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Influence of Season on Immunoglobulin Absorption and Status in Young Calves

Lynn Maureen Boyd

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INFLUENCE OF SEASON ON IMMUNOGLOBULIN ABSORPTION AND STATUS IN YOUNG
CALVES

BY

LYNN MAUREEN BOYD

A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science, Major in
Dairy Science, South Dakota
State University

1977

INFLUENCE OF SEASON ON IMMUNOGLOBULIN ABSORPTION AND STATUS IN YOUNG
CALVES

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser

Date

Head, Dairy Science Department

Date

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Lynn Boyd

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INTRODUCTION

A high rate of calf mortality can represent a major economic loss to the dairy farmer. Despite increased knowledge in calf rearing, mortality rates of 10 to as high as 25% are not uncommon. The loss of heifer calves alone cost dairymen an estimated \$81 million in 1975. This figure does not include the additional costs of extra labor, medication and veterinary expenses, and the loss of genetic potential.

The most critical period for calf survival is the first 2 to 3 wk of life. During this time, the calf depends upon colostral immunoglobulins absorbed during the first 24 h of life for protection against pathogenic microorganisms. Antigenic stimulation after birth activates the calf's own immune system, but significant endogenous synthesis of immunoglobulin does not occur until about the fourth week of life.

Studies on the newborn calf have shown that age at first feeding, amount of colostral immunoglobulin consumed, and "mothering" by the dam, all exert a strong influence on the amount of immunoglobulin absorbed. Attainment of an adequate level of circulating maternal immunoglobulins is of utmost importance for survival of the calf, since calf losses to infectious disease are highly correlated with low levels of serum immunoglobulins.

Season of the year has been related to the immunoglobulin status of young calves. A survey of serum immunoglobulin levels in 1-wk-old market calves in Scotland showed a marked seasonal variation in mean serum immunoglobulin concentration, with high mean values during summer months (21). Lowest mean values occurred during winter months

and coincided with the time of highest calf mortality. However, the observed seasonal variation may have been managerial in origin since the summer calves in this survey were born on pasture and nursed, while most winter calves were removed from their dam and bucket fed. A later study in Scotland (64), conducted from January thru July under uniform management conditions, showed no seasonal variation in immunoglobulin status of neonatal calves.

The influence of high temperature on immunoglobulin absorption was recently investigated (72) in Arizona. Newborn calves were housed under shade, cooled shade, or in hutches. Hutch-housed calves were exposed to higher ambient temperature and had lower serum immunoglobulin concentrations and a higher mortality rate.

This study examined the influence of season of the year (winter vs. summer) and the related factors of temperature and humidity on colostrum immunoglobulin absorption and immunoglobulin status of dairy calves raised in outdoor hutches in South Dakota. Other relationships studied included (1) influence of lactation number and season of the year on immunoglobulin concentration in colostrum, and (2) influence of season on feed intake and weight gain of calves.

LITERATURE REVIEW

Importance of colostrum in passive immunization of the newborn calf

Passive, naturally acquired immunity, is the immunity that an animal receives from its mother in utero or shortly after birth from ingestion of colostrum (6). Due to the structure of the bovine placenta, there is no transport of maternal immunoglobulins to the fetal circulation (9). The bovine is born essentially devoid of immunoglobulins (Ig) and requires ingestion of colostrum within the first 24 h of life to receive passive resistance (53, 74).

The importance of feeding colostrum to the newborn has long been appreciated. As early as 1905 Jensen (cited in 36) demonstrated that calves fed boiled milk died with an enteritis, while calves fed colostrum survived. In a series of papers in the 1920's Smith and his co-workers (27, 52, 69, 70) examined the mechanism of immunity provided by colostrum. These workers demonstrated that calves do not receive any immunity across the placenta, being born without detectable antibodies in their serum. They also showed that the newborn calf receives its immunity from the colostrum, and suggested that the colostrum antibodies were derived from the maternal serum. Newborn calves fed serum from normal lactating cows were protected against Escherichia coli (E. coli) septicemia (70). Later work showed that traces of immunoglobulins were present in the serum of calves at birth, but in too low a concentration to provide the calf with any degree of immunity (26, 31, 50).

Studies by Aschaffenburg et al. (1) demonstrated that the

protective factor in colostrum was associated with the whey proteins. Calves need colostrum whey, or the immunoglobulins contained therein, to survive. Newborn calves given just 80 ml of colostrum whey survived, while five of six calves not receiving colostrum whey died. It is now established that the protective factor in colostrum is associated with the immune lactoglobulin fraction of the whey protein (20).

Numerous authors have measured the concentration of acquired serum immunoglobulins in the neonatal calf in relation to the incidence of neonatal disease. In a study of market calves in Scotland, Gay et al. (22) precipitated serum immunoglobulins with zinc sulfate and quantitated their concentration by measuring the resultant turbidity (zinc sulfate turbidity units, 1 ZST unit = 1 mg immunoglobulin/ml serum). They found that purchased calves which died were those that had low serum immunoglobulin concentrations. McEwan et al. (49) studied immunoglobulin concentrations in market calves kept under standard management conditions. These workers observed that the type of disease occurring was related to serum immunoglobulin concentration. Calves with high concentrations of immunoglobulins remained healthy, those with lower concentrations had diarrhea but survived. Calves with still lower immunoglobulin concentrations suffered from diarrhea and died, while those with little or no immunoglobulin died of septicemia.

Results of farm surveys support the relationship between low serum immunoglobulin concentrations and a high incidence of disease. Boyd (7) measured the post-colostrum serum concentration of 227 2 to 8-

day-old Holstein calves born on, or introduced to, a farm in England over a 12-month period. The incidence of scours was 21.9% and of other diseases 11.4% in calves with below median (20 ZST units) immunoglobulin concentrations. In calves with above median immunoglobulin concentrations, the incidence of scours was only 5.3% and of other diseases 3.5%

Ferris and Thomas (18) measured immunoglobulin concentrations in serum of 2-day-old calves from 30 Michigan dairy herds. Concentrations were significantly lower in calves that died than in surviving calves. More calves with low immunoglobulin concentrations died in high mortality herds (21%) than in low mortality herds (7%). This suggests that a combination of low serum immunoglobulin concentrations and environmental conditions in high mortality herds increases the odds for neonatal mortality.

Colostrum immunoglobulin composition and production

Immunoglobulins are high molecular weight proteins synthesized by cells of the reticulo-endothelial system of mammals in response to antigenic stimulus (6). These proteins are primarily gamma globulins (γ -globulins) and occur in serum and other body fluids. The antibody function of immunoglobulins is to inactivate or destroy antigens which threaten the life of the host by combining specifically with the antigen which stimulated their production.

Several different classes and subclasses of immunoglobulins exist with classification based on their antigenic and physio-chemical characteristics (6). All classes are related by the structure of the

basic immunoglobulin molecule. All immunoglobulins appear to be either monomers or polymers of a four-chain molecule consisting of two light polypeptide chains (20,000 mw) and two heavy polypeptide chains (50,000 to 70,000 mw, depending on immunoglobulin class). Three distinct classes of immunoglobulins exist in the bovine; IgA, IgG, and IgM. Immunoglobulin IgG is further subdivided into IgG1 and IgG2 subclasses, while IgA can be found in two forms, serum IgA and secretory IgA (SIgA) (36).

The major immunoglobulins of the circulatory system are IgG and IgM. These immunoglobulins are produced by cells of the spleen and lymph nodes. Immunoglobulin IgM exists as a pentamer and its large size (900,000 to 1,000,000 mw) restricts it mainly to the intravascular spaces. Serum IgM represents 90% of the total body IgM, yet comprises less than 10% of the total serum immunoglobulins. Thus, IgG makes up the bulk (85 to 90%) of the serum immunoglobulin (31, 58). Immunoglobulin IgG (150,000 to 163,000 mw) exists as a monomer and is about equally distributed (1.2:1) between extravascular and intravascular pools (42).

Immunoglobulin IgA (300,000 to 400,000 mw) is the major immunoglobulin in many external secretions (74). It is produced by cells lining the gastrointestinal tract, salivary glands, and tissues near other mucosal surfaces. The IgA found in saliva, milk, colostrum, nasal, intestinal, and other secretions is known as secretory IgA (SIgA). It exists as a dimer of immunoglobulin molecules with a secretory piece attached between the molecules. The secretory piece

is a single peptide chain with a molecular weight of about 60,000 and is produced by epithelial cells (6). The secretory piece may prevent enzyme degradation of the IgA molecule in the small intestine (36).

Although the main site of serum IgA production is yet to be determined, evidence (6) indicates that IgA generated in the gastrointestinal tract is able to enter the vascular system. Serum IgA exists primarily in a dimer form, with SIgA comprising up to 20% of the total serum IgA immunoglobulins (13).

All three classes of immunoglobulin are found in bovine colostrum and accumulation of these immunoglobulins in the udder begins about 5 wk prior to parturition (11). Although there is evidence that the mammary tissue can synthesize all three immunoglobulins (60), the major accumulation of colostrum immunoglobulin is by way of transport from the maternal serum in an unaltered form (16, 35, 68).

Dixon et al. (16) made serial quantitative determinations of colostrum and serum γ -globulin (the main protein fraction containing immunoglobulins) in a pregnant cow before and after delivery. These workers demonstrated a decrease in serum γ -globulin concentration at the same time when an equivalent rise occurred in colostrum γ -globulin concentration. The amount of γ -globulin lost from the circulation during the period 3 wk prepartum corresponded closely with the amount (718 g) calculated to be in the udder at parturition. They also found that the γ -globulin concentration in colostrum was about five times that of serum at parturition.

More recent work has shown that transport of serum immunoglobulins

to colostrum is selective for the IgG1 subclass. Brandon et al. (11) studied changes in IgA, IgG1, IgG2, and IgM in serum and mammary secretions of fifteen cows and two heifers before and after parturition. In all animals serum IgG1 decreased abruptly, usually by more than 50%, 2 to 3 wk before parturition. During the same period the concentration of the other immunoglobulins remained unchanged. The ratio of IgG1 to IgG2 in colostrum was 7 to 1, even though their concentrations in blood were about equal. Subsequent work by Husband et al. (28) found colostrum IgG1 in concentrations two to five times the sum of the concentrations of the three remaining immunoglobulins. Related to these results, Sasaki et al. (62) found a greatly increased production and a shortened half-life or greater turnover of serum IgG1 1 to 3 days prior to parturition.

Even though IgA (secretory form) and IgM jointly account for less than 20% of the total colostrum immunoglobulins, they are concentrated seven times and two times their respective concentrations in maternal serum (59). The mode of concentration of IgA and IgM in colostrum, whether by local synthesis in the mammary gland or by transport from the serum, is yet to be determined. Brandon et al. (11) suggested that the large sizes of IgM and IgA may limit their transport from serum to colostrum secretion. Therefore, much of IgA and IgM in colostrum might be due to local synthesis within the mammary gland.

The selective mechanism for transport of immunoglobulins from serum to colostrum is believed to reside with the alveolar epithelial cells (16). These cells change in function from largely protein

synthesis during normal lactation, to primarily protein transport during the dry period. The presence of specific IgG1 receptor sites on the basal portion of these cells has been theorized (11).

Control of the selective transport of IgG1 into the mammary gland may be hormonal in nature. Smith et al. (68) injected two cows and two heifers with estrogen and progesterone at levels reported to exist at or near parturition and caused the formation of a fluid nearly identical to colostrum. These results suggest that changing estrogen and progesterone concentrations during the last 4 to 6 wk of pregnancy either directly or indirectly exert a controlling influence on the selective transport of IgG1 from serum to colostrum.

Factors related to colostrum immunoglobulin production were examined in an extensive study by Kruse (32). Experimental animals consisted of cows and heifers of the Black and White Danish, Red Danish, and Jersey breeds. A highly significant difference was found among breeds in yield of colostrum at first milking after calving and in the concentration of immunoglobulin in colostrum, Red Danish animals having the highest colostrum yield but the lowest immunoglobulin concentration. Kruse also found marked individual variation within breeds in colostrum yield and immunoglobulin concentration. Heifers had lower colostrum and immunoglobulin yields than cows in second and later lactations. No effect of season of the year was found on colostrum yield or immunoglobulin concentration.

Oyeniya et al. (55) followed changes in the IgG concentration in colostrum from the first three milkings of Holstein and Guernsey cows.

Results showed a marked decrease in IgG concentration at successive milkings for each breed. Breed differences in IgG production were evident, with Holstein colostrum containing a significantly greater concentration of IgG than Guernsey colostrum at first, second, and third milkings. In addition, Guernseys showed a greater rate of decrease in colostrum immunoglobulin concentrations by second and third milkings. A rapid decline in colostrum immunoglobulins at successive milkings has also been noted by Bush et al. (12), while Ferris and Thomas (18) found first colostrum to have an immunoglobulin concentration twice that of second milking colostrum.

Absorption of colostrum immunoglobulins and protection provided

The rapid absorption of colostrum immunoglobulins takes place in the small intestine of the newborn calf (14). Immunoglobulins are absorbed by the columnar epithelial cells by micropinocytosis, transported across the cells in vacuoles, and released into the lymph system within 1 to 2 h after feeding (3, 15). Blood serum values become elevated within 3 to 5 h (12, 18). The immunoglobulins are absorbed intact, being spared from digestion in the gut due to a powerful antitrypsin factor in colostrum and the absence of abomasal peptic activity during the first day of life (19).

The absorptive capacity of the small intestine declines linearly with time, with "gut closure" essentially complete by 24 h of life (4, 47, 57). McCoy et al. (47) demonstrated this closure when they deprived newborn calves of colostrum for 24 h, then fed colostrum. Blood samples taken at 31 h of age showed no difference in serum

γ -globulin concentration from precolostral blood samples. Penhale et al. (57) noted that not only is there a decrease in absorption with increasing age, but termination of absorption is different for each class of immunoglobulin. Gut closure began shortly after birth and was effectively complete by 16, 22, and 27 h for IgM, IgA, and IgG, respectively. Closure time for each class is related to size of the immunoglobulin, the largest, IgM, being excluded first. Under these circumstances, a calf first nursed at 10 to 12 h would acquire little IgM protection.

Possible causes of the decline in absorption with time are the turnover of the intestinal epithelial cell population and physiological changes in the epithelial cells due to hormonal mediators. El-Nageh (17) used fluorescent labeled colostral globulins to observe protein absorption in newborn calves. At 6 h of age protein was absorbed by all the epithelial cells of the villi. In 52-h-old calves fluorescence was limited to the apical end of the villus. El-Nageh related this to the normal cellular renewal of the epithelium. Cells continually lost from the apex of the villus are replaced by cells which migrate from the base of the villus to the apex. Thus, in the 52-h-old calves, the only "original" cells capable of immunoglobulin absorption left were on the tips of the villi, the rest having been extruded into the lumen of the intestine.

The possibility of a hormonal influence on gut closure was studied by Patt et al. (56) in newborn rats. Injection of 9-day-old rats with adrenal cortical stimulating hormone (ACTH) produced elevated

serum corticosterone levels, reduced serum γ -globulin concentration, and shortened the immunoglobulin absorption period for the rat from 21 to 15 days postpartum. Results suggest glucocorticoids may play a role in "gut closure" by reducing the permeability of intestinal epithelial cells.

Husband et al. (29) examined the effect of corticosteroids on absorption of immunoglobulins in newborn calves. Calves born of corticosteroid-treated cows and control calves were fed 2 liters of pooled colostrum within 6 h of birth. Blood samples taken at intervals after birth showed lower serum immunoglobulin concentrations in calves from treated dams, with the efficiency of absorption for each class of immunoglobulins being 50% that of untreated calves. Stott et al. (72) postulated that under normal neonatal conditions, physiological stress increases the calf's own adrenal steroid output, which in turn causes the decline in the immunoglobulin absorbing capacity of the intestinal epithelial cells during the critical 24 h postnatal period.

The efficiency of absorption of colostrum immunoglobulin has been examined by numerous research groups. Efficiencies of absorption of immunoglobulins measured at 24 h of age of 35.7% (4) and 45% (12) have been reported. McEwan et al. (48) based their estimate of efficiency of absorption of total immunoglobulins on a blood sample taken 72 h after colostrum feeding, allowing this time for equilibration of immunoglobulins between extravascular and intravascular pools. After correcting for an extravascular to intravascular ratio of 1.2:1 for IgG (42) an efficiency of absorption of 65% was reported.

Klaus et al. (31) examined the efficiency of absorption of individual classes of immunoglobulins. Concentrations of IgG and IgM in blood serum collected from calves 24 h after feeding were compared with the concentrations of these immunoglobulin classes in the colostrum fed. Absorption efficiencies of 49% and 60% were reported for IgM and IgG, respectively. Results of this study led these workers to conclude that absorption of these two classes of immunoglobulin was non-selective -- one class of immunoglobulin was not absorbed in preference to the other class of immunoglobulin. Brandon and Lascelles (10) reviewed the work by Klaus et al. (31) and pointed out that their conclusion did not take into account the fact that relatively more of the much larger IgM molecule would be retained in the blood vascular compartment compared with IgG. Therefore, absorption estimates based on immunoglobulin concentrations in blood would underestimate the efficiency of absorption of IgG relative to IgM.

In subsequent work, Brandon and Lascelles (10) set up a more exacting study to determine whether selective absorption of individual classes of immunoglobulin occurred. Newborn calves were fitted with lymphatico-venous shunts, and the concentrations of IgA, IgG1, IgG2, and IgM were measured in thoracic duct lymph shortly after the feeding of colostrum. By measuring the concentrations in this manner, the total change in immunoglobulin concentration within the calves due to intestinal absorption could be determined, since little time was allowed for passage of immunoglobulins into extravascular body fluids. The relative efficiency of absorption was determined by expressing the

concentration of each immunoglobulin in lymph as a proportion of the concentration of the analogous immunoglobulin in the colostrum fed. Results showed no significant difference in the efficiency of absorption of the four immunoglobulins studied. In support of this finding, Porter (59) noted that the ratio of specific immunoglobulin concentrations in calf serum matched fairly closely the ratio of immunoglobulin concentrations in the colostrum fed.

Persistence of passively acquired immunity was examined by Logan et al. (41). These workers monitored changes in serum immunoglobulin concentrations of 16 colostrum-fed calves during the first 12 wk of life. Serum concentration of each class of absorbed colostrum immunoglobulin reached a peak 24 h postpartum. Concentrations then declined (due to catabolism) at different rates reaching a minimum by 2 to 4 wk, after which IgG and IgM concentrations began to increase due to endogenous synthesis. Continuing low serum concentrations of IgA after the initial rise suggested that IgA plays little part in systemic protection. Half-lives of IgG, IgM, and IgA, estimated from the rate of decline of each immunoglobulin in serum, were 21.0, 4.0, and 2.8 days, respectively. Similar half-life values of 20, 4, and 2 days have been reported by Porter (59).

More recent work by Sasaki et al. (63) showed that the half-life value of 20 to 21 days previously noted for IgG may be an overestimate. Newborn calves were fed a meal of ^{125}I labeled IgG1 in colostrum derived from their dams (since subclass IgG1 comprises almost all of the colostrum IgG) and plasma levels of this immunoglobulin were

followed for a 3 wk period. Half-life as measured by the decrease in plasma concentration of IgG1 was 19.9 days. However, the half-life as measured by the disappearance of ^{125}I -IgG1 from the plasma was 11.5 days. These workers suggested that the latter half-life is closer to the true half-life because its value is not affected by endogenous production of IgG1 by the young calf.

Although colostrum immunoglobulins provide passive immunity to the calf, their presence in the calf has a suppressive effect on the animal's own immune system (53). In most species, the passive transfer of specific antibodies interferes with active immunization by the specific antigens (9). The antigen, instead of being presented to appropriate cells for immunization, interacts with circulating maternal antibodies and is cleared from the animal's system.

The degree of suppression of the immune response in the young calf appears to be related to the concentration of absorbed colostrum immunoglobulins. Logan et al. (38, 41) found that calves with high serum concentrations of maternal immunoglobulin did not synthesize significant amounts of immunoglobulin until 4 wk of age. In contrast, calves with low serum concentrations produced immunoglobulin within 1 wk of birth, while colostrum-deprived calves began to synthesize immunoglobulins within 48 h of birth.

Studies by Logan et al. (39, 40) showed that colostrum immunoglobulins provide both systemic protection and local intestinal protection in the newborn calf. In addition, these actions appear to be independent of each other. Systemically administered immunoglobulin

protected calves from septicemia, but had little or no influence on intestinal immunity (39). Conversely, colostrum immunoglobulin administered orally after the absorptive period inhibited enteric disease but not septicemia (40). Thus, for a calf to survive, immunoglobulins must be present in adequate quantities in serum and in the gastrointestinal tract.

In a subsequent study Logan and co-workers (37) examined the role of the individual classes of immunoglobulin in intestinal immunity. Newborn calves in this study were fed either colostrum, or colostrum immunoglobulin preparations of IgA, IgG, or IgM before oral challenge with an enteropathogenic strain of E. coli. While each immunoglobulin prevented death from enteric disease, no class of immunoglobulin alone was as effective as colostrum in prevention of diarrhea and fluid imbalance. Immunoglobulins IgG and IgM showed comparable activity in limiting diarrhea, while IgA treated calves suffered prolonged diarrhea and marked hemo-concentration. Results suggest that all three immunoglobulins probably have separate prophylactic qualities and may act in synergism to provide the full spectrum of protection obtained with colostrum.

Factors influencing colostrum immunoglobulin absorption

Newborn calves need colostrum immunoglobulins for immunological protection during the early neonatal period, yet many calves do not absorb immunoglobulins in quantities conducive to survival (8, 22, 34, 38, 64). Investigation of the problem of low concentrations of passively acquired immunoglobulins in neonatal calves has revealed several

factors that exert an influence on immunoglobulin absorption (74). The two most important factors appear to be age at first colostrum feeding and amount of colostrum immunoglobulins consumed.

As noted previously, there is a linear decline in the immunoglobulin absorptive capacity of the small intestine of the newborn calf with increasing age, culminating in termination of absorption by approximately 24 h postpartum (57). The practical aspect of this finding is that the sooner the calf is fed colostrum, the better its chance to absorb an adequate amount of colostral immunoglobulin. In a farm survey, Selman et al. (66) measured the serum immunoglobulin concentrations of 164 calves bucket-fed first colostrum and divided the calves into two groups: those fed before and those fed after 6 h postpartum. Calves fed before 6 h postpartum had significantly higher immunoglobulin concentrations. In like manner, a field study by Oxender et al. (54) noted a significant difference in calf mortality rate (CMR) in relation to time of first feeding of colostrum. Calves fed colostrum before 6 h postpartum had a lower CMR (10.2%) than those fed colostrum between 6 and 12 h postpartum (13.4%). Ferris and Thomas (18) found that calves fed colostrum 1 and 2 h after birth had higher serum immunoglobulin concentrations than those fed colostrum 6 or 12 h after birth.

The quantity of colostrum fed to the newborn has also been correlated with the serum immunoglobulin concentration of the neonatal calf. Ferris and Thomas (18) found that initial feeding of 1.36 kg vs. .45 kg of pooled colostrum resulted in higher serum immunoglobulin

concentrations at 12 h postpartum (5.6 vs. 1.2 ZST units) and also at 24 h postpartum (9.9 vs. 6.5). Calves receiving 1.36, 2.27, 2.73, or 3.18 kg of pooled colostrum had step-wise increased concentrations of immunoglobulins in their blood at 24 h.

In more specific terms, it is the total amount of immunoglobulin consumed, determined by the immunoglobulin concentration in colostrum and the total amount of colostrum fed, which influences the amount of immunoglobulin absorbed by the newborn calf. Work by Kruse (33) showed that more than 50% of the variation in immunoglobulin concentration in calf serum 24 h postpartum was due to mass or amount of immunoglobulin consumed. Similarly, Bush et al. (12) attributed 68% of the variation in serum immunoglobulin concentrations in calves at 24 h to differences in amount of immunoglobulin consumed per unit of body weight.

To obtain a more detailed insight into the factors influencing immunoglobulin absorption, Kruse (33) performed step-wise multiple linear regression on a number of variables associated with the calf's first immunoglobulin meal. Variables included amount of colostrum fed, colostrum immunoglobulin concentration, amount of immunoglobulin fed, birth weight of the calf, and age at first feeding. Of these - in order of appearance in the regression equation - amount of immunoglobulin fed, age at first feeding, and birth weight significantly influenced the increase in serum immunoglobulin concentration by 24 h of age. Amount of immunoglobulin fed had a positive regression coefficient, while age at first feeding and birth weight had negative

coefficients.

Maternal influence has also been cited as a factor related to immunoglobulin absorption in the newborn calf. In a field study conducted by Selman et al. (66), calves left with their dams for more than 12 h had significantly higher serum immunoglobulin concentrations than those removed from their dams at birth and fed by hand. A controlled study by Ferris and Thomas (18) produced similar results. Nine Holstein calves were allowed to remain in box stalls with their dam for 36 h postpartum, while nine other Holstein calves were separated from their dams 15 minutes after birth and hand-fed their dam's colostrum by nipple bottle. Non-mothered calves were fed .91 kg at 1 h and 1.82 kg at 12, 24, and 36 h after birth. Calves left with their mother and allowed to nurse had higher average serum immunoglobulin concentrations than hand-fed calves throughout the first 2 wk of life.

In examining the above results, caution must be taken when interpreting the relationship between presence of the dam and the calf's serum immunoglobulin concentration. Since there was no control over the amount of colostrum nursed, differences in serum immunoglobulin concentrations could have been due to quantity consumed rather than "mothering". However, in a study by Selman et al. (65) the amount of colostrum fed was controlled. Twenty newborn Ayrshire calves were fed pooled colostrum at the rate of 55 ml per kg of birth weight. Ten of these calves were removed from their dams at 15 minutes postpartum and fed. The other ten calves were fed at 15 minutes postpartum,

muzzled, and allowed to remain with their dams for a minimum of 18 h. Mean serum immunoglobulin concentrations of mothered calves were significantly greater than those of non-mothered calves. Serial blood sampling indicated that the difference in immunoglobulin concentrations was due, in part, to an increased rate of absorption in the mothered calves. The reasons for this are as yet unknown, although similar observations in young rats suggest that it may be an adrenal cortex-mediated phenomenon (25).

Tennant et al. (73) suggested a breed difference in ability to absorb colostrum immunoglobulins. Changes in serum protein concentrations of Holstein and Jersey calves allowed to suckle their dam for a period of 48 to 72 h were examined. Mean concentration of γ -globulin in serum of 1-day-old Jersey calves was more than two times that of 1-day-old Holstein calves. Since no measurement of the amount of colostrum nursed or its immunoglobulin concentration could be made, it was uncertain whether the difference in serum γ -globulin concentrations observed in these calves was due to breed of the calf or to total amount of immunoglobulin consumed.

Studies involving feeding of equivalent amounts of pooled colostrum have also shown a breed difference in absorption of colostrum immunoglobulins. Bauwart et al. (4) showed that Holstein calves were more efficient than Ayrshire calves in absorbing total γ -globulin, whereas differences between breeds in absorption of individual classes of immunoglobulin were non-significant. Similarly, Selman et al. (65) found 48 h serum immunoglobulin concentrations to be higher for

Holstein-cross-Ayrshire calves than for purebred Ayrshires.

A relationship between season of the year and serum immunoglobulin concentration in neonatal calves was first observed by Gay et al. (21). They measured serum γ -globulin concentrations of neonatal calves purchased from markets in Scotland over a 1 year period. Results showed a marked seasonal variation in serum immunoglobulin concentrations, with highest concentrations during summer months. Lowest serum concentrations occurred during winter months and coincided with the time of highest calf mortality. A later study by Selman and co-workers (66) examined the serum immunoglobulin concentrations of 327 2 to 7-day-old dairy heifer calves raised on 47 dairy farms in Scotland. Again, the same tendency toward greater serum immunoglobulin concentrations in summer months and lower serum concentrations in winter months was observed.

In contrast to the above findings, Smith et al. (67) found little or no seasonal variation in serum immunoglobulin concentration of calves born in England and Wales. They suggested that the lower immunoglobulin concentrations found in winter-born calves in Scotland, and not in similar calves in England and Wales, were due to differences in cow-calf management in these areas. During the summer months, calves in all areas were usually born on pasture and nursed their dams. However, different management practices occurred in the winter months. Calves in England and Wales were usually born in yards or box-stalls and still had an opportunity to nurse colostrum. In contrast, winter-born calves in Scotland were commonly removed from their dam soon after

birth and fed a limited amount of colostrum after the next regular milking. Thus, delay in initial colostrum consumption, lack of "mothering", and possibly an inadequate amount of colostrum consumed, all could have resulted in lower serum immunoglobulin concentrations in winter-born calves in Scotland.

Subsequent work by Selman et al. (64) supported the suggestion that the observed seasonal variation in neonatal serum immunoglobulin concentration was related to management. When 30 calves born at different times of the year were cared for under a uniform system of management (calves were born in box-stalls and left with their dams for the first 2 days of life), serum immunoglobulin concentrations of summer and winter-born calves were very similar.

In studies by Martin et al. (45, 46) in California, monthly CMR was found to be related to season of the year, and more specifically to changes in meteorological factors of temperature, humidity, rainfall, and wind velocity. Peak CMR occurred in midsummer and midwinter, with mortality rates in winter months being 20% greater than those in summer. Of the meteorological factors, temperature exerted the greatest influence on monthly CMR. During the winter months, the most consistent predictor of increased CMR was an increase in the number of days environmental temperature was below freezing, whereas in the summer months, increased maximum and average temperatures were the most consistent predictors of high CMR.

The influence of high environmental temperature on immunoglobulin absorption and viability of the newborn calf was recently studied by

Stott et al. (72) in Arizona. Holstein calves (108) born during hot summer months were removed from their dams at birth, placed in one of three different housing environments (shade, cooled shade, or hutch), weighed, blood sampled, and given 2 liters of first-milking colostrum. Colostrum feeding was repeated at 12 h and again at 24 h after birth. Post-colostrum blood samples were obtained at 2 and 10 days of age.

Calves in the hutches were exposed to higher ambient temperatures than those in the other two housing environments, and responded by having higher serum corticosteroid concentrations and lower serum IgG1 concentrations at 2 and 10 days of age. Hutch-housed calves also experienced the highest CMR (25% vs. less than 10% in shade or cooled shade areas). These results indicate that calves housed in the hutches were under a greater physiological stress due to a hotter environment and responded with a higher secretion of adrenal corticosteroids during neonatal stages. As discussed earlier, elevated corticosteroids may result in lower concentrations of absorbed immunoglobulins by causing a decrease in the permeability of the small intestine (25).

MATERIALS AND METHODS

Experimental animals. Thirty-eight newborn Holstein calves were obtained from the South Dakota State University herd. Eighteen calves (T1) were born during cold winter months (December thru March), while 20 calves (T2) were born during hot summer months (May thru September).

Experimental procedure. All calves were managed in a similar manner in order to minimize the effect(s) of variation in management practices on immunoglobulin absorption in the newborn calf. Dams of experimental animals were placed in a maternity pen prior to calving. Newborn calves were moved to an adjacent pen after a few minutes of grooming by the dam and precolostrum blood samples (Day 0) were obtained by jugular venipuncture.

Cows remained in the original maternity pen for 12 to 18 h. Three to 3.5 kg of colostrum were obtained by hand-milking shortly after parturition. Once a sample of this colostrum was collected (and subsequently frozen), calves were fed 2.7 kg within 1 to 2 h after birth. Colostrum from the first regular milking (6 to 12 h after parturition) was fed (2.7 kg) at 12 and 24 h after birth.

Blood was collected from calves before feeding at 48 h of age (Day 2). Calves were then removed from the maternity area and placed in individual outdoor hutches for the duration (10 wk) of the experiment. Calves were fed 3.6 kg of whole milk once daily from Day 2 thru Wk 4. Whole milk in the amount of 1.8 kg was fed once daily during Wk 5 to precondition the calves for weaning at the beginning of Wk 6. Alfalfa-concentrate pellets and fresh water were fed ad lib.

Weekly blood samples were collected in the morning prior to milk feeding at 1, 2, 3, 5, and 10 wk of age. Daily feed intake (pellets) and weekly weight change were recorded.

Sample analysis. Blood was allowed to clot at room temperature. Serum was separated by centrifugation and frozen for later analysis. Serum samples were analyzed for total protein by the biuret method (24), γ -globulin by electrophoresis on cellulose acetate strips (23), and bovine immunoglobulins (IgA, IgG, and IgM) by single radial immunodiffusion (RID) (44) using commercially prepared plates (51). Specific immunoglobulin classes could not be measured at all sampling ages, since concentrations of certain immunoglobulins at certain ages were below the sensitivity range of the given test. IgA was analyzed in Day 2 and Wk 1 samples. IgG was analyzed for all sampling ages (Day 0, Day 2, Wk 1, 2, 3, 5, and 10). IgM was analyzed for all sampling ages except Day 0.

Colostrum samples were initially frozen, and later analyzed for total protein by Kjeldahl procedure (2). Colostral whey was precipitated by use of commercial cheese rennet (32) and was analyzed for bovine immunoglobulins (IgA, IgG, and IgM) as above. Whey and serum were diluted and RID tests repeated when initial results exceeded the value of the largest reference standard.

The amount of a specific immunoglobulin consumed by individual calves in their first colostrum meal was determined by multiplying the volume of colostral whey consumed by the concentration of specific immunoglobulin in the whey. Whey was assumed to occupy 83% of the

colostrum volume (48).

Estimation of the amount of a specific immunoglobulin absorbed by individual calves by Day 2 was based on a neonatal plasma volume of 7% of body weight (48). The amount of a specific immunoglobulin absorbed was found by multiplying the calculated plasma volume by the Day 2 specific immunoglobulin concentration in serum.

Meteorological information. Temperature and relative humidity data for Brookings, South Dakota for the periods of December 24, 1975 thru May 21, 1976, and May 27, 1976 thru November 19, 1976, were obtained from the Agricultural Engineering Department, South Dakota State University. Variables included average, maximum, and minimum temperature, temperature range, and average relative humidity for a given sampling day. In order to more accurately reflect the meteorological variables that might have influenced serum protein components in experimental calves, and since change(s) in these components in response to a given variable would likely appear over time, the recorded value for each meteorological variable on a given sampling day was an average of sampling day data and data for the day preceeding it. Information on meteorological variables on Day 0 was from sampling day data only.

A temperature humidity index (THI) (a means of joint evaluation of the effects of temperature and humidity) was determined for each sampling day. THI was calculated using the formula: $THI = t_d - .55(1 - RH)(t_d - 58)$ where t_d = ambient temperature in degrees Fahrenheit, and RH = ambient relative humidity (30). Average temperature and average relative humidity, determined as above, were used to

calculate THI.

Statistical analysis. Statistical analyses of birth weight, average daily feed intake, average daily gain, colostrum and serum components, and meteorological variables were by least-squares analysis of variance (71). Birth weight was analyzed as a 2(season) X 2(sex) factorial (Appendix Table 1). Average daily feed intake and average daily gain were analyzed as 2(season) X 7(sampling age) X 2(sex) factorials (Appendix Table 2). A 2(season) X 3(calving number) factorial was used to analyze colostrum components (Appendix Table 3). Analysis of serum components was by a 2(season) X 7(sampling age) X 3(calving number) X 2(sex) factorial (Appendix Table 4). Meteorological variables were analyzed as a 2(season) X 7(sampling age) factorial (Appendix Table 5). Step-wise forward multiple linear regression (71) was used (1) to determine influences of meteorological variables, if any, on immunoglobulin absorption and status in the young calf, and (2) to predict immunoglobulin absorption (quantity absorbed) and serum concentration by use of equations incorporating meteorological variables.

RESULTS AND DISCUSSION

Birth weight, average daily feed intake, and average daily gain

Season of the year did not influence birth weight of experimental animals ($P > .05$) (Table 1). Male calves were heavier (47.8 kg; $P < .05$) than female calves (43.9 kg) at birth.

Average daily intake of dry feed increased ($P < .05$) with age, but was not influenced by season of the year (Table 2). Calves consumed an average of .82 kg of alfalfa-concentrate pellets per day over the first 10 wk of life.

Average daily gain was similar for winter and summer-born calves for the first 5 wk of age. From 5 to 10 wk of age, average daily gain was greater (.84 kg) in winter-born calves than in calves born during the summer (.69 kg). However, average daily gain over all ages (Wk 1 thru Wk 10) was not different due to season ($P > .05$). Thus, calves in both seasons performed equally well by 10 wk of age. Weight gains were acceptable for Holstein calves during this stage of life (61).

Colostrum protein components

Season had no effect ($P > .05$) on total protein or IgA, IgG, IgM, or total immunoglobulin concentrations in colostrum. Although not different ($P > .05$), total protein and immunoglobulin concentrations (IgA, IgG, IgM, and total) were higher in colostrum produced in winter months than in colostrum produced in summer months (Table 3).

Trends in colostrum protein composition due to calving number can be observed (Table 4). Concentration of IgA in colostrum tended to increase with calving number of the dam, while first-lactation heifers

TABLE 1. Birth weight of winter and summer-born calves.

Variable	Sex	Season		\bar{X}
		Winter	Summer	
		----- kg -----		
Birth weight	Female	44.9	42.8	43.9 ^a
	Male	48.1	47.5	47.8 ^b
	\bar{X}	46.5	45.1	

^{a,b} Means with unlike superscripts are significantly different (P<.05).

TABLE 2. Feed intake (alfalfa-concentrate pellets) and weight gain in winter and summer-born calves.

Variable	Season	Age in days					\bar{X}
		(0-7)	(8-14)	(15-21)	(22-35)	(36-70)	
		----- kg/day -----					
ADFI ^a	W ^b	.04	.18	.24	.78	2.73	.80
	S ^c	.02	.15	.25	.92	2.85	.84
	\bar{X}	.03	.16	.24	.85	2.79	
ADG ^d	W	.22	.32	.36	.38	.84	.42
	S	.18	.29	.35	.49	.69	.40
	\bar{X}	.20	.30	.35	.44	.77	

^aAverage daily feed intake.

^bWinter.

^cSummer.

^dAverage daily gain.

TABLE 3. Colostrum protein components by season.

Colostrum component	Season	
	Winter	Summer
Total protein (%)	13.82	12.19
	----- mg/ml -----	
IgA	9.21	7.85
IgG	57.25	53.60
IgM	8.28	7.57
Total Ig	74.74	69.02

TABLE 4. Colostrum protein components by calving number.

Colostrum component	Calving number		
	1	2	3
Total protein (%)	13.89	12.50	12.62
	----- mg/ml -----		
IgA	7.30	8.58	9.71
IgG	60.18	51.90	54.19
IgM	8.97	7.99	6.82
Total Ig	76.45	68.47	70.73

produced colostrum highest in total protein, IgG, IgM, and total immunoglobulin concentrations. However, differences in colostrum protein components in relation to season were not significant ($P > .05$).

Kruse (32) studied yield of colostrum and immunoglobulin in cattle at the first milking after parturition. No effect of season of the year on colostrum immunoglobulin concentration was observed. Calving number did influence the total immunoglobulin concentration of colostrum produced by cows of the Red Danish breed, older cows having a higher immunoglobulin concentration in colostrum than younger cows and heifers. However, no differences in immunoglobulin concentration due to calving number were found in colostrum produced by Black and White Danish or Jersey cows.

In the present study, neither season nor calving number influenced specific or total colostrum immunoglobulin concentrations. Therefore, on the average, either summer or winter-born experimental calves from first, second, or later lactation dams should receive similar amounts of immunoglobulins in colostrum. Variation in specific and total immunoglobulin concentrations in colostrum are probably due to genetic differences in the cow's ability to produce and/or concentrate immunoglobulins in the mammary gland during the last 4 to 5 wk of the dry period.

Colostrum IgG concentrations were similar to those reported by other workers (43, 57). Colostrum IgM concentrations were markedly higher than reported values (7.9 mg/ml vs. 5.0 mg/ml), as were colostrum IgA concentrations (8.5 mg/ml vs. 4.4 to 6.9 mg/ml). Consumption

of colostrum rich in IgM and IgA should have increased the probability of calves absorbing adequate amounts of these immunoglobulins.

Calf serum protein components

Age of experimental animals influenced serum protein components (Table 5). Total serum protein, γ -globulin, and specific and total immunoglobulin concentrations increased ($P < .01$) to maximum values at Day 2, then declined with age. By Wk 2, total serum protein had decreased to mature concentrations (5). Serum IgG concentrations declined slowly throughout the experimental period, while IgM concentrations reached a minimum by Wk 3, then began to increase. Decline of specific immunoglobulin concentration in calf serum from Day 2 to Wk 1 was greatest for IgA, followed by IgM then IgG.

The marked increase in total protein and specific and total immunoglobulin concentrations in serum of calves at Day 2 is the result of absorption of colostrum proteins, especially immunoglobulins. Decline in the concentrations of serum protein components after Day 2 represents catabolism of absorbed colostrum immunoglobulins. Logan et al. (41) noted different rates of decline in specific immunoglobulin concentrations in serum of young calves. Based on these rates of decline, half-lives of IgA, IgG, and IgM were determined to be 2.8, 21.0, and 4.0 days, respectively (41).

Increases in γ -globulin and IgM from Wk 5 to Wk 10 reflect synthesis of immunoglobulins by the calf's own immune system. Other researchers working with colostrum-fed calves noted endogenous immunoglobulin synthesis by approximately 4 wk of age (41). Since very

TABLE 5. Concentration of blood serum proteins in calves by sampling age.

Serum component	Sampling age							Level of significance ^a
	Day 0	Day 2	Wk 1	Wk 2	Wk 3	Wk 5	Wk 10	
	----- g/100 ml -----							
Total protein	4.77	7.14	6.82	6.14	6.12	6.23	6.22	b
γ-globulin	.17	1.89	1.32	1.03	.95	.88	.97	b
	----- mg/ml -----							
IgA	...	1.81	.53	
IgG	.28	26.11	21.45	22.12	20.65	18.19	17.21	b
IgM	...	2.76	1.29	.80	.68	.71	1.00	b

^aSampling age.

^b(P<.01).

recent research has shown a half-life of 11.5 days for IgG1 (63), endogenous production of immunoglobulin by calves in this experiment may mask a greater actual rate of decline in colostrum-derived IgG than that observed.

Absorption of colostrum immunoglobulins the first 2 days of life provided calves with systemic protection against invading microorganisms during the neonatal period. No instances of agammaglobulinemia in calves (lack or very low concentrations of immunoglobulins in serum) were observed. Serum concentrations of γ -globulin and IgM were lowest in calves 3 to 5 wk of age. This suggests that calves may have been more susceptible to diarrhea and septicemia at this time than at an earlier age. By 10 wk of age concentrations of IgG in serum approached adult levels (17.9 ml/ml), while concentrations of IgM in serum were less than half the IgM concentration reported in serum of mature cattle (2.6 mg/ml) (9).

Neither season nor calving number influenced serum protein components ($P > .05$), with the exception of serum IgA. Interaction of season and calving number did affect γ -globulin, IgA, IgG, and IgM concentrations ($P < .01$) (Table 6). Serum γ -globulin and IgG concentrations of winter-born calves increased with increasing calving number of the dam, but concentrations of the same serum components decreased with increasing calving number in summer-born calves. Serum IgA concentration increased with increasing calving number in calves born in winter months, with little variation in serum IgA concentration occurring in relation to calving number in summer-born calves. Maximum

TABLE 6. Concentration of blood serum proteins in calves by season and calving number.

Serum component	n ^a	Winter				Summer				Significant interaction ^b
		Calving number			\bar{X}	Calving number			\bar{X}	
		1	2	3		1	2	3		
----- g/100 ml -----										
Total protein	7	6.17	6.09	6.50	6.25	6.18	6.20	6.11	6.16	
γ-globulin	7	.88	.99	1.13	1.00	1.11	1.08	.99	1.06	d
----- mg/ml -----										
IgA	2	.83	1.50	1.71	1.35	.98	.90	1.12	1.00	c
IgG	7	15.46	18.02	20.51	18.00	19.23	17.92	16.89	18.01	d
IgM	6	1.02	1.42	1.24	1.23	1.31	1.06	1.19	1.19	d

^aNumber of ages at which samples were collected. Refer to Table 5 for sampling ages.

^bInteraction of season and calving number.

^c(P<.05).

^d(P<.01).

serum IgM concentration occurred in calves from second lactation dams in the winter months, while minimum serum IgM concentration appeared in calves from second lactation dams in the summer season. Thus, response of this interaction varied with each serum protein component, no consistent pattern being observed. Lowest concentration of each class of immunoglobulin occurred in serum of winter-born calves from first lactation heifers. The reasons for this are not easily explained, since analysis of colostrum fed to experimental animals revealed no difference ($P > .05$) in concentrations of specific immunoglobulins due to season or calving number.

Meteorological variables

Meteorological variables considered to be of possible importance in influencing immunoglobulin absorption and status of young calves are listed in Table 7. All meteorological variables were different due to season of the year ($P < .01$) (Table 8). Variables T_{\max} , T_{fluc} , RH, and THI varied with sampling age ($P < .01$), while T_{avg} and T_{\min} remained relatively constant over all sampling times. Differences in meteorological variables due to sampling age could be expected, since sampling dates, designated by age, extended into spring months and fall months for winter-born and summer-born calves, respectively.

With the exception of T_{fluc} , all meteorological variables were different due to the interaction of season and sampling age ($P < .01$). The response of this interaction indicates that a calf sampled at a given age in winter experienced different meteorological conditions than a similarly aged calf sampled in summer. Values of meteorological

TABLE 7. Meteorological variables.

Abbreviation	Description
T_{avg}	Average daily temperature, F
T_{max}	Maximum daily temperature, F
T_{min}	Minimum daily temperature, F
T_{fluc}	Daily temperature fluctuation, F
RH	Average relative humidity, percent
THI	Temperature humidity index

TABLE 8. Meteorological variables by season and sampling age^a.

Meteorological variable	Season	Sampling age							\bar{X}
		Day 0	Day 2	Wk 1	Wk 2	Wk 3	Wk 5	Wk 10	
T _{avg}	W ^b	20.8	21.1	21.1	23.6	30.0	35.0	45.8	28.2 ^d
	S ^c	67.6	68.5	69.5	65.6	64.6	66.1	55.2	65.3
T _{max}	W	28.8	31.1	31.6	33.3	39.5	45.8	58.2	38.3 ^d
	S	80.7	83.6	84.2	79.8	79.1	82.4	69.6	79.9
T _{min}	W	12.5	11.4	10.6	13.8	20.6	24.2	33.6	18.1 ^d
	S	54.0	53.6	55.1	51.8	50.3	50.2	41.3	50.9
T _{fluc}	W	16.3	19.7	21.0	19.4	18.9	21.4	24.6	20.2 ^d
	S	27.0	30.1	29.6	27.7	28.8	32.7	28.6	29.2
RH	W	80.3	81.1	79.3	74.0	75.6	71.2	56.1	73.9 ^d
	S	52.1	50.0	54.2	59.2	53.9	54.4	55.9	54.2
THI	W	24.8	25.0	25.1	28.6	33.4	38.0	48.4	31.9 ^d
	S	65.1	65.6	66.6	63.8	62.6	64.0	55.1	63.3

^aRefer to table 7 for definition of meteorological variables.

^bWinter.

^cSummer.

^dSignificantly different from summer (P<.01).

variables T_{avg} , T_{max} , T_{min} , T_{fluc} , and THI were greater during the summer season, while RH values were greater during the winter season.

Influence of meteorological variables on colostrum immunoglobulin absorption

Multiple regression was used to determine the effect of several variables on the quantity of specific colostrum-derived immunoglobulins present in serum of calves at 2 days of age. Independent variables included meteorological variables (Table 7) and the quantity of specific immunoglobulin consumed in the first colostrum meal. Equations predicting the quantity of a specific immunoglobulin in calf serum at Day 2 are presented in Table 9. Equations 1 and 3 show no influence of meteorological variables on either the amount of IgA or the amount of IgM absorbed by the calves. However, quantities of both IgA and IgM in serum of calves were influenced by the amount of the analogous immunoglobulin consumed in colostrum.

The amount of IgG absorbed (Equation 2) was influenced by T_{min} , T_{fluc} , and RH, as well as by the amount of IgG consumed in colostrum. Seventy-one percent of the variation in the amount of IgG absorbed by the calves could be explained by these variables. However, the amount of IgG consumed had the greatest influence on amount of IgG absorbed, and it alone accounted for 61% of the variation.

Kruse (33) found that more than 50% of the variation in concentration of total immunoglobulin in serum of calves 24 h of age was due to the mass of colostrum immunoglobulin fed. In addition, work by Bush (12) showed 68% of the variation in immunoglobulin concentration

TABLE 9. Step-wise (forward) multiple linear regression equations for predicting the quantity of a specific immunoglobulin in serum of calves 2 days of age^a.

Equation number	Prediction equation ^a	R ^{2b}
1	(g serum IgA) = 1.923 + .171 (g colostrum IgA) ^c	.354
2	(g serum IgG) = 131.522 + .427 (g colostrum IgG) ^c - .176 (T _{min}) ^d - 1.588 (T _{fluc}) ^d - .959 (RH) ^d	.711
3	(g serum IgM) = 2.001 ± .344 (g colostrum IgM) ^c	.501

^aVariables are in order of entry into prediction equations.

^bCoefficient of determination.

^cAmount of specific immunoglobulin consumed in first feeding of colostrum.

^dMeteorological variables defined in Table 7.

in calf serum was due to differences in the amount of immunoglobulin consumed per unit of body weight. In the present study, the amount of IgG absorbed was influenced by T_{\min} , T_{fluc} , and RH, but their combined effect on this variable was small when compared to the influence of quantity of colostrum-derived IgG consumed.

Influence of meteorological variables on immunoglobulin status in young calves

Concentrations of specific immunoglobulins in serum of experimental calves were analyzed for the influence of quantity of analogous colostrum-derived immunoglobulin in serum at Day 2, age in days, and meteorological variables. Prediction equations for IgA, IgG, and IgM concentrations in serum of calves 2 to 7 days of age are presented in Table 10.

In calves up to 1 wk of age, neither IgG (Equation 5) nor IgM (Equation 6) concentrations in serum were influenced by meteorological variables ($P > .05$). Concentrations of IgG and IgM were affected ($P < .05$) by age and amount of analogous colostrum-derived immunoglobulin in serum at Day 2.

Immunoglobulin IgA concentration in serum of calves 2 to 7 days old (Equation 4) was influenced by the combined effect of age, amount of IgA absorbed, and relative humidity ($P < .05$), with 64% of the variation in IgA concentration in serum being explained by these variables. However, addition of RH to the prediction equation explained little of the variation in serum IgA concentration, since the other two variables in combination already accounted for 62% of the variation.

TABLE 10. Step-wise (forward) multiple linear regression equations for predicting specific immunoglobulin concentrations in serum of calves 2 to 7 days of age^a.

Equation number	Prediction equation ^a	R ^{2b}
4	(mg/ml serum IgA) = 1.242 - .256 (age) + .104 (g serum IgA) ^c - .008 (RH) ^d	.642
5	(mg/ml serum IgG) = 19.614 + .116 (g serum IgG) ^c - .926 (age)	.342
6	(mg/ml serum IgM) = 2.317 - .297 (age) + .135 (g serum IgM) ^c	.624

^aVariables are in order of entry into prediction equations.

^bCoefficient of determination.

^cAmount of colostrum - derived immunoglobulin in serum at Day 2.

^dMeteorological variable defined in Table 7.

Prediction equations for determining IgG and IgM concentrations in serum of 2 to 21 day old calves are presented in Table 11. Amount of absorbed immunoglobulin in serum at Day 2, age, T_{fluc} , T_{avg} , and THI influenced the concentration of IgG in serum of calves 2 to 21 days old ($P < .05$) (Equation 7) yet their combined effect explained only 23% of the variation in this serum component. Concentration of IgM in calf serum (Equation 8) varied with age and with amount of colostrum-derived IgM absorbed ($P < .05$), but was not affected by meteorological variables.

In examining Equations 6 and 8, age and the amount of colostral IgM in serum at Day 2 explained over 50% of the variation in IgM serum concentration of calves 2 to 21 days of age. For the same time period, no effect of meteorological variables on IgM serum concentration was observed.

Meteorological variables did not influence the concentration of IgG in calf serum during the first week of life. However, when analyzed over the first 21 days of life, meteorological variables T_{fluc} , T_{avg} , and THI did explain a small portion of the variation in IgG concentration in serum.

Tables 10 and 11 show that in Equations 4 thru 8, age and quantity of colostrum-derived immunoglobulin in serum at Day 2 are the major variables explaining differences in specific immunoglobulin concentrations in calf serum, since these are the first two variables to enter the regression equations. For serum components IgA and IgM, age in days is the most important variable influencing their

TABLE 11. Step-wise (forward) multiple linear regression equations for predicting specific immunoglobulin concentrations in serum of calves 2 to 21 days of age^a.

Equation number	Prediction equation ^a	R ^{2b}
7	$ \begin{aligned} (\text{mg/ml serum IgG}) = & 17.177 + .090 (\text{g serum IgG})^c - .301 (\text{age}) \\ & - .139 (T_{\text{fluc}})^d - .753 (T_{\text{avg}})^d + .858 (\text{THI})^d \end{aligned} $.232
8	$ (\text{mg/ml serum IgM}) = 1.941 - .103 (\text{age}) + .737 (\text{g serum (IgM)})^c $.537

^aVariables are in order of entry into prediction equations.

^bCoefficient of determination.

^cAmount of colostrum-derived immunoglobulin in serum at Day 2.

^dMeteorological variables defined in Table 7.

concentrations in calf serum. However, for IgG, the amount of IgG absorbed by Day 2 was the most important variable influencing its concentration in serum. These results reflect the shorter half-lives of IgA and IgM in relation to the half-life of IgG. Concentrations of IgA and IgM in serum decline more rapidly with time compared to the rate of decline in serum IgG concentration.

SUMMARY

A study was conducted to determine the effects of season of the year, temperature, and relative humidity on immunoglobulin absorption and status in the young calf. Experimental animals were divided into two groups: those born in winter months (December thru March) and those born in summer months (May thru September).

Birth weights of experimental calves were not different ($P > .05$) due to season, but male calves were heavier ($P < .05$) than female calves at birth. Calves grew well and dry feed intake and average daily gain were similar for calves in both seasons. Health of calves was excellent with only a few cases of mild diarrhea being observed. This suggests that hand feeding of 2.7 kg of colostrum shortly after birth provided calves with an adequate amount of passive immunity for the neonatal period.

The immunoglobulin composition of colostrum (IgA, IgG, IgM, or total immunoglobulin concentration) was not influenced ($P > .05$) by either season or calving number of the dam. Therefore, whether born in winter or summer to first, second, or later lactation cows, experimental calves fed equal amounts of their dam's colostrum should consume similar amounts of colostral immunoglobulin.

Calf serum protein components were not different ($P > .05$) due to sex of the calf. Therefore, discussion of all other factors was pooled over sex. Concentrations of blood serum proteins in calves were different ($P < .01$) due to sampling age. Immunoglobulin (IgA, IgG, and IgM) concentrations increased from negligible levels at birth

to maximum levels at 2 days of age due to absorption of immunoglobulins in colostrum. Concentrations of these immunoglobulins then began to decrease with time due to catabolism. The rate of decline of immunoglobulin in serum of the calves (from Day 2 to Wk 1) was greatest for IgA, followed by IgM then IgG. Between 5 and 10 wk of age, increased concentrations of γ -globulin and IgM reflected endogenous synthesis of immunoglobulins.

Calf serum protein components were not different ($P > .05$) due to season or calving number of the dam (with the exception of IgA). However, there was a significant interaction of season and calving number ($P < .01$) for γ -globulin, IgA, IgG, and IgM concentrations in serum (differences in IgA due to season and calving number are contained in this interaction). Response of the interaction, season by calving number, varied with each protein component, no consistent pattern being observed. The reasons for this interaction are not easily explained, since colostrum composition was not different ($P > .05$) due to season or calving number. Observed differences in calf serum protein components may actually reflect the individual calf's ability to absorb immunoglobulins from colostrum and/or the influence of physiological stress at or shortly after birth on immunoglobulin absorption.

Meteorological variables were different ($P < .01$) due to season. Variables T_{\max} , T_{fluc} , RH, and THI varied ($P < .01$) with sampling age. With the exception of T_{fluc} , all meteorological variables were different ($P < .01$) for the interaction of season and sampling age. Therefore, for a given sampling age, calves born in winter months experienced different

meteorological conditions than a calf born in summer months. Differences in meteorological variables due to season ($P < .01$) should have made possible the detection of differences in calf serum protein components due to season, if any existed.

Development of prediction equations by step-wise multiple regression analysis revealed little influence of temperature or relative humidity on the quantity of specific immunoglobulin in serum of calves 2 days of age. In each prediction equation, the quantity of specific immunoglobulin consumed in the first colostrum meal was the most important variable influencing the amount of a specific immunoglobulin in serum at Day 2.

Prediction equations for determining the concentration of a specific immunoglobulin in serum of calves 2 to 21 days of age were also developed. Age of the calf and amount of colostrum-derived immunoglobulin in serum at day 2 were the most important variables in explaining variation in concentrations of specific immunoglobulins in serum. Although certain meteorological variables did enter some of these regression equations, their contribution in explaining variation in serum immunoglobulin concentrations was small.

Results of this experiment indicate that when newborn calves were cared for under standardized management - hand-feeding of a large volume of colostrum shortly after birth - immunoglobulin absorption and status were similar in winter and summer-born calves. Even when season was further broken down into the effects of temperature and relative humidity, little of the variation in immunoglobulin absorption

and status in young calves was explained by these variables.

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APPENDIX

APPENDIX TABLE 1. Least-squares analysis of variance of birth weight.

Source	Degrees of freedom	Birth weight mean squares
Total	37	
Season (A)	1	69.80
Sex (D)	1	607.08*
A x D	1	23.64
Error	34	146.80

*F-test significant ($P < .05$).

APPENDIX TABLE 2. Least-squares analysis of variance of average daily feed intake and average daily gain.

Source	Degrees of freedom	Variables	
		Average daily feed intake	Average daily gain
----- mean squares -----			
Total	173		
Season (A)	1	.30	.09
Sampling age (B)	4	180.31**	6.36**
Sex (C)	1	.00	.48
A x B	4	.27	.38
A x C	1	.36	.57
B x C	4	.17	.06
Error	158	.36	.32

** F-test significant (P<.01)

APPENDIX TABLE 3. Least-squares analysis of variance of colostrum components.

Source	Degrees of freedom	Colostrum components				
		Total protein	IgA	IgG	IgM	Total Ig
		----- mean squares -----				
Total	34					
Season (A)	1	22.00	15.39	110.30	4.24	271.77
Calving no. (C)	2	7.37	18.66	222.62	14.51	205.57
A x C	2	15.49	2.58	318.83	31.12	592.15
Error	29	6.86	14.85	346.07	10.60	478.90

APPENDIX TABLE 4. Least-squares analysis of variance of serum components.^a

Source	Degrees of freedom	Serum component (SC)			Degrees of freedom	(SC)	Degrees of freedom	(SC)
		Total protein	γ -globulin	IgG		IgA		IgM
		----- mean squares (ms) -----					-(ms)-	
Total	263				74		225	
Season (A)	1	.40	.19	.01	1	1.69*	1	.07
Sampling age (B)	6	15.83**	7.62**	1990.00**	1	23.42**	5	18.06**
Calving no. (C)	2	.53	.10	41.08	2	1.71**	2	.10
Sex of calf (D)	1	.00	.16	.39	1	.02	1	.04
A x B	6	.28	.04	41.58	1	.71	5	.17
A x C	2	1.34	.81**	306.47**	2	1.16*	2	1.71**
B x C	12	.57	.05	11.33	2	1.28*	10	.09
A x B x C	12	.32	.12	29.69	2	.85*	10	.90**
A x D	1	.30	.41	103.09	1	.05	1	1.33
B x D	6	.21	.05	6.61	1	.03	5	.09
A x B x D	6	.10	.09	8.83	1	.07	5	.30
Error	208	.44	.13	36.84	59	.26	178	.35

^aInteractions C x D, A x C x D, and B x C x D not included due to incomplete cells.

*F-test significant (P<.05).

**F-test significant (P<.01).

APPENDIX TABLE 5. Least-squares analysis of variance of meteorological variables.

Source	Degrees of freedom	Meteorological variables					
		T _{avg}	T _{max}	T _{min}	T _{fluc}	RH	THI
Total	263						
Season (A)	1	90522**	113674**	70530**	5331**	25549**	64828**
Sampling age (B)	6	286	490**	177	132**	540**	289**
A x B	6	1789**	2032**	1571**	56	1008**	1424**
Error	250	143	158	148	38	97	97

** F-test significant ($P < .01$).