From Feeding to Feeding Systems

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ABSTRACT

Major developments characterized changes in feeding and feeding systems during the past 25 yr. The amount of concentrate fed nearly tripled, which was impossible to achieve during twice daily milking in parlors. Herd sizes increased, milk production per cow doubled, and the nutritional significance of social and taste behavior of cows housed in groups and given options for several feeds was gradually recognized; all contributed to the development and adoption of the complete ration system of feeding, especially in larger herds. Computer formulated least-cost rations by linear programming, followed by computer formulation of maximum income programs and development of programmable calculators, increased the economy, accuracy, and ease with which rations can be formulated and feed distributed to dairy cattle.

INTRODUCTION

Dairymen appropriately are concerned about feeding and nutrition because of their appreciation for the close relationship to production and intimate involvement with herd health and reproductive performance and because feed represents the premier production cost. Nationally, feed averaged 42% of the total production costs in 1979 (4); studies (79) show higher costs ranging from 50 to 70%. Since 1955, halving of dairy cow numbers in the US to 10,810,000 has been matched by a doubling of milk production per cow to about 5,266 kg (5), with individual herds averaging over 10,000 kg per year. This increase in production has been associated with a corresponding increase in nutrient requirements as reflected by the increase in grain and other concentrates fed from 798 kg in 1955 to about 2270 kg in 1980 (5).

Of the variation among cows in milk production, 25% are genetic effects (11). It also is thought (70) that increasing genetic trend during the past 25 yr has been responsible for 30% of the increase in milk yield. The widespread use today of genetically superior sires through artificial insemination has ensured genetic ability for high milk production in the dairy cow population. It is a formidable challenge to formulate diets and design feeding systems that allow full expression of that genetic ability for high milk production within the constraints of physical capacity of the gastrointestinal tract and physiological demand to consume feed. The average size (weight) of mature Holstein cows does not appear to have changed much during the past 25 yr, so physical capacity is and will continue to be a major constraint.

The increase in US herd size (over 10 cows)

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from 23 to about 55 (49) compares to Dairy Herd Improvement Association (DHIA) averages of 30 to 77 (32), but Florida now has more than 400 dairies that average more than 490 cows (90). This increase has reduced greatly the emphasis on individual attention and directed efforts toward management of cows in groups. Feeding systems too, are based on groups of cows with recognition of the importance of feeding and social behavior of cows in groups. Increase in herd size also is reflected in changes in housing and milking systems. Hoglund (50) estimated that 6% of the dairy cows in the US were milked in parlors in 1955 compared to 60% in 1980. Recognition of problems associated with attempting to feed all concentrates in the parlor prompted innovations in feeding methods and a continuing evolutionary process to develop alternative systems of feeding the dairy herd.

FEEDING SYSTEM PROGRESSION

Historical

Twenty-five years ago pasture was a dominant forage for most dairy herds, followed by hay and silage. Seasonal and geographic differences were large with months of pasturing ranging from 3 to 5 in the north and 10 to 12 in the South and parts of the West. In some of the northern areas, corn silage was a dominant part of the forage supply whereas in much of the South and West forage supplemental to pasture was usually hay. At least one forage was nearly always offered ad libitum. Much more uniform was the system of feeding concentrates. Nearly all dairies fed concentrates in the barn during milking; in northern regions this was the barn where the cows were housed. Although loose housing slowly was gaining acceptance, the 6% estimate (50) of the cows milked in parlors in 1955 probably reflects those housed in that way. Most cows were fed concentrates in some general way according to production and immediately preceding milking so that eating occurred during milking. The "flat barn" of the South and West held some fraction of the herd, and the time allowed to eat concentrates was limited to the time required to feed and milk that subunit of the herd. Time ranged 20 to 30 min per milking. Because grain allocations were rather low compared to today, there was ample time for cows to consume their allocated concentrate. In the North, barns housed the entire herd, and there was no time constraint on concentrate consumption. Allocation according to production was generally in the order of 1 kg of concentrate to 3 kg of milk, probably because of the appreciation for the principle that energy required for milk secretion was related directly to volume produced and concentrate was relatively expensive. Allocation in most cases was by volume (scoop) rather than by weight. In most herds, every cow and her lifetime history was known thoroughly by the operator. In addition to milk volume, other bases for concentrate allocation included age, size, milk fat test, gestation, and body condition, which also were considered by conscientious operators. From the perspective of cow handling and cow health, there is much to commend this system. Each cow was handled and fed as an individual; it was difficult to miss a cow who refused some of her feed and who needed special attention. It was easy to treat cows for almost any condition following milking in this system.

In the late 50's and early 60's, an important discovery was made concerning the ability of lactating dairy cows to respond to additional concentrates (52). In large commercial field trials (21), cows responded dramatically to increased concentrate feeding above the feeding standards then used. Three field trials were in 1960, 1961, and 1962 with a total of 735 Holstein cows, which were challenged with grain feeding of 2% body weight or grain to appetite for periods of about 75 days beginning 15 to 57 days postpartum (21). After the test period, grain was reduced to an amount that would not lower yield. The average production response was 922, 1,118, and 1,702 kg for 3 yr, respectively. From this and similar trials evolved the concept of "challenge feeding", which suggested that cows should be fed sharply increasing concentrate postpartum until the limit of appetite was reached. Then offering should be adjusted for current milk production in relation to requirements. If production requirement equaled or exceeded the concentrate at appetite, feeding was held to appetite until production declined, at which time concentrate feeding was ideally to follow milk production down the lactation curve (73).

About this time another practice came into use – "lead feeding" – which will be defined here as the practice of increasing grain feeding beginning about 3 wk prepartum to 1 to 1.5% of body weight by expected parturition date. It seemed reasonable to use lead feeding prepartum to facilitate adjustment to higher grain feeding postpartum (i.e., to challenge feeding). However, early in the 1960's the value of lead feeding was not proven experimentally apart from higher grain feeding postpartum. Later Gardner (43) showed no advantage to lead feeding if high energy was provided postpartum. Lead feeding severely depressed forage consumption near parturition, which appeared to induce displaced abomasum under some conditions. In addition, energy consumed above requirements by the dry-pregnant cow could be stored only as fat. Enzyme systems of the cow, which serve in fat deposition, are not the same as those which function in fat mobilization. Consequently, lead feeding may increase stress on the cow at calving by gearing enzyme systems to fat deposition, when immediately following calving, the cow usually must mobilize energy to support milk production.

Although initially dairymen felt that health problems would occur from high grain feeding (52), the concept of challenge feeding was adopted quickly, and sharp increases in production were evident as in Figure 1. Between 1960 to 1965 the number of NY-DHI herds producing more than 227 kg of milk fat/cow/year increased from 200 to 1200. These results proved the presence of widespread genetic ability for high milk production in the dairy cow population.

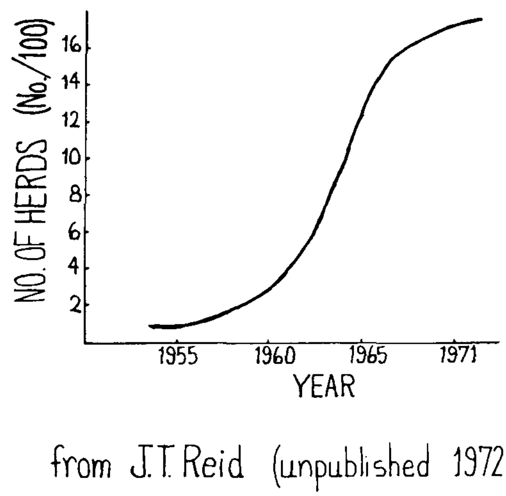

Figure 1. The increase in number of NY-DHI herds with production greater than 227 kg of milk fat per cow per year.

The vivid response of cows to additional energy above feeding standards caused researchers to ask whether requirements were correct. Reid and his students (74) were among those who showed a marked depression in digestibility of mixed diets by high producing cows that averaged about 4% for each unit of intake above maintenance. Because total digestible nutrients (TDN) of most feeds had been determined at about maintenance intake, textbook TDN's were too high for calculating diets for lactating cows. At the tissue level, the textbook requirement of .3 kg of TDN per kg of 4% fat corrected milk (FCM) was correct, but because of the depression in digestibility, textbook TDN's for feeds were overestimated. During the 1960's this finding was incorporated into feeding guides (78) by scaling up the TDN requirement as milk production increased. This had the effect of increasing the concentrate allowance considerably. More recently (and more correctly), the 1978 NRC requirements for dairy cattle reduces net energy for lactation (NE_l) for feeds by 8% for an average plane of nutrition of three times maintenance and an average depression in digestibility of 4% per unit of maintenance.

As average herd size increased in the 1960's, there was greater emphasis on labor efficiency and a corresponding increase in construction of milking parlors. There seemed to be a uniform tendency to feed all concentrate in the milking parlor, and parlors with associated feeding equipment were designed accordingly (see Figure 2). Electronic and mechanical devices became available that, if calibrated, would deliver a prescribed amount of concentrate to the parlor feed manger. As production increased and greater mechanization further reduced the time cows spent in the parlor, the inability of cows to consume their required concentrate even if they had the appetite to do so became glaringly evident. Even if additional time was provided and precision equipment was operated carefully, there was no way to ensure the appetite of the cow would induce

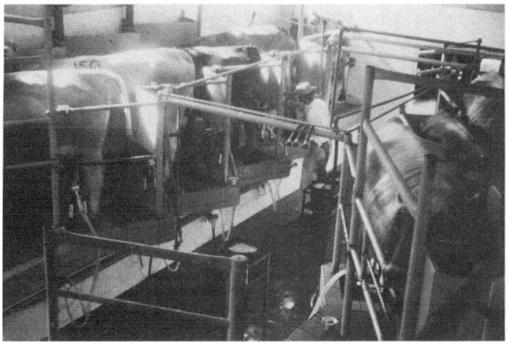

Figure 2. Parlor grain feeding has been used widely because of better cow entry and availability of equipment.

her to consume the required concentrate. Most grain feeding in the parlor then became free choice grain feeding in two 10-min intervals per day.

The resolution of the dilemma of parlor grain feeding has taken several forms and is an evolutionary process destined to continue for some time. An important outgrowth of this progression of feeding systems has been gradual recognition of the importance of social behavior, taste expression, and feeding behavior in groups and the importance of integrating the feeding system into the total dairy management system.

Resolutions to the Parlor Grain Feeding Dilemma

Some dairymen add concentrate to the forage that is fed outside in a bunk in addition to parlor grain feeding. However, this often aggravates the problem of providing a correct protein-energy ratio across the complete production spectrum of the herd. Low producers may receive too much energy by this system, but they still may demand some grain during milking in the parlor. High producers, too, may suffer from this approach, especially if protein supplementation is via the parlor grain mixture, because there is less chance a cow will enter the parlor with the desired appetite to eat the required protein supplement. In some cases, a fat cow results.

Stoddard (84) described a study in which cows producing from 8 to 40 kg/day were group-fed all of their concentrate, and they produced as well as when fed concentrate according to production in the milking parlor. This approach does not appear to have been adopted widely. During the 1970's several types of mechanical and electronic grain feeding devices became available, primarily to resolve the problem of parlor grain feeding.

Magnet-Activated Feeders

An automated feeding system designed to allow feeding of more concentrates to high producers outside of the milking parlor relies on a magnetically activated feeder (53). A cow that is to receive extra feed has a magnet attached to a rope or chain around her neck. Feed is stored in an overhead bin connected to the feeder by an auger (see Figure 3). When a cow equipped with a magnet puts her head into the feeder, the magnet makes contact with a metal plate on the front of the feeder bowl. Feed is dribbled continuously into the feeder as long as the magnet remains in contact with the front plate. When the cow backs away

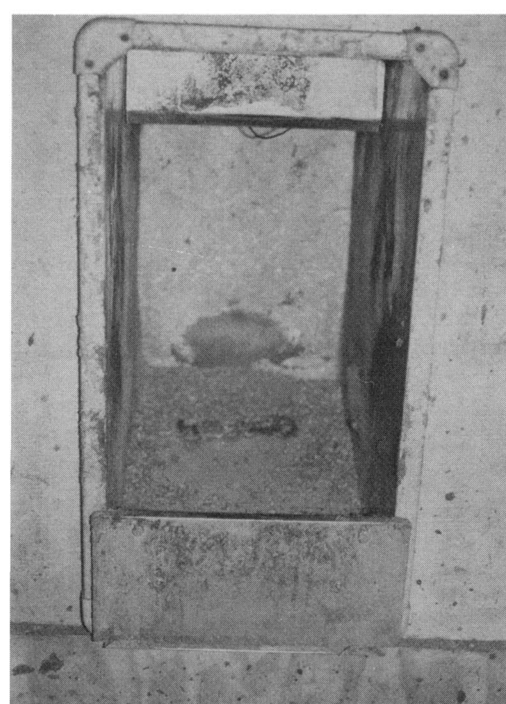

Figure 3. A magnet activated feeder allows a cow carrying a magnet to obtain additional concentrate.

the circuit is broken, the motor stops, and no more feed drops into the feeder bowl. Cows without magnets on their neck chains cannot operate the motor.

One feeder can handle 20 to 30 cows equipped with magnets. However, there is no measure of individual feed intake because the feed is free-choice so long as the cow keeps her head in the feed bowl area. Also, there are problems with boss cows chasing the more timid cows away from the feeder, especially if the feeder is not equipped with guard rails to protect the cow while she is eating. The approximate cost of a magnet feeder and auxiliary equipment in 1980 was $1,000 to $1,400.

Transponder-Activated Feeders

Another system providing concentrates to specially-equipped cows utilizes a transponder rather than a magnet to activate the feeder (71). The transponder is similar to the device used to operate an electronic garage door opener. Each cow's transponder is electronically coded according to her milk production. When a cow moves her neck through a loop-formed interrogator antenna built into the feeder, high frequency radio energy flows in the transponder. The transponder's coded memory device begins to charge electronically and drives a signal generator which causes feed to dispense at .45 kg/min. When the transponder is charged fully, the feed delivery system stops. Length of charging time can be adjusted on the transponder, so feed amounts can be varied for each cow. When the cow leaves the feeder, the transponder gradually discharges over 24 h. Therefore, each day the cow is allowed a certain time when feed will be delivered to her, which she can use up in one feeding or spread out over many feedings during the day. Feed that is available to her at any time is dependent upon the alloted feed she has not eaten during the preceding 24 h (see Figure 4).

Transponder feeders are more accurate than magnet feeders in allotting concentrates to cows according to production, but they also are much more expensive. One unit to handle 25 to 30 cows cost about $3,500 in 1980.

Calan Electronic Doors

The Calan system uses electronically controlled feeding doors positioned on a feeding fence or bunk and a cadmium plated key on the neck chain of the cow (17). When the cow approaches the door, the key comes close enough to the door to activate the electronic circuit, withdrawing a bolt lock. The cow then can push the door open with her head and reach the feed behind the door. Feed can be available free-choice or limited to certain amounts by the dairyman. Cows without keys on their neck chains cannot open the doors and get to the feed. The manufacturer recomends a minimum of two units, which can handle a total of 25 to 30 cows. Cost for the two units in 1980 was about $800.

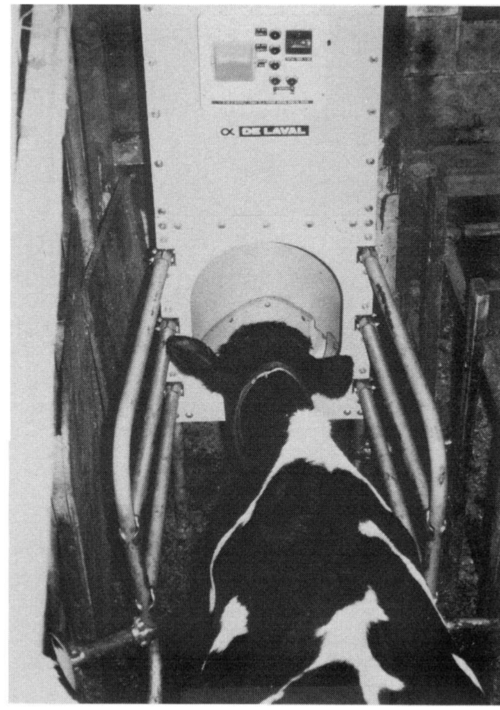

Figure 4. A transponder type supplemental feeder that permits allocation of prescribed amounts of feed.

Computer Controlled Feeders

Three companies recently developed and are marketing computer-controlled concentrate feeders. In each case a mini- or micro-computer controls the feed dispensed to each cow in a herd based on the amounts keyed into the computer by the dairyman (see Figure 5). Each cow wears a neckstrap with a transponder

Figure 5. A mini-computer that can process many types of data on a dairy farm.

that identifies the cow to the computer when she enters the feeding stall. The computer allocates predetermined portions of her total daily concentrate allotment and signals the feeder to deliver it slowly to the cow while she is in the feeding stall. When her allotment is used up, or she leaves the stall, the feeder stops. Any of her unused allotment is recorded by the computer and is available the next time the cow enters a feeding stall. If a cow does not consume her total allotment, the amount left over is recorded and can be printed out. This can help identify cows that are off-feed sooner than they normally would be noticed.

The number of cows that can be handled by the computer varies from 180 to 999 depending on the size of the computer and the number of feeding stations. Costs of the systems vary depending on the number of cows and auxiliary equipment such as computer program. Estimates for the basic system (computer, stall, transponders, neckstraps, and power supply) given by the manufacturers in 1980 were from $110 to $200 per cow.

Each of the companies is developing additional equipment that can be added to the feeding module. Such information as electronic identification, automatic milk yield recording, cow temperature sensing for health status, complete health and production records, farm accounting, and many other herd management programs will be available in the future.

Although these latter systems can allocate concentrated individually and precisely, they suffer the same imprecision in total diet allocation noted later for conventional feeding systems. These computer operated systems have greatest value in loose housing systems where grouping is not feasible.

Social Behavior and Its Relationship to Feeding Behavior

Many people who work closely with cattle recognize a social order within a group or herd. Not only is there a boss cow, but each cow has a relatively specific place or order within the social heirarchy of the herd. Woodbury (92) suggested that horns play a large role in establishment of dominance and that the position of a cow could be changed by dehorning. He stated that a more fundamental understanding should be possible through experimental investigation. Such work was reported in the 1950's by Schein and Fohrman (76) and Guhl and Atkeson (47); this work provided much basic information in this important dimension of management. Schein and Fohrman (76) reported that a social order was established in a herd through a sequence of aggressive acts, which proceed as follows: 1) the approach (active or passive), 2) the threat, and 3) the physical contact, which is usually by butting or bunting with the head. Upon summarizing about 5000 individual contests, they concluded that a herd or group is organized in a linear order of dominance. Dominance order or rank (DR) was related to age and weight, and they assumed age or seniority was the more important factor. The early Kansas work (47) supports this assumption with a correlation of .84 between age and DR, established by a cow through bluffing or fighting upon her first entrance into the herd. The review of social behavior by Albright (3) suggests that dominance order may be considerably more complex than simple straight line, but here we are concerned about the relationship of social behavior and dominance to feeding behavior and feeding systems.

As Bryant (19) observed, the function of the dominance heirarchy operates when there are scarce resources, in this context feed(s), so that high ranking individuals receive precedence over low ranking individuals. Several authors (35, 76) note a low correlation between DR and milk yield.

In the conventional system of feeding, those feeds offered to groups (usually silage or hay) often were fed in limited amounts, which invoked the principle of DR. Under ad libitum feed conditions and especially when cows have become accustomed to this system, there is little value to DR and less apparent evidence of its expression.

Feeding Behavior of Cows in Groups

Under dry lot conditions with grain fed ad libitum in the milking parlor, Webb et al. (87) found that lactating cows spent an average of 6.4 h/day eating silage and hay. Friend and Polan (39) used time-lapse photography to obtain data on feeding behavior and free-stall use by 21 Holstein cows through an equivalent of five 24 h days. Silage was fed in a bunk top dressed with 45 kg of concentrates once/day and two bales of alfalfa hay were offered in the bunk once daily. Feed bunk space of .5 m/cow permitted about two-thirds of the cows to eat simultaneously. Strong competition was evident at the bunk 30 min after return from the milking parlor, which was expressed as a correlation of .59 with DR. This work illustrates the important principle that when a competitive condition exists for a limited feed, dominant cows assert their rank. This could be undesirable if there is a low correlation between DR and milk yield (35). Friend and Polan (41) showed that production variables seemed more important than DR in explaining access to limited feed and limited resting stalls.

Cows offered a complete ration (CR) ad libitum with .41 and .31 m of bunk/cow spent 4.6 and 4.4/h day at the bunk (40). Reduction of feed bunk to .21 and .1 m/cow reduced time spent at the bunk to 4.4 and 3.0 h. Time spent at the bunk with the two longer spaces was not correlated with DR, but correlation was .60 with DR with the two shorter spaces. It was concluded that .21 m of linear bunk space/cow per day is ample if cows have at least 4.4 h of access to a CR/day. This seems reasonable, as noted in recent work by Vasilatos and Wangsness (85), who recorded 12 meals per day with an average of 20.9 min with 4.2 h per day of defined meal time by cows offered a CR ad libitum in individual stalls. However, only 58% of the total defined meal time was actually spent eating. Therefore, there seems little reason to require enough bunk space for all cows to eat simultaneously if the same feed is continuously available. And after cows adjust to feed continuously available, there appears to be a large reduction in competition at the bunks and correspondingly, there is much less bunk space required per cow.

The reason for feeding a CR ad libitum is evident from results of Goings and Braund (44), who fed two groups of 24 lactating cows in a double reversal trial. One group was offered a CR free-choice (ca. 50% corn silage: 50% concentrate; .63 m/bunk per cow), and the other group received the same diet but with the bunk empty 4.5 h/day. Milk yield and diet dry matter (DM) consumed averaged 25.9 and 20.1 vs. 25.3 and 18.9 kg/day. One could ask whether cows might adapt to this feeding regimen given more time, but these results suggest a cleam bunk may reduce DM consumption. However, access to silage immediately before milking may cause a milk flavor problem. Fettman et al. (38) compared milk flavor scores from cows whose silage-based CR had been withheld 0, 2, or 4 h before milking. An experienced taste panel ranked the samples consistently with the best flavor scores for milk from cows without feed 4 h prior to milking.

A comparison of feeding frequencies of 1, 2, and 3/day of a CR offered ad libitum was with three groups of 20 lactating cows each (45). No differences were detectable in milk production or DM intake, even though the act of feeding caused cows to come to the bunk to eat. Ad libitum feeding is probably the explanation for no differences in this comparison, although ambient conditions, which cause deterioration in a silage based CR fed once daily, might reduce intake and production.

Reduction of space (bunk, free stall, or open) can result in stress, which has been estimated in several ways. Arave and others (7) used two groups of 19 cows to determine whether cows required to change social rank changed in blood corticoids. At wk 4, the 5 cows highest in DR from each group were combined to form a new group, and the remaining subordinate cows formed a second group. This social disruption did not cause a difference between groups in total blood corticoids. However, Friend and others (42) showed that glucocorticoid response to 200 IU of exogenous ACTH by lactating Holstein cows was time dependent following a stress of increased animal density and social disruption. Adrenal response measured in this way occurred within 2 days following the stress.

Expresssion of Choice for Available Feeds

Although grazing cattle select a diet (at least from an abundant sward) higher in digestibility and lower in fiber than the total plant available to them, there is a large and consistent variation among Holstein cows in their preference for excellent stored forages whenever they are given a two-choice option (29). This expression occurred either with a simultaneous choice or when the choice was limited to one forage in the a.m. and the other in the p.m. In one typical comparison the range in variation among 30 cows offered corn silage and alfalfa hay simultaneously was from 23.6 to 77.7% corn silage DM. The opportunity to select a preferred forage is most serious when two forages such as corn silage and alfalfa are offered becasue of the great difference in their nutrient profiles which greatly limits precision of concentrate formulation to match some "average" forage ratio. There was no indication in (29) that cows that selected the low protein forage (corn silage) and were then protein deficient would through time switch their choice to the higher protein forage (alfalfa).

It seems probable that the same kind of diet selection occurs by cows offered forage(s) and concentrates at near ad libitum amounts in early lactation and between energy fortified forage mixtures and protein supplements. In a grazing study with sheep, Marten and Andersen (56) compared the relative palatability of 12 weed species to oats and found no relationship between palatability and nutritive value, which indicated that sheep have little nutritional wisdom.

Nutritional Wisdom or Specific Appetite. Another feature of feeding behavior that received attention during the 1970's was the question of specific appetite of cattle for free choice mineral supplements (25, 68). This practice had been recommended for many years by authorities in animal nutrition (12, 59), and it seems to suggest that cattle have the ability to select needed mineral elements from materials available to them. This ability sometimes is described as nutritional wisdom or specific appetite. The experimental evidence to support the assumption that cattle will eat mineral supplements when they need them and in relation to their requirements never had been critically demonstrated, and with the exception of two elements, recent studies raise serious questions about the nutritional wisdom of cattle.

Contributing to the popular notion of nutritional wisdom by cattle was the observation by Green (46) of South Africa in 1925 that phosphorus deficient cattle had a marked craving for bones, which were the only source of supplemental phosphorus available to them. However, if precipitated calcium phosphate or other unfamiliar source of available phosphorus was offered in a trough, no craving was shown for it by the cattle deficient in phosphorus.

The introduction of salt into a mineral mixture adds a confounding effect because of the possibility of a specific appetite for sodium or chloride in the salt but not for the elements in the primary mixture. Denton and Sabine (34) showed that sodium depletion of sheep by parotid fistula greatly increased the appetite for sodium. In the absence of a sodium deficiency, sheep also drank a solution containing sodium with large individual variation expressed. Large individual differences in salt intake by dairy cows also have been described (83). Apparently sheep and, probably cattle, as shown in other work (1), have a specific appetite for both sodium and chloride (27).

In studies at Cornell with lactating dairy cows (28), individual intakes of dicalcium phosphate were measured on a daily basis for 154 days. In this trial cows were fed a calcium and phosphorus adequate diet for 8 wk with the supplement option, to determine which cows ate supplement when they did not need it. Then they were fed a calcium deficient diet for 9 wk (no supplement option) and then the supplement was offered for 4 additional wk. The calcium eaten from the free choice supplement during the final 4 wk of this study was not enough to meet calcium requirements for milk and body maintenance. A similar trial in which a phosphorus deficient diet was fed showed that although the average consumption in the final 4 wk was more than enough to meet the average requirement, three cows are hardly any at all, and one ate none, even though she ate during the preliminary period.

More critical studies were reported in Vermont (88) on voluntary intake of phosphorus supplements by phosphorus deficient cows. Cows were fed a phosphorus deficient diet during a 103-day trial, which depressed milk production (25.0 to 17.1 kg) and blood phosphorus (7.2 to 2.9 mg/100 ml), and phosphorus balance was negative(-7.02 g/day). Abnormal appetite (pica) was in all deficient cows. When offered an array of phosphorus supplements, deficient cows consumed .12 g sandy soil, .58 g dical, and 13.44 g monosodium phosphate free choice daily compared to control cows that consumed 33.25 g, 11.50 g, and 41.64 g, respectively. Supplemental consumption by phosphorus deficient cows did not meet phosphorus requirements. There was no evidence in these two trials of specific appetite for phosphorus.

Work at South Dakota (62) involved two trials with lactating dairy cows to evaluate 10 minerals plus vitamins offered in a cafeteria (separate compartments) type feeder. A corn silage forage group and an alfalfa forage group were fed an unsupplemented concentrate mixture, but their consumption of the minerals did not differ, despite the great difference in calcium, magnesium, and potassium concentration between corn silage and alfalfa. In a second trial, a group of cows fed a mineral-vitamin supplement to meet NRC requirements were compared to a group receiving no mineral-vitamin supplement. The only difference in consumption from the cafeteria mineral feeders was that the supplemented cows ate more sodium bicarbonate. These trials lend support to the belief that cows have little ability to select mineral elements on their real need for those elements, and that a lot of luxury consumption occurs. Whenever possible, hand feeding or blending into other dietary mixtures is the preferred method of feeding mineral supplements.

Another practice that relates to feeding behavior is the use of liquid supplements fed through lick-wheel tanks. Liquid supplements are not new, but their application to dairy cattle nutrition evolved primarily during the 1960's. As one writer (31) noted, "A liquid supplement is used in much the same way as a dry supplement and the performance in each case is related to the ability of the specific formulation adequately to supplement the other feeds in the total ration." The mode of feeding through lick-wheel tanks to groups of cattle may result in the expression of DR and certainly the option to express preference for the supplement. Variation in consumption of cows individually fed with small lick wheel tanks ranged from less than .25 kg/day to over 2.5 kg/day even though average consumption was about 1.0 kg/day (86). One would expect this range to be even greater under group feeding conditions. Braund (16) has suggested that under some conditions cows will consume a liquid supplement in relation to their needs for protein. This may have occurred because of the declining quality or acceptability of the forage available. It would seem that much more uniform consumption of a liquid supplement would be achieved if it were blended into a forage, concentrate mixture, or a CR.

Complete Ration

The term complete ration (CR) is used synonomously with complete feed, total mixed ration, total blended ration, etc. It is defined here as a quantitative mixture of all dietary ingredients, blended thoroughly enough to prevent separation and sorting, formulated to specific nutrient content, and offered ad libitum. The CR was used much earlier for other livestock species and only recently has been used for dairy cattle. This probably occurred because dairy nutritionists felt that it had limited application because of the wide range in energy requirements within any herd. Many of the earlier studies of CR's for dairy cattle (57) were with limited forage and by-products such as corn cobs, cottonseed hulls, rice hulls, etc., where the primary objective was to use minimum forage. Early reviews (30, 58, 65, 66, 72) showed an interest worldwide in this new system of feeding. Recent surveys of dairymen using CR's reveal that most were pleased with the system. Within the past 15 yr, the development and widespread adoption of the CR system has been the most significant feature of dairy cattle feeding systems (26, 55, 67, 75).

A summary of advantages and disadvantages taken primarily from (26) follows. Advantages include: 1) No expression of choice among available feeds is permitted. Consequently, each bite consumed is a uniform, definable, and as nearly as we can make it, a nutritively complete diet. This aspect of CR's is especially valuable when attempting to troubleshoot a problem in a herd characterized by a high incidence of some disorder. One survey (15) found fewer metabolic problems in herds fed CR's. 2) High production with CR's has not only been demonstrated in research trials but by dairymen, who with large herds have production of over 8,000 kg per cow per year. 3) Free-choice mineral supplements are no longer necessary. 4) Complete rations coupled with lactation groups permit special formulation for high producers (extra protein) that cannot consume enough feed energy to sustain their production. 5) Complete rations fed ad libitum result in few digestive upsets early in lactation as cows are changed from high forage diets to high concentrate diets immediately postpartum (48). Complete rations seem to result in a steady-state condition conducive to continuous rumen function and ingesta flow. 6) Nonprotein nitrogen compounds, especially urea, release ammonia rapidly upon contact with rumen fluid. Therefore, for maximum efficiency, urea (and quickly degradable proteins) should be fed several times throughout the day with an energy source containing starch. Consequently, an easy way to achieve multiple feedings is to offer the CR ad libitum. Some recent observations have shown that milking cows fed high energy CR's ate about 10 meals per day with a meal duration of about 30 min. 7) A CR with a forage base of silage serves to dilute and mask the flavor of any unpalatable ingredients such as urea. This feature offers significant advantage, because it increases the flexibility and minimizes the number and magnitude of constraints that must be imposed on least cost computer formulated concentrate mixtures. In effect, one can make large changes in formulation as prices change without inducing an off-feed problem (51). Also, dairymen are especially impressed with the sudden changes in forage types possible without depressing intake or milk production. 8) Some reduction in labor required for feeding grain accrues through this system. 9) By providing a specific and obligatory ratio of forage to concentrate, one can prevent some cases of milk fat depression by insuring fiber in the consumed diet necessary to maintain milk fat test. 10) It is no longer necessary to feed grain in the milking parlor although some adjustment will be necessary by cows accustomed to receiving grain there: a) no grain feeding equipment is needed and, therefore, part of the construction costs are reduced; b) cows are quieter during milking and apparently defecate less; c) there is less feed dust in the parlor; d) movement through the parlor is quicker because cows do not delay to finish eating; 3) more cows per man per hour are possible when parlor operators do not spend time dispensing grain. 11) It is possible to mechanize a conventional tie-stall barn for complete feeds. Small moblie mixer carts with load cells, which have mixing and delivery capability, are available. 12) The total diet can be formulated quantitatively. 13) Concentrate ingredients can be purchased in bulk at considerable savings and blended with forages on the farm (Figure 6). 14) The increase in formulation precision, which CR's permit, allows reduction in the safety margin for mineral elements and thereby reduces the mineral load in manure.

Included among the disadvantages are: 1) Hay stored in bales or long form must be chopped before it can be blended with silage or grain. Hay crops should be stored as silage. 2) Mixer wagons, which thoroughly blend ingredients, are expensive; electronic load cells are highly recommended to quantitate the blending process, but they too are costly (Figure 7). Although less expensive innovations, including grain metering into forage delivered by auger, are being used, most are not quantitative. 3) Too many housing systems have been designed without concern for the number of groups appropriate and the resulting cow traffic flow. 4) There is only a modest amount of experimental data on which sound recommendations can be made for the number

Figure 6. A large bulk storage bin that permits a dairyman to buy and store ingredients in bulk.

Figure 7. The load cell mixer wagon allows quantitative blending and delivery on the farm.

of cows per group and the exact ration specifications that will permit the most efficient use of concentrates. 5) It may not be economically feasible to use CR's in small herds. For those herds that are pastured, complete rations have limited applicability during the pasture season, although one author (75) suggested the use of a CR as a supplemental feed during the decline in pasture quality. 6) More arithmetic calculations are necessary on the farm to implement the use of the CR, especially with groups that may require different concentrate formulations, as well as different ratios of forage to concentrate. Chandler (20) has emphasized the importance of management skills to make this system work effectively.

Rationale for Grouping

1) We expect greater milk production and more efficient use of feed when cows are fed in relation to their energy requirements, with higher concentrate diets in early lactation and higher forage-lower energy diets as lactation progresses. Production groups permit these diet changes. Spahr (82) presented a well-balanced perspective of a constant energy diet (a one group system) vs. multiple energy diets. Dry cows overconsume if given the opportunity (60, 61), and fat cow syndrome is a serious problem when this occurs. This discussion assumes a separate dry cow group and the interest here is in the value of varying energy concentration in CR's for the milking herd.

A number of studies have shown no milk production advantage for more than one diet through the entire lactation (2, 33, 37, 93), and several reviewers suggest only one diet is needed (58, 67). One diet advocacy assumes no serious problem will arise from relative underfeeding in early lactation and overfeeding in late lactation. Some of each is a natural phenomenon in nearly all feeding systems. However, with diets offered ad libitum and based on corn silage, there seems to be a tendency to overconsume in late lactation (61). In the two lactation study by Everson et al. (37) there was a large year by treatment interaction in which the group fed a variable energy diet produced 193 kg less milk the 1st yr but 672 kg more the 2nd yr, which suggests the one diet group did not fully replete tissue reserve by the end of the 1st yr. The variable diet group had a more positive energy balance during early lactation, consumed more DM, lost less body weight, had higher blood glucose and lower ketone, and exhibited an earlier postpartum estrus. As Spahr (82) noted, most studies comparing these two systems had too few diets (usually two) in the multiple group treatment to avoid a sharp drop in production as the diet changed. And cows on the one diet treatment usually had greater persistency in mid to late lactation and higher energy diets than the variable energy treatments. As herd size continues to increase, many dairymen will group cows for other managerial reasons, as noted below, and feed those groups diets varying in nutrient concentration (Figure 8).

2) When nutrients are less expensive from

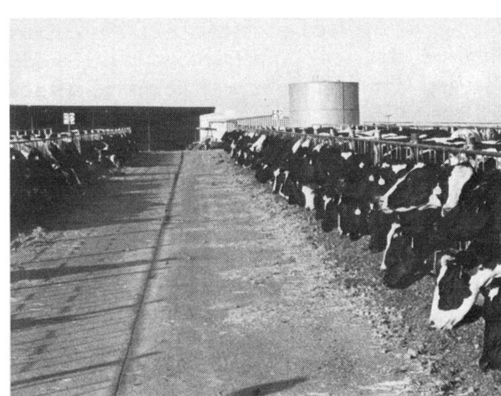

Figure 8. As herds became larger, more interest in group feeding evolved.

forage and low energy by products, feed costs will be lower with production groups because lower producing cows can be fed a diet of a higher percentage of lower cost ingredients. Smith and others (80) achieved $30/cow per lactation greater income over feed cost in a two-group system vs. a one-group system even with 183 kg less milk. Polan et al. (69) obtained greater production and $77 greater income over feed cost with three groups vs. one group.

3) It is now common for high producing cows to assume a condition of negative energy balance for several weeks in early lactation, even though high energy diets are offered ad libitum. The magnitude of this energy deficit can be expected to increase as genetic trend increases and management skills are sharpened. The diet formulation strategy that will help sustain milk production through this deficit period is one that provides a relatively higher nutrient concentration in the diet than is needed when energy balance is achieved. The logic for this suggestion is based on the assumption that the cow has limited body reserves (e.g., protein) of most nutrients relative to body energy reserves. One important advantage of production groups is that the group with the highest producers can be fed a diet so formulated as well as an energy concentration as high as consistent with maintenance of milk fat percentage. This should reduce potential nutrient deficiencies in those cows in severe negative energy balance.

4) Britt (18) has described advantages for grouping cows according to their reproductive status – classifying cows into five categories: a) early postpartum, prebreeding, b) breeding groups, c) pregnant cows, lactating, d) pregnant cows, nonlactating, and e) problem cows, open more than 100 days. In addition, he noted that many features of herd health programs were made easier with groups based primarily on stage of lactation.

5) More homogenous milking times will occur when cows are grouped according to production (13).

Disadvantages of Grouping

1) Many housing systems (especially for smaller herds) were designed without group handling capabilities, and redesign may not be economical or even possible.

2) Additional labor and time are required periodically to regroup cows, although good facility design can alleviate this job.

3) More diet formulations are necessary with groups if each group is fed a different diet. Depending on the forage base, a different concentrate formulation also may be required if precise nutrient specifications are used. Programmable calculators and microcomputers make these calculations practical, relatively easy, and convenient.

4) The most significant disadvantage to grouping is the drop in milk production (Figure 9) that usually occurs when cows are switched from high energy to lower energy diets (2, 61). However, a change to a new group usually means two changes, a dietary change and a social change. We prefer to look at these effects separately.

Social Effects

Schein et al. (77) combined 15 lactating cows and a group of 35 heifers and dry cows

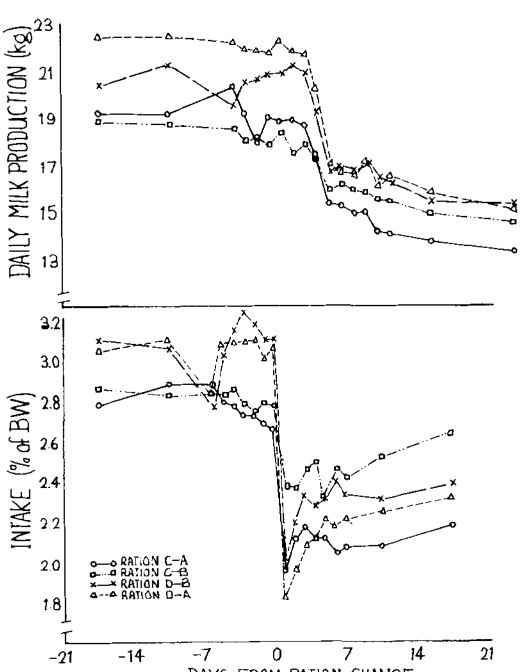

Figure 9. The effect of abrupt change to higher forage-lower energy diets on DM intakes and milk production (61). Diets A, B, C, and D are forage to concentrate DM ratios of 95:5, 80:20, 60:40, and 40:60.

(diet constant) with the predictable social disturbance, which appeared to cause a 5.5% greater drop in milk production than control cows remaining in the herd. Arave and Albright (6) transferred six cows between two 17-cow groups with an observed 5% drop in milk production for both transferred and nontransferred cows but no effect on leucocyte concentration in milk. Collis et al. (24) transferred cows between two groups managed the same and noted that social reestablishment was completed within 24 h, although there was a doubling of aggressive activity during this time. But there was no effect on milk yield. A similar study (14) showed a small decrease in milk yield for 1 day following the transfer.

Dietary Changes

Large reductions in dietary energy density that may occur as cows are transferred to lower producing groups can depress milk production sharply (2, 80). Moseley et al. (61) fed cows in a conventional stanchion barn to define the effect of CR density on DM consumption and milk production. Abrupt dietary changes to simulate a group change at wk 12 of lactation from 40:60 (forage to concentrate DM) depressed energy intake and milk production. Reduction in energy density at wk 30 from 40:60 or 60:40 energy to 80:20 or 95:5 also caused sharp declines in energy intake and milk production (Figure 9). Although partial recovery in energy intake occurred during a 5-day post ration change period, there was no corresponding increase in milk production (Figure 9). It is probably critical that the energy concentration of the new diet be high enough to permit transferred cows to remain in positive energy balance if the only cows transferred are beyond peak production. It appears that of social and dietary effects, dietary changes (if substantial) have a greater adverse effect on milk production than social disturbance. Some studies have not detected a drop in production with group transfer. Clark and others (22) compared high (H), medium (M), and low (L) systems to a control (C) group with the diet for H and C groups formulated at 110% of group average requirements and the other two groups at 100% of the average requirements. Changes in milk production 5 days pre- and post-group change did not differ between systems. In a large field trial, Sowerby and Polan (81) measured effects on production of shifting cows between production groups. A decrease of .99 kg per cow per day was observed between test days (about 10 days) and 3 or 4 days after the transfer in transferred cows but only .33 kg/cow per day in cows not transferred. An important observation was that there was a decrease in loss as time progressed, indicating that cows adapt to being shifted. Field observations of large herds in CA also indicate that cows experienced with group transfer suffer less adverse effects than cows unaccustomed to this procedure (8).

In contrast to the problem of transferring cows from high energy to low energy diets, Hernandez et al. (48) showed that it was possible to change cows abruptly from a high forage CR (95:5) to a high energy CR (40:60) 4 days postpartum without digestive disturbance or accumulation of lactic acid in the rumen. These results are understandable from observations of eating behavior of cows fed CR ad libitum. There is a great advantage to eating many small meals throughout the day when increases in energy density are sudden. In conventional feeding systems where forage and concentrate are offered separately, rapid increases in energy (concentrate) postpartum may cause digestive disturbances, but decreases can be gradual; the reverse occurs in CR systems. Several suggestions can be made to reduce the drop in production as cows are transferred to lower energy diets. 1) No major transfers need occur if synchronized heifers or cows that freshen within a few weeks of each other form a group in which dietary changes can be gradual as their lactations advance. 2) More groups allow smaller dietary changes between groups; we suggest a minimum of three lactating cow groups. 3) High energy forage (minimum concentrate) will result in smaller dietary energy changes. 4) If parlor grain feeding equipment is available, extra grain may be fed there during the period following transfer to a new group. 5) Dietary changes could be gradual by temporary increase of energy of the receiving group and after cow transfer, gradual return to the lower dietary energy. Additional guidelines for production grouping have been suggested by Bath et al. (8, 11).

We feel the primary criteria for grouping are: a) milk energy secretion (or to some degree, stage of lactation); all cows should enter a high energy group postpartum which allows them to express their genetic ability for milk production, b) reproductive status, c) parity (need for additional growth), and d) body condition.

The complexity of decision making concerning production groups, how many, etc., suggests the need for modeling systems analyses. Information on the effect of production variation within herd and calving patterns on grouping systems was given by Wiktorsson and Stone (89), but much more work will be needed to provide the data necessary for this type of analysis.

ECONOMIC COMPARISONS

There is little information here, but with the principles reasonably well established, this seems like a productive area for simulation and systems research. Napper (63) used published information plus data from a detailed survey of 42 dairymen using CR's in NY to derive a partial budget analysis of two dairy feeding systems, a CR vs. a parlor grain feeding layout representative of an 80 cow NY dairy farm in 1976. Major elements of this comparison are in Table 1, which show an increase in annual net income of $2,434 in favor of the CR system. This study addressed the economic consequences of a CR system vs. a conventional parlor grain feeding system. Several assumptions were necessary because of a paucity of research data, but sensitivity analysis showed that the effect of feeding system on milk production was more important than any other measured factor on the optimum solution. If the assumptions in this analysis are

TABLE 1. Partial budget comparison of a complete ration vs. a parlor grain feeding system in a new 80 cow, free-stall set up with horizontal silos, haycrop silage, and corn silage.[1]

Items that add to net income			
Added returns			
Added milk production,[2] 1217 kg on 12 cows	2,779.		
3% more silage saved	576.		
Total		$3,355.	
Reduced costs			
Lower veterinary bills (10%)	110.		
Lower average annual ownership costs on alternative feeding system	570.		
Savings on grain purchases[3] (5%)	1,431.		
Savings on ownership on parlor feeding system	320.		
Faster milking and cleanup – 30 min/day @ $3/h	548.		
Total		$2,979.	
Total added returns and reduced costs			$6,334.
Items that reduce net income			
Added costs			
Mixer wagon – average annual ownership and operating costs	1,995.		
Moisture tester and calculator	30.		
Management, feeding, and formulating time	1,100.		
Crowd gate	200.		
Additional 12 ton grain bin – average annual ownership and operating costs	575.		
Total		$3,900.	
Total added returns and reduced costs			$6,334.
Total reduced returns and added costs			−3,900.
Net increase in farm income			$2,434.

[1] Data from Napper (63) based on prices prevailing in 1975.

[2] Milk price assumed was $8.64/cwt.

[3] Used two grain mixes and savings on free-choice minerals.

generally applicable, the CR system has strong economic justification.

Further economic support for a CR system is the possibility of rapid concentrate formulation changes as prices change, without off-feed disturbance (51). In addition, a mixer wagon makes feasible and convenient the use of individual concentrate ingredients purchased at bulk savings.

USE OF COMPUTERS AND CALCULATORS

Formulation of rations by computer for dairy cattle and other classes of livestock has had a marked effect on feeding practices since the mid-1960's. Efficacy of least-cost complete rations for dairy cattle was reported in 1968 by Howard et al. (51). Cost savings realized from feeding least-cost concentrate mixes to lactating dairy cows were reported the same year by Bath and others (10). Subsequently many computerized programs for ration formulation were implemented at various institutions and have been of great benefit to dairymen in determining economical feeding programs for their herds. Greater use will develop as dairy farms become larger and as more people become proficient in using the tremendous amount of information available from a computer. Today most commercial feed companies use computerized linear programs to establish ingredient formulas for concentrate mixes sold to dairymen.

Availability and Use of Computer Programs. Computer formulation of dairy rations is by commercial centers, private nutrition consultants, DHI Records Processing Centers, and in some states by the state university. Charges for this service vary with the computing center but currently are about $5 per ration formulation. In some cases, cost of computer formulation is included in the fee charged by private consultants for their advice and services to clients. Some programs have been offered free of charge by a few state universities through their Extension Services during development and testing of the programs.

Most feed companies and some individual dairymen have used this tool since the mid-1960's. High cost of computer time and lack of knowledge about its possible benefits are the principal reasons that it has not been used more extensively by dairymen.

Remote Computer Terminals. A major limitation on early use of computer programs for ration formulation was the time required in the mails to send input information and receive output from the computer. Most computers take less than a minute to formulate a ration once they have received the necessary input data, but mail time, card punching, and addressing return mail took several days. This reduced use and effectiveness of computer programs, because many feeding and management decisions cannot wait that long. A dairyman is more likely to implement recommendations from the computer if answers to his questions are immediate rather than days or weeks later.

Remote computer terminals now make it possible to obtain ration formulations directly by connecting with the central computer over telephone lines. Input data, such as prices of available ingredients, size of cow, milk fat test, milk price, and milk production are typed on the keyboard of the terminal and sent to the computer, which has ration requirements, feedstuff composition, and other program data on file. The central computer calculates the optimum ration formula and other related management data and prints it out on paper at the remote terminal or on a television-type screen. Development, testing, and implementation of a dairy cattle feeding model that can be accessed by remote computer terminals has been described by Bath and Bennett (9). Utilization of a similar model by Virginia dairymen was discussed by Jones et al. (54), and other models are available in many other states.

Example of a Computer Formulated Ration. An example output from a computer terminal is in Figure 10. The example was formulated for a 590-kg cow producing 30 kg of milk with 3.5% milk fat. The output contains much management information in addition to amounts of feed ingredients recommended for the optimum ration. Items listed include ingredient percentage composition of the roughage and concentrate portions of the ration, roughage-concentrate ratio, ranges between which ingredient prices can vary without affecting optimum solutions, feed cost, nutrient composition of concentrate mix, roughage, total ration, and opportunity prices on ingredients not selected for the optimum ration.

Information from computer programs such as this has been of great benefit to dairymen in

C A L I F O R N I A   D A I R Y   R A T I O N
(MAXIMUM INCOME ABOVE FEED COSTS)

JOE DAIRYMAN 9/16/80 16:28:11 HOURS

SPECIFICATIONS:

PRODUCTION CURVE MAXIMUM...........	= 70 LBS
AVERAGE MILK FAT..................	= 3.5 %
AVERAGE COW WEIGHT................	= 1300 LBS
BLEND PRICE.......................	= $ 13.00/CWT
NE(L) FOR ACTIVITY................	= 10 % OF MAINTENANCE
FIRST LACTATION HEIFERS IN GROUP...	= 30 %
SECOND LACTATION HEIFERS IN GROUP..	= 20 %

FEEDS USED IN RATION:	LB/DAY AS FED	%ROUGHAGE AS FED	%ROUGHAGE DM	PRICE $/CWT	---RANGE--- LOWER	---RANGE--- UPPER	---CONSTRAINTS---- AS FED -POUNDS- MIN	AS FED -POUNDS- MAX	100% DM -%ROUGH- MIN	100% DM -%ROUGH- MAX
CORN SILAGE,30% DM	29.92	66.1	39.4	1.20	1.18	1.21	20.0			
ALFALFA HAY, 20% CP	15.33	33.9	60.6	4.20	4.18	4.24	10.0			
TOTAL ROUGHAGE...	45.25	(22.77 LBS DM)								

		%CONCENTRATE AS FED	%CONCENTRATE DM				AS FED -POUNDS- MIN	AS FED -POUNDS- MAX	100% DM -%CONC.- MIN	100% DM -%CONC.- MAX
BARLEY,46-48#	8.90	33.7	33.1	6.80	6.79	6.85				80.0
BEET PULP,DRIED	6.58	24.9	25.0	6.35	4.82	6.36				25.0
COTTONSEED,WHOLE	5.15	19.5	20.0	8.00	6.04	8.31				20.0
WHEAT MILL RUN	3.22	12.2	12.1	6.50	6.47	6.60				25.0
COTTONSEED MEAL,41 S	2.56	9.7	9.8	9.00	8.88	9.04				25.0
TOTAL CONCENTRATE.	26.41*	(23.96 LBS DM)								

*NOTE: PROVIDE SALT FREE CHOICE OR AS 0.5% OF CONCENTRATE MIX.
PROVIDE OTHER ESSENTIAL MINERALS NOT SUPPLIED IN ADEQUATE AMOUNTS
BY FEEDS IN RATION LISTED ABOVE.

ROUGHAGE:CONCENTRATE RATIO = 49:51 (DM)

	LB/COW	$/COW	PRICE PER CWT	LOWER RANGE	UPPER RANGE
OPTIMUM DAILY MILK PRODUCTION:	66.0	8.58	13.00	12.73	16.98
TOTAL FEED COST		2.88			
TOTAL DAILY INCOME ABOVE FEED COST:		5.70			

ESTIMATED ANALYSIS: (100% DM)	CONCENTRATE	ROUGHAGE	TOTAL RATION	-CONSTRAINTS-- MIN	MAX
DRY MATTER PCT	90.69 %	50.33 %	65.21 %		
NE(L)	0.86 MCAL/LB	0.62 MCAL/LB	0.75 MCAL/LB		
ENE	812.49 KCAL/LB	494.55 KCAL/LB	657.54 KCAL/LB		
TDN	82.54 %	60.76 %	71.93 %		
CRUDE PROTEIN	16.98 %	14.97 %	16.00 %	16.00%	
CRUDE FAT	5.90 %	2.70 %	4.34 %		
CRUDE FIBER	13.78 %	25.21 %	19.35 %	17.00%	
ADF	20.45 %	32.21 %	26.18 %		
ASH	4.09 %	7.88 %	5.94 %		
CALCIUM	0.26 %	0.95 %	0.60 %	0.60%	
PHOSPHORUS	0.56 %	0.23 %	0.40 %	0.40%	
CA:PHOS RATIO	0.47	4.15	1.50	1.50	
NPN	0.00 %	0.00 %	0.00 %		0.50%
COST AS FED	$ 7.10 /CWT	$ 2.22 /CWT	$ 4.02 /CWT		
COST DRY MATTER	$ 7.83 /CWT	$ 4.40 /CWT	$ 6.16 /CWT		

FEEDS NOT USED IN RATION:	------PRICE------ AT FORMULATION	OPPORTUNITY
CORN GRAIN,CRACKED	6.90	6.57
DICALCIUM PHOSPHATE	14.00	-1.09
LIMESTONE,GROUND	3.50	1.82

FIG. 10. An example of a printout from an income maximizing computer program.

recent years for designing profitable feeding programs. It is expected that computers will have an even greater effect as similar programs become available to operate on inexpensive microcomputers, which will become commonplace on dairy farms in the future.

Programmable Calculators

Recently, the programmable hand-held, battery-powered calculator (PC) has been developed with capability to perform at least 50 functions from memory and 500 or more steps in program execution (36). This sophistication has been appreciated and used especially by extension specialists, feed company nutritionists, farmers, and all those who have spent many hours doing the repetitious hand calculations of ration balancing problems. The Extension Service of several universities has been quick to offer packages of programs for the PC's with those programs relating to ration balancing, batch mixing, DM intake prediction, etc., being especially popular and applicable to those working with nutrition. At this time, the primary restrictions of PC's are their limited memory and the corresponding requirement that the operator have a high degree of skill and understanding to use them successfully. For example, at this time their capability does not extend to least cost formulation by linear programming technique, but their capability will increase even more in the future. And even today, they are being used widely and successfully by many people in the feed industry.

FUTURE FEEDING SYSTEMS

Feeding systems that will prevail in the future are those that effectively and efficiently can serve needs of future cows. Cows with high production potential will be common, and problems associated with overfeeding energy will diminish as problems associated with longer periods of negative energy balance will assume greater importance. Systems that facilitate consumption of large amounts of feed energy will be imperative. Smith (79) showed that even under condition of high feed cost, high potential cows responded profitably to increased grain feeding to the point where problems of milk fat depression occurred.

Use of the CR system will increase rapidly as more cows are resident in larger herds, managed in groups, and fed large amounts of feeds. However, there seems to be some trend away from all silage forage to at least some hay (especially alfalfa). Additional research studies and innovations of dairymen partially will resolve and minimize presently identified limitations of the CR system.

Computer controlled concentrate feeders for individual cows provide no control over or accounting for forage intake of individual cows, and, therefore, total diet allocation is not as precise as suggested. In addition, as the appetite of cows for total feed becomes more constraining, the separate feeding of forage and grain allows a choice between these two feeds and may cause a greater discrepancy between the diet offered to groups and the diet consumed by individuals. To minimize metabolic problems in high producers, it will be necessary to control the diet consumed qualitatively, although the quantity will be subject to the ad libitum option of individual cows.

Basic nutrition research areas including rumen protein by-pass, protected lipids, proteins, and carbohydrates, regulation of post-ruminal pH, milk secretion investigations, and metabolic studies all may influence future feeding systems.

As milk production continues to increase, greater metabolic heat production will occur incident to metabolism of nutrients to support that high production. In areas with high ambient temperature, shade management to reduce heat stress will be especially valuable (23). Increased use of forage and feed testing will occur as more precise total diet formulation becomes the economic imperative. This will allow safety margins to be narrowed and the possibility of nutrient deficiencies to be reduced greatly.

Computers will play a larger role in the future in nearly all features of dairy cattle management including feeding and nutrition. Variation in nutrient requirements among cows (manifested primarily by differences in among cow digestibility) precludes any attempt to quantitate precisely nutrient allocation to individuals.

CONCLUSIONS

During the past 25 yr, major changes occurred in feeding systems, most of which were in response to increases in herd size, doubling of milk production per cow, automation in parlor milking systems, and gradual recognition of the nutritional significance of social and taste behavior of cows housed in groups and given options for several feeds. Concentrate feeding has nearly tripled. The most fundamental and pervasive change has been adoption of the complete ration system, especially in larger herds. Availability of the load cell mixer wagon greatly facilitated transition to this system of feeding. Sophisticated computer formulated ration programs are now available to most dairymen. Mechanical concentrate feeders and highly sophisticated computer operated concentrate feeding devices also have become available and have found greatest acceptance in smaller herds and in those where grouping is not easily done. Because of increasing genetic trend, high milk producing ability is rapidly becoming the norm, and it will be a continuing challenge to formulate diets and design feeding systems that permit expression of that genetic ability for high milk production.

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