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Abstract

Milk flow measurements on 124 cows were analyzed to determine how they are affected by vacuum level, pulsation rate, pulsation ratio of the milking machine, and the breed, age, stage of lactation, and milk yield of the cow. Average rate of flow prior to machine stripping, yield during the first minute, and yield during the first 2 min of milking were highly correlated with maximum rate of milk flow. These measurements were significantly increased by days in milk, vacuum level, pulsation rate, pulsation ratio, and total yield. Age at calving had a slight effect on yield during the first minute of milking. The use of yield during the first 2 min of milking is outlined as a method for evaluation of milk flow of daughters of bulls used in artificial insemination.

With increased competition for labor in the dairy industry, more emphasis is being placed on increasing the efficiency of the milking operation. One measure of milking efficiency is number of cows milked per man-hour. This, in turn, is influenced by the milking rate of the cows. Milking rate is dependent, in part, upon the anatomy of the teat (1); therefore, it would appear to be a heritable trait and selection for faster milking cows would seem possible.

Selection for milking rate will probably receive emphasis in the future because of labor requirements, even though the amount of such selection by artificial breeding establishments at the present is somewhat limited and the subjective measurements, such as the farmer's opinion of a cow's milking rate, are somewhat crude. Since milking machine factors, such as vacuum level, pulsation rate, and pulsation ratio affect milking [for summary, see Schmidt et al. (6)], selection for a particular milk flow determination should be done under standardized conditions or the milk flow records corrected for a standard vacuum level, pulsation rate, and ratio.

The objectives of this study were to determine the influence of machine factors, age, stage of lactation, breed, and milk yield on milk flow measurements and to develop a procedure to evaluate the milk flow characteristics of daughters of bulls used in artificial breeding organizations.

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Experimental Procedure

Part of the data from which milk flow rate correction factors have been developed have been reported previously (5, 6). These papers reported the effect of changes in milking machine design on the milk flow determinations.

Milk flow measurements were made with a milker pail suspended from a dairy scales. Milk yields were recorded at 15-sec intervals. Machine stripping was begun when the yield dropped .14 kg or less during a 15-sec interval. The machine was removed when milk flow had stopped. The cows in the experiments were milked for periods ranging from 14 to 56 days, with 59% of the cows milked for 28-day periods. Morning milk flow measurements were recorded on Days 1, 4, and 7 of the first week and twice during each succeeding week. Milk flow determinations reported in this paper are averages for the experimental periods.

Measurements obtained include time before machine stripping, machine stripping time, total milking time, yield before machine stripping, machine stripping yield, total milk yield, average rate of flow prior to machine stripping, average rate of flow including machine stripping, maximum rate of milk flow (peak flow rate), yield during the first minute of milking, yield during the second minute of milking, and yield during the first 2 min of milking. The machine factors measured were: vacuum levels, 12, 12.5, 15, 18, and 24 in. Hg; pulsation rates, 40, 50, 60, 80, and 120; and pulsation ratios, 1:1, 2:1, 3:1. Other variables studied in these trials but not included in the analyses were type of liner, type of milker unit, presence or absence of an air bleed in the claw, and adding weights to the teat cup claw assembly. Two types of milker units, De Laval and Perfection, were used.

Most cows produced between 9 and 14 kg of milk during the morning milking and were past their peak of lactation when the experiments were begun. Cows of all age groups were included. Age was calculated in months at the time when the experiment was begun, which is

different from most experiments, where age is calculated at the time of calving.

Three breeds used were Holstein, Ayrshire, and Brown Swiss. A total of 368 experimental periods with 124 cows were conducted using various combinations of milking machine factors. These involved 11 Ayrshire, 15 Brown Swiss, and 98 Holstein cows.

Simple correlation coefficients were calculated among the variables used in the study and are shown in Table 1. The independent and dependent variables used in the study are listed in Table 2. Partial regression coefficients and squared multiple correlation coefficients (R^2) were calculated from multiple regression analyses. The residual mean squares are the mean-square deviations from regression. In the first analysis, all 15 independent variables were used (Table 2). In the second analysis, the quadratic independent variables and product variables were eliminated (Table 3). The third analysis (Table 4) included independent variables that had standard partial regression coefficients outside the range of ±0.10 in the second analysis. The fourth analysis included independent variables with the three or four highest standard partial regressions. The fifth analysis included only milk yield as the independent variable. The simple correlations had 367 degrees of freedom and the degrees of freedom for the regressions were equal to the number of observations minus number of independent variables minus one.

Results and Discussion

In developing a selection program for milk flow determinations, it is desirable to use only one measurement. Griffin and Dodd (4) concluded that maximum rate of milk flow is the most valuable single measure of milking rate that can be used in a breeding program, their reasons being that the milking rate is anatomically controlled (1), the maximum rate of flow has the greatest influence on the milking time of the cow (3), and since most milk flow determinations are influenced by milk yield, the maximum rate of flow in early lactation is less related to milk yield at the time of recording than the other measures (3).

Four of the dependent variables measured

TABLE 1. Simple correlation coefficients among the variables in the study.[a]

Variable	Time before strip.	Total milking time	Strip. yield	Rate of flow Avg	Rate of flow Max	Yield 1 min	Yield 2 min
	(min)	(min)	(kg)	(kg/min)	(kg/min)	(kg)	(kg)
Breed	−.18	−.14	.07	.22	.23	.17	.18
Breed (A vs. B)[b]	.15	.12	−.02	−.14	−.15	−.11	−.12
Days in milk	−.32	−.28	.13	−.02	−.06	−.02	−.09
Age (months)	−.01	.09	.25	.04	.07	.16	.10
Vacuum (inches Hg)	−.40	−.20	.35	.46	.46	.53	.44
Pulsation rate	−.25	−.20	.13	.26	.22	.25	.19
Pulsation ratio	−.27	−.16	.24	.26	.27	.31	.23
Vacuum × rate	−.37	−.24	.29	.41	.37	.43	.32
Vacuum × ratio	−.32	−.22	.25	.33	.29	.35	.25
Rate × ratio	−.30	−.20	.25	.30	.28	.33	.23
Milk yield (kg)	.36	.41	.32	.27	.35	.23	.39
Time before stripping (min)		.84	.02	−.73	−.64	−.69	−.64
Total milking time (min)			.49	−.63	−.53	−.54	−.54
Stripping yield (kg)				.04	.07	.14	.05
Average rate (kg/min)					.93	.90	.92
Maximum rate (kg/min)						.88	.93
Yield, 1 min (kg)							.92

[a] Values greater than ±.10 are significantly different from zero at the 5% level of probability and those greater than .13 are significant at the 1% level of probability.

[b] Ayrshire versus Brown Swiss.

in the study are not listed in the tables. These include stripping time, yield before stripping, average rate of flow including stripping, and yield during the second minute. Stripping time was not included because it was highly correlated with stripping yield (+.86) and the R^2 value in the first analysis was only .16, which indicates that very little of the variation in stripping time could be explained by the independent variables used in this study. Yield before stripping was eliminated from the study because of its high correlation with total milk yield (+.96). Average rate of flow including stripping time and yield was eliminated because of the high correlation with the average rate of flow before machine stripping (+.90). The R^2 value for predicting average rate of flow including machine stripping was 0.26 for all variables studied; whereas, the R^2 value for predicting the average rate of flow before machine stripping was .42 (Table 2). Average rate of flow including stripping includes the variation of machine stripping, which is influenced by machine factors, such as vacuum level, pulsation ratio, pulsation rate and their interactions, as well as days in milk and age (Table 1). Yield during the second minute was eliminated because of its relatively low correlation with maximum rate of flow (0.66). In contrast, yield during the first minute and yield during 2 min had much higher correlations with maximum rate of flow (Table 1).

The determination of maximum rate of flow requires specialized equipment and becomes somewhat cumbersome to perform on commercial dairy farms. It requires either a kymograph to record milk yields or a technician or dairyman to record yields at various time intervals. For this reason, emphasis has been placed on using measurements that have high correlations with maximum rate of milk flow. Griffin and Dodd (4) indicated that yield obtained during the second minute of milking gave a good prediction of a maximum rate of milk flow, since they found a correlation of +.945 between the two measures. Their animals were limited to first- and second-lactation cows in their first three months of lactation. Results of the trial reported here indicate that the yield during the second minute of milking has a much lower correlation with maximum rate of flow than does yield during the first minute or yield during the first 2 min. Beck et al. (2) found a correlation of 0.922 between percentage of milk yield obtained during the first 2 min of milking and machine time. They defined machine time as the time between application of the fourth teat cup and completion of milking. No correlation coefficient was reported between percentage yield in 2 min and maximum rate of flow.

If maximum rate of flow is the best measure of inherited milk flow rate, the results of this experiment indicate that yield during the first 2 min and average rate of flow prior to machine stripping give good estimates of maximum flow rate, both having correlation coefficients of +0.93. These measurements can be obtained in milking parlors with accurate weigh jars or Milk-O-Meters, in which yield is recorded either at the end of 2 min or just prior to machine stripping.

The relationships among vacuum levels, pulsation rates, and ratios have been reported previously (6). Increases in vacuum level, pulsation rate, and ratio reduce the time prior to machine stripping and total milking time and increase stripping yield (Table 1).

Results in Table 2 indicate that 42 to 50% of the variation in time before stripping, average and maximum rates of flow, and yields during the first minute and first 2 min can be accounted for by the 15 variables studied in this trial. One variable not analyzed in this trial was the differences due to cows. A large portion of the remaining variation might be attributable to differences among cows. These differences were not measured because the primary emphasis was to measure the effect of the machine factors that influence milking rate.

Three breeds were used, thus only two degrees of freedom were available to compare breed differences. Least-squares estimates of breed differences compared Holsteins to Ayrshires and Brown Swiss (H vs. A and B) and Ayrshires to Brown Swiss (A vs. B). Holsteins differed significantly from the Ayrshires and Brown Swiss in average and maximum rates of flow and yield during the first minute. There were no significant differences between the Ayrshire and Brown Swiss (Tables 2, 3, and 4). In most cases, the Holsteins had the fastest rate of milk flow, independent of milk yield.

Results in Table 3 indicate that days in milk at the start of each experimental trial had a significant effect on the milk flow measurements, with the exception of stripping yield. Even though the partial regression coefficients were significantly different from zero, they are of little relative importance, since 100 days' difference in the days in milk at the time of the experimental trial would result in a difference of only 0.3 kg in the maximum rate of milk flow. Age at the start of each trial had no

TABLE 2. Partial regression coefficients and squared multiple correlation coefficients (R^2) using all variables in the study.

Independent variable	Dependent variable: Time before strip.	Total milking time	Strip. yield	Rate of flow: Avg	Rate of flow: Max	Yield: 1 min	Yield: 2 min
	(min)	(min)	(kg)	(kg/min)	(kg/min)	(kg)	(kg)
Breed (H vs. A and B)[a]	−.34	−.27	.17	.32*	.44*	.55*	.59
Breed (A vs. B)	.14	.19	.06	.01	−.08	−.05	−.18
Days in milk	−.001	.005	.004**	−.0001	.0001	.001	.001
$Days^2$	−.000008	.00002**	.000008**	.000007*	.000008	.000006	.00001
Age (months)	.003	.006	.010	−.005	.002	.017	.006
Age^2	−.00004	−.00004	−.00004	.00004	.000008	−.00006	.0000006
Vacuum (inches Hg)	−.72**	−.76**	−.17	.39**	.58**	.69**	1.39**
$Vacuum^2$	.013**	.016**	.006**	−.009**	−.013**	−.011**	−.027**
Rate	−.076	−.051	.006	−.002	.004	.045	.110
$Rate^2$	.001	.00006	−.0001	−.0001	.0001	−.00006	−.0003
Ratio	−.60**	−.65*	.01	.41**	.63**	.60**	1.18**
Vacuum × rate	.003	−.002	−.0006	.001	.001	−.001	−.050
Vacuum × ratio	−.00001	.000004	.000007	−.000009	−.00001	.0000004	.00002
Rate × ratio	.004	.006	.002	−.002	−.004	−.003	−.009*
Milk yield (kg)	.07**	.12**	.04**	.06**	.09**	.07**	.17**
R^2	.50	.35	.34	.42	.46	.46	.45
Residual mean square	.79	1.85	.33	.49	.79	1.33	2.70

* $P < 0.05$ student's "t" test.
** $P < 0.01$ student's "t" test.
[a] Holstein versus Ayrshire and Brown Swiss.

significant effect on milk flow measurements for analyses shown in Table 2, but analyses with fewer independent variables showed that age had a significant effect on stripping yield and yield during the first minute (Tables 3 and 4). A 12-month difference in age at a milk flow determination would affect the yield during the first minute by approximately 0.1 kg.

Reducing the number of independent variables from 15 to 8, as shown in Table 3, caused some reduction in the percentage of the variation attributable to the independent variables. In most cases, the R^2 values were reduced by about 5%; i.e., total milking time was reduced from 35 to 30%. The milk flow measurements, except stripping yield, were significantly affected by days in milk, vacuum level, pulsation rate, pulsation ratio, and milk yield.

The third analysis eliminated the Ayrshire versus Brown Swiss comparison and the age effect, except for analyses of stripping yield and yield during the first minute. There was no marked decrease in the percentage of the variation accounted for by the other variables (Table 4). Using only three or four independent variables in the fourth analysis (Table 4) resulted in a marked reduction in the percentage of variation accounted for by regression. For example, the R^2 for predicting maximum rate of flow decreased from 42 to 33%. In most cases, days in milk, vacuum level, and milk yield were included as independent variables and had significant effects on the milk flow measurements. Using only milk yield as the independent variable resulted in a marked decrease in the percentage of the variation attributable to the independent variable (fifth analysis, Table 4). These results indicate that maximum rate of milk flow or its indicators, such as yield during the first minute, yield during the second minute, or average rate of flow, need to be adjusted for days in milk, vacuum level, pulsation rate, pulsation ratio, and daily milk yield when it is used to evaluate the milking rate of a group of cows.

Application to Sire Evaluation

Milk flow data on dairy cows will be used primarily by artificial breeding organizations to evaluate sires. The initial proving of sires is done as early as possible in the sire's life, to practice maximum utilization of the best proven sires. The selection is usually made on first-lactation records or even on partial lactation records. If the measurements were made during the second and third months of lactation, the largest adjustment of maximum rate of flow due to days would be 0.18 kg and could probably be eliminated. Use of first-lactation records would also minimize the effect of age.

TABLE 3. Partial regression coefficients and R^2 values using a limited number of independent variables.

Independent variable	Dependent variable						
	Time before strip.	Total milking time	Strip. yield	Rate of flow		Yield	
				Avg	Max	1 min	2 min
	(min)		(kg)	(kg/min)		(kg)	
Breed (H vs. A and B)	−.28	−.23	.19	.28*	.39*	.48*	.51
Breed (A vs. B)	.106	.080	.025	.032	−.036	−.006	−.100
Days in milk	−.004**	−.004**	.0004	.003**	.003**	.004**	.005**
Age (months)	−.002	.003	.006**	−.00008	.002	.008**	.005
Vacuum (inches Hg)	−.14**	−.10**	.05**	.10**	.12**	.20**	.22**
Pulsation rate	−.009**	−.012**	.002	.007**	.007**	.010**	.011**
Pulsation ratio	−.28**	−.21*	.15**	.21**	.29**	.39**	.44**
Milk yield (kg)	−.06**	.11**	.04**	.06**	.10**	.08**	.19**
R^2	.45	.30	.29	.39	.42	.43	.39
Residual mean square	.84	1.96	.35	.51	.84	1.36	2.95

* $P < 0.05$ student's "t" test.
** $P < 0.01$ student's "t" test.

TABLE 4. Partial regression coefficients and R^2 values using selected independent variables.

Independent variable	Dependent variable						
	Time before strip.	Total milking time	Strip. yield	Rate of flow		Yield	
				Avg	Max	1 min	2 min
	(min)		(kg)	(kg/min)		(kg)	
	Third analysis						
Breed (H vs. A and B)	−.29[a]		.20[a]	.26	.37	.48	.45[a]
Days in milk	−.005	−.003		.003	.004	.004	.006
Age (months)			.006			.008	
Vacuum (inches Hg)	−.14	−.11	.05	.10	.12	.20	.22
Pulsation rate	−.009	−.013		.007	.007	.010	.011
Pulsation ratio	−.28		.15	.21	.30	.39	.46
Milk yield (kg)	.06	.11	.03	.06	.10	.08	.19
R^2	.45	.28	.29	.39	.42	.43	.39
Residual mean square	.84	1.99	.35	.50	.84	1.36	2.94
	Fourth analysis						
Days in milk	−.004			.002	.003	.005	.005
Age (months)			.005				
Vacuum (inches Hg)	−.17		.06	.12	.15	.21	.26
Pulsation ratio						.48	
Milk yield (kg)	.07		.03	.06	.09	.09	.18
R^2	.37		.25	.30	.33	.39	.34
Residual mean square	.96		.36	.57	.95	1.46	3.17
	Fifth analysis						
Milk yield (kg)	.08	.13	.04	.05	.08	.07	.16
R^2	.13	.17	.10	.07	.12	.05	.15
Residual mean square	1.32	2.27	.43	.75	1.24	2.23	4.04

[a] All partial regression coefficients are highly significant ($P < 0.01$) by student's "t" test, except those marked by [a], which are significant ($P < 0.05$).

All sire proving would be done within breed, so breed corrections could be eliminated.

The variation in the pulsation rate of milking machines used in the United States is small; therefore, the change in milk flow measurements due to rate would be relatively small. A change of 20 pulsations per minute would change the maximum rate of flow by only .14 kg. From a quantitative standpoint the three components that contribute most to the variaion in milk flow measurements are vacuum level, pulsation ratio, and milk yield.

A program of measuring the inherited milk flow rate of daughters of a bull could be implemented. Since the yield during the first 2 min is highly correlated with maximum rate of flow, and since it is somewhat easier to obtain than the average rate of flow, it would be the method of choice. This measurement could be obtained in a milking parlor with calibrated weigh jars or Milk-O-Meters, or could be obtained in stall barns by a milker pail suspended from a scales attached to a tripod. In most cases, the milk flow measurements need to be made on a relatively small sample of daughters; consequently, all measurements could be confined to milking parlor installations. Since the milk flow measurements are highly repeatable from day to day, from week to week, and from lactation to lactation during similar stages of lactation (2), one or two measurements per cow would suffice. These records

could be collected on first-calf heifers during early lactation. Yields during the first 2 min of milking could be corrected to a standard vacuum level, pulsation rate, pulsation ratio, and daily milk yield, and the milking rates of daughters of bulls thus compared.

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