10	7.30

[a]Number in parentheses indicates number of observations.

development should produce little or no difference between left and right quarters. Any deviation from bilateral symmetry may result from errors in development or mastitis. Cows were milked in stanchion barns from the right side. Front differed from rear for all traits except duration of maximum rate. Rear quarters (Table 5) produced .78 kg more milk at .12 kg/min faster maximum rate than front quarters. Matthews et al. (7) also found that rear quarters milked faster. Deviation from front-rear and side patterns was examined through interaction of side by front-rear which was significant for all yield traits. This asymmetry may be from permanent environmental differences caused by mastitis or injury.

Machines differed for maximum and average rates and duration of maximum rate, with faster rates being associated with cows milked by the De Laval 100. The De Laval 100 had a higher operating vacuum, more pulsations, and a rest pulsation ratio different from the old De Laval. Smith and Peterson (11), Baxter (1), and Smith et al. (10) found that increased vacuum caused faster rates for whole udders. Interactions of stage by side, stage by front-rear, machine by side, and the three way interaction of side by front-rear by machine were unimportant. Interaction of stage with machine affected maximum rate and duration of maximum rate. These results are similar to those on whole udders by Smith et al. (10). The interaction of machine by front-rear was also important for maximum and average rate. Different operating characteristics of machines (vacuum, pulsation ratio, number of pulsations) extracted milk at rates that differed from the average patterns expected for front vs. rear. This difference is strong evidence that machine design should take into account front and rear variation.

Cow effects were important for all traits. Repeatabilities for the traits ranged from a low of .1 for yield during period of maximum rate to .60 and .63 for average and maximum rate. These repeatabilities are close to those by Smith et al. (10) for whole udders because definitions of traits are similar.

SUMMARY AND CONCLUSIONS

Measures of yield and rate of milk flow and volume were examined for effects of lactation, stage of lactation, quarters, and machine type to measure differences among quarters. Front differed from rear for nearly all traits whereas sides differed for maximum and average rate. Interactions between side and front and rear existed for yield traits. Interaction of front-rear with machine was significant also for average and maximum rate. These patterns could be used in milking machine engineering by one of two approaches. Units could be removed at different times from each quarter or removed at the same time if machine controls could be

TABLE 3. Means, standard deviations, and ranges for quarter traits (data set 2).

Trait	Quarter			
	Left front	Right front	Left rear	Right rear
Yield/quarter (kg)	(448)[a]	(447)	(448)	(447)
Mean	2.06	2.09	2.91	2.76
Standard deviation	.68	.69	.94	.91
Maximum	4.49	5.53	6.39	6.53
Minimum	1.13	1.13	1.18	1.13
Maximum rate (kg/min)				
Mean	.59	.58	.70	.68
Standard deviation	.22	.23	.27	.27
Maximum	1.50	1.36	1.91	2.09
Minimum	.18	.14	.23	.14
Duration of maximum rate (min)				
Mean	2.61	2.56	2.70	2.55
Standard deviation	1.49	1.47	1.46	1.48
Maximum	12.00	10.67	10.33	12.67
Minimum	.67	1.00	1.00	1.00
Yield during period of maximum rate (kg)				
Mean	1.35	1.30	1.68	1.51
Standard deviation	.51	.52	.69	.61
Maximum	3.76	3.60	5.49	3.81
Minimum	.32	.36	.36	.36
Time to strip (min)				
Mean	5.12	5.55	6.07	5.97
Standard deviation	2.31	2.60	2.60	2.46
Maximum	18.67	19.67	19.00	18.33
Minimum	2.00	2.00	1.67	2.00
Strip time (min)				
Mean	2.92	2.49	1.97	2.07
Standard deviation	1.70	1.55	1.30	1.50
Maximum	12.33	11.67	9.00	11.00
Minimum	.00	.00	.33	.33
Yield to strip (kg)				
Mean	1.96	1.98	2.82	2.67
Standard deviation	.68	.69	.94	.92
Maximum	4.35	5.53	6.35	6.35
Minimum	1.00	1.00	1.09	1.04
Strip yield (kg)				
Mean	.11	.12	.09	.10
Standard deviation	.08	.09	.09	.09
Maximum	.41	.45	.54	.54
Minimum	.00	.00	.00	.00
Average rate (kg/min)				
Mean	.42	.40	.51	.49
Standard deviation	.15	.16	.19	.19
Maximum	1.09	1.00	1.50	1.31
Minimum	.09	.05	.14	.09

[a]Number in parentheses indicates number of observations.

TABLE 4. Mean squares for lactation, stage, side, front-rear, machine, and cow and their interactions for quarter flow traits.

	Mean squares for effects[a]													
	Lactation no.	Stage	Side	Front-rear	Side by front-rear	Stage by side	Stage by front-rear	Machine	Machine by side	Front-rear by machine	Stage by machine	Side by front-rear by machine	Cow	Error
Degrees of freedom	2	2	1	1	1	2	2	1	1	1	2	1	167	1605
Quarter trait														
Yield	15.647**	76.983**	.923	157.578**	2.439**	.077	.587	1.051	.022	.960	.066	.014	1.812**	.316
Maximum rate	.504**	.601**	.124*	3.633**	.039	.030	.010	.561**	.005	.130*	.075*	.029	.423**	.023
Duration of maximum rate	32.224**	22.514**	.647	.371	.964	.783	4.501*	16.92**	.694	2.635	5.174*	.128	8.423**	1.432
Yield during period of maximum rate	3.027**	12.463**	2.661**	26.437**	1.713*	.245	.849	.377	.000	.515	.540	.367	.681**	.287
Time to strip	174.525**	228.950**	6.690	112.185**	10.247*	1.194	.247	89.441**	.915	.253	3.082	3.972	34.180**	2.393
Strip time	3.493	4.226	6.843	111.562**	11.342*	1.278	.287	.735	.938	.241	1.046	3.207	5.781**	1.882
Yield to strip	15.375**	77.895**	1.183	164.613**	2.235**	.081	.512	.938	.030	.884	.083	.005	1.798**	.325
Strip yield	.001	.037**	.016	.077**	.004	.007	.003	.003	.001	.002	.004	.002	.016**	.006
Average rate	.121**	.475**	.090**	2.878**	.010	.009	.023	.310**	.005	.066*	.010	.029	.195**	.012

[a]Tests for main effects for which interactions were included in the model reflect differences of main effects averaged over interaction effects.

*$P<.05$.

**$P<.01$.

TABLE 5. Least squares means[a] for quarter milk flow rate traits by sides and front and rear.

Quarter trait	Quarters							
	Left		Right		Front		Rear	
	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE
Yield/quarter (kg)	2.360	.031	2.301	.031	1.940	.031	2.721	.031
Maximum rate (kg/min)	.640	.008	.619	.008	.570	.008	.689	.008
Duration of maximum rate (min)	2.455	.066	2.405	.066	2.411	.066	2.449	.066
Yield during period of maximum rate (kg)	1.450	.029	1.348	.029	1.239	.029	1.559	.029
Time to strip (min)	5.165	.085	5.326	.085	4.916	.085	5.575	.085
Strip time (kg)	2.479	.075	2.316	.075	2.726	.075	2.069	.075
Yield to strip (kg)	2.256	.031	2.189	.031	1.823	.031	2.622	.031
Strip yield (kg)	.104	.004	.112	.004	.117	.004	.099	.004
Average rate (kg/min)	.459	.006	.440	.006	.397	.006	.503	.006

[a]Least square means represent estimable functions of main effects averaged over interactions.

adjusted to account for yields and milking rates in different quarters. These changes may be worthwhile for possible hazards such as overmilking and incorrect machine control for certain quarters. Deviations from the front-rear and side patterns in interaction of side with front-rear for the yield traits are individual for each cow and may be more difficult to manage and less important. More work is needed to measure costs of overmilking and possible gains if milking machines could account for differences among quarters.

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