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Factors affecting feed intake and feed efficiency of lactating dairy cows

by

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INTRODUCTION

Today, people are more concerned with the relative costs of production than ever before. Environmentologists ask about the costs to the environment of technological advances; industry is concerned with the costs per unit of goods produced; farmers are, or should be, concerned with the costs of providing agricultural commodities. With specific reference to the dairy farmer, this includes costs of animal housing and milking facilities, labor and veterinary fees, and feed costs per unit of milk produced.

The relative importance of milk production, diet and feed intake, body weight, and body weight change in affecting feed efficiency in dairy cows has been studied, often under restricted feeding conditions and/or utilizing conventional rations, where the roughage and concentrates were fed separately. Ration digestibility usually has not been included in these studies, although much of the variation in net energy for milk of a diet may be due to differences in digestibility. Therefore it is the intent of this study to examine the interrelationships of these factors with feed intake and feed efficiency, by using a completely mixed ration fed *ad libitum*, and by including a digestibility trial in mid-lactation.

LITERATURE REVIEW

Lactation feed efficiency is a function of characteristics which are influenced by genetic and environmental forces, and it is likely to be affected by these same influences. For instance, adding urea to a poor-quality roughage could increase both feed consumption and milk production. However, the magnitude of the responses is not always uniform for both. Thus, variations in efficiency result.

Research conducted at Beltsville (58,59,76) has indicated that the correlation between feed efficiency (fat-corrected milk/estimated net energy) and fat-corrected milk production is considerably larger than that between efficiency and estimated net energy consumed. Data were obtained from cows fed approximately 115% of Morrison's maximum estimated requirements by employing concentrates and roughage in a conventional type of ration (roughage fed to appetite and grain fed to balance the energy requirements). Thus, milk production and therms of estimated net energy consumed were highly correlated, but the relationship between feed intake and feed efficiency was apparently negligible.

Milk Production

Factors affecting milk production are numerous and range from those over which a farmer has little control, as age, to those which he can influence, as feeding to allow full expression of his cows' potential. The nature and direction of some of the influences will be discussed further.

The relationships between age and production have been rather thoroughly studied. In general, whole-lactation milk yield increases until the fourth or fifth lactation, at which point it levels off for about three lactations and then declines with increasing age (22,74,100,109). Fat and solids-nonfat percentages are highest for first-lactation heifers, but actual yields reflect the trends in milk yield (1,22,74, 95,100,109).

The stage of the lactation also affects production, with peak milk production observed by 30 to 60 days post partum, and peaks in butterfat and solids-nonfat yields seen during the first month (95,100,109). With regard to percent fat and percent solids-nonfat, the highest values usually are observed during the final month of the lactation (23,95,100,109). However, during the later stages of pregnancy, solids-nonfat percent appears to be increased, perhaps due to circulating estrogen (1,23,47); therefore, some of the increase in percent solids-nonfat usually observed in late lactation may be due to this rather than to the stage of lactation *per se*.

Season of calving also has been evaluated with respect to its effect on milk production (42,100,109,115). Some of this may in fact be related to management and climatic variations. Wunder and McGilliard (115) observed greater effects on production due to season of calving with groups of cows kept on drylots than with pasture herds, and first quartile (higher-producing) herds were more subject to seasonal variation in yield than were lower quartile herds. Production of younger cows appeared to be less affected by season than that of older cows. In their work these authors observed the greatest yields from cows calving in January-February; yields were smallest from cows calving in July-August. However, upper and lower peaks for milk production have also been observed from cows calving in May-June and November-December, respectively (100). Fat and solids-nonfat yields exhibited similar trends in this latter work, and the patterns observed for percent fat and percent solids-nonfat were essentially the opposite, with upper and lower peaks in November-December and July-August, respectively.

Body size is positively correlated with milk production (35), especially measures of body depth and height (36,69). Measures of fleshiness (body weight, heart girth, etc.) and of body weight change tend to be negatively correlated with milk production (56,69,74,76). This reflects either the tendency of a fleshy dairy cow to divert feed energy from milk production to fat deposition or her body's failure to adequately mobilize fat reserves when feed energy is inadequate, particularly during early lactation.

Other influences upon milk production, excluding nutritional factors, include degree of inbreeding, which has a negative correlation with production traits (103,117), and the genetic correlations among various production traits according to which cows are selected (for instance, the negative correlation between milk yield and percent solids-nonfat) (54, 114).

It is obvious with regard to nutrition that an inadequate or highly imbalanced supply of nutrients cannot provide for a level of milk production that is representative of a cow's capabilities (34,51). It may also be true that a dietary regimen which supplies energy in great excess of that required for milk production and maintenance of the cow is also less than ideal. Perhaps such excesses in energy stimulate early weight gain and fat deposition, which may alter the efficiency of energy utilization for milk production and may predispose the cow to other difficulties (86).

Food Intake Regulation

Food intake regulation in ruminants is an area that has received considerable attention in the past decade. In some ways, particularly with respect to long term maintenance of energy balance, ruminants are not unlike nonruminant animals. Upon attainment of a certain body energy composition, perhaps predefined genetically and including a degree of fatness, the mature ruminant maintains a rather uniform balance of energy intake and output, much as do nonruminants (8,26). Most workers agree that changes in body fat, which reflect changes in energy balance rather quickly, effect this long term regulation (8,26,55,62).

The means by which the degree of fatness is communicated to the controlling center, the hypothalamus, is still unclear, although Hervey (55) has suggested that progesterone and estrogen act to reset the hypothalamic "thermostat" to the level appropriate to counteract the excess or deficiency of body tissue energy. Baumgardt (26) also supports the concept of lipostatic control of long term energy balance and suggests that plasma free fatty acids serve as signal metabolites to a center of control higher than the ventromedial and lateral regions of the hypothalamus, which are believed to regulate short term meal size. Continuing the analogy with a thermostat, he suggests that the "set point" is higher in those animals which have been selected for a predisposition to fatten (as beef cattle).

The role of the hypothalamus in regulating the short term food intake of ruminants has been rather thoroughly studied, primarily by Baile and coworkers (8,10,13,15,17-19,21). Perfusion of the ventrocisternal system of satiated goats with sodium pentobarbital, a depressant, results in marked hyperphagia (10). Lesions in the ventromedial hypothalamus induced by electrodes produce similar results (17,21). However, attempts to induce ventromedial hypothalamic lesions in goats with gold thioglucose have been unsuccessful (15). This is not too surprising in light of additional evidence which indicates that glucostatic mechanisms of short term food intake regulation do not apply to ruminants. No effect on feed intake has been observed after intraperitoneal (97), intraruminal (14), or intravenous (15,45,67) injections of glucose in sheep (67), goats (14,15), or cattle (45,97). Insulin-induced hypoglycemia or intravenous injections of glucagon also do not affect feed consumption in goats (12).

The lateral hypothalamus has been shown to exert an initiating effect on food and water consumption in ruminants similar to that observed in nonruminants. Bilateral, electrically-induced lesions in this region of goats cause aphagia, lasting 4 to 12 days, and adipsia, lasting 8 to 23 days, after which intakes of feed and water return to pre-lesion levels (19). It can be concluded from this, together with the results with ventromedial lesions, that stimuli from the lateral hypothalamus lead to the initiation of eating unless signals from the ventromedial hypothalamus, the satiety center, block them. This is essentially what is believed to occur in nonruminant animals (71).

The temporary nature of the effects of inducing lesions in both the lateral (19) and the ventromedial (21) regions lends support to the previously mentioned suggestion of Baumgardt (26) regarding an even higher center of energy balance regulation. It could be that damage to these short term control regions leads eventually to exertion of food intake control by this higher center. Apparently time is required to "inform" it of changes in energy balance; hence the lag between lesion induction and return to normal food and water consumption. A similar lag is seen between the periods of peak production and peak feed intake in lactating cows (59, 105), which may also lend itself to explanation on this basis. This further indicates that short and long term food intake regulation may not be entirely independent.

As was previously mentioned, glucose does not appear to be an important feedback metabolite in the short term regulation of food intake in ruminants. However, volatile fatty acids, particularly acetic and propionic acids, appear to adequately serve this purpose. Injection of propionate into the ruminal vein of goats causes a marked depression of feed consumption (7), as does intraruminal infusion of acetate and/or propionate, either prior to or during a meal (7,9,11,14, 16,20,27,30,73,85,97,111). It has also been observed in fistulated cows that the concentration of rumen volatile fatty acids increases within 2 hours after feeding and peaks by 4 to 6 hours, which coincides with apparent satiety (96).

Injections of volatile fatty acids into the jugular vein of ruminants causes only slight, if any, decrease in feed consumption (7,11). Thus, it is believed that the receptors sensitive to changes in concentration of acetate and propionate are not located in the hypothalamus. Those for acetate are located on the mucosal side of the wall of the dorsal rumen (9), and those for prioionate appear to be located in the portal system (in either the ruminal or portal vein, or in the liver) (7, 9 ,68) and possibly over the entire mucosal side of the wall of the rumen (9). Concentration of these acids above a critical level causes cessation or reduction of eating, while dilution of the ruminal contents during a meal prolongs the meal (9).

The existence of a thermostatic system of food intake regulation in ruminants similar to one that has been reported in nonruminants (71) has also been studied. Addition of cold or warm water to the rumen had no effect on consumption of a hay diet by cows, but more frequent infusions of warm or cold water decreased or increased, respectively, consumption of a pelleted ration (29). In another study, local cooling of the preoptic area and rostral hypothalamus induced eating in goats, while warming the region caused cessation of eating, even where changes in body temperature were negligible (2). However, the changes in hypothalamic temperature were rather large and may not correspond to what normally occurs in the animal.

Other experiments have been conducted in which temperature changes at both the ventromedial and the lateral centers of the hypothalamus were monitored in goats in relation to initiation and cessation of meals (13,18,44). In no case was there a noticeable relationship between hypothalamic temperature and meal pattern which could not be attributed equally well to other factors, such as the temperature rise which occurred when resting goats stood up in anticipation of meals or when they were disturbed for any other reason. These workers did not monitor temperature changes at the preoptic center, but for the most part, changes in internal temperature have been discounted as important influences on feeding behavior. Extremes in ambient temperature may affect feed consumption; however, this might be related more to their effects on energy balance (3,70,99).

Finally, among "metabolic" systems of food intake regulation in ruminants, the effects of rumen pH and osmolality have been evaluated to a limited extent. In separate experiments, intraruminal infusions of both dilute acid solutions (28) and solutions of sodium salts (27) have resulted in decreased feed consumption. However, the resulting pH and osmolality have usually exceeded the normal physiological levels. Therefore, neither is considered likely to be of great importance in regulation of meal size under normal circumstances.

In spite of the importance of hypothalamic regulation of food intake with concentrated diets (over 2.5 kcal digestible energy/kg dry matter) (26), under many feeding conditions a system of food intake limitation based on physical characteristics of both the ration and of the animal consuming the ration appears to be primary in the control of meal size.

The major components of this physical system include the capacity of the rumenoreticulum (reflected by body weight and measures of body depth), digestibility, rate of passage, and energy concentration (31,38,107). Consumption of coarse feeds and of some high-roughage diets can be decreased proportionately by the addition of digesta or inert, bulky substances to the rumen (39,111). Likewise, removal of digesta from the rumen during consumption of such a meal can prolong meal time considerably over the usual for the animal (39).

Rate of passage is quite important with coarse, fibrous feeds, as the longer feed residues remain in the rumenoreticulum the more full the animal will feel at any one time (24). As a result, the voluntary consumption of feeds of this sort may be limited by rate of passage (24,31,39,111,112,113).

Grinding is a process which tends to decrease retention time, primarily by making the feed particles physically smaller (33,41,90,112). In addition, grinding may enhance microbial breakdown of feed residues. Thus, the size and, where applicable, the frequency of meals is increased (31,41,90, 112).

The addition of concentrates to and/or increasing the protein content of a high-roughage ration brings about an effect similar to grinding, by yielding a substrate more suitable for rapid degradation by rumen microorganisms (24,46, 112,113). Where the energy concentration is increased, as by feeding concentrates in addition to the roughage, consumption of the forage may not change, but total dry matter and energy consumption will both increase (43,84,90), usually with a resulting increase in digestibility. Similarly, feeding high-roughage diets of increasing digestibility results in increased intake (40,107,113). In fact, one could say that the change in digestibility reflects the increase in nutritive quality of the feed (with respect to energy and protein).

Physical limitations are probably in effect when feed intake of cows or ewes in late pregnancy is decreased due to the large size of the fetus(es) (37,50,53,65). However, Forbes (50) believes that an interaction of circulating estrogen and progesterone in late pregnancy may effect reduced meal size, even with more concentrated diets.

It has been shown that fat animals, with large deposits of abdominal fat, will eat less than those which are thin (32,101); however, some of the reduced feed consumption by fat animals may be the result of regulatory stimuli from excessive energy stores, while the greater feed intake of thinner animals may reflect the opposite condition.

On the other hand, an increase in the capacity of the rumen has been reported in early lactation (87). This may reflect the increased space available that had been occupied by the gravid uterus and/or it may be due to the utilization of abdominal fat to meet energy demands. There has been a report indicating increased feed intake in early pregnancy, perhaps stimulated by low levels of circulating progesterone (50).

In grazing ruminants, the physical and physiological factors affecting feed intake discussed previously remain important. However, social and climatic stresses and pasture conditions may play a similarly important role in affecting the amount of feed consumed by the individual (5). Arnold (5) has reviewed rather thoroughly the literature pertaining to grazing ruminants, and the reader is referred to his paper for further details. It may be supposed too that social, and to some extent, climatic factors affect feeding behavior and feed intake of animals under the more intensive drylot conditions often seen today, particularly in the beef and lamb industries.

In summary, factors affecting voluntary feed consumption of ruminants can, for the most part, be considered as either physical or metabolic in nature. Where characteristics of the ration and, to some extent, of the animal itself dictate, feed intake increases with increasing body weight of the animal (capacity), with increasing digestibility of the ration, and with processing the feed in such a way as to increase rate of passage (as by grinding, pelleting, etc.) (43). In this case, output, as of milk or weight gain, is geared down to balance with the energy supply. However, above digestibility levels of 65 to 70% (43) or digestible energy concentrations of 2.5 kcal/kg ration dry matter (26), voluntary feed intake is regulated by the nutritional demands of the body so that, over the long run, input of energy is geared to match the output.

Feed Efficiency

It is rather easy to see that in most situations neither feed consumption nor milk production changes independently of the other, nor do these two main components of lactation feed efficiency often change to the same extent at the same time. Therefore, it is reasonable to investigate not only how various treatments and stresses affect milk production and feed intake, but also how they affect feed efficiency, a function of the two.

By utilizing tabulated estimates of the energy content of the ration, most data have been based on a rather crude definition of efficiency--milk yield/dry matter intake or milk yield/estimated energy intake. For the most part, this is satisfactory because it represents an applied interpretation of efficiency. On the other hand, it may not be as informative from a scientific basis as an expression that attempts to account for differences among cows in apportioning energy to the various outputs, among them growth, maintenance, fat deposition, and milk production. A variety of formulas have been developed to account for variations in, for example, milk energy or to account for maintenance losses (61,72). However, most work by far is still done with efficiency = milk yield/energy or dry matter input.

Milk production, for the most part, is positively correlated with efficiency, even though food intake may have to increase to meet the demands of increased production (58,59, 64,69,76). This is because the proportion of the total feed which is utilized for milk production rather than for maintenance is increased. For the same reasons an increase in energy input results in greater efficiency, if the cow nas the capability to respond with increased milk production.

At some point the relationship becomes less clear, and certain negative influences come into play. One such influence is the apparent tendency for the digestibility of a given feed to decrease with increased consumption (33,66,79,81). However, in many cases the relative decrease in digestibility is less than the increase in total nutrients available over maintenance (81). Thus, we do not encounter the law of diminishing returns until extremely high levels of feed consumption are necessary to maintain milk production (i.e., several times maintenance). On the other hand, feeding high levels of energy to a cow which has a predisposition to fatten rather than to produce more milk will decrease lactation efficiency because of the utilization of an increasing fraction of the input for fat deposition.

For instance, in one feeding trial an all-forage ration was compared with a forage plus concentrate ration (94). Estimated net energy consumption of the cows on the all-forage ration was only 58% of that of the cows receiving the forage plus concentrates, probably due to physical limitations on food intake. However, their milk production was maintained at 83% of the level of the forage plus concentrates group; thus, these cows were significantly more efficient, where efficiency = milk production/estimated net energy consumed.

In another experiment, cows fed uniform amounts of concentrates daily, based on expected production levels, were significantly more efficient over three lactations than challenge-fed cows (92). Perhaps the challenge-fed cows gained more weight during the lactation, or more likely, they utilized less of their body fat stores during early lactation. Moe, Tyrrell, and Flatt (82) have reported that the energetic efficiency for production of milk from body tissue is 82 to 84%, while the efficiency of conversion of feed to milk is only 63 to 66%. Furthermore, they have estimated that the energetic efficiency of milk production from tissue regained during the dry period is around 48%, while the efficiency of producing milk from tissue gained during the lactation is over

60%. Thus, during the lactation, the uniform-fed cows of Rakes and Davenport (92) may have regained more of the tissue lost (as feed energy inputs probably exceeded milk energy outputs during the latter stages of each lactation), while the challenge-fed cows replenished their stores during the dry period, which may have enhanced the differences.

There has been much research conducted to examine the effects on feed efficiency of various dietary regimens (60,61, 78,88,92,94,102). However, the question to which this thesis addresses itself is, what are the factors causing variation in efficiency among cows receiving a similar ration, assuming they are fed to adequately meet nutritional requirements. Only data which might be helpful in answering this question will be discussed further.

As stated earlier, work at Beltsville has indicated that milk production is much more highly correlated with efficiency than is feed intake (58,59,76). Body weight change is negatively correlated with efficiency (56,58,76), and cows that are below the breed average in body weight tend to be more efficient within their breed, probably because of their smaller maintenance requirement (56,58,75).

However, Lamb et al. (64) reported a linear increase in efficiency with an increase in body weight at parturition. Of 17 variables, feed efficiency was positively correlated with age, the number of days open, total dry matter consumption, grain consumption, percent grain in the ration, actual production, mature equivalent production, and body weight. A negative relationship existed between efficiency and weight change. Concurring with this is additional work which shows that the partial regression of feed efficiency on body weight observed during the first month of lactation is useful as a predictor of future feed efficiency (77). However, the correlations between body weight and efficiency become more negative as the lactation progresses.

It has recently been suggested (116) that variation in cow-care costs (i.e., costs of labor directly involved with individual cows and costs of veterinary services) may be worthy of more attention on the part of the farmer than variation in feed efficiency, because 1) to a considerable extent, feed efficiency is highly correlated with milk production, and 2) records of labor and veterinary costs would be more easily kept by most farmers than individual records of feed intake. With data on both milk production and cow-care costs, it would be rather easy to devise a more economically-oriented estimate of the lactation efficiency of each cow, as

$$\text{Efficiency} = \frac{\text{Milk income}}{\text{Cow-care costs}} .$$

This is something which should be more thoroughly studied, particularly with reference to its applicability among farmers.

Except for studies conducted with the intent of evaluating net energy, not very much has been done to investigate the relationship of differences among cows in digestibility with differences in efficiency. Those studies appear to have been concerned mainly with the effects on net energy of different rations (level of concentrate) (48,49,78,79,80,104), different levels of feeding (48,79), or different productive states (pregnant vs nonpregnant (49), lactating vs dry (48)). However, from these studies it is apparent that most of the variability in net energy resulted from variations in the amount of energy lost in the feces, i.e., from differences in digestibility of the energy.

Therefore, we conducted this feeding trial, including a digestibility trial with each cow, to examine the interrelationships among various factors affecting both the voluntary feed intake and the feed efficiency of lactating cows fed a single completely mixed ration throughout the lactation. An attempt was also made to relate easily observable traits, such as milk production, body weight, and body weight change to feed efficiency, for purposes of obtaining some applicable results.

EXPERIMENTAL PROCEDURES

Twenty-seven Holstein cows, calving between August 25 and December 30, 1970, were selected from the Iowa State University dairy herd. This included most of the Holsteins freshening during that period. The experimental animals included both first-calf heifers and mature cows, ranging in age at calving from 23 months to 6 years. Table 1 lists the cows, together with some descriptive data.

The cows were housed from October 1970 to May 1971 in a stanchion barn equipped for measuring individual feed intake. During the remainder of the experiment they were housed either outside or in the barn, and feed intake was not assessed. They were milked twice a day at 3 PM and 3 AM, and mastitis incidence and milk weights were recorded at each milking. Every two weeks throughout the lactation, samples were taken of each cow's milk from two consecutive milkings. They were analyzed for fat by the Babcock method and for total solids by lactometer (110), and an average for the two-week period around the sampling days was computed, weighted by the production during the sampled milkings. Solids-non-fat was estimated by difference.

Between October and May, feed for each cow was weighed out into tubs before each feeding and the tubs were emptied into the mangers during milking. The mangers were regularly cleaned at the morning milking before feeding, and weighbacks

Table 1. Background information on experimental cows

Cow number	Age at calving	Number of previous lactations	Calving date (1970)[a]	Date off experiment (1971)	Fecal collections initiated (1971)[b]
6009	3 yr. 11 mo.	1	Aug. 25	Aug. 20	Jan. 3
6164	2 1	0	Sept. 2	Oct. 5	Jan. 3
6134	2 4	0	Sept. 10	July 19	Jan. 14
6153	2 2	0	Sept. 20	July 15	Jan. 14
5718	5 2	4	Sept. 27	Aug. 11	Feb. 4
6175	2 1	0	Oct. 4	May 5	Feb. 4
6020	3 3	1	Oct. 7	July 16	Feb. 4
6050	3 0	1	Oct. 23	Aug. 7	Feb. 24
6197	1 11	0	Oct. 29	May 5	Feb. 28
6036	3 2	1	Oct. 31	Sept. 19	Feb. 28
6109	2 8	1	Oct. 31	June 13	Feb. 28
6196	2 0	0	Nov. 8	May 24	Mar. 8
6179	2 1	0	Nov. 8	Nov. 15	Mar. 8
5660	5 9	4	Nov. 13	Oct. 24	Mar. 8
6192	2 0	0	Nov. 16	July 28	Mar. 8
6203	1 11	0	Nov. 21	Dec. 13	Mar. 22
5903	4 0	2	Nov. 26	Jan. 7, 1972	Mar. 22
5563	6 5	5	Nov. 26	Sept. 28	Mar. 22
5695	5 7	4	Dec. 3	Oct. 10	Apr. 5
5781	5 0	3	Dec. 4	Sept. 12	Apr. 5
6211	2 0	0	Dec. 10	Oct. 22	Apr. 13
6057	3 1	1	Dec. 12	Oct. 15	Apr. 13

5600[c]	5	0	4	Sept. 14	Aug. 20	Jan. 14
5758[c]	4	11	3	Oct. 2	May 24	Feb. 4
5801[c]	4	11	3	Dec. 30	Oct. 24	Apr. 29
6047[d]	3	0	1	Oct. 22	Oct. 24	Feb. 24
6055[d]	2	11	1	Oct. 25	Apr. 18	Feb. 24

[a]Is the date on experiment.

[b]Is the date fecal collections began.

[c]Data eliminated from feed intake study because of persistent mastitis.

[d]Data eliminated from feed intake study due to failure to consume chromic oxide.

were taken before the afternoon milking on Mondays, Wednesdays, and Fridays; thus, most of the data on orts is based on single feedings. Feed allowances were sufficient to result in refusals of about 5 kg per day.

The cows were weighed weekly during their lactations at 1:30 PM. One animal, 6057, refused to walk on the scale, which necessitated the use of a heart-girth weight-tape to estimate her body weight.

A complete ration based on corn silage, concentrate mix, and dehydrated alfalfa pellets was used in this trial. A similar ration has been used in other work at this station (98). It was expected that with adequate mixing, more uniform intake of the feed components among the cows would result, reducing the interpretive problems that arise when the proportions of concentrate and roughage vary with feeding and/or production levels in conventional rations. Greater ease in assessing the nutritive worth of the weighbacks was another anticipated result.

The ration as formulated contained 9 parts corn silage, 1 part dehydrated alfalfa pellets, and 5 parts concentrate mix (wet weight basis). The composition of the concentrate mix can be found in Table 2. Initially feed was mixed in a small cement mixer; however, by early 1971 a large mixer wagon[1] was

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[1]Ensilmixer, Oswalt Industries, Garden City, Kansas.

Table 2. Herd concentrate mix

Ingredient	kg/1000 kg
Crushed shelled corn	657.5
Crushed or rolled oats	162.5
Soybean oil meal (44%)	150.0
Dicalcium phosphate	10.0
Trace mineralized salt	10.0
Urea	10.0

in use for this purpose. This ration was fed to the cows throughout the lactation.

Samples were periodically taken of the components of the ration and of the complete mix. These were dried in aluminum pie pans in a forced-air oven at 60 C for 24 to 28 hours (to constant weight) to determine dry matter, and then were ground in a Wiley Mill with a 60-mesh screen. The dried, ground samples were stored at room temperature in air-tight plastic bags until analyzed for the following nutritive components: crude protein by the Kjeldahl method (6), ether extract (6), acid-detergent fiber (108), and ash (6). Gross energy was determined with an adiabatic bomb calorimeter (91). The results are in Appendix I, Table 12, and are summarized in Table 3.

Table 3. Summary of feed analyses

Feedstuff	No. of samples	Dry matter		Crude protein		Ether extract	
		Mean	S.E.	Mean	S.E.	Mean	S.E.
		%					
Concentrate	4	87.9	0.53	22.3	0.86	4.01	0.348
Alfalfa pellets	4	94.2	1.01	19.6	0.52	4.01	0.124
Corn silage	10	48.4	1.45	9.2	0.64	3.12	0.168
Complete mix	11	64.2	0.72	15.5	0.88	3.92	0.140

Acid-detergent fiber		Ash		Gross energy	
Mean	S.E.	Mean	S.E.	Mean	S.E.
%				kcal/kg	
7.2	0.21	5.43	0.482	4.47	0.041
29.9	1.53	10.64	0.814	4.50	0.041
24.7	0.59	4.46	0.113	4.52	0.012
19.6	0.46	5.24	0.143	4.46	0.014

Feed intake was measured between November 1970 and May 1971. However, the main period of interest for each cow, which will be referred to as the feed intake period, extended from the 90th to 150th day after the cow entered the milking herd. This period was chosen because of its apparently high correlation with the feed efficiency and milk production of an entire lactation (59). Data utilized were from this period and to a limited extent from 60 to 89 days.

A digestibility trial was initiated at about 110 days into the lactation of each cow. For a week to 10 days 43 to 48 g of shredded chromic oxide paper[1] (33% chromic oxide) was mixed with the cow's afternoon feed allowance. During this time, the manger was not cleaned in the morning, and weighbacks, representing two feedings, were taken each afternoon. The refused feed was sampled two or three times during this period to estimate differences in composition between the feed as fed and that consumed, and to estimate the amount of chromic oxide that was not ingested. These samples were processed and analyzed for dry matter and gross energy by the methods used for the feed samples. Chromic oxide was determined by a modification of the method of Kimura and Miller (63). Rather than centrifuging or decanting the 100 ml volumetric flask to

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[1]Purchased from the Rowett Research Institute, Aberdeen, Scotland.

keep silica from interfering with the readings, the final solution was filtered into test tubes through Whatman 2V prefolded filter paper.

After a preliminary period lasting about a week, eight fecal grab samples were obtained over three days, according to the following schedule: days 1 and 3 - 7:30 AM, 4:30 PM, and 9:00 PM, day 2 - 3:00 PM and 7:00 PM. Fecal samples were prepared and stored in the same manner as the feed samples. However, before further analysis, 10 g portions from each of the eight samples from a cow were pooled. These resulting composite samples were then analyzed for gross energy and for chromic oxide. Apparent digestibilities of dry matter and energy were calculated from the formula

$$\text{Apparent digestibility (\%)} = \frac{\text{Concentration of chromic oxide in feed}}{\text{Concentration of chromic oxide in feces}}$$

$$\times \frac{\text{Concentration of ingredient in feces}}{\text{Concentration of ingredient in feed}} \times 100.$$

Some cows left feed residues consisting primarily of corn stalks and cobs, some left mostly pellets, and a few left grain. It thus seemed undesirable to assign to the feed consumed by each cow the average dry matter of the feed as fed, so the following formula was used to estimate the concentration of dry matter in the consumed feed.

$$\text{Dry matter of feed consumed (\%)} = \frac{\left(\text{Amount of feed fed}\right)\left(\text{Dry matter \% of feed as fed}\right) - \left(\text{Amount of weighback}\right)\left(\text{Dry matter \% of weighback}\right)}{\text{Amount of feed consumed (wet weight)}}.$$

A similar formula was used for the energy content of the feed consumed.

$$\text{Energy concentration of feed consumed (kcal/kg DM)} = \frac{\left(\text{Amount of DM fed}\right)\left(\text{Energy conc. of feed as fed}\right) - \left(\text{Amount of weighback DM}\right)\left(\text{Energy conc. of weighback}\right)}{\text{Amount of feed dry matter consumed}}.$$

These formulas still fail to eliminate error from alteration of the refused feed, particularly with respect to weight and dry matter percent, resulting from contamination by cow's saliva, runoff from watering cups, or feed spillover into or out of the manger. However, any estimates of feed intake based on orts which have been left in a manger for more than two or three hours might be subject to the same sources of error. As yet there are no reliable ways of estimating the magnitude of these errors.

Upon completion of the experiment, it was decided to exclude data from five cows from further evaluation. Three were culled because of persistent mastitis and two because of failure to consume sufficient chromic oxide for reliable estimates of digestibility.

A number of calculations were then performed on the raw data, which resulted in 53 variables representing particular traits of interest. A list of all these variables together with definitions can be found in Table 4.

Milk production during 60 to 89 days, 90 to 150 days, and over the entire lactation was converted to solids-corrected-milk (SCM) by the formula of Tyrrell and Reid (106). Whole lactation production (SCM306DA) was truncated at 306 days for those cows with longer records, and factors developed by Spike (100) were used to extend the records of cows which were sold prior to completion of their lactations. The length of the whole lactation period is 306 days rather than the conventional 305 days because the extension factors used are based on actual production records with an average first month of 31.5 rather than 30.5 days.

To reduce variability, least squares constants, which had been derived by Spike (100) for production of milk and milk constituents, were used to develop ratio factors to correct the 90-to-150-day data to the level of a cow six years old, calving in November or December. This corrected SCM yield may in fact not be accurate, as the constants were developed from whole-lactation data, while here they were applied to only two months of the lactation. Therefore, both the uncorrected (SCMRAW) and corrected (SCMCORR) SCM yields were used in subsequent analyses to represent production during the feed intake

Table 4. Variables used in the data analysis

Measures of body weight:

AVEWT61 = Average of observations, 90-150 days (kg)

WT61SQ = $(\text{AVEWT61})^2$ (kg^2)

METWT61 = $(\text{AVEWT61})^{.75}$ ($kg^{.75}$)

Measures of body weight change:

WTCHNG61 = Final - initial weight, 90-150 days (kg)

RATE61 = Linear regression of body weight on week, 90-150 days (kg/week)

WTCHNG30 = Final - initial weight, 60-89 days (kg)

RATE30 = Linear regression of body weight on week, 60-89 days (kg/week)

Measures of milk production:

MPROD61 = Daily milk production, 90-150 days (kg)

MPROD306 = Total milk yield, 306 days (kg)

SCMRAW = Daily SCM yield, 90-150 days, uncorrected for age or season of calving (kg)

SCMCORR = Daily SCM yield, 90-150 days, corrected to a cow between 6 and 9 years of age, calving in November or December (kg)

SCM306DA = Total SCM yield, 306 days (kg)

SCM30 = Daily SCM yield, 60-89 days, uncorrected (kg)

SCMRMET = SCMRAW/METWT61 (kg SCM/$kg^{.75}$ body weight)

SCMCMET = SCMCORR/METWT61 (kg SCM/$kg^{.75}$ body weight)

MPRODMET = MPROD61/METWT61 (kg milk/$kg^{.75}$ body weight)

Measures of feed consumption (daily basis):

DM = Dry matter intake, 90-150 days (kg)

DDM = Digestible dry matter intake = DM x dry matter digestibility (kg)

DMMET = DM/METWT61 (kg DM/$kg^{.75}$ body weight)

DDMMET = DDM/METWT61 (kg DDM/$kg^{.75}$ body weight)

GE = Gross energy intake, 90-150 days (kcal)

Table 4 (Continued)

Measures of feed consumption (daily basis) (continued):

DEOBS = Digestible energy intake = GE x energy digestibility (kcal)

DEOBSMET = DEOBS/METWT61 (kcal/kg$^{.75}$)

DECALC = DM x 3.29 kcal/kg DM (kcal)[a]

DMINBWT = 100 x DM/AVEWT61 (%)

MAINT = Maintenance requirement in DE, based on NRC requirements (89) (kcal)

TOTREQ = Total DE requirement, based on NRC requirements (89) (kcal)

DEOPCENT = 100 x DEOBS/TOTREQ (%)

DECPCENT = 100 x DECALC/TOTREQ (%)

DEOMILK = DEOBS - MAINT (kcal)

DECMILK = DECALC - MAINT (kcal)

Measures of feed efficiency:

SCMRDM = SCMRAW/DM (kg SCM/kg DM)

SCMCDM = SCMCORR/DM (kg SCM/kg DM)

MPRODDM = MPROD61/DM (kg milk/kg DM)

SCMRDDM = SCMRAW/DDM (kg SCM/kg DDM)

SCMCDDM = SCMCORR/DDM (kg SCM/kg DDM)

MPRODDDM = MPROD61/DDM (kg milk/kg DDM)

SCMRGE = SCMRAW/GE (kg SCM/kcal GE)

SCMCGE = SCMCORR/GE (kg SCM/kcal GE)

MPRODGE = MPROD61/GE (kg milk/kcal GE)

SCMRDEO = SCMRAW/DEOBS (kg SCM/kcal DE)

SCMCDEO = SCMCORR/DEOBS (kg SCM/kcal DE)

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[a]3.29 kcal/kg DM is the theoretical DE concentration in the ration, based on current NRC feed composition tables (89). Note that all calculations involving DECALC may in fact reflect primarily characteristics of dry matter consumption.

Table 4 (Continued)

Measures of feed efficiency (Continued):

MPRODDEO = MPROD61/DEOBS (kg milk/kcal DE)
NETEFFRO = SCMRAW/DEOMILK (kg SCM/kcal DE)
NETEFFCO = SCMCORR/DEOMILK (kg SCM/kcal DE)
NETEFFMO = MPROD61/DEOMILK (kg milk/kcal DE)
NETEFFRC = SCMRAW/DECMILK (kg SCM/kcal DE)
NETEFFCC = SCMCORR/DECMILK (kg SCM/kcal DE)
NETEFFMC = MPROD61/DECMILK (kg milk/kcal DE)

Miscellaneous:

DMDIGEST = Dry matter digestibility coefficient
EDIGEST = Energy digestibility coefficient
AGE = Age of the cow at calving
MONTH = Month of calving (August = 1,...,December = 5)
DAYSPREG = Number of days pregnant the cow was by 150 days

period. SCM yield during 60 to 89 days (SCM30) was not subjected to this procedure.

Daily dry matter intake (DM) was estimated for each cow by doubling the average observed weighback and subtracting that from the average amount of feed offered per day during 90 to 150 days. Daily intake of gross energy (GE) was estimated in a similar manner, utilizing the average energy content of the refusals and the gross energy of the feed as fed.

DAYSPREG was included because of the variable lengths of time the cows were pregnant. Nine were not pregnant during 90 to 150 days, while some had conceived up to a month prior to the feed intake period. On examination of breeding records, it appears that reasonable attempts were made to breed all the cows during this period, even though some were subsequently culled for lack of size or for low production records.

No expressions have been used to represent body weight or body weight change over the entire lactation, as some of the cows were sold before completion of their lactations and there was no way to estimate the final weight had the cows been retained longer.

Correlation coefficients were computed among the various measures of feed efficiency and among the measures of milk production, excluding SCM30. These can be found in Tables 5 and 6, respectively. If two or more variables representing the same sort of trait were highly correlated ($r \geq 0.9$) and were similarly correlated with the other variables, all but one were excluded.

On the basis of these correlations only the following terms were retained for further analysis: SCMRDM, SCMCDM, SCMRDEO, SCMCDEO as measures of gross efficiency, NETEFFRO, NETEFFCO, NETEFFRC, and NETEFFCC as measures of net efficiency

Table 5. Correlations among measures of feed efficiency (all significant at P < .01)

	SCMRDM	SCMCDM	MPRODDM	SCMRDDM	SCMCDDM	MPRODDDM	SCMRGE	SCMCGE	MPRODGE
SCMCDM	0.905	1.000							
MPRODDM	0.959	0.829	1.000						
SCMRDDM	0.860	0.758	0.812	1.000					
SCMCDDM	0.842	0.883	0.766	0.942	1.000				
MPRODDDM	0.849	0.720	0.861	0.978	0.899	1.000			
SCMRGE	0.999	0.905	0.959	0.860	0.842	0.849	1.000		
SCMCGE	0.906	0.999	0.829	0.758	0.883	0.720	0.905	1.000	
MPRODGE	0.959	0.829	0.999	0.812	0.766	0.861	0.959	0.829	1.000
SCMRDEO	0.859	0.758	0.811	0.999	0.944	0.977	0.859	0.759	0.811
SCMCDEO	0.840	0.881	0.764	0.941	0.999	0.898	0.840	0.881	0.764
MPRODDEO	0.848	0.720	0.860	0.978	0.901	0.999	0.848	0.720	0.860
NETEFFRO	0.728	0.762	0.657	0.856	0.917	0.814	0.728	0.762	0.658
NETEFFCO	0.695	0.780	0.616	0.803	0.906	0.755	0.695	0.780	0.617
NETEFFMO	0.736	0.759	0.690	0.862	0.915	0.838	0.736	0.760	0.690
NETEFFRC	0.891	0.905	0.837	0.734	0.804	0.715	0.889	0.904	0.836
NETEFFCC	0.828	0.940	0.758	0.681	0.822	0.648	0.827	0.939	0.757
NETEFFMC	0.887	0.881	0.880	0.724	0.778	0.739	0.885	0.880	0.879

Table 5 (Continued)

	SCMRDEO	SCMCDEO	MPRODDEO	NETEFFRO	NETEFFCO	NETEFFMO	NETEFFRC	NETEFFCC	
SCMCDM									
MPRODDM									
SCMRDDM									
SCMCDDM									
MPRODDDM									
SCMRGE									
SCMCGE									
MPRODGE									
SCMRDEO	1.000								
SCMCDEO	0.943	1.000							
MPRODDEO	0.978	0.900	1.000						
NETEFFRO	0.859	0.919	0.817	1.000					
NETEFFCO	0.807	0.908	0.759	0.992	1.000				
NETEFFMO	0.865	0.917	0.842	0.996	0.985	1.000			
NETEFFRC	0.732	0.802	0.713	0.786	0.780	0.791	1.000		
NETEFFCC	0.681	0.820	0.648	0.796	0.817	0.795	0.973	1.000	
NETEFFMC	0.722	0.775	0.737	0.756	0.745	0.776	0.986	0.950	1.000

Table 6. Correlations among measures of milk production

	MPROD61	SCMRAW	SCMCORR	MPRODMET	SCMRMET	SCMCMET	MPRO0306	
SCMRAW	0.943	1.000						
SCMCORR	0.702	0.834	1.000					
MPRODMET	0.874	0.830	0.750	1.000				
SCMRMET	0.782	0.856	0.870	0.935	1.000			
SCMCMET	0.328	0.453*	0.797	0.665	0.801	1.000		
MPROD306	0.958	0.902	0.604	0.818	0.727	0.236*	1.000	
SCM306DA	0.898	0.936	0.683	0.758	0.767	0.303*	0.946	1.000

*Not significantly different from 0 (P > .05). All other values significantly different from 0 (P < .05).

(utilization of that energy supplied over maintenance), and SCMRAW, SCMRMET, SCMCORR, and SCMCMET, and SCM306DA as measures of milk production.

The following data were then subjected to factor analysis: DM, DDM, DEOBS, DMINBWT, DMMET, DDMMET, DEOBSMET, DEOMILK, DECMILK, DEOPCENT, DECPCENT, SCMRAW, SCMRMET, SCMCORR, SCMCMET, SCM306DA, AVEWT61, METWT61, WTCHNG61, RATE61, WTCHNG30, RATE30, AGE, MONTH, DMDIGEST, EDIGEST, DAYSPREG, SCMRDM, SCMCDM, SCMRDEO, SCMCDEO, NETEFFRO, NETEFFCO, NETEFFRC, NETEFFCC. The reader is referred to Appendix II for a brief description of the principles involved in factor analysis.

Some of the variables were processed by a stepwise regression procedure to see 1) if the variation in some of the traits of interest (feed intake, efficiency) could be explained by a linear model of other traits which were observed, and 2) if the differences between the cows in efficiency could be adequately described or estimated by differences in traits that are easily observed up through the fifth month of lactation--something of more importance to the producer. A list of the various dependent variables and the independent variables used for each is presented in Table 7.

The stepwise procedure used was the Maximum R^2 Improvement Procedure of the Statistical Analysis System (25). All possible one-variable models are determined, and the one which results in the largest R^2 is declared the "best" one-variable

Table 7. Dependent variables and possible independent variables considered in a stepwise model-building procedure

Dependent variable	Independent variables considered
DMMET	SCMRMET, SCMCMET, SCM306DA, SCM30, AGE, MONTH, AVEWT61, WT61SQ, METWT61, WTCHNG61, RATE61, WTCHNG30, RATE30, DMDIGEST, DAYSPREG, SCMRDM, NETEFFRC
DEOBSMET	SCMRMET, SCMCMET, SCM306DA, SCM30, AGE, MONTH, AVEWT61, WT61SQ, METWT61, WTCHNG61, RATE61, WTCHNG30, RATE30, EDIGEST, DAYSPREG, SCMRDEO, NETEFFRO
SCMRDM (Descriptive)	DMMET, SCMRMET, DMINBWT, AGE, MONTH, SCM306DA, SCM30, AVEWT61, WT61SQ, WTCHNG61, RATE61, WTCHNG30, RATE30, DMDIGEST, DAYSPREG
SCMRDEO (Descriptive)	DEOBSMET, SCMRMET, DMINBWT, AGE, MONTH, SCM306DA, SCM30, AVEWT61, WT61SQ, WTCHNG61, RATE61, WTCHNG30, RATE30, EDIGEST, DAYSPREG
NETEFFRO (Descriptive)	DEOBSMET, SCMRMET, DMINBWT, AGE, MONTH, SCM306DA, SCM30, AVEWT61, WT61SQ, WTCHNG61, RATE61, WTCHNG30, RATE30, EDIGEST, DEOMILK, DEOPCENT, DAYSPREG
SCMRDM-P, SCMRDEO-P, NETEFFRO-P (Practical)	SCMRAW, AGE, MONTH, SCM30, AVEWT61, WT61SQ, WTCHNG61, WTCHNG30, DAYSPREG

model (R^2 = the proportion of the total variation which is accounted for by the model). Then all possible two-variable models are computed, and the one which results in the largest R^2 is again selected as the "best" two-variable model. This continues, using increasingly larger models, until all the possible independent variables are included. For each size, information is printed to help the researcher determine which model, among all these "best" models, fits his data most satisfactorily. (Included in this information are the variables used in the "best" model of each size, the coefficient of each variable, the R^2, and analyses of variance with both sequential and partial breakdown of the sums of squares.) There is no guarantee that the larger models will be much more informative than the smaller ones, nor is there a guarantee that the models will make sense. However, it is a fast method of examining a set of data. For this study, it was decided that models in which any partial regressions were not significantly different from zero at the 0.10 probability level would be excluded.

RESULTS AND DISCUSSION

Individual cow results for the 53 traits examined can be found in Appendix I, Table 13. The traits which have been subjected to either factor or regression analysis are summarized in Table 8. It can readily be seen that there was a lot of variability among the cows.

For instance, the average energy digestibility of the ration was 73.9%, which is in line with that reported by Moe, Flatt, and Tyrrell (80) for a ration of similar digestible energy concentration. However, the range extended from 50.3 to 84.5%, which is considerably broader than one would expect.

This variability may be due to a lack of consistency in the weighbacks during the digestibility trial. It appears that on several occasions the mangers were cleaned during the morning feeding, resulting in apparently small refusals the following day.

Data were utilized from six of the cows to examine this possibility more thoroughly. The proportion of the feed allotment which was not consumed was computed for each observation from two weeks prior to the digestibility trial to two weeks after, and the proportions were averaged for three periods: a) before, b) during, and c) after the digestibility trial. These averages are presented in Table 9, and one can see that in all cases, the average proportion of the feed which was refused is less in period b than in periods a and c.

Table 8. Statistical summary of traits examined with 22 cows

Variable	Mean ± S.E.	High value Low value	Coefficient of variation[a]
DM (kg)	16.66 0.881	25.60 8.72	24.8
DDM (kg)	12.43 0.758	19.38 4.99	28.6
DEOBS (kcal)	55.14 3.353	85.59 21.97	28.6
DMMET ($kg/kg^{.75}$)	0.1411 0.0071	0.2229 0.0829	23.5
DDMMET ($kg/kg^{.75}$)	0.1052 0.0062	0.1686 0.0548	27.8
DEOBSMET ($kcal/kg^{.75}$)	0.4667 0.0276	0.7455 0.2416	27.8
DMINBWT (%)	2.882 0.1456	4.587 1.641	23.7
DEOPCENT (%)	102.63 5.968	167.17 50.04	27.3
DECPCENT (%)	101.78 4.801	164.47 65.39	22.2
DEOMILK (kcal)	34.84 3.181	64.19 5.27	42.8
DECMILK (kcal)	34.51 2.789	62.81 12.01	37.9
MPROD61 (kg)	25.71 1.130	34.77 18.64	20.6
MPROD306 (kg)	7,063.37 302.289	9,942.27 5,521.82	20.1
SCMRAW (kg)	23.39 0.974	31.61 17.20	19.5
SCMCORR (kg)	26.8 0.83	33.7 19.6	14.5

[a]Coefficient of variation = $\frac{100 \times \text{standard deviation}}{\text{mean}}$.

Table 8 (Continued)

Variable	Mean ± S.E.	High value Low value	Coefficient of variation[a]
SCMRMET (kg/kg$^{.75}$)	0.1990 0.0076	0.2652 0.1452	17.9
SCMCMET (kg/kg$^{.75}$)	0.2298 0.0084	0.3053 0.1506	17.2
SCM306DA (kg)	6,250.0 251.16	8,787. 4,920.	18.8
SCM30 (kg)	25.64 1.083	34.0 19.2	19.8
AVEWT61 (kg)	579.75 16.638	729.7 409.6	13.5
METWT61 (kg$^{.75}$)	117.95 2.563	140.4 91.05	10.2
WTCHNG61 (kg)	19.0 3.90	67. -6.	96.6
RATE61 (kg/wk)	2.35 0.398	7.38 0.10	79.5
WTCHNG30 (kg)	8.8 2.45	32. -13.	130.1
RATE30 (kg/wk)	2.64 0.698	9.50 -2.74	124.0
DMDIGEST (%)	74.37 2.041	84.7 50.4	12.9
EDIGEST (%)	73.94 2.054	84.5 50.3	13.0
AGE (mo)	39.0 3.71	77. 23.	44.6
MONTH --	3.4 0.24	5. 1.	33.4
DAYSPREG (days)	28.7 7.55	94. 0.	123.3
SCMRDM (kgSCM/kgDM)	1.463 0.0722	2.16 0.80	23.1
SCMCDM (kgSCM/kgDM)	1.697 0.0952	2.81 0.98	26.3

Table 8 (Continued)

Variable	Mean ± S.E.	High value Low value	Coefficient of variation[a]
SCMRDEO (kgSCM/kcalDEO)	0.457 0.0323	0.86 0.24	33.1
SCMCDEO (kgSCM/kcalDEO)	0.529 0.0398	1.12 0.29	35.3
NETEFFRO (kgSCM/kcalDEO)	0.872 0.1435	3.58 0.32	77.2
NETEFFCO (kgSCM/kcalDEO)	1.026 0.1877	4.65 0.39	85.8
NETEFFRC (kgSCM/kcalDEO)	0.774 0.0676	1.57 0.33	41.0
NETEFFCC (kgSCM/kcalDEO)	0.906 0.0885	2.04 0.40	45.8

Thus, there may have been some instances when the weighbacks in fact represented orts from a half-day rather than a whole day. This might give the impression that the cow consumed more feed than she did, which would tend to increase the estimate of digestibility from that cow.

It was then temporarily assumed that the weighbacks observed during the digestibility trial did represent only refusals from the morning feed, and new coefficients of digestibility were computed for these six cows by doubling the average daily weighback to estimate the amount of feed not consumed during a day. In this process the estimate of the amount of chromic oxide not consumed was also increased, which

Table 9. Examination of consistency of weighbacks

Cow number	Average Proportion of feed fed refused			Dry matter Digestibility coefficient	
	Period a[a]	Period b	Period c	Original	Revised[b]
6020	0.16	0.13	0.32	84.74	80.47
6175	0.24	0.10	0.29	84.70	81.72
5660	0.25	0.08	0.07	50.38	41.56
6196	0.46	0.18	0.29	56.51	50.35
5781	0.25	0.12	0.23	69.28	64.26
6197	0.25	0.14	0.32	71.08	60.80

[a]Period a--two weeks prior to digestibility trial
Period b--during digestibility trial
Period c--two weeks after digestibility trial.

[b]Calculated by doubling all weighbacks during digestibility trial.

tends to increase digestibility coefficients. Therefore, the revised estimates shown in Table 9 are not markedly different from the original figures, although they all have been decreased slightly.

Finally the data were left alone, as it would have been rather difficult and arbitrary to determine firstly, which cows had incorrect estimates of weighbacks, and secondly, which specific observations were in error. It therefore is not unreasonable to be somewhat skeptical of any relationships involving observed digestibility traits. However, over a long period, such as from 90 to 150 days, the errors incurred by assuming that the weighbacks during the fourteen-day digestibility trial represented full-day orts are probably not greater than five percent.

The Simple Correlations

There were a variety of interesting correlations among the variables included in the factor analysis, and all these correlations are listed in Appendix I, Table 14. In general, the groups of measures (as measures of feed intake or measures of milk production) exhibited consistent trends with only occasional deviations from the group tendencies.

Correlations among the measures of feed intake were large and positive, reflecting the functional dependence of all of them on dry matter consumption. Digestibility of dry matter and of energy were highly correlated with intakes of digestible dry matter and energy, but the correlation of digestibility with dry matter consumption per se was essentially zero. It may be that the energy concentration of this ration was sufficiently high so that digestibility was not a factor either causing or reflecting variations among the cows in dry matter consumption.

Measures of body weight and of body weight change were apparently unimportant as factors influencing feed intake. Likewise, there were only three instances in which milk production and feed intake were significantly correlated ($P < .05$). These were the correlations between SCMRAW and DM, SCMRAW and DECMILK, and SCM306DA and DECMILK. There appears no reasonable biological interpretation for this although SCMRAW and DM were the basic observations from which most other measures of feed intake and milk production were calculated for each cow.

There was a negative correlation between measures of feed intake and month of calving, where the latter ranged from August through December. Perhaps this reflects improved weather conditions during the feed intake period for cows which calved in November and December. The feed intake period of cows calving in September fell during December and January, with average temperatures in the area of -5 C; they may have required more feed to maintain body heat than the later-calving cows whose feed consumption was measured during March and

April with temperatures around 6 C.

Among the more surprising things observed was the apparent lack of correlation between milk production and feed efficiency, while the correlations between efficiency and feed consumption were negative and highly significant (P < .01), which is the opposite of what has usually been reported (58,69,75,76). To some extent this correlation between feed intake and efficiency is a functional relationship. However it may indicate that under ad libitum feeding conditions, where feed allotment is not limited by level of production, variation in feed intake among cows with similar levels of milk production will accentuate differences among cows in efficiency. Nevertheless, the data in this evaluation are limited, and there is no intent on our part to use them to contradict the results obtained by others with larger, more comprehensive studies.

For the most part, the various measures of solids-corrected milk (SCM) production were significantly correlated among themselves (P < .01). The correlation between SCMRAW and AGE was 0.488 (P < .05), while that between SCMCORR and AGE was essentially zero. Thus, it appears that the correction factors used were helpful in reducing the relationship between age and production. However, there were no more significant correlations observed involving SCMCORR than there were with SCMRAW.

Relating production to metabolic weight, as with SCMRMET and SCMCMET, produced some interesting correlations. Among them was the highly significant ($P < .01$) negative relationship which existed between SCMCMET (SCMCORR/METWT61) and measures of body weight (AVEWT61 and METWT61). This probably reflects the increased SCM production of the younger, smaller cows, which resulted from application of the age-correction factors. However, as no factors were applied to equalize body weight, SCMCMET of a cow of lower body weight could be greater than that of an older, heavier cow.

One could also examine the correlations between measures of body weight and either SCMRAW or SCMCORR. Correcting production for age apparently also corrected it for weight differences; the difference between SCMRAW and SCMCORR is greater for smaller than for larger cows.

All the measures of production had negative correlation coefficients with WTCHNG61 and RATE61, measures of weight change during the feed intake period. Many are significant at the 0.10 level of probability, which tends to substantiate previous evidence that weight gain is negatively correlated with milk production, although the amount of variation in SCM production accounted for by weight change alone was less than 10 percent.

Again, the relationships between measures of production and measures of feed efficiency were small, although there was a trend towards positive correlations between gross measures of efficiency (SCMRDM, SCMCDM, SCMRDEO, and SCMCDEO) and either SCMRMET or SCMCMET.

Measures of efficiency also were highly correlated with one another, indicating that they did represent essentially the same thing. The coefficients seem to be slightly greater when both terms in the pair are based on either the same estimate of feed intake (SCMRDM and NETEFFCC--both based on dry matter consumption) and/or the same estimate of milk production (SCMRDM and SCMRDEO--both based on SCMRAW).

As was discussed previously, efficiency was highly negatively correlated with feed intake and exhibited no consistent relationship with SCM production. When either NETEFFRC or NETEFFCC, which represent net efficiency based on dry matter intake, was related to measures of feed consumption, there was a tendency for the coefficients to be slightly higher than when NETEFFRO or NETEFFCO was used. The relative variability of NETEFFRC and NETEFFCC was less than that of NETEFFRO and NETEFFCO, which may have affected the magnitude of the coefficients. The tendency for feed intake to have larger (more negative) correlations with SCMRDM or SCMCDM than with SCMRDEO or SCMCDEO also may reflect differences in variability.

There seemed to be a negative relationship between body weight and measures of efficiency, although not all the correlations were significant ($P > .05$). This is in agreement with results obtained by others (56,75,77). Weight change during the feed intake period also was apparently negatively correlated with efficiency, although all but one of the coefficients were below critical levels for statistical significance ($P > .05$).

Month of calving exhibited a positive relationship ($P < .05$) with feed efficiency, probably because of its negative effect on feed consumption. Digestibilities of energy and of dry matter were negatively correlated ($P < .01$) with those measures of efficiency which were based on DEOBS; however, the relationship between digestibility and other estimates of efficiency, though consistently negative, was considerably smaller.

Not many other relationships appeared outstanding. There was a highly significant negative correlation ($P < .01$) between month of calving and weight change during the 30 days preceding the feed intake period. This may reflect differences between the environments of early- and late-calving cows in this trial, as the average temperature during the 60-to-89-day period was 7 to 8 C higher for cows which freshened in September than for those which freshened in December.

Age was related to SCM306DA and SCMRAW, and to AVEWT61 and METWT61. The correlation between age and RATE30 was significant ($P < .05$) and negative, as one might expect the younger cows, still growing, to begin to gain weight before the older, fully grown cows. However, other measures of weight change, either prior to or during the feed intake period, exhibited only a small relationship to age.

Both representations of weight change, WTCHNG and RATE, appear to indicate the same trait, within 60 to 89 or 90 to 150 days. There was a correlation ($P < .05$) between RATE61 and RATE30, but the relationship between WTCHNG61 and WTCHNG30 was negligible.

Finally, the correlation between digestibility of dry matter and of energy was particularly high. The regression of percent energy digestibility on percent dry matter digestibility using these data was

$$EDIGEST = 1.006DMDIGEST - 0.878,$$

with $s_{y.x} = 0.288$ and $R^2 = 99.9$. This is quite comparable with similar regressions computed by others (4,52,83), and it lends support to the suggestion voiced by Graham (52) that it should not be necessary to determine digestibility of feed energy if one is already determining dry matter digestibility.

The Factor Analysis

The five factors which were first generated from the correlation matrix and then rotated are presented in Table 10. These five factors accounted for 91% of the total variance among the 22 cows over 35 variables. The factors appear to be representative of the classes of measures which were taken on

Table 10. Rotated factor matrix and percent of variance accounted for by each factor

Variable	Correlation of variable with factor 1	2	3	4	5
DM	0.93	0.26	0.20	-0.08	0.04
DDM	0.90	0.13	0.11	0.33	0.12
DEOBS	0.90	0.13	0.12	0.33	0.13
DMMET	0.94	0.25	-0.13	-0.12	0.00
DDMMET	0.91	0.12	-0.16	0.32	0.08
DEOBSMET	0.91	0.12	-0.16	0.32	0.09
DMINBWT	0.91	0.24	-0.25	-0.13	0.00
DEOMILK	0.91	0.16	0.07	0.30	0.08
DECMILK	0.92	0.29	0.15	-0.14	-0.02
DEOPCENT	0.89	-0.21	-0.04	0.33	0.17
DECPCENT	0.97	-0.17	0.00	-0.08	0.08
SCMRAW	0.15	0.90	0.33	-0.04	-0.18
SCMCORR	0.12	0.93	-0.05	0.03	-0.06
SCMRMET	0.04	0.94	-0.15	-0.13	-0.23
SCMCMET	-0.06	0.74	-0.59	-0.07	-0.08
SCM306DA	0.12	0.80	0.48	-0.17	-0.15
AVEWT61	0.17	0.00	0.93	0.13	0.11
METWT61	0.18	0.00	0.93	0.13	0.11
WTCHNG61	0.13	-0.27	0.27	0.02	0.81
RATE61	0.17	-0.31	0.23	-0.06	0.83
WTCHNG30	0.12	0.06	-0.40	0.34	0.58
RATE30	0.00	-0.08	-0.27	0.28	0.77
AGE	-0.01	0.19	0.68	-0.22	-0.41
MONTH	-0.62	0.08	0.38	-0.14	-0.06
DMDIGEST	0.25	-0.15	-0.02	0.92	0.20
EDIGEST	0.24	-0.15	-0.01	0.92	0.20
DAYSPREG	-0.36	0.31	0.40	0.54	-0.30
SCMRDM	-0.87	0.40	-0.14	-0.01	-0.17
SCMCDM	-0.85	0.22	-0.44	0.01	-0.05
SCMRDEO	-0.73	0.38	-0.14	-0.51	-0.17
SCMCDEO	-0.76	0.25	-0.38	-0.44	-0.09
METEFFRO	-0.69	0.07	-0.37	-0.47	-0.05
NETEFFRC	-0.91	0.03	-0.24	0.01	-0.03
NETEFFCO	-0.67	0.02	-0.46	-0.42	-0.02
NETEFFCC	-0.87	0.02	-0.41	0.01	0.02
Percent of total variance accounted for (%)	43.6	14.3	13.6	11.0	8.5

the cows. In order of importance with respect to accounting for the variability, they can be interpreted as representing feed intake (Factor 1), milk production (Factor 2), body weight (Factor 3), digestibility (Factor 4), and body weight change (Factor 5).

A sixth factor could have been generated. In that case, Factor 5 would have represented weight change during the feed intake period, and Factor 6 would have represented weight change during 60 to 89 days. However, the six factors would have accounted for only an additional four percent of the variance, so it was decided that five factors would adequately represent the data.

Again, the values in the columns are the correlations of the observed variables with the factors. Thus, it can be seen that measures of feed intake are positively correlated with Factor 1, while those of feed efficiency are similarly negatively correlated with it. Month of calving is also negatively correlated with Factor 1, but to a lesser extent. Factor 2 is positively correlated with measures of milk production and exhibits relationships, although not as strongly, with weight change during 90 to 150 days (negative), and with DAYSPREG, SCMRDM, and SCMRDEO (positive).

DAYSPREG was not particularly highly correlated with any one factor, but seemed to be positively related to milk production, average body weight, and digestibility, and negatively related to factors representing feed intake and weight change. It cannot be said with certainty that these relationships are due to pregnancy *per se*. They may be more characteristic of cows which conceive easily, or of cows which eventually produce more milk, as some of the nonpregnant cows were later culled for low production.

Factor 3 was positively correlated with AVEWT61 and METWT61. Age, month, SCMRAW, and SCM306DA also exhibited positive, but smaller correlations with this factor. SCMCMET and measures of feed efficiency involving SCMCORR were moderately negatively correlated with Factor 3. Possible reasons for this have already been discussed in a previous section. There was also a hint of a negative relationship between Factor 3 and weight change during 60 to 89 days. This is probably comparable to the correlation between age and body weight change, which has also been discussed. In fact, the lowest body weights observed on the smaller, younger heifers occurred during the first month, while the lower weights of the older cows occurred more frequently during the second or third month of the lactation.

Digestibility of dry matter and of energy are both highly correlated with Factor 4 and bring into the relationship estimates of digestible nutrient intake (positively) and estimates of feed efficiency computed with DEOBS (negatively).

Body weight change is apparently the trait represented by the fifth factor. However, the correlations of the factor with the four measures are not as high as if, for example, the sixth factor had been generated. No other measures with the exception of DAYSPREG (negative) and age (positive) have any relationship with the factor, and it is the least important in accounting for the variability among the cows over all the traits.

The Regression Models

The regressions of DMMET, DEOBSMET, SCMRDM, and SCMRDEO were quite successful, as all the models utilized resulted in R^2's of 90% or above. Variation in NETEFFRO, which was considerably greater, was not reduced as well, although the R^2 was still larger than 80%. SCMRDM-P, SCMRDEO-P, and NETEFFRO-P, which were regressed on traits not representative of feed intake, were also not fitted as successfully, with R^2's ranging from 60 to 70% for the "satisfactory" models. The models which seemed most appropriate are listed in Table 11, together with the R^2's for each.

Some of the partial regressions are as would be expected, at least with respect to sign. Included in this category are the regressions of feed intake (DMMET or DEOBSMET) on milk production -- positive, and gross efficiency (SCMRDM or SCMRDEO) -- negative, and the regressions of gross efficiency (SCMRDM or SCMRDEO) and feed intake -- negative, milk production -- positive, body weight -- negative, (body weight)^2 -- positive, and energy digestibility (because of its

Table 11. Models resulting from application of a stepwise model-building procedure[a]

Dependent variable	Most satisfactory model, R^2
DMMET	0.152 + 0.110NETEFFRC + 1.050SCMRMET - 0.208SCMRDM - 0.001RATE30, 97.7%
DEOBSMET	0.714 - 1.642SCMRDEO + 3.002SCMRMET + 0.136NETEFFRO - 0.003EDIGEST, 96.5%
SCMRDM	1.546 - 9.117DMMET + 8.397SCMRMET - 0.0001SCM306DA, 94.4%
SCMRDEO	1.722 - 0.741DEOBSMET + 1.948SCMRMET - 0.003AVEWT61 + 0.000003WT61SQ - 0.003EDIGEST, 96.9%
NETEFFRO	14.674 - 0.010DEOPCENT - 0.038AVEWT61 + 0.00003WT61SQ - 0.016EDIGEST, 83.0%
SCMRDM-P	6.922 + 0.0103MONTH - 0.020AVEWT61 + 0.00001WT61SQ + 0.004DAYSPREG + 0.025SCMRAW, 71.4%
SCMRDEO-P	2.957 + 0.051MONTH - 0.010AVEWT61 + 0.00001WT61SQ + 0.003AGE + 0.012SCMRAW, 70.6%
NETEFFRO-P	15.94 - 0.051AVEWT61 + 0.00004WT61SQ + 0.170MONTH, 61.6%

[a]All coefficients significantly different from 0 ($P < .10$).

effect on observed digestible energy consumption) -- negative.

There were also a number of terms used in these models for which it is difficult to interpret the sign of the regression, such as the positive partial regressions of DMMET on NETEFFRC and of DEOBSMET on NETEFFRO. Apparently an increase in the utilization for milk of feed nutrients above maintenance results in increased consumption of feed per unit of metabolic body weight. The partial regression of DMMET on RATE30 was negative, and it may be that cows, which lost more weight in the month preceding measurement of feed intake, consumed more during 90 to 150 days. Likewise, a unit increase in energy digestibility resulted in a decrease in DEOBSMET of 0.003 kcal/kg$^{.75}$. However, with as much variability as exists here, it would probably be wiser to refrain from molding the data to fit the numbers.

For NETEFFRO and the three "predictor" dependent variables, solids-corrected milk production appeared to have been relatively unimportant as an independent variable. In fact, in the models chosen there were no significant ($P < .10$) partial regressions of NETEFFRO on production measures. With respect to other traits which were included in the models for SCMRDM-P, SCMRDEO-P, and NETEFFRO-P, none of the regressions are contrary to what would be expected from previous reports. With respect to the apparent significance of month of calving, there was a negative correlation between MONTH (at least from August through December) and measures of feed intake; thus, one would expect a positive regression of efficiency on MONTH.

These results can be summarized briefly as follows: Any one of the various types of measurements used, such as of feed intake, milk production, or body weight, seemed to be adequate to represent the other traits in its class, although the correlations were, in general, not perfect. Therefore, different estimates of efficiency, at least in the rather crude sense as is defined here, can be reasonably safely judged to demonstrate the same qualities from one experiment to the next. Similarly, differences among cows in voluntary feed consumption remain essentially the same regardless of the formula used to define it.

Ad libitum feed intake as an observed trait appeared to be influenced primarily by nutritional requirements for milk production, tempered by efficiency. Furthermore, variations in feed consumption were the main factors effecting differences among the cows in lactation feed efficiency, and most other factors, which appeared to be involved, were probably effective by causing differences in feed intake. Milk production, on the other hand, did not exert a particularly important influence on efficiency, especially when measures of feed intake were ignored.

Measures of body weight and of body weight change appeared to play a role in effecting variation in both feed intake and efficiency, as shown by the regression models listed in Table 11; however, simple correlations between measures (or factors) of feed intake and body weight change would not have indicated any significant effect.

If one could have faith in the digestibility coefficients observed, it would seem that, of itself, variation among cows in the ability to digest a feed are not adequate to explain differences in efficiency of utilization of feed dry matter. However, this would be the weakest of our conclusions, because of the difficulties in obtaining reliable estimates of feed intake during the digestibility trial.

It would be interesting to conduct another study of this sort, hopefully employing more cows, covering a greater part of the year, and with steps taken to insure more precision. A completely mixed feed, fed to appetite, would still be useful, so that differences among the cows in producing ability and in the quality and quantity of feed offered are not confunded. It also would be desirable to examine some measure of economic efficiency, perhaps including estimates of cow-care costs as suggested by Young (116), to provide for a more complete perspective on lactation efficiency.

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APPENDIX I

Table 12. Results of chemical analyses performed on feeds used[a]

Feedstuff	Sample number	Dry matter	Crude protein	Ether extract	Acid-detergent fiber	Ash	Gross energy kcal/kg
		%					
Concentrate	1	87.6	24.4	3.99	7.4	6.72	4.53
	2	86.9	22.7	3.04	7.0	5.61	4.55
	3	87.8	20.4	4.63	7.7	4.60	4.40
	4	89.4	21.6	4.37	6.8	4.80	4.40
Alfalfa pellets	1	93.1	20.4	3.97	27.6	11.26	4.55
	2	92.6	20.5	3.74	30.3	11.15	4.53
	3	94.2	18.7	4.34	34.1	11.90	4.38
	4	97.1	18.6	3.99	27.8	8.25	4.55
Corn silage	1	40.5	8.0	2.22	25.5	4.07	4.55
	2	52.0	8.4	3.18	24.8	4.06	4.54
	3	53.2	8.2	3.18	26.5	4.34	4.51
	4	40.1	14.8	3.46	23.6	4.28	4.55
	5	49.5	8.3	2.94	26.0	4.68	4.58
	6	52.3	8.6	4.10	20.9	4.25	4.51
	7	50.3	8.0	2.94	24.6	4.81	4.53
	8	47.9	9.0	3.07	27.6	4.32	4.47
	9	48.0	9.5	2.54	24.1	4.64	4.45
	10	50.0	9.2	3.60	23.5	5.18	4.52
Complete mix	1	60.7	15.7	3.88	17.9	5.77	4.56
	2	61.9	13.9	4.12	20.2	5.38	4.51
	3	65.8	14.6	4.41	21.6	5.85	4.45
	4	60.1	21.6	4.18	17.8	4.94	4.48
	5	65.2	13.6	3.19	21.0	5.00	4.45
	6	64.2	14.2	3.79	17.8	4.57	4.42
	7	67.5	13.8	4.24	20.8	5.66	4.48
	8	64.4	14.2	3.53	19.6	5.29	4.48
	9	66.6	21.0	4.25	19.6	5.06	4.46
	10	64.4	14.1	3.12	21.6	5.63	4.38
	11	65.7	14.0	4.42	18.2	4.45	4.47

[a]All analyses performed in duplicate.

Table 13. Individual cow data for traits examined

	AVEWT61 kg	METWT61 $kg^{.75}$	WTCHNG61 kg	RATE61 kg/wk	WTCHNG30 kg	RATE30 kg/wk
6009	585	118	-6	1.15	18	5.50
6164	534	111	28	3.68	25	6.60
6134	580	118	11	1.52	22	5.30
6153	558	115	26	4.35	2	-0.20
5718	569	116	2	0.48	22	4.10
6175	497	105	29	1.78	11	3.90
6020	730	140	67	7.38	32	9.50
6050	681	133	16	1.42	8	2.34
6197	430	94	-1	0.88	11	2.90
6036	582	118	2	0.10	8	-0.80
6109	600	121	16	1.78	7	1.20
6196	410	91	5	1.04	10	3.50
6179	555	114	49	4.45	-6	-0.70
5660	562	115	5	1.30	5	0.29
6192	557	115	13	1.89	13	3.10
6203	561	115	48	4.98	16	8.80
5903	630	126	26	2.73	-4	0.20
5563	660	130	24	3.48	-5	-0.60
5695	637	127	9	0.35	-5	-1.57
5781	677	133	0	0.25	-13	-2.74
6211	509	107	18	2.45	17	3.54
6057	652	129	30	4.23	0	3.90

Table 13 (Continued)

	MPROD61	MPROD306	SCMRAW	SCMCORR	SCM306DA	SCM30
	kg					
6009	32.0	8696	28.5	29.7	7442	29.4
6164	24.7	6183	22.2	27.2	5306	19.4
6134	23.8	6267	19.6	24.1	5025	19.2
6153	19.5	5566[a]	20.5	25.2	5409[a]	20.9
5718	32.6	8965	26.7	26.0	7135	27.8
6175	21.2	5974[a]	20.1	25.4	5649[a]	22.2
6020	21.7	6440[a]	21.8	23.3	6231[a]	27.6
6050	34.8	8666	31.6	33.7	7585	34.0
6197	21.6	5627[a]	19.0	24.7	4931[a]	19.2
6036	23.4	6377	22.2	24.9	5687	26.8
6109	20.3	5561[a]	19.6	25.4	5372[a]	22.0
6196	19.8	5204[a]	18.9	24.5	4920[a]	19.9
6179	24.5	6996	22.3	28.9	5822	23.6
5660	32.1	9067	30.6	31.5	8787	31.8
6192	25.4	6084	23.9	31.0	5678	27.2
6203	18.6	5522	17.2	22.3	5236	19.2
5903	34.4	9942	30.9	31.4	8413	33.6
5563	24.3	7384	18.9	19.6	5986	24.5
5695	33.2	8942	31.1	31.8	8077	32.2
5781	29.2	7799	23.4	24.1	6465	32.8
6211	26.9	7666	25.2	32.7	6873	26.0
6057	21.6	6108	20.3	22.8	5472	24.9

[a]Incomplete records extended to 306 days.

Table 13 (Continued)

	SCMRMET	SCMCMET	MPRODMET	DM	DDM	DMMET	DDMMET	GE
		$kg/kg^{.75}$		kg	kg	$kg/kg^{.75}$	$kg/kg^{.75}$	kcal
6009	0.240	0.250	0.271	23.4	18.8	0.197	0.097	105
6164	0.200	0.245	0.222	22.0	16.9	0.198	0.093	98
6134	0.166	0.204	0.202	13.6	10.7	0.115	0.055	61
6153	0.179	0.219	0.170	25.6	19.4	0.223	0.103	114
5718	0.229	0.223	0.281	16.2	13.4	0.139	0.070	72
6175	0.190	0.241	0.202	16.8	14.2	0.159	0.082	75
6020	0.156	0.166	0.155	18.8	15.9	0.134	0.069	84
6050	0.237	0.253	0.262	19.7	15.0	0.147	0.069	87
6197	0.202	0.262	0.230	9.8	7.0	0.104	0.045	44
6036	0.187	0.210	0.198	15.9	12.7	0.134	0.066	71
6109	0.162	0.210	0.168	17.4	12.8	0.144	0.064	78
6196	0.207	0.269	0.218	8.7	5.0	0.096	0.033	39
6179	0.194	0.253	0.215	16.4	13.3	0.143	0.071	73
5660	0.265	0.273	0.279	18.2	9.2	0.158	0.048	81
6192	0.208	0.270	0.221	15.3	11.0	0.134	0.058	68
6203	0.149	0.194	0.162	15.1	11.8	0.131	0.063	68
5903	0.246	0.250	0.273	20.1	11.2	0.160	0.054	90
5563	0.145	0.150	0.187	14.0	9.1	0.108	0.042	63
5695	0.246	0.251	0.261	17.2	13.9	0.136	0.067	77
5781	0.176	0.182	0.220	17.7	12.3	0.134	0.056	79
6211	0.235	0.305	0.251	13.7	11.3	0.128	0.064	61
6057	0.158	0.177	0.167	10.7	8.6	0.083	0.040	48

Table 13 (Continued)

	DEOBS kcal	DEOBSMET kcal/kg$^{.75}$	DECALC kcal	DMINBWT %	MAINT kcal	TOTREQ kcal
6009	83.7	0.704	77.1	4.01	20.3	61.6
6164	74.8	0.673	72.3	4.12	20.6	52.0
6134	47.6	0.403	44.6	2.34	22.1	49.9
6153	85.6	0.746	84.2	4.59	21.4	51.2
5718	59.6	0.511	53.4	2.85	18.1	56.0
6175	63.2	0.600	55.1	3.37	19.4	48.6
6020	70.8	0.504	61.9	2.58	23.8	55.0
6050	66.0	0.495	64.7	2.89	22.7	68.0
6197	31.0	0.328	32.4	2.29	17.3	44.2
6036	56.5	0.477	52.4	2.74	20.2	51.1
6109	56.7	0.468	57.3	2.90	20.8	48.4
6196	22.0	0.241	28.7	2.13	16.7	43.9
6179	58.7	0.513	53.8	2.94	21.2	50.8
5660	40.9	0.354	59.9	3.24	17.9	63.2
6192	48.3	0.422	50.5	2.76	21.4	54.7
6203	52.8	0.459	49.8	2.70	21.5	46.5
5903	49.6	0.394	66.1	3.19	19.4	63.8
5563	40.4	0.310	46.2	2.13	20.0	48.0
5695	61.8	0.488	56.7	2.71	19.6	64.5
5781	54.6	0.411	58.3	2.62	20.5	54.8
6211	50.3	0.470	45.1	2.70	19.8	55.1
6057	38.2	0.296	35.2	1.64	21.8	51.1

Table 13 (Continued)

	DEOPCENT %	DECPCENT %	DEOMILK kcal	DECMILK kcal	SCMRDM	SCMCDM	MPRODDM
					kg milk/kg DM		
6009	136	125	63.4	56.8	1.22	1.27	1.37
6164	144	139	54.2	51.7	1.01	1.24	1.12
6134	95	89	25.5	22.5	1.45	1.78	1.75
6153	167	164	64.2	62.8	0.80	0.98	0.76
5718	106	95	41.5	35.3	1.64	1.60	2.01
6175	130	113	43.8	35.7	1.20	1.52	1.26
6020	129	112	47.0	38.1	1.16	1.24	1.15
6050	97	95	43.3	42.0	1.61	1.71	1.77
6197	70	73	13.7	15.1	1.93	2.50	2.20
6026	110	103	36.3	32.2	1.39	1.56	1.47
6109	117	118	35.9	36.5	1.13	1.46	1.17
6196	50	65	5.3	12.0	2.16	2.81	2.28
6179	116	106	37.5	32.6	1.36	1.77	1.49
5660	65	95	23.0	42.0	1.68	1.73	1.76
6192	88	92	26.9	29.1	1.56	2.02	1.66
6203	114	107	31.3	28.3	1.14	1.47	1.23
5903	78	104	30.2	46.7	1.54	1.56	1.71
5563	84	96	20.4	26.2	1.35	1.40	1.74
5695	96	88	42.2	37.1	1.80	1.84	1.93
5781	100	106	34.0	37.8	1.32	1.36	1.65
6211	91	82	30.5	25.3	1.84	2.38	1.96
6057	75	69	16.4	13.4	1.90	2.13	2.02

Table 13 (Continued)

	SCMRDDM	SCMCDDM	MPRODDDM	SCMRGE	SCMCGE	MPRODGE
	kg milk/kg DDM			kg milk/kcal GE		
6009	1.51	1.58	1.70	0.272	0.283	0.305
6164	1.32	1.61	1.46	0.226	0.278	0.252
6134	1.84	2.25	2.22	0.324	0.395	0.390
6153	1.06	1.30	1.00	0.180	0.221	0.171
5718	1.98	1.94	2.43	0.369	0.361	0.453
6175	1.41	1.79	1.49	0.268	0.339	0.283
6020	1.37	1.46	1.36	0.260	0.277	0.258
6050	2.10	2.25	2.32	0.362	0.387	0.400
6197	2.72	3.53	3.08	0.432	0.561	0.491
6036	1.74	1.96	1.84	0.312	0.351	0.330
6109	1.54	1.98	1.58	0.253	0.326	0.260
6196	3.78	4.90	3.96	0.485	0.628	0.508
6179	1.68	2.17	1.84	0.306	0.396	0.336
5660	3.34	3.42	3.49	0.377	0.389	0.396
6192	2.18	2.82	2.31	0.349	0.456	0.374
6203	1.45	1.89	1.58	0.254	0.328	0.274
5903	2.75	2.80	3.07	0.345	0.349	0.382
5563	2.08	2.15	2.67	0.302	0.311	0.386
5695	2.24	2.29	2.39	0.404	0.413	0.431
5781	1.91	1.96	2.37	0.296	0.305	0.370
6211	2.23	2.89	2.38	0.412	0.536	0.441
6057	2.38	2.65	2.51	0.426	0.475	0.450

Table 13 (Continued)

	SCMRDEO	SCMCDEO	MPRODDEO	NETEFFRO	NETEFFCO	NETEFFMO	NETEFFRC
	kg milk/kcal DE						
6009	0.340	0.355	0.382	0.450	0.468	0.505	0.502
6164	0.297	0.364	0.330	0.410	0.502	0.456	0.429
6134	0.412	0.506	0.500	0.769	0.945	0.933	0.872
6153	0.240	0.294	0.228	0.320	0.392	0.304	0.327
5718	0.448	0.436	0.547	0.643	0.627	0.786	0.755
6175	0.318	0.402	0.335	0.459	0.580	0.484	0.562
6020	0.308	0.329	0.306	0.464	0.495	0.462	0.574
6050	0.479	0.510	0.527	0.729	0.778	0.804	0.752
6197	0.615	0.797	0.697	1.392	1.805	1.577	1.259
6036	0.392	0.441	0.414	0.686	0.687	0.645	0.687
6109	0.346	0.448	0.358	0.706	0.539	0.565	0.539
6196	0.859	1.115	0.900	4.652	1.572	3.736	1.572
6179	0.379	0.492	0.417	0.770	0.683	0.653	0.683
5660	0.749	0.770	0.785	1.371	0.730	1.396	0.730
6192	0.494	0.642	0.526	1.152	0.821	0.944	0.821
6203	0.325	0.422	0.352	0.712	0.607	0.594	0.607
5903	0.624	0.633	0.694	1.041	0.662	1.139	0.662
5563	0.468	0.486	0.601	0.963	0.723	1.191	0.723
5695	0.504	0.514	0.537	0.753	0.838	0.787	0.838
5781	0.429	0.442	0.535	0.708	0.619	0.859	0.619
6211	0.501	0.650	0.535	1.072	0.996	0.882	0.996
6057	0.532	0.596	0.565	1.387	1.520	1.317	1.520

Table 13 (Continued)

	NETEFFCC	NETEFFMC	DMDIGEST	EDIGEST	AGE	MONTH	DAYSPREG
	kg milk/kcal DE		%	%	month	-	days
6009	0.523	0.563	80.4	80.0	47	1	0
6164	0.526	0.478	76.8	76.1	25	2	0
6134	1.072	1.058	78.8	78.5	28	2	64
6153	0.401	0.310	75.7	74.9	26	2	0
5718	0.736	0.924	82.9	82.4	62	2	66
6175	0.711	0.594	84.7	84.4	25	3	17
6020	0.612	0.570	84.7	84.5	39	3	0
6050	0.802	0.828	76.5	75.6	36	3	94
6197	1.633	1.430	71.1	70.3	23	3	0
6036	0.772	0.727	79.8	79.4	38	3	7
6109	0.677	0.556	73.4	73.1	32	3	0
6196	2.040	1.650	57.2	56.5	24	4	0
6179	0.886	0.752	81.1	80.7	25	4	5
5660	0.750	0.764	50.4	50.3	69	4	19
6192	1.066	0.873	71.4	70.6	24	4	13
6203	0.787	0.657	78.3	78.2	23	4	0
5903	0.672	0.737	56.0	55.3	48	4	0
5563	0.749	0.927	64.7	64.4	77	4	28
5695	0.856	0.895	80.6	80.3	67	5	78
5781	0.637	0.772	69.3	68.9	60	5	78
6211	1.292	1.063	82.3	82.2	24	5	88
6057	1.704	1.612	80.0	84.7	37	5	75

Table 14. Correlations among variables used in the factor analysis[a,b]

	DM	DDM	DEOBS	DMMET	DDMMET	DEOBSMET	DMINBWT	DEOMILK	DECMILK
DDM	0.892								
DEOBS	0.889	0.999							
DMMET	0.934	0.836	0.833						
DDMMET	0.829	0.951	0.951	0.885					
DEOBSMET	0.826	0.951	0.951	0.883	0.999				
DMINBWT	0.881	0.789	0.786	0.992	0.877	0.874			
DEOMILK	0.896	0.995	0.995	0.862	0.964	0.964	0.822		
DECMILK	0.992	0.860	0.857	0.952	0.818	0.816	0.908	0.876	
DEOPCENT	0.750	0.916	0.918	0.762	0.929	0.931	0.742	0.910	0.714
DECPCENT	0.880	0.844	0.844	0.894	0.854	0.853	0.871	0.848	0.867
SCMRAW	0.436	0.261	0.257	0.321	0.157	0.153	0.270	0.280	0.465
SCMCORR	0.330	0.214	0.208	0.344	0.222	0.217	0.338	0.228	0.353
SCMRMET	0.232	0.062	0.057	0.299	0.111	0.106	0.314	0.115	0.304
SCMCMET	0.001	-0.074	-0.079	0.216	0.104	0.099	0.286	-0.029	0.064
SCM306DA	0.398	0.178	0.177	0.260	0.056	0.055	0.201	0.203	0.433
AVEWT61	0.372	0.347	0.348	0.022	0.051	0.052	-0.104	0.288	0.297
METWT61	0.381	0.355	0.357	0.033	0.061	0.062	-0.093	0.297	0.306
WTCHNG61	0.114	0.215	0.217	0.026	0.142	0.143	-0.004	0.160	0.039
RATE61	0.170	0.235	0.237	0.093	0.165	0.167	0.064	0.181	0.098

WTCHNG30	0.035	0.227	0.230	0.114	0.285	0.287	0.140	0.222	0.014
RATE30	-0.063	0.132	0.136	-0.020	0.162	0.166	-0.003	0.110	-0.104
AGE	0.146	-0.037	-0.035	-0.044	-0.200	-0.198	-0.112	-0.012	-0.180
MONTH	-0.480	-0.556	-0.554	-0.564	-0.620	-0.618	-0.577	-0.573	-0.486
DMDIGEST	0.114	0.539	0.544	0.089	0.534	0.539	0.076	0.514	0.051
EDIGEST	0.106	0.531	0.537	0.080	0.525	0.531	0.066	0.507	0.043
DAYSPREG	-0.191	-0.086	-0.085	-0.331	-0.191	-0.190	-0.372	-0.106	-0.217
SCMRDM	-0.733	-0.754	-0.756	-0.696	-0.727	-0.729	-0.660	-0.735	-0.692
SCMCDM	-0.823	-0.782	-0.784	-0.669	-0.671	-0.672	-0.618	-0.769	-0.789
SCMRDEO	-0.564	-0.797	-0.800	-0.510	-0.765	-0.769	-0.473	-0.767	-0.498
SCMCDEO	-0.679	-0.838	-0.842	-0.552	-0.743	-0.747	-0.486	-0.813	-0.620
NETEFFRO	-0.632	-0.753	-0.756	-0.524	-0.680	-0.684	-0.464	-0.728	-0.579
NETEFFRC	-0.856	-0.803	-0.803	-0.796	-0.756	-0.756	-0.748	-0.802	-0.838
NETEFFCO	-0.647	-0.734	-0.737	-0.513	-0.639	-0.643	-0.446	-0.711	-0.597
NETEFFCC	-0.872	-0.797	-0.798	-0.757	-0.704	-0.705	-0.691	-0.796	-0.855

[a]Coefficients greater than 0.423 are significant at $P \leq .05$.

[b]Coefficients greater than 0.537 are significant at $P \leq .01$.

Table 14 (Continued)

	DEOPCENT	DECPCENT	SCMRAW	SCMCORR	SCMRMET	SCMCMET	SCM306DA	AVEWT61	METWT61
DDM									
DEOBS									
DMMET									
DDMMET									
DEOBSMET									
DMINBWT									
DEOMILK									
DECMILK									
DEOPCENT									
DECPCENT	0.901								
SCMRAW	-0.128	-0.027							
SCMCORR	-0.092	-0.036	0.834						
SCMRMET	-0.248	-0.143	0.858	0.870					
SCMCMET	-0.214	-0.172	0.453	0.797	0.801				
SCM306DA	-0.177	-0.038	0.937	0.683	0.767	0.303			
AVEWT61	0.172	0.171	0.327	0.026	-0.198	-0.617	0.392		
METWT61	0.181	0.181	0.331	-0.020	-0.195	-0.614	0.396	0.999	
WTCHNG61	0.337	0.252	-0.304	-0.233	-0.478	-0.352	-0.210	0.304	0.302
RATE61	0.358	0.321	-0.349	-0.305	-0.506	-0.392	-0.249	0.291	0.288

WTCHNG30	0.274	0.096	-0.154	-0.048	-0.038	0.091	-0.223	-0.198	-0.199
RATE30	0.209	0.026	-0.286	-0.201	-0.229	-0.083	-0.299	-0.107	-0.110
AGE	-0.234	0.092	0.488	0.014	0.243	-0.297	0.659	0.522	0.523
MONTH	-0.583	-0.554	0.057	0.093	0.002	0.030	0.163	0.136	0.131
DMDIGEST	0.606	0.208	-0.178	-0.097	-0.282	-0.182	-0.275	0.151	0.155
EDIGEST	0.601	0.201	-0.183	-0.103	-0.288	-0.191	-0.270	0.157	0.162
DAYSPREG	-0.261	-0.415	0.362	0.249	0.189	-0.004	0.318	0.348	0.348
SCMRDM	-0.878	-0.922	0.226	0.250	0.418	0.416	0.188	-0.297	-0.306
SCMCDM	-0.780	-0.856	-0.074	0.166	0.245	0.508	-0.146	-0.560	-0.569
SCMRDEO	-0.917	-0.744	0.252	0.233	0.465	0.418	0.278	-0.328	-0.306
SCMCDEO	-0.866	-0.745	0.018	0.162	0.334	0.493	0.005	-0.541	-0.551
NETEFFRO	-0.743	-0.636	-0.127	-0.072	0.154	0.277	-0.129	-0.484	-0.497
NETEFFRC	-0.789	-0.876	-0.170	-0.097	0.036	0.176	-0.207	-0.350	-0.361
NETEFFCO	-0.693	-0.610	-0.205	-0.091	0.108	0.302	-0.223	-0.551	-0.564
NETEFFCC	-0.727	-0.820	-0.297	-0.110	-0.018	0.254	-0.351	-0.497	-0.508

Table 14 (Continued)

	WTCHNG61	RATE61	WTCHNG30	RATE30	AGE	MONTH	DMDIGEST	EDIGEST
DDM								
DEOBS								
DMMET								
DDMMET								
DEOBSMET								
DMINBWT								
DEOMILK								
DECMILK								
DEOPCENT								
DECPCENT								
SCMRAW								
SCMCORR								
SCMRMET								
SCMCMET								
SCM306DA								
AVEWT61								
METWT61								
WTCHNG61								
RATE61	0.928							

WTCHNG30	0.162	0.228						
RATE30	0.412	0.478	0.870					
AGE	-0.288	-0.268	-0.393	-0.445				
MONTH	0.133	0.022	-0.580	-0.379	0.191			
DMDIGEST	0.296	0.217	0.392	0.374	-0.320	-0.265		
EDIGEST	0.301	0.222	0.390	0.376	-0.311	-0.254	0.999	
DAYSPREG	-0.251	-0.318	-0.180	-0.199	0.307	0.371	0.244	0.249
SCMRDM	-0.403	-0.427	-0.137	-0.135	0.106	0.495	-0.304	-0.301
SCMCDM	-0.292	-0.316	-0.024	-0.008	-0.270	0.447	-0.225	-0.225
SCMRDEO	-0.410	-0.394	-0.246	-0.239	0.213	0.451	-0.735	-0.737
SCMCDEO	-0.348	-0.334	-0.145	-0.129	-0.082	0.423	-0.640	-0.640
NETEFFRO	-0.282	-0.242	-0.107	-0.048	-0.063	0.309	-0.597	-0.597
NETEFFRC	-0.232	-0.197	-0.081	0.033	-0.132	0.446	-0.208	-0.205
NETEFFCO	-0.255	-0.219	-0.059	-0.003	-0.172	0.278	-0.538	-0.539
NETEFFCC	-0.190	-0.160	-0.015	0.090	-0.318	0.402	-0.182	-0.181

Table 14 (Continued)

	DAYSPREG	SCMRDM	SCMCDM	SCMRDEO	SCMCDEO	NETEFFRO	NETEFFRC	NETEFFCO
DDM								
DECBS								
DMMET								
DDMMET								
DECBSMET								
DMINBWT								
DECMILK								
DECMILK								
DECPCENT								
DECPCENT								
SCMRAW								
SCMCORR								
SCMRMET								
SCMCMET								
SCM306DA								
AVEWT61								
METWT61								
WTCHNG61								
RATE61								

WTCHNG30								
RATE30								
AGE								
MONTH								
DMDIGEST								
EDIGEST								
DAYSPREG								
SCMRDM	0.407							
SCMCDM	0.214	0.905						
SCMRDEO	0.111	0.859	0.758					
SCMCDEO	0.001	0.840	0.881	0.943				
NETEFFRO	-0.072	0.728	0.762	0.859	0.919			
NETEFFRC	0.276	0.891	0.905	0.732	0.802	0.786		
NETEFFCO	-0.114	0.695	0.780	0.807	0.908	0.992	0.780	
NETEFFCC	0.159	0.828	0.940	0.681	0.820	0.796	0.973	0.817

APPENDIX II

If several variables or responses are measured on each of many individuals, the interrelationships among the variables can be summarized in a square, symmetrical correlation matrix. A question of interest, especially when many variables are involved, is whether the information in the correlation matrix could be summarized in a few factors. These factors are defined by linear combinations of the variables, and the definition, extraction, and interpretation of the factors is called factor analysis.

The procedure used here is that in the Statistical Analysis System Manual (25). The results are printed as a matrix of correlation coefficients. These correlation coefficients, or loadings, represent the extent to which each variable is correlated with each factor. Often the matrix is rotated so that the factors are orthogonal; this procedure tends to emphasize the large loadings and decrease those which are small. It is necessary to examine the coefficients to ascertain what trait each factor represents. For instance, if measures of feed intake have loadings of 0.85 to 0.95 in column 1, while those of weight change have similarly high loadings in column 2, one could say that Factor 1 represents feed intake, while Factor 2 relates more to weight change. Often loadings of 0.3 to 0.5 are present, indicating less influence or a response that is not so highly correlated with the factor. Values of less than 0.10 usually indicate the absence of a relationship.

One can use the loadings from a rotated matrix as coefficients of the variables in linear functions, to represent less numerous characteristics or traits. These traits are stochastically independent, and one can thus reduce the amount of data used to study treatment effects or to compare individuals from, for instance, 45 measured variables to five or six factors representing essentially the same things. (It is not recommended to apply the coefficients to the same data set which generated them. However, given a set of loadings derived from similar individuals, one can use them to reduce experimental or evaluative data, as long as the necessary variables have been measured.)