Input-Output Studies With Dairy Cows Using Controlled Grain Feeding and Free-Choice Roughage Intake

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Since feed is usually considered to be the largest single item of cost in milk production, the optimum ration is of great economic importance to the dairyman. Numerous investigations have shown that the return over feed cost per 100 pounds of 4% fat-corrected milk (FCM) was greater for a low grain-high roughage ration than for a ration of high grain-low roughage composition (1, 2, 4, 5, 11, 12). However, efficiency from this standpoint is not always the most profitable feeding plan. The point at which the greatest net return can be realized is where the cost of the last unit of feed added equals the value of the additional milk produced.

The "rule of thumb" system is used quite extensively in allotting grain to dairy cows, although there is considerable disagreement among dairymen as to what ratio of grain to milk is optimum for the greatest economic return (1, 4, 5, 9, 11, 12). The daily recommended allowance for each additional pound of FCM above maintenance is 0.32 pounds of TDN as prescribed by the Committee on Animal Nutrition of the National Research Council (3) and by Morrison (10). However, in the various commonly used methods of apportioning concentrates to cows, changing grain-cost and milk-price conditions are not considered.

In order to prescribe the most profitable level of feeding to use under various feed-cost and milk-price conditions an estimation of the amount of milk to expect from a given input of feed must be available. A quite extensive study was made by Jensen *et al.* (7) in which 469 yearly milk production records were used. Functions describing feed input-milk output relationships were obtained and supplemented with grain-cost/milk-price ratios to determine the most profitable rate of feeding for various cost-price conditions. This study provided for cows to be fed at stomach capacity, *i.e.,* controlled grain feeding with free and unlimited access to forage.

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Heady *et al.* (6) described a study in which milk production functions were formulated which described feed input-milk output relationships under particular conditions and grain-hay substitution rates. The variables considered in the model were grain intake, hay intake, time point in the lactation period and producing ability of the cow. With a function of this type the most profitable levels of grain and hay to feed may be determined for given prices of grain, hay, and milk, within the limitations connected with the study.

Since roughage is usually a cheaper source of nutrients than is grain in the Southwest, the primary objective of the work conducted at this station was to derive mathematical functions which would describe feed input-milk output relationships under conditions where roughage is fed free-choice. Such a function could be supplemented with feed-cost/milk-price ratios to specify the most profitable feeding plan.

The study described in this report was conducted primarily for the purpose of exploring this particular approach to determining economic optima in dairy cattle feeding. The treatments to which the animals were subjected are representative of practical conditions in Oklahoma with respect to roughage allowance, type and quality of roughage, grain allowance, and management of the cows.

EXPERIMENTAL PROCEDURE

Design of the Experiment

Twelve Holstein cows selected from the Oklahoma State University dairy herd were assigned at random to three groups. During three successive 30-day periods each group was subjected to three levels of grain feeding in a manner described by a 3 x 3 Latin-square experimental design. After completing this 90-day experimental period, the cows were re-randomized into new groups and the revised groups were given the three levels of grain for another 90 days as in the previous period.

Feeding and Management

The cows were placed on trial approximately four weeks after calving. All the cows began the trial at the same time except two which began one month later. Excellent quality sorghum silage and good quality alfalfa hay were available to the cows free-choice at all times. The three levels of grain feeding used were 110%, 70% and 42% of Morrison's recommended grain allowances for cows receiving liberal allowances of roughage. The composition of the concentrate mixture was such that a nutritionally balanced ration resulted when it was fed with the roughage used in this trial.

Milk weights were recorded twice daily and butterfat tests were made monthly. Weekly adjustments in grain allowances were made in accordance with the cows' most recent production and butterfat percentage.

Statistical Procedure

For the purpose of statistical treatment of the data, 18 ten-day totals of 4% FCM production and grain consumption were obtained from the two 90-day experimental periods. The following equation was fitted to the data to describe the input-output relationship when three variables were considered: $Y = f\ (X_1,X_2,X_3)$. Here, Y refers to FCM production for a 10-day period, X_1 refers to grain consumption for the 10-day period, X_2 refers to the 10-day period during the lactation (periods 1, 2, etc.), and X_3 refers to the producing ability of the cow measured by production of 4% FCM in a preliminary period.

RESULTS AND DISCUSSION

Three milk production functions were obtained from the 180-day data shown in the Appendix. Function (I) was obtained by fitting the equation to the data obtained during all 18 of the 10-day periods of the experiment. Function (II) was derived by omitting the first 10 days spent on each level of grain-feeding and fitting the equation to only the last 20 days of each 30-day period. Function (III) was determined by using only the last 10 days of each of the 30-day periods. Functions (II) and (III) were derived in an attempt to determine whether or not carry-over effects were influencing the milk production response for the different rates of grain feeding.

The three production functions derived are as follows:

$$\text{(I)}\quad Y=5.106\, X_1^{.2202}\, X_2^{-.1075}\, X_3^{.5616}\quad R^2=.6572$$

$$\text{(II)}\quad Y=5.096\, X_1^{.2153}\, X_2^{-.1316}\, X_3^{.5733}\quad R^2=.6665$$

$$\text{(III)}\quad Y=4.524\, X_1^{.2220}\, X_2^{-.1380}\, X_3^{.5898}\quad R^3=.6807$$

The R^2 values (percentage of variation in milk production explained by the equation) of the above equations are lower than that of the following equation derived by Heady *et al.* (6). M represents milk output, H is hay intake, G is grain intake, A is producing ability of the cow, and T is a time period during the lactation.

$$M=4.1937\, H^{.1506}\, G^{.3082}\, A^{.3716}\, T^{-.1973}\quad R^2=.7490$$

This difference in R^2 values can be explained probably by the fact that the roughage intake was limited to prescribed amounts in the Heady study while in this study roughage intake was not controlled or measured.

A function of this type which adequately characterizes input-output relationship under given conditions may be supplemented with grain-cost/milk-price ratios to obtain values which would represent the most profitable amount of grain to feed under the given conditions.

By obtaining the partial derivative, $\frac{\delta m}{\delta g}$, and equating it to the grain-milk price ratio, $\frac{Pg}{Pm}$, the optimum level of grain feeding may be determined:

$$Y = 4.524\ X_1^{.2220}\ X_2^{-.1380}\ X_3^{.5898}$$

$$\frac{\delta m}{\delta g} = 1.004\ X_1^{-.7780}\ X_2^{-.1388}\ X_3^{.5898}$$

$$\frac{Pg}{Pm} = 1.004\ X_1^{-.7780}\ X_2^{-.1388}\ X_3^{.5898}$$

Using Function (III) with producing ability and time period assigned constant values and various grain-cost/milk-price ratios, the following table was prepared to serve as an illustration of one of the practical economic aspects of refined milk production-prediction equations of this type. The grain level was determined where the value of the added input of grain would equal the value of the resulting increase in output of milk. This level of grain allowance represents the most profitable level at which to feed a cow of a certain production capacity, during a particular period during the lactation, under various grain-cost/milk-price conditions when roughage is of similar type to that used in this study and is fed free-choice. These values were determined entirely for exploratory purposes with respect to the practical aspects of this approach to determining economic optima in dairy feeding. The values obtained appeared quite logical from a nutritional and economical standpoint.

GENERAL DISCUSSION

It is believed that the approach to determining optimum feeding rates for dairy cows by using input-output and cost-price relationships is quite logical. The dairy farmer's problem is not one of feeding at a

Table 1.—Example of Daily Recommended Grain Allowances for Cows Allotted Roughage Free-Choice, at Three Producing-Ability Levels, for the First 10-day Period After the Peak of Lactation, Based on a Function Predicted from a 12-cow Experiment, 1956-57.

Price of Grain per Cwt.	Price of Milk Per Hundred Pounds																	
	$3.50			$4.00			$4.50			$5.00			$5.50			$6.00		
	Producing Ability at Peak of Lactation (Pounds per Day)																	
	30	50	70	30	50	70	30	50	70	30	50	70	30	50	70	30	50	70
$2.00	13.3	19.6	25.3	15.2	22.4	28.9	17.1	25.2	32.5	19.0	27.9	36.1	20.9	30.7	39.6	22.8	33.5	43.3
$2.50	10.6	15.7	20.2	12.1	17.9	23.1	13.7	20.1	26.0	15.2	22.4	28.9	16.7	24.6	31.7	18.2	26.8	34.6
$3 00	8.9	13 0	16.8	10 1	14.9	19.2	11.4	16.8	21.7	12.7	18.6	24.0	13.9	20.5	26.5	15.2	22.4	28.9
$3.50	7.6	11.2	14.4	8.7	12.8	16.5	9.8	14.4	18.6	10.8	16.0	20.6	11.9	17.6	22.7	13.0	19.2	24.7
$4.00	6.6	9.8	12.6	7.6	11.2	14.4	8.5	12.6	16.3	9.5	14.0	18.0	10.4	15.4	19.9	11.4	16.8	21.7
$4.50	5.9	8.7	11.2	6.8	9.9	12.8	7.6	11.2	14.4	8.4	12.4	16.0	9.4	13.8	17.8	10.1	14.9	19.2

level to maximize milk output per cow nor feeding at a level where greatest technical efficiency is attained; rather, the problem is one of determining the level of feeding which pays best as feed costs and milk prices change.

In this study grain-hay substitution rates were not considered. This is not believed to be a fallacy since in this area of the country roughage is usually available at a farm value considerably less than the price of grain; and self-feeding roughage usually saves considerable labor costs. If areas or conditions are such that restricted roughage allowance may be necessary, an input-output relationship model which includes hay-grain substitution rates would be more applicable.

Feeding rates derived from production functions have little practical value when applied under conditions that differ greatly from those under which the data were obtained. Due to the tremendous variation in climate, soil conditions, types of crops, methods of feeding and management, and many other factors, one research model will not be relevant to all areas of the country. Also, new developments in all the fields related to dairy farming will cause input-output relationships to change over periods of time.

SUMMARY

A feeding trial was conducted in order to derive mathematical functions which would describe grain-input/milk-output relationships under various conditions. Roughage was fed free-choice in unlimited amounts while grain was allotted at three measured levels. The three levels of grain feeding used were 110%, 70% and 42% of Morrison's recommendations. Twelve cows were assigned the three grain feeding levels for 180 days in a manner prescribed by a 3 x 3 Latin-square experimental design.

The equation which best described the input-output relationship of the experimental data is as follows:

$$Y = 4.524 \, X_1^{.2220} \, X_2^{-.1380} \, X_3^{.5898}$$

Y refers to 4% FCM output, X_1 to grain intake, X_2 to the time period during the lactation (periods 1, 2, etc.), and X_3 to producing ability of the cow measured by production of FCM in a preliminary period. Such a function can be supplemented with grain-cost/milk-price ratios to specify the most profitable feeding plan under various grain-cost and milk-price conditions. This study was largely methodological in nature, conducted for the purpose of exploring this particular approach to determining economic optima in feeding dairy cattle.

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APPENDIX

Feed Consumption and 4 Percent FCM Production per 10-Day Period and Bodyweight per 30-Day Period.

10-Day Time Period During the Trial	Cow No. 1 Conc.	Cow No. 1 FCM	Cow No. 1 Bwt.	Cow No. 2 Conc.	Cow No. 2 FCM	Cow No. 2 Bwt.	Cow No. 3 Conc.	Cow No. 3 FCM	Cow No. 3 Bwt.	Cow No. 4 Conc.	Cow No. 4 FCM	Cow No. 4 Bwt.
	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
Preliminary	---	478	1203	---	523	1325	---	584	1279	---	580	1312
1	170	468		230	531		230	573		171	465	
2	176	515		242	543		224	488		192	580	
3	198	483	1273	241	542	1363	184	494	1313	211	584	1325
4	70	425		100	570		77	505		80	485	
5	64	362		94	520		64	471		74	462	
6	51	345	1217	88	451	1410	60	430	1320	61	457	1325
7	77	353		110	474		84	381		110	459	
8	70	332		104	445		70	380		110	467	
9	70	340	1317	100	442	1434	70	376	1350	101	435	1340
10	123	411		90	382		50	363		172	487	
11	130	401		90	372		50	354		218	508	
12	121	391	1318	90	379	1384	48	268	1329	221	492	1317
13	40	346		159	440		60	274		80	480	
14	40	340		180	440		60	260		80	482	
15	40	323	1267	198	452	1404	60	262	1342	82	485	1278
16	60	301		80	412		90	268		150	557	
17	66	300		74	355		84	242		144	544	
18	70	307	1237	61	355	1329	71	242	1360	140	551	1268

APPENDIX—Cont.

10-Day Time Period During the Trial	Cow No. 5 Conc.	Cow No. 5 FCM	Cow No. 5 Bwt.	Cow No. 6 Conc.	Cow No. 6 FCM	Cow No. 6 Bwt.	Cow No. 7 Conc.	Cow No. 7 FCM	Cow No. 7 Bwt.	Cow No. 8 Conc.	Cow No. 8 FCM	Cow No. 8 Bwt.
	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
Preliminary	---	428	1290	---	268	1370	---	521	1388	---	350	1301
1	100	380		67	258		124	375		64	300	
2	100	406		60	272		110	392		56	282	
3	100	390	1378	69	277	1448	119	369	1411	51	266	1318
4	150	393		110	328		180	435	87	341		
5	162	397		116	339		180	302		74	335	
6	161	384	1387	118	315	1470	156	351	1470	70	305	1333
7	60	425		40	289		50	397		100	345	
8	54	406		40	275		50	407		94	307	
9	50	382	1379	40	261	1473	50	390	1437	90	303	1368
10	50	332		60	275		47	333		80	266	
11	50	315		60	259		40	331		80	244	
12	50	305	1361	51	238	1481	40	321	1431	80	229	1390
13	80	315		90	242		73	317		30	216	
14	80	313		90	230		80	316		30	205	
15	80	300	1340	90	222	1450	80	327	1414	30	204	1359
16	123	321		30	214		120	332		40	201	
17	130	310		30	204		120	339		40	208	
18	121	315	1296	30	186	1398	120	332	1424	40	207	1377

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APPENDIX—Cont.

10-Day Time Period During the Trial	Cow No. 9 Conc.	Cow No. 9 FCM	Cow No. 9 Bwt.	Cow No. 10 Conc.	Cow No. 10 FCM	Cow No. 10 Bwt.	Cow No. 11 Conc.	Cow No. 11 FCM	Cow No. 11 Bwt.
	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
Preliminary	---	450	1414	---	428	1384	---	475	1303
1	67	384		77	319		80	485	
2	60	352		58	270		74	464	
3	60	333	1453	52	271	1424	79	469	1332
4	90	355		77	295		107	417	
5	84	342		64	281		88	376	
6	80	335	1479	67	255	1466	89	335	1399
7	120	348		80	270		100	348	
8	120	352		86	274		106	355	
9	120	321	1459	81	245	1497	101	289	1437
10	40	301		70	242		60	277	
11	34	268		70	222		60	270	
12	30	254	1488	61	216	1496	60	277	1435
13	50	247		30	220		100	273	
14	50	242		30	220		94	270	
15	59	241	1462	30	212	1481	90	244	1451
16	87	228		40	201		37	233	
17	80	220		40	199		30	248	
18	71	213	1471	40	207	1461	30	280	1413