Relationships Among Udder Characteristics, Milk Yield, and Nonyield Traits[1]

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ABSTRACT

A total of 1604 udder measurements of the area bounded by the four teats was collected on 147 cows to determine relationships among udder area, indices of udder collapsibility, milk yield, rates of milk flow, California Mastitis Test scores, persistency of lactation, and visual appraisal of udder conformation. Direct measurements of the udder were highly repeatable both within and among lactations. Indices of udder collapsibility were not as repeatable. Correlations among udder measurements were large and positive. Milk yield on the day of measure was highly and positively correlated with udder measurements, but correlations with mature equivalent milk yield were lower. Correlations among udder measurements, rates of milk flow, persistency of lactation, and many traits of udder conformation were small. Larger udders were associated generally with higher mastitis test scores, with deeper udders that were more bulgy in front and looser in rear and with flatter udder floors. Indices of udder collapsibility were unrelated to visual appraisal of udder quality.

INTRODUCTION

The udder is one of the most important physiological and conformational characteristics of the dairy cow. However, few research data are available for objectively determining characteristics of the udder that are related to production and other physiologically and economically important traits. Burnside et al. (1) and Tomaszewski and Legates (6) reported positive correlations between udder depth and milk yield. Grantham et al. (5) has reported negative genetic and phenotypic relationships between "desirable" udder conformation and milk yield. Young et al. (7) reported that deeper udders were associated with increased incidence of mastitis. Donald (4) found that higher yielding cows tended to have larger udders as measured by the area bounded by four teats, and Burnside and Simpson (2) indicated a considerable reduction in udder dimensions after milking.

The objectives of this study were to characterize area measurements of the udder, and to examine phenotypic relationships among these measurements, milk yield, and other traits including udder conformation, persistency of lactation, California Mastitis Test (CMT) scores, and rate of milk flow.

MATERIALS AND METHODS

Data were collected in the Virginia Polytechnic Institute and State University dairy herd from October, 1969, through November, 1972. Milking rates were recorded twice per lactation (30 to 60 and 60 to 90 days postpartum). When the teat caps were attached a stopwatch was started, and milk weights were recorded from the metering device at 30-s intervals. Recording ceased when less than .45 kg of milk was produced in 30-s interval or when machine stripping was initiated. Total milk yield also was recorded. All milking rates and udder measurements were recorded once each month at the afternoon milking. A total of 434 observations on 147 cows was recorded. Variables calculated from rates of milk flow included peak flow (kg/min), average flow (kg/min), 2-min milk, 3-min milk, and machine time.

Udder measurements were recorded while cows were in the parlor during the first 30 days after calving if it appeared that the swelling from edema had subsided and every month thereafter through the 9th mo of lactation. A special template was placed in contact with tips

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of teats immediately after the udder had been washed prior to milking. The position of each teat was marked to denote the teat position before milking. When milking was completed, the template was placed again against the teats. Positions of the tips of the teats were marked to denote the location of teats after milking. A total of 1604 udder measurements made on 147 cows was included. Variables from the measurements were distances (cm) between fore teats before (FORE B) and after (FORE A) milking, rear teats (REAR B and REAR A), left side (LEFT B and LEFT A), right side (RIGHT B and RIGHT A), diagonally left front to right rear (LFRR B and LFRR A), area (Cm^2) bounded by the four teats before (AREA B), area after (AREA A), area before minus area after (ABMAA), coefficient of udder expansion (CUE) calculated as ABMAA divided by AREA A, and coefficient of udder collapsibility (CUC) calculated as ABMAA divided by AREA B.

Other traits in the analysis included milk yield in afternoon on the day udder measurements and milk flow rate were recorded; 2X-305 mature equivalent (ME) lactation production records, persistency of lactation, and CMT scores as recorded by the Southern Regional Dairy Records Processing Center; and visual appraisal of udder conformation including overall mammary system, fore udder and rear udder scored as 1 = excellent to 6 = poor, and several descriptive udder traits scored as shown in Table 1.

RESULTS AND DISCUSSION

Means and standard diviations are in Table 2. Average distances between teats before and after milking were similar to those reported by Burnside and Simpson (2), and Chyr et al. (3). Area before (AREA B), area after (AREA A), area before minus area after (ABMAA), CUC, and CUE values were slightly smaller than those reported by Tomaszewski and Legates (6). However, milk in afternoon and 305-day ME milk per cow were slightly higher in our study than those reported by Tomaszewski and Legates (6) or Chyr et al. (3). Milk flow characteristics are similar to those in other studies (3, 6). Means for udder measurements before and

TABLE 1. Descriptive codes visually to appraise udder conformation.

Trait	Code	Trait	Code
Udder depth	1 Too deep 2 Deep 3 Intermediate 4 Shallow	Udder floor	1 Defined halving 2 Too flat 3 Broken
		Udder quality	1 Soft 2 Intermediate 3 Meaty
Length, fore udder	1 Too long 2 Moderate 3 Short		
		Teat length, fore	1 Long 2 Normal 3 Short
Length, rear udder	1 High, wide 2 Intermediate 3 Narrow, low		
		Teat length, rear	1 Long 2 Normal 3 Short
Attachment, fore udder	1 Strong 2 Slightly bulgy 3 Bulgy 4 Loose, broken		
		Teat location	1 Front too wide 2 Well spaced 3 Rear too close 4 Side too close 5 Bunched
Attachment, rear udder	1 Strong 2 Intermediate 3 Loose, broken		

TABLE 2. Means and standard deviations for traits.

Trait	Mean	SD
Fore before (FORE B) (cm)	19.4	4.4
Fore after (FORE A)	15.5	4.3
Rear before (REAR B)	10.5	3.9
Rear after (REAR A)	7.9	3.8
Left before (LEFT B)	13.8	2.8
Left after (LEFT A)	10.8	2.4
Right before (RIGHT B)	13.4	2.9
Right after (RIGHT A)	10.5	2.4
Left front to right rear before (LFRR B)	19.7	4.3
Left front to right rear after (LFRR A)	15.5	4.1
Area before (AREA B) $(cm)^2$	193.1	85.2
Area after (AREA A)	118.1	64.0
Area before minus area after (ABMAA)	75.0	37.1
Coefficient of udder collapsibility (CUC)	.40	.12
Coefficient of udder expansion (CUE)	.73	.39
Peak flow (kg/min)	3.6	1.1
Average flow	2.4	.7
Machine time (min)	5.5	1.0
2-minute milk (kg)	5.2	1.8
3-minute milk (kg)	7.6	2.5
Total afternoon milk	10.1	3.3
305-day ME milk (kg)	8090.0	1399.0
Persistency (%)	101.4	6.7
CMT[a]	.4	.9
Mammary system	3.9	.9
Fore udder	4.0	.9
Rear udder	3.7	1.0
Udder depth	2.5	.7
Length, fore udder	2.2	.5
Length, rear udder	1.9	.6
Attachment, fore udder	2.3	.9
Attachment, rear udder	1.9	.7
Udder floor	1.3	.5
Udder quality	1.9	.5
Teat length, fore	2.0	.4
Teat length, rear	2.2	.4
Teat location	1.6	.7

[a]Negative = 0, Trace = 1, 1 = 2, 2 = 3, 3 = 4.

after milking indicated considerable reduction in dimensions after milking, with a 20 to 25% reduction in the space between the teats and a 40% (CUC) reduction in total area bounded by the teats.

Udder Measurements Over the Lactation

Monthly means and trends for mo 1 to 9 of lactation are in Fig. 1, 2, and 3 for udder measurements. Effects of lactation number and milk yield in afternoon on day of measure were included in the model to develop regression equations. There was generally a linear decline in distance between the teats for all traits from mo 1 through 6. This indicates that udder measurements could be recorded at any time during the first 6 mo of lactation and linearly regressed to a common base month with little sacrifice in accuracy. Coefficients of variation (Table 3) indicated that there was little difference in precision of these measurements from month to month. Coefficients of variation for mo 5 were silightly lower than the others. Therefore, mo 5 of lactation should be the optimal base month for recording these measurements or for adjustment to a common base month if these measurements were to be recorded once during the lactation. Additional justification for this conclusion is based upon regression analysis. The R^2 values were highest (.8 to .9) when data recorded in other months were regressed to mo 5.

Estimates of repeatability within and among lactations are in Table 4. Distance and area traits within lactations were similar to those reported by Chyr et al. (3). However, those for area change and measures of collapsibility were considerably less than those reported by Tomszewski and Legates (6). The magnitude of repeatabilities within and among lactations indicated that there was little need to record udder measurements more than once during a

TABLE 3. Coefficients of variation for each month of measure.

Month of lactation	Coefficient of variation (%)[a]		
	AREA B	AREA A	ABMAA
1	35	48	43
2	38	47	48
3	42	51	48
4	38	50	43
5	35	47	41
6	41	52	41
7	42	53	44
8	43	54	48
9	48	53	58

[a]Area between teats before milking (AREA B), after milking (AREA A), and area before minus area after (ABMAA).

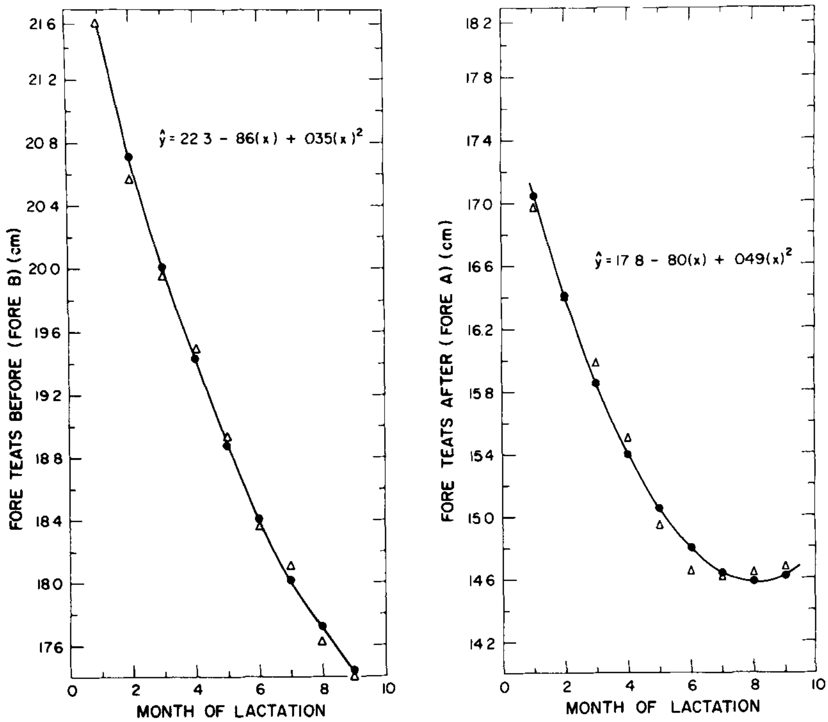

FIG. 1a. Regression for FORE B and FORE A on month of lactation.

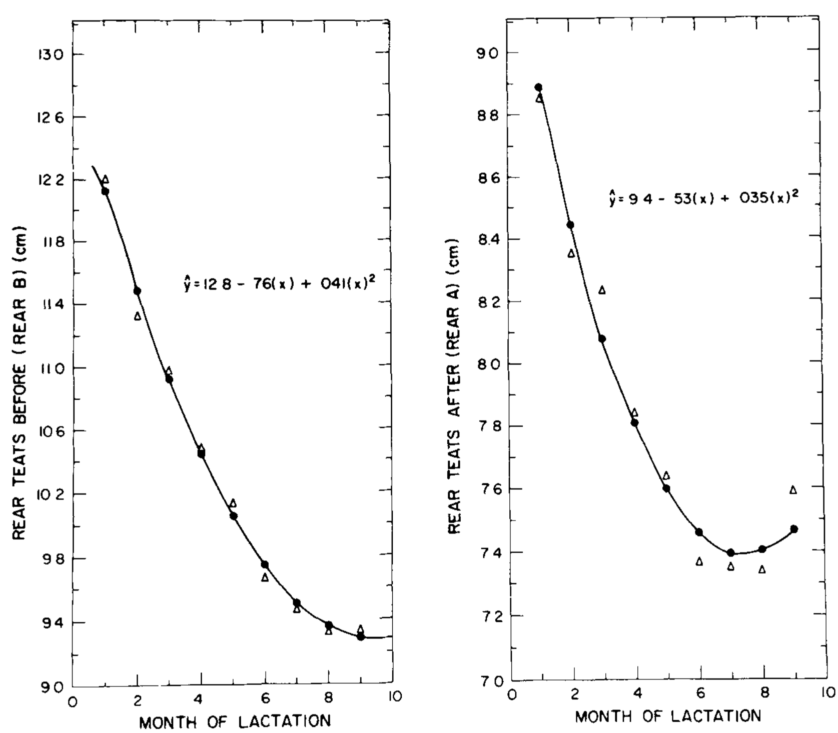

FIG. 1b. Regression of REAR B and REAR A on month of lactation.

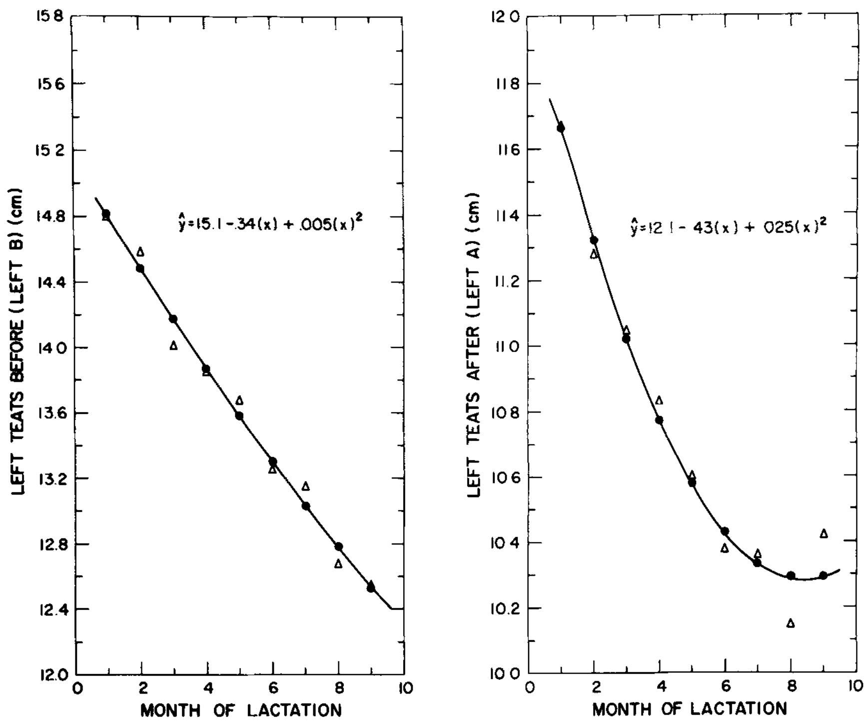

FIG. 2a. Regression of LEFT B and LEFT A on month of lactation.

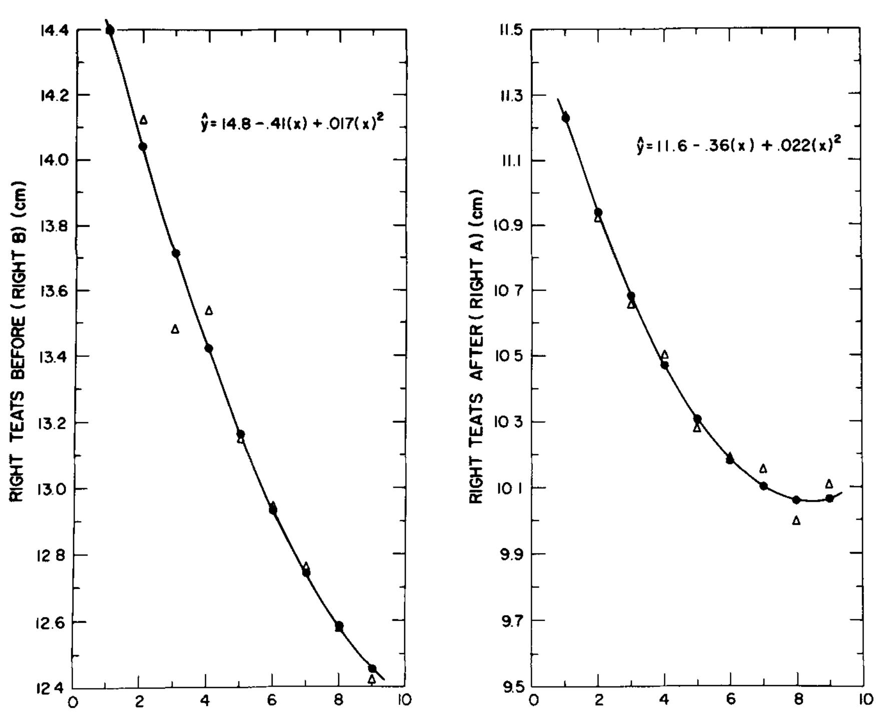

FIG. 2b. Regression of RIGHT B and RIGHT A on month of lactation.

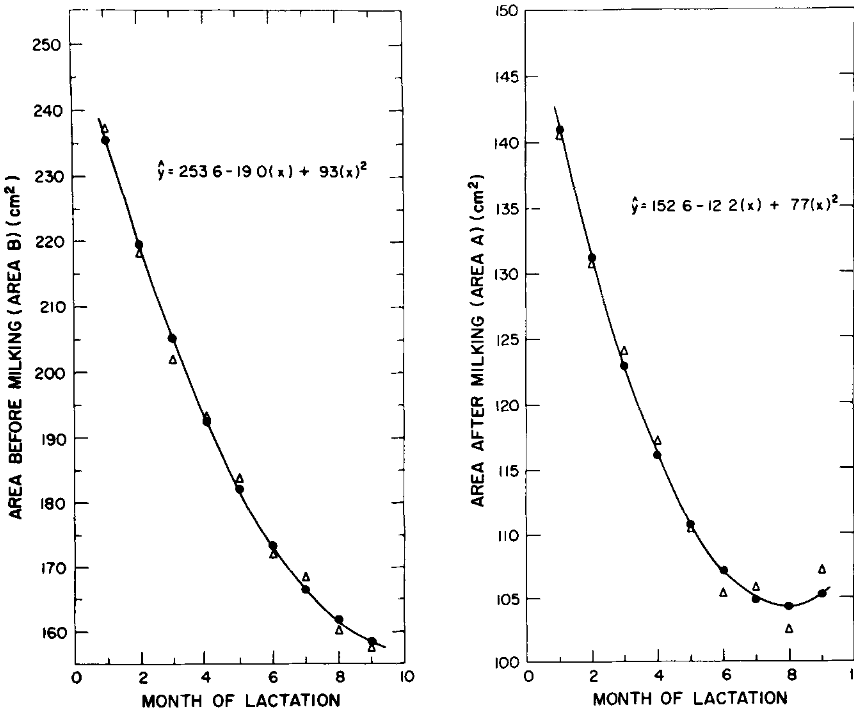

FIG. 3a. Regression of AREA B and AREA A on month of lactation.

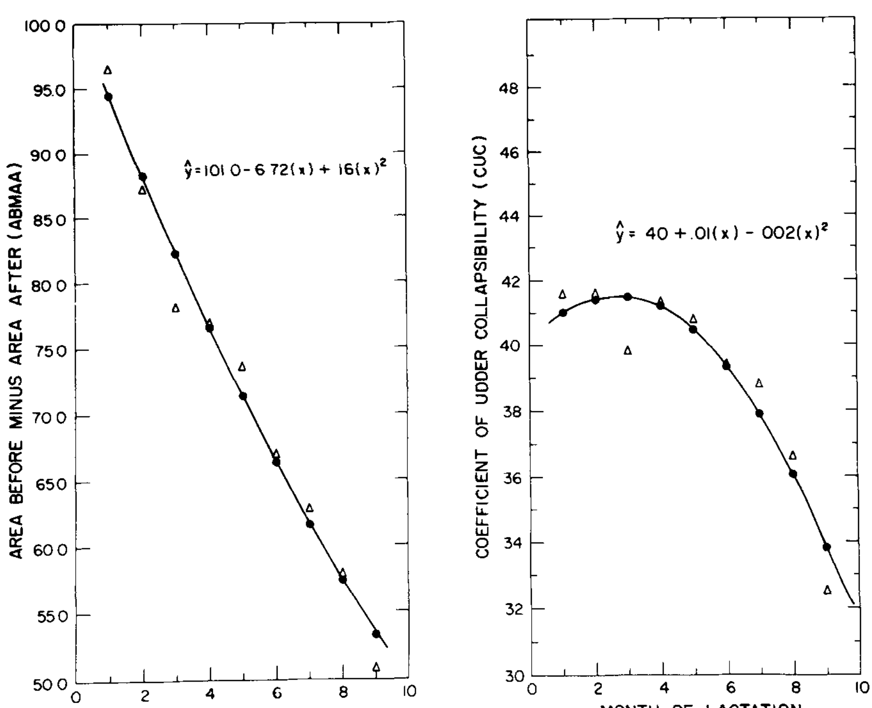

FIG. 3b. Regression of ABMAA and CUC on month of lactation.

TABLE 4. Repeatability of udder measurements within and among lactations.[a]

Trait	Within lactation	Among lactations
FORE B	.87	.81
FORE A	.84	.80
REAR B	.86	.80
REAR A	.79	.75
LEFT B	.66	.61
LEFT A	.72	.66
RIGHT B	.67	.62
RIGHT A	.70	.66
LFRR B	.76	.71
LFRR A	.79	.73
AREA B	.80	.72
AREA A	.83	.74
ABMAA	.34	.29
CUC	.48	.35
CUE	.27	.26

[a]Measurement abbreviations are defined in Table 2.

lactation and no more than twice during the lifetime of the cow.

Correlations Among Udder Measurements and Other Traits

Pheonotypic correlations among udder measurements were large and positive and between udder measurements and collapsibility indices were negative and considerably smaller (Table 5). These results agree with those of Chyr et al. (3). The highest positive correlations were between measurements before and after milking, between diagonal (LFRR B and LFRR A) and direct measurements (FORE B, FORE A, etc.), and between all direct and calculated area (AREA B and AREA A) measurements. Positive correlations were considerably smaller between fore and side and rear and side measurements and between area difference (ABMAA) and all other direct measures. Collapsibility indices were more highly correlated with milking measurements after milking than before (Table 5).

Correlations between udder measurements and milk yield, milk flow rates CMT, persistency, and udder conformation traits are in Table 6. These correlations were calculated several different ways. Udder measurements were averaged over the lactation for correlations with traits measured only once during the lactation (ME milk and udder conformation). Correlations of monthly observations were calculated for those traits that were measured monthly such as afternoon milk, CMT, and persistency. In addition, correlations among lactation averages for these three traits and udder measurements were calculated. For the traits of milk flow of rate, correlations were calculated using udder measurements recorded at the same time as flow rates (30 to 60 and 60 to 90 days after calving). Correlations among averages and among averages and individual observations were adjusted to a single measurement basis using the number of observations in the averages and repeatabilities of the traits involved.

All the direct udder measurements were positively correlated with both daily and ME milk yield ($P < .01$). These results agreed generally with those of Chyr et al. (3) and demonstrated a generally positive relationship between udder size and milk yield. However, none of the correlations was large enough to be useful as a phenotypic predictor of milk yield. Negative correlations between average in milk yield in afternoon, ME milk yield, and collapsibility indices were a result of the inverse relationship between udder size and collapsibility. However, only one of the correlations (−.18) was statistically significant.

Correlations between measurements of udder and rates of milk flow were positive but were moderate to small. This indicates that usefulness of udder measurements in predicting rate of milk flow would be limited. Similar results were reported by Tomaszewski and Legates (6).

Correlations among direct udder measurements and CMT scores were generally positive and significant. This indicates that larger udders may tend to be associated with greater udder stress or injury. However, the negative correlations between udder collapsibility indices and CMT scores indicated that udders that milk-out well tend to have lower cell counts. Correlations between udder measurements and persistency were generally small and not significant.

With a few notable exceptions, udder conformation scores were not correlated significantly with udder measurements. Udder depth was correlated negatively with udder measurements. This indicated that larger udders

TABLE 5. Phenotypic correlations among udder measurements[a].

	FORE B	FORE A	REAR B	REAR A	LEFT B	LEFT A	RIGHT B	RIGHT A	LFRR B	LFRR A	AREA B	AREA A	ABMAA	CUC
FORE A	.92													
REAR B	.75	.75												
REAR A	.69	.76	.90											
LEFT B	.51	.45	.46	.41										
LEFT A	.53	.53	.49	.45	.83									
RIGHT B	.43	.39	.39	.38	.79	.73								
RIGHT A	.44	.45	.42	.41	.72	.80	.83							
LFRR B	.82	.77	.84	.77	.76	.72	.67	.66						
LFRR A	.78	.84	.82	.85	.65	.75	.60	.66	.89					
AREA B	.81	.77	.85	.78	.79	.76	.76	.70	.94	.88				
AREA A	.77	.83	.82	.86	.66	.78	.64	.73	.87	.94	.92			
ABMAA	.53	.33	.52	.30	.67	.40	.63	.34	.66	.40	.72	.37		
CUC	-.21	-.44	-.25	-.48	.01[b]	-.33	-.02[b]	-.35	-.18	-.48	-.16	-.51	.51	
CUE	-.18	-.38	-.20	-.41	.00[b]	-.29	-.02[b]	-.32	-.15	-.40	-.14	-.45	.45	.89

[a]Measurement abbreviations are defined in Table 2.

[b]Not significant ($P > .05$); all others significant ($P < .01$).

TABLE 6. Correlations among udder measurements and other traits[a].

	FORE B	FORE A	REAR B	REAR A	LEFT B	LEFT A	RIGHT B	RIGHT A	LFRR B	LFRR A	AREA B	AREA A	ABMAA	CUC	CUE
PM milk[b]	.51	.38	.49	.36	.58	.50	.54	.46	.62	.48	.63	.48	.60	.12	.10
Avg PM milk[d]	.46	.42	.49	.44	.56	.57	.53	.53	.59	.56	.60	.55	.41	-.18	-.14
ME milk[d]	.24	.21	.28	.24	.35	.35	.32	.32	.36	.32	.35	.34	.22	-.10	-.02
Peak flow[c]	.16	.12	.13	.08	.31	.26	.31	.26	.25	.19	.25	.18	.25	.04	.03
Avg flow[c]	.09	.06	.06	.02	.23	.23	.27	.22	.18	.15	.17	.13	.18	.04	.02
2-min milk[c]	.14	.10	.09	.05	.28	.27	.31	.27	.23	.18	.22	.17	.21	.02	.01
3-min milk[c]	.20	.14	.16	.11	.36	.34	.37	.33	.31	.25	.31	.24	.28	.04	.03
Machine time[c]	.41	.33	.43	.35	.35	.32	.27	.30	.45	.37	.43	.36	.36	-.04	-.02
CMT[b]	.08	.14	.10	.16	.12	.17	.12	.18	.12	.19	.13	.20	-.05	-.18	-.16
Avg CMT[d]	.18	.22	.19	.25	.25	.26	.24	.28	.23	.27	.32	.37	.08	-.24	-.19
Persistency[b]	.08	.08	.11	.10	.12	.08	.09	.05	.08	.07	.12	.10	.10	.02	.02
Avg persistency[d]	.06	.06	.11	.10	.14	.12	.11	.11	.13	.12	.13	.11	.08	-.04	-.03
Mammary system[d]	.11	.16	.15	.18	.08	.12	-.03	-.01	.12	.15	.12	.16	-.04	-.14	-.11
Fore udder[d]	.13	.17	.10	.12	.08	.10	-.03	.01	.10	.12	.08	.11	-.04	-.12	-.09
Rear udder[d]	.07	.12	.17	.19	.01	.11	-.02	.00	.13	.15	.13	.17	-.05	-.13	-.09
Udder depth[d]	-.36	-.38	-.33	-.33	-.38	-.45	-.33	-.38	-.39	-.42	-.41	-.44	-.09	.28	.22
Fore udder length[d]	.06	.06	.01	-.02	.01	.04	.02	.02	-.04	.03	.00	-.02	.10	.00	.01
Rear udder length[d]	-.11	-.11	-.06	-.04	-.04	-.04	-.07	-.08	-.05	-.06	-.07	-.07	-.05	.02	.03
Fore udder att[d]	.24	.25	.21	.22	.22	.26	.15	.18	.22	.25	.24	.26	.14	-.18	-.14
Rear udder att[d]	.10	.12	.17	.20	.18	.19	.08	.11	.17	.18	.18	.20	.11	-.15	-.12
Udder floor[d]	.37	.42	.43	.46	.30	.34	.22	.28	.41	.46	.43	.49	.07	-.32	-.26
Udder quality[d]	.06	.08	.06	.08	-.06	-.05	-.10	-.07	-.01	.02	.01	.05	-.01	-.07	-.05
Fore teat length[d]	-.20	-.20	-.20	-.19	-.02	-.03	.02	-.01	-.14	-.15	-.13	-.14	-.01	.11	.08
Rear teat length[d]	-.09	-.09	-.17	-.15	.02	.01	.03	.02	-.09	-.08	-.08	-.08	-.01	.05	.04
Teat location[d]	-.20	-.19	-.21	-.20	-.02	.03	.01	.02	-.05	-.02	-.04	-.01	-.08	-.05	-.05

[a] Measurement abbreviations are defined in Table 2.

[b] Correlations: ⩾ .05, Significant ($P < .05$); and ⩾ .07, Significant ($P < .01$).

[c] Correlations: ⩾ .09, Significant ($P < .05$); and ⩾ .12, Significant ($P < .01$).

[d] Correlations: ⩾ .16, Significant ($P < .05$); and ⩾ .21, Significant ($P < .01$).

tended to be deeper. The positive correlations between udder measurements and fore and rear udder attachments indicated that larger udders were more bulgy and more loosely attached. Positive correlations between udder floor and udder measurements indicated that larger udders tended to be flatter with less defined halving. One of the purposes of this experiment was to develop an objective measure of udder quality. However, correlations between udder measurements and visual appraisal for udder quality were virtually zero.

CONCLUSION

Although direct udder measurements are rather easy to record and are highly repeatable both within and among lactations, their usefulness in predicting either production or milk flow rates is limited. Additionally, their relationships to CMT scores, persistency, and udder conformation were small. Therefore, it is doubtful that these measurements would find any lasting usefulness in dairy cattle breeding.

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