Advances in Nutrition and Management of Calves and Heifers

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ABSTRACT

Strides have been significant in the knowledge of calf and heifer rearing during the last 25 yr. Much information has been gathered on digestive enzymes, development of the digestive system, and metabolism. Investigations have clarified further the role of colostrum in immunity and nutrition of the young calf. Several sources of nutrients have been tested for their suitability in formulation of acceptable milk replacers and calf starters. Once-a-day feeding of milk, colostrum, or milk replacer and early weaning are practical management procedures. Labor and cost efficient methods of feeding and caring for young calves have developed. Extensive work on rearing rates and methods of rearing was published during these 25 yr.

Successful schemes have evolved for feeding heifers to freshen at an optimal age and to occupy a respectful position in the milking line. Developments in housing have been phenomenal – from the calf hutch to environmentally controlled nurseries for calves. Heifer housing has ranged from relatively simple, but labor-efficient housing, to complete confinement systems. Herd health programs have developed to minimize many disease problems that can be particularly disastrous in large herds. Contract rearing of herd replacements has become a more frequently chosen option in this period. Budgets for rearing calves from birth to freshening have appeared in recommendations for raising heifers.

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INTRODUCTION

This paper is to review advances in knowledge of nutrition, physiology, and management of young dairy animals. Because of the large amount of research and developments, reviews and reports from proceedings are cited in most instances rather than original references. Complete coverage has not been attempted. Many scientists, producers, and others have been responsible for progress in calf rearing. The reader is referred to the several reviews used for citations of individual studies and developments and to other papers in this 75th Anniversary issue.

ADVANCES IN DIGESTIVE PHYSIOLOGY

Events in the Abomasum

Although considerable knowledge had accumulated on digestion of liquid feed by young calves before 1956, investigations on the digestive process have continued. Upon the feeding of milk or a milk replacer, the esophageal groove closes, causing liquids to flow from the esophagus to the omasal-abomasal canal. Coagulation of milk in the abomasum occurs quickly after feeding. However, clotting does not occur with plant proteins or milk products dried at excessive temperatures. Gastric secretions are stimulated by feeding and together with saliva increase the volume of material to twice that fed. The pH of the abomasum is 1 to 2 before feeding, increasing to 6 after feeding, and then decreasing to prefeeding pH. The amount of acid secreted into the abomasum increases with age (55).

After coagulation, the liquid portion, whey, moves into the small intestine. Whey appears in the duodenum within 5 min after feeding (57). The largest flow from the abomasum occurs shortly after feeding, but the overall rate is half the volume every 2 h. Transit time through the small intestine is about 3 h (55, 63).

Lipolytic Enzymes

An oral lipase was known prior to 1956, but information concerning its site of secretion, characteristics, and physiological significance to animals was not established. This group of salivary lipases, collectively known as pregastric esterase, is secreted from the region of the vallate papillae, the glosso-epiglottic area, and the pharyngeal end of the esophagus (47). Although not isolated, at least six esterases have been detected electrophoretically. Evidence has accumulated to show that these enzymes preferentially hydrolyze short-chain fatty acids from triglycerides. Considerable lipolysis occurs with milk fat and coconut fat, but activity is limited with lard, tallow, and vegetable oils. Secretion of salivary lipase is not affected by age or diet, although its significance appears to be with the milk-fed animal. Most of the lipolysis of milk fat by pregastric esterase occurs in the abomasum with little or no action by gastric lipase. Recent studies (17) show greater release of longchain fatty acids by pancreatic lipase when milk-fat is subjected to pregastric esterase before pancreatic lipase. Pancreatic lipase activity is low at birth and during the 1st wk of life (27); hence, some importance may be ascribed to pregastric esterase during this early period of life even though its exact physiological significance has not been elucidated fully.

Carbohydrate Enzymes

In the late 1950's and early 60's evidence showed that newborn calves possessed large quantities of lactase. Enzymes decrease with increasing age and changing diet, but intestinal lactase can be increased or maintained by feeding lactose (27, 57).

Preruminant calves under 100 days of age make insignificant use of starch (44). Salivary amylases and other carbohydrate digesting enzymes are either in insignificant amounts or absent. Pancreatic amylolytic activity and juice flow rates increase with age (27). The virtual absence of sucrase has been established, and metabolism of sucrose is primarily a consequence of microbial activity in the lower tract. Use of this carbohydrate in diets for young calves is not recommended because of diarrheic problems. Monosaccharides, glucose, galactose, and xylose, are absorbed readily from the small intestine. Fructose is not absorbed, however (57).

Protease

Rennin is responsible for coagulation of milk in the abomasum. Evidence collected during the last 25 yr indicates that casein increases secretion of rennin, but soy, fish, and whey proteins decrease secretion (20). Pepsin secretion is not affected by protein substrate. Protease activity of pancreatic tissue increases during the 1st wk of life (27). The increased activity plus increased flow rate of pancreatic juice probably accounts for the increased digestibility of many proteins as the calf grows older.

Rumen Development

Knowledge of rumen development in 1956 (60) included the rapid increase in tissue weight and papillary size with age when dry feeds were fed. The suggestion was made that the chemical nature of the rumen ingesta stimulated rumen development as inert materials did not elicit a response. Also, "cud inoculation" of calves was studied with inconsistent results.

Research during this 25 yr showed that papillary development and absorptive capacity of the rumen are responsive to volatile fatty acid production, Structural development of the rumen is related to increased metabolic activity of rumen epithelial tissue (27). Other work (83) showed that young milk-fed calves do possess the metabolic capacity for utilization of rumen fermentation end products and can adsorb volatile fatty acids from the small intestine. Rumination in calves is functional as early as 2 wk of age and in all calves by 6 to 8 wk if they are offered solid feed (14). Studies of rumen microbes from calves inoculated with rumen contents and from isolated calves showed different bacterial populations, but some groups of typical rumen bacteria were in contents of isolated calves. If offered solid feed, rumen of calves will develop adult characteristics by 3 mo of age. Blood glucose decreases with age and reaches constancy by about 8 wk (27).

COLOSTRUM

Reid (60) reviewed the status of colostrum to 1956. It had been established that the calf had little circulating antibody at birth and was dependent upon colostrum for passive immunity. The absorption period for immune globulins was during the first 24 h of life. Calves were not protected necessarily by colostrum from microbial challenges outside the dam's environment. The nutritional value of colostrum as well as its immunological properties was recognized.

Since then three classes of immune globulins have been identified in bovine colostrum. The IgG comprises the greatest fraction, 85 to 90% of immune globulins, and is divided into two subclasses, IgG1 with 163,000 molecular weight and IgG2 with 150,000 molecular weight. The IgM with a molecular weight of 900,000 makes up an additional 10%. An IgA is the other immune globulin that has been identified. Butler (11) prepared an extensive review on characteristics and properties of immune globulins.

Considerable research effort has been on absorption of immune globulins, much of it within the last 5 to 10 yr. The ultrastructure of cells of the jejunum and ileum have been described (10). Pinocytosis is the method of absorption of γ-globulin and is greatest in the distal portion of the small intestine with little in the duodenum. Colostral whey proteins are absorbed without selectivity in newborn calves. Also of importance is that cells of *Escherichia coli* are absorbed through ileal cells of calves not fed colostrum. Colostrum-deprived calves exhibited large numbers of *E. coli* in the ileal mucosa and mesenteric lymph nodes, but no bacteria were in cells and lymph nodes of colostrum-fed calves. Ability of the calf to absorb immune globulins continues for 24 to 36 h; however, intestinal closure occurs at 24 ± 4 h after birth. Intestinal closure to immune globulins begins spontaneously after 12 h of life in the absence of feeding. If calves are fed colostrum shortly after birth, more time will be available for absorption than if fed several hours later, even though closure time is delayed with later feeding.

Total amount of immune globulin consumed appears to be a more important factor influencing serum than concentration of immune globulins in colostrum (10). Roy (61) has suggested 1.7 kg/feeding at four intervals during the first 36 to 48 h of life; others suggest 2 liters at first feeding (10). Concentration of immune globulins varies considerably in colostrum from different cows, but older cows have greater concentrations than younger cows. Efficiency of absorption of IgG and IgA does not change as intake increases, whereas absorption of IgM increases with decreasing concentrations and amounts (10). Immunological activity of IgM is greater than that of IgG. Absorption of immunoglobulins appears to be superior for calves that suckled their dams as compared to those that were separated from their dams and hand-fed pooled colostrum at birth. There is suggestive evidence that breed affects absorptive ability of calves, but further clarification appears warranted. Chemical additives such as salts of organic acids, glucose-6-phosphate, inorganic phosphate, and low molecular weight proteins increase absorption of γ-globulin experimentally, but there was no effect when the additives were included with colostrum and fed to intact calves (10). Absorption of colostral proteins is reduced when colostrum is fermented, but this can be inproved through additions of sodium bicarbonate to colostrum (19). Feeding of glucose solutions at birth did not alter closure time, but inoculations with duodenal fluid reduced absorption (10).

Longevity of acquired immunity is 14 to 67 days (11). Half-lives up to 20 to 25 days for IgG were reported with 4 days for IgM and 2 to 2.8 days for IgA. The calf is capable of endogenous production of IgG at about 1 g/day during the first 3 wk of life (16). The bovine fetus is capable of producing immune globulins if antigens are introduced into amniotic fluid (13).

Turbidity tests measure the immunological status of the calf (61). A colostrometer has been developed (18) to measure specific gravity of colostrum which is correlated with its immune globulin content. Blood assays of marketed young calves show many are hypogammaglobulinemic. Brignolle and Stott (7) found that 42% of 983 calves left with their dams 24 h after birth failed to suckle or absorb immunoglobulins. Bottle feeding of colostrum at 24 h resulted in 70% of the calves absorbing immunoglobulins. Colostral immunoglobulins also may provide local immunity within the intestine as survival of calves with low systemic immunoglobulin concentrations is good.

LIQUID FEEDS FOR CALVES

Whole Milk

Milk was predominately the liquid feed before 1956. Feeding rates were liberal. Most reports now suggest that milk be fed at 8% of birth weight. Whole milk often is a standard of comparison in experiments with other liquid feeds.

Milk Replacers

Usage of milk replacers has increased tremendously during the past 25 yr. The first true milk replacers were developed about 1950 (66). Previously milk replacers were really milk extenders and consisted of linseed oil meal, wheat middlings, wheat red dog, and oat flour. These were fed as gruels and were successful only if supplemented with milk (15). During the late 1950's and early 1960's, milk replacers were formulated from dried skim milk, dried buttermilk, dried whey, and animal fat. Dried skim milk was the principal source of protein and carbohydrate because of its low cost. Fat was added directly to milk products and batch-mixed – a process that permitted incorporation of fat to less than 10%. Consequently, energy content of milk replacers was not much higher than that of skim milk (66). Methods for inclusion of fat were improved by homogenization of the mixture before spray drying, and proportions of fat in replacers were increased to 10% or more. As a result, high quality replacers were available, but high heat in drying of skim milk produced an inferior product (61). Use of such replacers containing large amounts of heated skim milk often induced severe diarrhea. Lister and Emmons (34) showed severe diarrhea in calves fed milk replacers formulated with powders from skim milk heated for 30 min at 85°C. Much less diarrhea occurred when replacers were manufactured from skim milk preheated to 60°C or 74°C for 30 min before spray drying.

In 1966 prices of skim milk increased, and substitutes for dried skim milk were sought (66). Casein and whey were available at moderate cost, and the industry shifted to these products with little reduction in quality.

Later, prices of casein increased because of subsidized slaughter of dairy cows in Australia and New Zealand, the major casein producing countries, and industry looked to alternate sources of protein for replacers (66). Some replacers containing protein other than milk were marketed, but growth of calves was restricted. Several studies on improving nonmilk proteins for replacers occurred during the 1960's and early 1970's. Meat solubles composed largely of collagen, soy flour, distillers dried solubles, brewers dried yeast, wheat flour, and fish protein concentrate generally have not supported performance when incorporated into replacers in large amounts. Soy protein concentrates and soy isolates have been used in milk replacers with good results and are in large amounts in present day formulations. Chemical treatment of soy flour has been studied extensively, and the product shows promise in milk replacers (58). Soy protein concentrates are prepared by treating oil-extracted soybeans with water and alcohol to remove soluble carbohydrates and heating to inactivate inhibitors. The concentrate is 71% protein and has been a replacement for milk protein in several studies. Polzin (54) concluded that at least 50% of milk protein can be replaced by soy protein concentrates.

Fish protein concentrates as the principal source of protein in milk replacers have not yielded good results, but recently Opstvedt et al. (49) successfully raised calves to 63 days of age on replacers containing fish protein concentrate. Digestibility of the milk replacer containing fish protein was lower than that of all-milk replacer, particularly during the first 3 wk. Performance of calves fed replacers of fish protein concentrate and dried whey was equal to calves fed an all-milk replacer. In the abomasum, the fish protein concentrate swelled and resembled the coagulation of casein.

Other protein sources for milk replacers are fababean, rapeseed, and alfalfa protein concentrates. These protein concentrates can be included in milk replacers up to 25% of the protein for fababean (82), 30% for low glucosinolate rapeseed (21), and 50% for alfalfa (1) for acceptable calf performance.

Fats in milk replacers include animal fat, hydrogenated vegetable oil, and coconut fat (59). Tallow and choice white pork grease have been used extensively, but recently milk fat, palm oil, sunflower oil, soybean oil, hydrogenated soybean oil, and partially hydrogenated fish oil all have been used successfully (65). Soy lecithin improved fat utilization and mixing qualities of replacer. Fat in milk replacers reduces incidence of diarrha (15). Homogenization of fat improves digestibility and retention of nitrogen from milk replacers (57). The amount of fat in milk replacers is 10 to 20% (57). Additions beyond 20% do not seem to be warranted.

Lactose is the primary carbohydrate in milk replacers. Glucose generally has been uneconomical. Other carbohydrates have not produced satisfactory responses in calves (9), probably a result of the lack of specific enzymes for digestion. Supplementation of milk replacers with amylolytic and proteolytic enzymes (15, 50) has not improved calf performance, nor have products of lactobacillus fermentation. Based on work previous to 1956, milk replacers are supplemented with vitamins, minerals, and frequently antibiotics.

Reconstitution of milk replacer powder with water was studied by Pettyjohn et al. (53). Their trials indicated that liquid diets containing 15% dry matter elicited optimal performance. Most recommendations call for powders to be reconstituted to 12 to 18% solids (3).

Colostrum

Colostrum as a liquid diet beyond 3 days of age had been advocated prior to 1956, but little was used. Work during the 1960's and early 1970's stimulated dairy producers to include surplus colostrum in feeding programs. Enough surplus colostrum is produced in most dairy herds to feed heifer calves born into the herd from birth to weaning at 28 to 35 days of age (19). However, suitable storage of the surplus must be provided. Freezing of colostrum is an acceptable storage method, and calves fed colostrum stored by freezing show equal or better performance to weaning than those fed whole milk (3). However, prior to the late 1960's freezing of colostrum was not a feasible alternative, and it was common to discard excess colostrum.

One of the first reports of feeding nonrefrigerated colostrum was by Swannack (72). He discovered an English farmer who successfully had fed colostrum stored at ambient temperature to calves. Swannack's subsequent research stimulated interest among dairy operators and scientists, and use of fermented colostrum became increasing popular. Studies on effects of time, and temperature fermentation, microbial composition of fermented colostrum, dilution rate, changes in composition during fermentation, amounts of colostrum to feed, acceptability, feeding value, and methods were conducted during this period. Chemical agents including organic acids, formaldehyde, and others have been tested as preserving agents. Those used most frequently are propionic, acetic, and formic acids. Some problems occur with acceptability at larger amounts of acid, but these can be alleviated with neutralization with sodium bicarbonate to pH 6. Recommendations developed from these studies were reviewed (19).

Mastitic Milk

Until recently, limited controlled studies of feeding mastitic milk to calves had been reported. Kesler (30) summarized 10 experiments that included mastitic milk fed as fresh, fermented, or acidified milk. Gains of calves fed mastitic milk were similar or superior to those of calves fed control diets. In general, health problems did not differ between groups. Limited evidence suggests that incidence of mastitis in lactating animals that were fed mastitic milk as calves is no greater than that in cows fed other liquid feed as calves. Separate pens for calves fed mastitic milk was recommended to prevent introduction of mastitic organisms into udders of calves nursing each other.

FEEDING METHODS AND WEANING

Since 1956 once-a-day feeding of liquid has become acceptable management. A review (3) of several experiments indicated good performance of calves fed milk, colostrum, or milk replacer once daily. Quality, amount, and concentration of milk replacer require careful attention, but labor requirements for feeding can be reduced as much as 40% (45). Reduction of liquid feeding to six times per week also has been reported. Although this procedure resulted in satisfactory gains and health, it has not been adopted by calf growers.

Feeding milk or milk replacer by open pail is common, although nipple feeding by pail or bottle is chosen by many calf raisers. No advantage in calf health or performance has been shown for either method. Feeding large numbers of calves by either of these methods is slow and tedious, and producers have been interested in automated feeding. Mobile units with refrigerated storage of feed that automatically dispense feed at given intervals have been used where large numbers of calves are fed. Stationary automatic dispensers also have been used. Pelissier (52) reported that many large operators dispense milk by hose from mobile thermos tanks into individual pails rather than to use automated systems. Others have organized feeding with equipment for mixing and transporting liquid feed in nipple bottles or pails. Time for clean-up of equipment also has been reduced through organization and provision of good facilities.

The offering of liquid diets at cold rather than warm temperatures was investigated. Cold milk or milk replacer fed in moderate environmental temperatures generally has supported gains equal to or superior to warm liquid. For veal calves fed ad libitum, warm liquid is preferred. There was some indication of increased diarrhea with cold milk feeding, but growth was not suppressed (3, 67).

Abrupt weaning of calves at an early age is an acceptable practice (3, 45). If weaned at 21 days, calves may suffer from slightly depressed growth rates. However, by 12 wk of age, early-weaned calves and later-weaned calves (6 wk) are of similar weights. Weaning according to starter intake has found some acceptance, but abrupt weaning usually stimulates dry feed consumption. Starter intake can be stimulated by placing the dry feed in the pail immediately after liquid has been consumed. In general, weaning age has been reduced sharply and good results can be obtained with weaning at 21 to 35 days of age.

CALF STARTERS

Work on calf starters during the past 25 yr probably did not bring dramatic breakthroughs, but there was steady progress in this area of nutrition and management of calves. Quality calf starters that are consumed readily are essential to early weaning programs. Recommended nutrient content for starters has appeared in publications of the National Research Council (46). Ingredient composition of starters has been studied (42) and, in general, simple well-balanced preparations have supported good growth as well as more complicated formulations. Various sources of protein such as soybean, linseed, cottonseed, rapeseed, peanut, sunflower, meat, and fish meals were satisfactory in starters, and dried skim milk was not superior to vegetable protein. Dried poultry manure also has been used with success, but nonprotein nitrogen in calf starters has produced variable results and usually is not recommended (45). In addition, supplementation of starters with amino acids has not proven beneficial.

Extremely low crude fiber does not support gains as well as moderate fiber. The exact percentage has not been ascertained and probably depends on other factors such as physical form of fiber (77). Fiber below 5 to 6% probably will not produce best growth, and some bloating may occur (42). Simple mixtures with 13.9% crude fiber supported growth as well as a complex mixture containing 6% crude fiber. Pellets are not accepted as well as coarsely ground mash (78). Mashes generally have a higher proportion of larger particles, suggesting that 50% of the particles should be larger than 1190 μm (16 mesh) (78).

Complete or all-in-one rations have been developed for calves. These rations have reduced the labor requirement in rearing and assure a uniform intake of nutrients. Various sources of forages have been used with amounts depending on source (25), but most results have been satisfactory with 25 to 35% roughage. Often the diet has been pelleted, and Bartley (4) found .48 cm pellets preferable to .95 cm pellets. Warner et al. (78) developed formulations of all-in-one diets for calves from birth to 32 wk. Starters vary in protein and fiber concentration according to age of calf.

NUTRITIVE REQUIREMENTS

The 1978 Nutrient Requirements for dairy cattle (46) contain the most recent recommended nutrient requirements for calves and heifers. Much of the information on calves' nutrient requirements is discussed elsewhere in this paper or issue. The most recent studies since Jacobson's review (28) of energy and protein requirements and accepted recommendations on nutrient requirements (46) have been concerned with amino acid requirements. The requirements for DL-methionine range from .17 to .23 g/day per kg of body weight (76) and lysine from .27 to .31 g/day per kg of body weight (81). Amino acid and mineral composition of preruminant calves has been determined by Williams (80).

REARING RATES OF HEIFERS

Prior to 1956 information was limited on rearing rates of heifers, and it was general practice to calve heifers well beyond 24 mo of age. Reid (60) reported that several experiments on rearing rates were in progress or being completed, but little of the information had been summarized. Most of the research involved overconditioning or liberal feeding of heifers; however, some work suggested that heifers raised on low or medium nutrition produced slightly more milk than heifers raised on high nutrition. Since then objectives of several studies (8, 62, 68, 74) have concerned a rate of development that allows for calving at 24 mo, efficient use of feed during rearing, delivery of a healthy, vigorous calf, few calving problems, production at maximum genetic potential in first lactation, resistance to metabolic problems and infections, enough size successfully to compete for feed, and longevity.

A considerable body of data indicates that excessive fattening of dairy heifers is detrimental to conception rates, calving ease, production, and longevity. Swanson's work (75) showed that udders of heifers fed liberally throughout rearing did not develop normally. Milk production of fat heifers was substantially less than that of heifers reared "normally"; however, extreme underfeeding during growth delayed onset of estrus. Heifers within a breed appear to reach puberty at approximately similar weights regardless of age (68, 74).

Underfeeding of bred heifers resulted in calves only slightly smaller than those from well-fed heifers. More calving difficulties are encountered with undersized heifers than with those that are well-grown. Swanson (74) recommended 567 kg for precalving weight and 500 kg for postcalving weights of heifers from large breeds. Recommendation for age of heifers at first calving is approximately 24 mo. Suggested growth rates (46) are less than the maximum that could be expected and are based on the work of several investigations during this 25 yr. These allowances were developed to achieve goals mentioned previously. To calve at 24 mo at desired size, heifers of large breeds must gain approximately .7 kg/day (74). Heifers with average daily gain less than this will require longer to attain desired calving weights. However, heifers fed to gain .8 kg per day could calve at 22 mo. Heifers that are fed less than "normal" produce well and grow if fed liberally after calving.

First estrus occurs earlier and at lower weights for small breeds than for large breeds. If heifers are fed to gain .9 to 1.0 kg/day, first estrus may be as early as 6 to 8 mo for Holsteins (62). Swanson (73) has predicted puberty at 10 mo with .82 kg gain/day, 11 mo with .68 kg gain/day, and 14 mo with .54 kg gain/day.

Norman et al. (48) showed that up to 23 or 24 mo of age each month delay in freshening yields 35 to 180 kg more milk for Holsteins and 90 kg for Jerseys, but only 18 kg could be expected for each month delay after 27 mo for Holsteins and about 9 kg for Jerseys.

Swanson (73) reviewed several experiments in which feeding was below recommended standards for all of gestation except for the last 2 or 3 mo before calving. Feeding rate was increased for rapid growth through the last part of gestation. Production was greater for these heifers than for controls, indicating a stimulatory effect on lactation. Swanson (73) proposed several schemes of feeding: 1) rapid growth during the 1st yr followed by roughage feeding; 2) uniform rate of gain at .68 kg/day throughout rearing; 3) slow growth of calves through use of low quality feeds followed by grain feeding during last 4 mo of gestation; 4) slow growth, delayed breeding for calving at 27 or 28 mo; 5) underfeeding with breeding at 20 to 21 mo; grain-feeding during last 3 or 4 mo. Scheme 1 may tend to overfatten heifers, schemes 2 and 3 apparently work well, scheme 4 would be useful for heifers calving late for seasonal reasons, and scheme 5, while economical in use of feeds, generally would require careful management to avoid problems associated with underfeeding.

HOUSING

Prior to 1956 few research projects had been on housing of calves and heifers. Calves and heifers often have been housed in the same building as the milking herd or in sheds. As herd size increased, more dairymen began using separate facilities or attempted to extend use of existing facilities. Problems associated with inadequate housing emerged, particularly increased incidence of respiratory ailments and diarrhea. Research on and development of facilities consistent with good health, optimal growth, labor efficiency, and low construction or remodeling costs increased. Reports of research and field experience (6, 22) set forth criteria for satisfactory housing of dairy animals. Cleanliness, isolation of small calves from the milking herd, low humidity, freedom from drafts, dry beds, and provisions for ventilation and shade were vital for calves and heifers. Equipment for handling heifers during breeding and treatment was recommended. Individual pens or stalls were advocated for calves fed liquid diets. Group pens with limited numbers of animals of similar size and age were recommended for recently weaned calves. Older heifers could be kept in large groups so long as access to feed and water was satisfactory.

Although many dairymen in certain areas continue to house calves with the milking herd, separate buildings or rooms are becoming more popular as herd size increases. Buildings have been cold uninsulated buildings with open eave and open ridge type of ventilation or warm, insulated, mechanically ventilated units. For calves fed liquid diets, individual stalls or pens often are recommended. The elevated stall of steel or wood construction has become commonplace. These stalls help to keep calves clean and dry. The separate pen or stall prevents nursing. The elevated stall with slotted flooring also eliminates the need for bedding. Housing for calves can be either a controlled or climatic environment. In cold climates the most successful buildings are those that remove moisture and stale air. Incidence of respiratory problems is greater in barns with insufficient ventilation than in those adequately ventilated (5). At least four air exchanges are required per hour to remove aerosol contaminants and moisture. More exchanges are needed in warm weather. Temperature in calf barns is not as critical as humidity and air exchange. Calves tolerate temperatures to 5°C or lower with no discomfort (79), provided adequate shelter, bedding, and feed are available. In very hot environments, higher mortality may occur. Under these conditions calves may have higher serum corticosteroid concentrations and lower IgG concentrations than controls (71).

Because of increased and continued incidences of problems in conventional housing, many dairy producers have abandoned traditional housing (2) and have switched to hutches for young calves. Many experiment stations have developed plans for these individual calf units. Hutches have improved calf health and growth where problems, seemingly unsolvable by other means, existed. Although successful even in cold climates, caring for and feeding of calves in hutches may be uncomfortable for the calf caretaker. Jorgenson et al. (29) compared good indoor facilities with hutches and found no differences in growth, health, or weaning age of calves. Calves in hutches may be stressed during extreme cold, especially those less than 1 wk of age. More feed is consumed, and more labor is required by calves in hutches (40) as compared to calves in conventional housing.

Housing for older heifers has been in open lots, pole sheds, confinement buildings with slatted floors, and barns with free stalls. Open-side sheds continue to provide comfortable housing for heifers if adequate bedding is used. Free stall layouts for heifers have been developed and are satisfactory if stall size is correct. The newest design in loose housing is the counterslope, where bedding and feeding areas are sloped in opposite directions to a common center manure alley (12). Grouping animals according to age and size is important in the success of heifer loose housing units (32).

High intensity housing for heifers has been developed and may reduce building space by 70%. In such units, either warm or cold, 3.6 m^2 of space has been used successfully for large bred heifers gaining .68 kg/day. Less space is used for smaller heifers. Floors are slatted in these barns with manure storage underneath, and free stalls may or may not be used. Details on calf and heifer housing are in many sources (6, 12, 32, 35, 43).

CALF HEALTH

Mortality rates of dairy calves averaged about 10% with ranges from 8 to 25% prior to 1956 (23, 37, 51). Reports from New York (24), Michigan (51, 70), and California (37) indicate little or no advancements in reducing calfhood mortality during the last 25 yr. A survey of 477 Michigan dairy farms revealed total mortality rates of 17.7% with 11.3% of the deaths between birth and 2 mo of age (51). Mortality rates ranged from 3.7 to 32.1% with an average loss of 20.2% of heifers born live on 16 farms in California (38).

Many factors are associated with calf mortality, but herd size seems to be most highly related to mortality. Table 1 lists the mortality rates of calves according to herd size for surveys in Michigan and New York. Speicher and Hepp (70) have hypothesized that: 1) in smaller herds stanchion barns often are the choice for housing both cows and calves; hence, sickness may be detected earlier as calves are observed more frequently; 2) expanded dairy facilities often neglect to provide adequate freshening and youngstock housing; and 3) management becomes diluted with expansion as it becomes spread over a greater number of animals.

The two major health disorders affecting calves are enteric and respiratory (61). Enteric disorders, in the form of neonatal diarrhea, primarily affect calves the first 2 wk of life. Respiratory disorders are more apparent in older calves and closely related to environmental conditions.

Neonatal diarrhea or "scours" is the clinical appearance of hypersecretion of fluids into the alimentary tract in response to an irritant (56). Irritants can be either infections, chemical, or physical. Infectious agents include both bacteria and viruses. The major bacteria associated with enteritis are *E. coli* and *Salmonella.* Roy (61) has stated that the basic knowledge on *E. coli* infections was established in the 1920's and is being reconfirmed every 20 to 25 yr. Knowledge on isolating and identifying viral agents and their interactions with enteropathogenic strains of *E. coli* has broadened during the last 25 yr. Mebus (41) found the rota and corona viruses increased the severity of enteric infections when accompanied by bacteria. McClurkin (39) also has indicated that diseases produced by viruses are not necessarily severe or fatal, but severities are increased greatly when accompanied by other disease organisms or stresses associated with most farm conditions.

Respiratory disorders are a greater problem than enteric diseases in calves 6 to 8 wk of age. High population density with inadequate venti-

TABLE 1. Relationship of herd sizes to calf mortality.

Herd size	No. of herds	Live births	Mortality 0–14 days	Mortality 15–60 days	Total mortality
		(%)			
Michigan[a]					
50	217	93.9	7.5	2.5	16.1
50–100	199	93.6	8.8	2.9	18.1
100–200	56	92.5	10.6	2.8	21.1
200	5	89.6	18.1	6.3	34.9
			0–90 days		
New York[b]					
40–50	76	93.2	7.4		14.2
51–75	94	92.6	8.7		16.1
76–100	37	91.5	9.6		18.1
101–125	23	92.0	9.7		17.7
126–200	14	93.2	14.2		21.0
201–350	3	87.9	21.3		33.4

[a]Reference (51).

[b]Reference (24).

lation usually are associated with higher incidences of the problem. Respiratory disorders are accentuated during periods of low relative humidities at high environmental temperatures and high relative humidity at low environmental temperatures (64). California workers (36, 38) suggest calf mortalities increase during cold, wet, and windy weather in winter and to less extent with hot dry weather in summer. Speicher and Hepp (70) indicated higher mortality rates in winter than in summer. Calves housed within the stanchion barn were shown (24, 70) to have lower mortality rates than calves housed separately from the dairy herd.

Perhaps one of the major advancements in health knowledge during the last 25 yr has been in the treatment of diarrhea in calves. While the effectiveness of broad spectrum antibiotics is unknown, replacement therapy of fluids with electrolytes has been valuable in preventing dehydration, metabolic acidosis, and subsequent death (56). However, the best control method is adequate intake of colostral immunoglobulins by calves shortly after birth (61). Enhancement of immune mechanisms through immunization programs should be in support of and not in place of colostral antibodies or good nutrition and management. Vaccination programs (69) will vary according to geographical area, current knowledge of product immunogenicity, resistance developed by vaccinated animal, and risks of not vaccinating animals.

MANAGEMENT CONSIDERATIONS

Rearing Options

Prior to 1956 most heifers entering the herd were either home-bred and reared or purchased. These two methods of replacing milking cows still are used extensively, but contract rearing of replacements also has appeared as an option. This is especially true in the case of extremely large herds where labor and management focus is on the milking herd. Appleman (2) described two types of contracts: 1) the contractor raises the dairy heifers for a fee, but the dairy operator retains ownership of the heifers; 2) the heifers are purchased by the contractor and the dairy operator has an option to buy back the heifers before freshening.

Costs in Rearing Replacements

Budget guides have been developed for estimating costs of heifer rearing. Expenses vary, but 55 to 65% of the cost is feed (2) with 95% of the cost postweaning. Labor requirements, the next largest item in heifer rearing, can be extremely variable and are dependent upon size of operation, convenience of facilities, and incidence of health problems. Appleman (2) estimated 912.5 h/yr are required for care of heifers in a 100 cow herd. Housing needs and costs vary considerably depending on climate. Sick calves require, on the average, 53 min extra care. Breeding fees, power, miscellaneous supplies, interest, insurance, and taxes will account for 6 to 10% of total expense in raising replacement heifers.

CONCLUSIONS

Research should continue on efficiency of producing dairy replacements, an objective of NC-119 (31). Work by this committee has yielded much information. This group has developed guidelines (33) for uniform measuring and reporting of research on calves and heifers which should be useful for publishing data in years to come.

What the next 25 yr will bring is, of course, speculative, but new information appears to be unfolding in the areas of immunity, amino acid requirements, disease control, and environment. Alternate sources of nutrients and modification of feedstuffs for economical milk replacers and growing rations probably will result from ongoing and future research. Continued research will be needed to define nutrient requirements under different conditions of rearing and to add to present knowledge on digestion and metabolism in growing animals. Certainly, studies to use energy more efficiently in rearing calves will have a place in research priorities.

With advances in genetics and reproductive physiology, genetically superior animals will be available to producers. However, the livability, growth, and health of these animals from calves to freshening will continue to be a major problem. Continuation of educational programs with existing and future knowledge will be an important aspect of dairying and the successful, practical, and economical rearing of replacement animals.

REFERENCES

1 Alpan, S. O., J. E. Oldfield, D. W. Claypool, and G. O. Kohler. 1979. Digestibility of alfalfa protein concentrate (Pro-Xan) in milk replacer diets for calves. J. Dairy Sci. 62 (Suppl. 1):86. (Abstr.)

2 Appleman, R. D. 1978. Replacement economics. *In* Large dairy herd management. C. J. Wilcox and H. H. Van Horn, ed. Univ. Presses of Florida, Gainesville.

3 Appleman, R. D., and F. G. Owen. 1975. Breeding, housing, and feeding management. J. Dairy Sci. 58:447.

4 Bartley, E. E. 1973. Effects of a self-fed pelleted mixture of hay and calf starter on the performance of young dairy calves. J. Dairy Sci. 56:817.

5 Bates, D. W., and J. F. Anderson. 1979. Calculation of ventilation needs for confined cattle. J. Am. Vet. Med. Assoc. 174:581.

6 Bates, D. W., T. J. Johnson, D. W. Johnson, R. K. Keith, and J. H. Pedersen. 1976. Dairy Housing and Equipment Handbook. MWPS-7. Midwest Plan Serv., Iowa State University, Ames.

7 Brignolle, T. J., and G. H. Stott. 1980. Effect of suckling followed by bottle feeding colostrum on immunoglobulin absorption and calf survival. J. Dairy Sci. 63:451.

8 Burt, A.W.A. 1956. Influence of level of feeding during rearing and in late pregnancy upon the productivity of the dairy cow. Dairy Sci. Abstr. 18: 884.

9 Burt, A.W.A., and S. M. Irvine. 1970. Carbohydrates in milk replacers for calves. J. Sci. Food Agric. 21:342.

10 Bush, L. J., and T. E. Staley. 1980. Absorption of colostral immunoglobulins in newborn calves. J. Dairy Sci. 63:672.

11 Butler, J. E. 1969. Bovine immunoglobulins: A review. J. Dairy Sci. 52:1895.

12 Collins, W. H., and W. R. Murley. 1976. Countersloped, self-cleaning cattle confinement structures. Proc. Southeast Reg. Mtg. Am. Soc. Agric. Eng., Univ. of Virginia.

13 Conner, G. H., M. Richardson, G. R. Carter, and J.P.O. Wamukoya. 1977. Immune responses of the bovine fetus. J. Dairy Sci. 60:289.

14 Conrad, H. R., J. W. Hibbs, and N. Frank. 1958. High roughage system for raising calves based on early development of rumen function. IX. Effect of rumen inoculations and chlortetracycline on rumen function of calves fed high roughage pellets. J. Dairy Sci. 41:1248.

15 Crane, F. M., M. Hansen, and L. Schugel. 1967. Calf milk replacers. Page 95 *in* Proc. Minnesota Nutr. Conf.

16 Devery, J. L., C. L. Davis, and B. L. Larson. 1979. Endogenous production of immunoglobulin IgG1 in newborn calves. J. Dairy Sci. 62:1814.

17 Edwards-Webb, J. D., and S. Y. Thompson. 1977. Studies on lipid digestion in the preruminant calf. 2. A comparison of the products of lipolysis in milk fat by salivary and pancreatic lipases in vitro. Brit. J. Nutr. 37:431.

18 Fleenor, W. A., and G. H. Stott. 1980. Hydrometer test for estimation of immunoglobulin concentration in bovine colostrum. J. Dairy Sci. 63:973.

19 Foley, J. A., and D. E. Otterby. 1978. Availability, storage, treatment, composition, and feeding value of surplus colostrum: A review. J. Dairy Sci. 61: 1033.

20 Garnot, P., R. Toullec, J. L. Thapon, P. Martin, Minh-Thu Hoang, C. M. Mathieu, and B. R. Dumas. 1977. Influence of age, dietary protein, and weaning on calf abomasal enzymic secretions. J. Dairy Res. 44:9.

21 Gorrill, A.D.L., J. D. Jones, and J.W.G. Nicholson. 1976. Low- and high-gluconsinolate rapeseed flours and rapeseed oil in milk replacers for calves: their effects on growth, nutrient digestion, and nitrogen retention. Can. J. Anim. Sci. 56:409.

22 Grout, A. R., and S. B. Guss. 1973. Requirements for heifer rearing. Page 315 *in* Proc. Nat. Dairy Housing Conf. Spec. Pub. 01-73. Am. Soc. Agr. Eng., St. Joseph, MI.

23 Grunsel, C. S. 1956. Mortality and morbidity in calves. Vet. Rec. 68:788.

24 Hartman, D. A., R. W. Everett, S. T. Slack, and R. G. Warner. 1974. Calf mortality. J. Dairy Sci. 57:576.

25 Hibbs, J. W., and H. R. Conrad. 1978. A high roughage system for raising calves. XIII Corn cobs in complete high roughage diets. J. Dairy Sci. 61:337.

26 House, J. A. 1978. Economic impact of rotavirus and other neonatal disease agents in animals. J. Am. Vet. Med. Assoc. 173:573.

27 Huber, J. T. 1969. Calf nutrition and rearing. Development of the digestive and metabolic apparatus of the calf. J. Dairy Sci. 52:1303.

28 Jacobson, N. L. 1969. Energy and protein requirements of the calf. J. Dairy Sci. 52:1316.

29 Jorgenson, L. J., N. A. Jorgensen, D. J. Schingoethe, and M. J. Owens. 1970. Indoor versus outdoor calf rearing at three weaning ages. J. Dairy Sci. 53:813.

30 Kesler, E. M. 1980. Feeding mastitis milk to calves: Preservation, calf performance, and animal health. Paper presented at 75th Annu. Mtg., Am. Dairy Sci. Assoc., Blacksburg, VA.

31 Lamb, R. C. 1978. Improving large dairy herd management practices: Review of regional project NC-119. J. Dairy Sci. 61:1284.

32 Larsen, H. J., G. H. Tenpas, and T. J. Brevik. 1973. Low cost housing for dairy heifers and steers. Page 336 *in* Proc. Nat. Dairy Housing Conf. Spec. Pub. 01-73. Am. Soc. Agr. Eng., St. Joseph, MI.

33 Larson, L. L., F. G. Owen, J. L. Albright, R. D. Appleman, R. C. Lamb, and L. D. Muller. 1977. Guidelines toward more uniformity in measuring and reporting calf experimental data. J. Dairy Sci. 60:989.

34 Lister, E. E., and D. B. Emmons. 1976. Quality of protein in milk replacers for young calves. II. Effects of heat treatment of skimmilk powder and fat levels on calf growth, feed intake, and nitrogen balance. Can. J. Anim. Sci. 56:327.

35 Martin, R. O. 1973. Design and operation of a complete herd replacement facility. Page 321 *in* Proc. Nat. Dairy Housing Conf. Spec. Pub. 01-73. Am. Soc. Agr. Eng., St. Joseph, MI.

36 Martin, S. W., C. W. Schwabe, and C. E. Franti. 1975. Dairy calf mortality rate: the association of daily meteorological factors and calf mortality. Can. J. Comp. Med. 37:377.
37 Martin, S. W., C. W. Schwabe, and C. E. Franti. 1975. Dairy calf mortality rate: characteristics of calf mortality rates in Tulare County of California. Am. J. Vet. Res. 36:1099.
38 Martin, S. W., C. W. Schwabe, and C. E. Franti. 1975. Dairy calf mortality rate: influence of meteorological factors on calf mortality rate in Tulare County, California. Am. J. Vet. Res. 36: 1105.
39 McClurkin, A. W. 1977. Probable role of viruses in calfhood disease. J. Dairy Sci. 60:278.
40 McKnight. 1978. Performance of newborn dairy calves in hutch housing. Can. J. Anim. Sci. 58: 517.
41 Mebus, C. A. 1976. Viral calf enteritis. J. Dairy Sci. 59:1175.
42 Miller, W. J., Martin, Y. G., and P. R. Fowler. 1969. Effects of addition of fiber to simplified and to complex starters fed to young dairy calves. J. Dairy Sci. 52:672.
43 Mitchell, D. 1978. Calf housing handbook. Scottapress Pub. Ltd., Aberdeen.
44 Morrill, J. L., W. E. Stewart, and R. J. McCormick. 1970. Pancreatic amylase secretion by young calves. J. Dairy Sci. 53:72.
45 Muller, L. D. 1972. Feeding and managing dairy replacement heifers. Page 91 *in* Proc. Minnesota Nutr. Conf.
46 National Research Council. 1978. Nutrient requirements of dairy cattle. Nat. Acad. Sci., Washington, DC.
47 Nelson, J. H., R. G. Jensen, and R. E. Pitas. 1977. Pregastric esterase and other oral lipases – A review. J. Dairy Sci. 60:327.
48 Norman, H. D., P. D. Miller, B. T. McDaniel, F. N. Dickinson, and C. R. Henderson. 1974. UDSA-DHIA factors for standardizing 305-day lactation records for age and month of calving. USDA-ARS-NE-40.
49 Opstvedt, J., Gøbstad, and P. Hansen. 1978. Functional fish protein concentrate in milk replacers for calves. J. Dairy Sci. 61:72.
50 Otterby, D. E., and J. G. Linn. 1980. Recent advances in dairy cattle nutrition. Page 128 *in* Proc. 28th Annu. Pfizer Res. Conf.
51 Oxender, W. D., L. E. Newman, and D. A. Morrow. 1973. Factors influencing dairy calf mortality in Michigan. J. Am. Vet. Med. Assoc. 162:458.
52 Pelissier, C. L. 1969. Automated calf-raising systems. J. Dairy Sci. 52:1330.
53 Pettyjohn, J. D., J. P. Everett, Jr., and R. D. Mochrie. 1964. Responses of dairy calves to milk replacer fed at various concentrations. J. Dairy Sci. 47:710.
54 Polzin, H. W. 1978. Soy protein concentrate in milk replacers. Page 16 *in* Proc. 38th Annu. Mtg. Nutr. Council. Am. Feed Mfg. Assoc.
55 Porter, J.W.G. 1969. Digestion in the preruminant animal. Proc. Nutr. Soc. 28:115.
56 Radostits, O. M. 1975. Treatment and control of neonatal diarrhea in calves. J. Dairy Sci. 58:464.
57 Radostits, O. M., and J. M. Bell. 1970. Nutrition of the preruminant dairy calf with special reference to the digestion and absorption of nutrients: A rereview. Can. J. Anim. Sci. 50:405.
58 Ramsey, H. A., and T. R. Willard. 1975. Recent advances in calf rearing. Soy protein for milk replacers. J. Dairy Sci. 58:436.
59 Raven, A. M. 1970. Fat in milk replacers for calves. J. Sci. Food Agric. 21:352.
60 Reid, J. T. 1956. Nutrition and feeding of dairy cattle. J. Dairy Sci. 39:735.
61 Roy, J.H.B. 1980. Disease prevention in calves. Factors affecting susceptibility of calves to disease. J. Dairy Sci. 63:650.
62 Roy, J.H.B. 1978. Rearing dairy herd replacements. J. Soc. Dairy Tech. 31:73.
63 Roy, J.H.B., and I.J.F. Stobo. 1975. Nutrition of the preruminant calf. *In* Digestion and metabolism in the ruminant. Proc. IV Int. Symp. Ruminant Physiol. Sydney, Australia. I. W. McDonald and A.C.I. Warner, ed. Univ. New England Pub. Unit, Armidale, New South Wales.
64 Roy, J.H.B., I.J.F. Stobo, H. J. Gaston, P. Ganderson, S. M. Shotton, and D. C. Ostler. 1971. The effect of environmental temperature on the performance and health of the preruminant and ruminant calf. Brit. J. Nutr. 26:363.
65 Schugel, L. M. 1980. Recent calf milk replacer research. Page 37 *in* Proc. Minnesota Nutr. Conf.
66 Schugel, L. 1974. Milk replacers for preruminant calves, formulations, problems, economics. Page 132 *in* Proc. 7th Annu. Conf. Am. Assoc. Bovine Pract.
67 Schugel, L. M. 1973. Recent calf nutrition developments. Page 23 *in* Proc. Minnesota Nutr. Conf.
68 Schultz, L. H. 1969. Relationship of rearing rate of dairy heifers to mature performance. J. Dairy Sci. 52:1321.
69 Smith, P. C. 1977. Proposed calfhood immunization program for the commercial dairy herd. J. Dairy Sci. 60:294.
70 Speicher, J. A., and R. E. Hepp. 1973. Factors associated with calf mortality in Michigan dairy herds. J. Am. Vet. Med. Assoc. 162:463.
71 Stott, G. H., and B. E. Menefee. 1978. Selective absorption of immunoglobulin IgM in the newborn calf. J. Dairy Sci. 61:461.
72 Swannack, K. P. 1972. Recent developments in calf rearing based largely on studies at experimental husbandry farms. Agric. Dev. Advis. Serv. Quart. Rev. 4:167.
73 Swanson, E. W. 1978. Heifer performance standards: Relation of rearing systems to lactation. *In* Large dairy herd management. C. J. Wilcox and H. H. Van Horn, ed. Univ. Presses of Florida, Gainesville.
74 Swanson, E. W. 1977. Effects of level of nutrition on growth, reproduction, and lactation. Page 125 *in* Proc. Georgia Nutr. Conf.
75 Swanson, E. W. 1967. Optimum growth patterns for dairy cattle. J. Dairy Sci. 50:244.
76 Tzeng, D., and C. L. Davis. 1980. Amino acid nutrition of the young calf. Estimation of methionine and lysine requirements. J. Dairy Sci. 63: 441.

77 Warner, R. G., J. C. Porter, and S. T. Slack. 1973. Calf starter formulation for neonatal calves fed no hay. Page 116 *in* Proc. Cornell Nutr. Conf.

78 Warner, R. G., S. T. Slack, and W. W. Irish. 1978. All-in-one calf starters: research and field observations. Page 100 *in* Proc. Cornell Nutr. Conf.

79 Webster, A.J.F., J. G. Gordon, and R. McGregor. 1978. The cold tolerance of beef and dairy type calves in the first weeks of life. Anim. Prod. 26: 85.

80 Williams, A. P. 1978. The amino acids, collagen, and mineral composition of preruminant calves. J. Agric. Sci. 90:617.

81 Williams, A. P., and D. Hewitt. 1979. The amino acid requirements of the preruminant calf. Brit. J. Nutr. 41:311.

82 Wittenberg, K. M., and J. R. Ingalls. 1979. Utilization of fababean protein concentrate in milk substitute diets by preruminant calves. J. Dairy Sci. 62:1626.

83 Young, J. W., S. B. Tove, and H. A. Ramsey. 1965. Metabolism of acetate, propionate, and n-butyrate in young milk-fed calves. J. Dairy Sci. 48:1079.