# The Effect of Different Levels of Protein Degradability in Starter- and Finishing Diets on Veal Calf Performance

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# DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

# Abstract

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| Title | : | The effect of different levels of protein degradability in starter- and finishing diets on veal calf performance. |
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Veal production is a specialised form of calf rearing in which calves were traditionally raised on all-liquid diets. The early weaning of calves onto concentrated diets provides an economically viable alternative rearing method with comparable calf performance. The emphasis in meat production has shifted to the production of lean meat, therefore the deposition of protein instead of fat has become a priority. The optimum level of dietary crude protein for growing calves is well established. Very little, however, is known about the influence of protein degradability in the diet of young ruminants. Recommendations by the NRC are derived from data obtained using lactating dairy cows. The aim was to obtain data on which recommendations for the level of degradable protein in starter and finisher diets for calves could be based.

Two experiments were conducted to examine the effect of different levels of dietary crude protein degradability in starter and finisher calf diets on veal calf performance. In both experiments Holstein bull calves were 3 - 10 days of age at the onset, weaned at 4 weeks of age and slaughtered at 20 weeks of age for veal. In Experiment 1 calves were randomly assigned to one of three treatments: low (LD), medium (MD) and high (HD) rumen degradable protein. Calves received a starter diet up to 11 weeks of age and finisher diets from week 12 - 20. In Experiment 2 calves received a starter diet either high or low in rumen degradable protein up to 10 weeks of age. In the finishing period (week 11 - 20) both the low and high groups were again divided into a low and high group, resulting effectively in 4 treatments, viz. LL, LH, HL and HH. The diets in both experiments were formulated to be iso-nitrogenous and iso-caloric, differing only in rumen undegradable protein content within periods and respective experiments.

Body weight gain, feed intake and feed conversion efficiency data for the preweaning, starter, finishing and total experimental period was compared between treatments. There were no significant differences for feed intake, body weight gain or feed efficiency in the starter period of both experiments between treatments. In the finishing period of Experiment 1 the average daily gain for the LD treatment was significantly higher than for the HD treatment, with the MD treatment having an intermediate value. The feed conversion ratio (FCR) for the LD treatment was also significantly better than for the other two treatments. In Experiment 2 the FCR tended (P = 0.0984) to differ between treatments in the finishing period. Calves from the LL and HL treatments had a more favourable FCR than calves from the LH treatment. The HH treatment had an intermediate FCR. According to these results crude protein degradability appears to have an effect on the FCR in the finishing period.

The lack of response to higher levels of undegradable dietary protein in calves younger than 10 weeks may be due to underdeveloped rumen functions and it seems possible for high degradable protein to escape degradation to a higher extent than at a later age. In a third experiment, Holstein bull calves and Holstein cows were used to determine and compare the dry matter and crude protein degradability of the four calf diets used in Experiment 2. Rumen VFA concentrations, pH level and $NH_3$-N concentrations were measured for the cannulated Holstein calves to evaluate the level of rumen metabolic maturity of growing calves. Five Holstein bull calves were ruminally cannulated at 6 weeks of age. Dry matter and crude protein degradability were determined once weekly from week 8 – 20 by means of 24 h *in sacco* incubations. Three ruminally cannulated Holstein cows were used to determine the comparable values for mature ruminants.

Dry matter and crude protein degradability differed significantly between the low and high degradable diets for both calves and cows. Dry matter and crude protein degradability in calves increased up to 11 and 12 weeks of age respectively, and then appeared to remain constant to week 20. Dry matter and crude protein degradability values of the starter diets were lower for the calves than for the cows, but values were similar for the finisher diets. Rumen VFA concentrations, pH level and $NH_3$-N concentration showed some fluctuation between weeks, but were similar to literature values for mature animals.

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# Samevatting

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| Titel | : | Die invloed van verskillende vlakke van proteïendegradeer-baarheid in aanvangs- en afrondingsdiëte op kalfprestasie in 'n kalfsvleisproduksiestelsel. |
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Kalfsvleisproduksie is 'n gespesialiseerde grootmaakstelsel wat tradisioneel alleenlik op vloeistofdiëte gebaseer was. 'n Stelsel waar kalwers vroeg gespeen word en 'n volledige aanvangs- en afrondingsrantsoen ontvang, bied 'n alternatiewe metode wat ekonomies lewensvatbaar is en vergelykbare kalfprestasie tot gevolg het. Die klem in vleisproduksie het verskuif na die produksie van maervleis. Die neerlegging van proteïen in plaas van vet het dus 'n prioriteit geword. Die optimale vlak van dieetproteïen vir groeiende kalwers is deeglik nagevors. Baie min is egter bekend oor die invloed van proteïendegradeerbaarheid in die dieet van jong herkouende diere. Aanbevelings deur die NRC is afkomstig van data verkry van studies met melkproduserende koeie. Die doel was om data te bekom waarop aanbevelings vir die vlak van degradeerbare proteïen in aanvangs- en afrondingsdiëte vir kalwers gegrond kan word.

Twee eksperimente is uitgevoer om die invloed van verskillende vlakke van proteïendegradeerbaarheid in aanvangs- en afrondingsdiëte op kalfprestasie in 'n kalfsvleisproduksiestelsel te ondersoek. Holstein bulkalwers was 3 - 10 dae oud met die aanvang van beide eksperimente, is gespeen op 4 weke ouderdom en op 20 weke ouderdom vir kalfsvleis geslag. In Eksperiment 1 is kalwers ewekansig aan een van drie behandelings toegewys: lae (LD), medium (MD) en hoë (HD) rumen degradeerbare proteïen. Kalwers het tot op 11 weke ouderdom aanvangsdiëte ontvang, terwyl afrondingsdiëte vanaf 12 - 20 weke ouderdom aangebied is. In Eksperiment 2 het

kalwers tot op 10 weke ouderdom 'n dieet wat óf hoog óf laag in rumen degradeerbare proteïen was, ontvang. In die afrondingsperiode (week 11 – 20) is die lae en hoë groepe elk vervolgens in 'n lae en hoë groep verdeel wat effektief tot 4 behandelings gelei het, nl. LL, LH, HL en HH. Die diëte in albei eksperimente was geformuleer om iso-nitrogenies en iso-kalories te wees. Slegs die rumen degradeerbare proteïeninhoud het tussen die onderskeie diëte binne 'n bepaalde periode en eksperiment verskil.

Gewigstoename, voerinname en voeromsettingsdoeltreffendheid vir die voorspeense-, aanvangs-, afrondings- en totale eksperimentele periode is tussen behandelings vergelyk. In beide eksperimente is geen betekenisvolle verskille gedurende die aanvangsperiode waargeneem t.o.v. voerinname, massatoename en voeromsettings-doeltreffendheid (VOD) nie. In die afrondingsperiode van Eksperiment 1 was die gemiddelde daaglikse massatoename van die LD behandeling betekenisvol hoër as dié van die HD behandeling, terwyl die MD behandeling 'n intermediêre waarde gehad het. Die VOD vir die LD behandeling was ook betekenisvol beter as vir die ander twee behandelings. Die VOD in die afrondingsperiode van Eksperiment 2 het geneig (P = 0.0984) om te verskil tussen behandelings en kalwers van die LL en HL behandelings het 'n meer gunstige VOD as kalwers van die LH behandeling gehad. Die HH behandeling het 'n intermediêre VOD gehad. Volgens die resultate van hierdie eksperimente het proteïendegradeerbaarheid in kalfrantsoene waarskynlik 'n invloed op VOD in die afrondingsperiode.

Die gebrek aan respons as gevolg van hoër insluitingsvlakke van nie-degradeerbare proteïen in die rantsoen by kalwers jonger as 10 weke kan moontlik toegeskryf word aan onderontwikkelde rumenfunksies. Dit blyk moontlik te wees dat die hoë degradeerbare proteïenfraksie by jonger kalwers rumendegradering in 'n hoër mate as op 'n latere ouderdom vrygespring het.

In 'n derde eksperiment is Holstein bulkalwers en Holstein koeie gebruik om die droëmateriaal- en proteïendegradeerbaarheid van die vier diëte wat in Eksperiment 2 gebruik is, te bepaal en te vergelyk. Rumen VVS-konsentrasies, pH-vlak en $NH_3$-N-konsentrasies is vir die kalwers gemeet om die vlak van metaboliese rumen volwassenheid van groeiende kalwers te evalueer. Vyf Holstein kalwers is op 6 weke

ouderdom ruminaal gekannuleer. Droëmateriaal- en proteïen-degradeerbaarheid is een maal per week vanaf week 8 – 20 deur middel van 24 h *in sacco* inkubasies bepaal. Drie rumen-gekannuleerde Holstein koeie is gebruik om die vergelykbare waardes van volwasse herkouers te bepaal.

Droëmateriaal- en proteïendegradeerbaarheid het betekenisvol tussen die lae en hoë degradeerbare diëte vir beide die kalwers en koeie verskil. Droëmateriaal- en proteïendegradeerbaarheid by die kalwers het tot op 11 en 12 weke ouderdom, onderskeidelik, verhoog en daarna tot week 20 relatief konstant gebly. Die droëmateriaal- en proteïendegradeerbaarheidswaardes van die aanvangsdiëte was laer vir die kalwers as vir die koeie, maar die waardes vir die afrondingsdiëte was eenders. Rumen VVS-konsentrasies, pH-vlak en $NH_3$-N-konsentrasies het 'n mate van fluktuasie tussen weke getoon, maar was soortgelyk aan literatuurwaardes vir volwasse diere.

# *To my Mother and Father*

*Thank you for teaching me the virtue of perseverance*

*and for always believing in me*

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To be successful, the first thing to do is fall in love with your work.
Sister Mary Lauretta

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# CHAPTER 1

# GENERAL INTRODUCTION

## 1.    Veal production

Veal production is an intensive and specialised form of calf rearing. Calves intended for "white veal" production are reared solely on liquid diets (milk or milk replacers) until at least 12 weeks of age (Roy, 1980), but sometimes up to 5 – 6 months of age (Moran, 1990).  The high cost associated with milk feeding of calves (Gorrill, 1975) resulted in the formulation of milk replacers, though calves normally do better on whole milk than milk replacers (Cruywagen, 1993).  A marked change in veal calf production in Eastern Canada have seen a renewed interest in the development of production systems based on the early *ad lib*. feeding of grain rations due to the high cost of milk and milk replacers (Latrille *et al.*, 1983).

Nutrients fed as a liquid are generally more efficiently utilised by the calf than the same nutrients fed dry (Beauchemin *et al.*, 1990).  This difference can be attributed to a greater loss of nutrients by rumen fermentation compared to digestion in the abomasum.   Consumption of solid feed and rumen development has several advantages that offset the less efficient use of ingested nutrients.  These include less risk of some bacterial infections, metabolic disorders, the use of cheaper feed ingredients and lower labour requirements (Gorrill, 1975).   About 1 kg weight gain/day can be obtained by either a liquid or dry feed regime.   Under these conditions the dry matter of liquid diets should not be more than about twice the cost of dry foods to be competitive (Gorrill, 1975; Roy, 1980).

Cruywagen & Horn (1985a) reported that calves can be reared successfully until weaning age on mixtures of soybean flour, whey powder and surplus colostrum, with a saving in preweaning feeding costs of 67 – 70 % when compared to whole milk.  In a subsequent study Friesian bull calves were reared successfully for veal production by weaning them at 30 days with the above mentioned regime, followed by a fattening period of 4 months on a high concentrate diet until slaughtering at 20 weeks of age (Cruywagen & Horn, 1985b).

Several authors have reported that calves utilise processed grain efficiently with performances comparable to that of calves fed all-milk diets (Bouchard *et al.*, 1980; Latrille *et al.*, 1983). Beauchemin *et al.* (1990) reported a trend towards a higher average daily gain (ADG) for milk-fed calves compared to grain-fed calves at a carcass weight of 88 kg. This advantage was lost when calves were slaughtered at a heavier carcass weight of 108 kg. Johnson *et al.* (1992) also compared the performance of milk- and grain-fed veal calves and found growth rates to be essentially equal. Calves receiving the milk diet had slightly higher gains during the first 28 days, while calves receiving grain diets grew faster in the period after 28 days until calves were slaughtered at 140 kg body weight. Veal calves should gain 1.0 – 1.4 kg live weight/day (Gorrill, 1975; Ralston, 1975). Live weight gains of 0.5 kg/day (Cummins *et al.*, 1982) up to 1.2 kg/day (Lapierre *et al.*, 1990) have been reported for calves receiving concentrate diets.

In a series of experiments Bergström & Dijkstra (1991) fattened calves with a reduced amount of milk replacer supplemented with maize silage/concentrate mix. This resulted in a higher growth rate and lower feed cost but the meat colour was darker than in calves fed only milk replacer. Attempts to influence the meat colour of grain-fed calves by returning to feeding only milk for 8 weeks prior to slaughter had no effect. White veal is light in colour, has low levels of fat and the meat is generally firm in texture and quite tender (Moran, 1990). Several studies reported darker meat for grain-fed calves as compared to milk-fed calves (Brekke & Wellington, 1969; Beauchemin *et al.*, 1990). Grain-fed calves are often slaughtered at a later age and it has been documented that increased slaughter age lead to darker meat (St.-Laurent & Brisson, 1967). The relationship between colour and palatability is reported to be poor (Agboola *et al.*, 1990; Johnson *et al.*, 1992). Meat produced from veal calves receiving concentrates and hay is known as pink veal, because of the darker colour.

Veal calves should be finished so that there is a thin, even layer of fat covering the rump, back and shoulders; the kidneys must be well covered with fat; and the inside of the ribs should also show indications of fat. The fat should be white in colour, the flesh firm and of pale-pinkish colour described by the meat trade as 'white' (Roy, 1980). Calves fed a whole milk diet had slightly more subcutaneous and internal fat at the same carcass weight and had lighter, more youthful lean colour, and higher

levels of flank fat streaking. Loin chops from calves fed a whole milk diet had lower Warner-Bratzler shear values, while other palatability traits were not influenced by feeding management nor related to veal colour (Johnson *et al.*, 1992).

Several studies demonstrated that acceptable veal can be produced with high-energy dry rations (Gardner & Wallentine, 1972; Bouchard *et al.* 1980; Latrille *et al.*, 1983; Johnson *et al.*, 1992). The practical applications of these findings may be limited, because of the presumption that an inferior product would be produced (Gardner & Wallentine, 1972) and the degree of consumer acceptance of darker meat (Beauchemin *et al.*, 1990). Lower quality grade scores for concentrate-fed veal calves did not relate to ultimate meat palatability (Bray *et al.*, 1959; Beauchemin *et al.*, 1990). The meat is generally similar in terms of tenderness and juiciness to white veal and some consumers even consider pink veal to have better meat flavour and palatability (Roy, 1980; Moran, 1990; Bergström & Dijkstra, 1991).

Common veal production practices have been criticised and are under close scrutiny by some animal rights groups (Johnson *et al.*, 1992). Rearing calves on concentrate diets also offer potential solutions to welfare concerns regarding traditional veal production systems (Beauchemin *et al.*, 1990).

## 2.    Rumen development

The anatomical, physiological and metabolic changes taking place in the digestive system of the young ruminant are characterised by a transition from a monogastric to a ruminant-type digestion. This transition covers the period from birth to 3 – 4 months of age in the calf. Changes which occur from that time on are usually proportional (Ralston, 1975).

Although Young *et al.* (1965) showed that young milk-fed calves do possess the metabolic capacity for utilisation of rumen fermentation end products and can absorb volatile fatty acids (VFA's) from the small intestine, development of mature ruminal function appears to depend on dry feed intake. Changes in the size of the reticulo-rumen (Tamate *et al.*, 1962), metabolic activity of rumen mucosa (Sutton *et al.*, 1963b), the concentration of ruminal VFA's (Anderson *et al.*, 1987a; Quigley *et al.*,

1985), speciation of rumen microflora (Bryant *et al.*, 1958; Lengemann & Allen, 1959), and the proportion of bacterial nitrogen (N) in abomasal N (Quigley *et al.*, 1985) depend on initiation of dry feed intake. If offered solid feed, the rumen of the calf will develop adult characteristics by 3 months of age (Otterby & Linn, 1981). Rumination in calves may occur as early as 5 days of age when given limited quantities of a liquid diet (Roy, 1980), but the majority of calves do so by 6 – 8 weeks if offered solid feed (Conrad *et al.*, 1958).

## 2.1    Anatomical development

### 2.1.1  Size and volume

At birth the four-compartment stomach of the calf is very different from the stomach of the mature cow (Morrill, 1991). Figure 1 illustrates the difference between the four-part stomach of the calf (A) at birth and that of the mature ruminant (B) (Ørskov, 1992). In the young suckling calf the rumen and reticulum are relatively undeveloped and small in comparison with the abomasum. In the preweaning period the abomasum is functionally more important because milk, the primary diet of the young calf, goes directly to the abomasum when the oesophageal groove is closed. The abomasum gradually regresses in relative size, although not in absolute size. Godfrey (1961a) indicated that the development of the abomasum, expressed as a percentage of live weight, was completed at the age of 5 weeks. The omasum develops slowly in relative size up to 36 – 38 weeks in cattle, taking longer to reach relative mature size than the reticulum or rumen (Church, 1975).

The rumen of the young calf lack the size, absorptive ability and microbial population found in the rumen of the mature animal (Morrill, 1991), but the special pattern of motility is already established (Roy, 1980; Ørskov, 1992). Although the greatest rate of development of the reticulo-rumen occur between 2 and 6 weeks of age, calves have not reach mature rumen size (expressed as a percentage of live weight) by 17 weeks of age (Godfrey *et al.*, 1961a). Blaxter *et al.* (1952) indicated that it can occur as late as 6 – 9 months of age, which may be dependent on the diet the calves receive (Church, 1975). Tamate *et al.* (1962) reported rapid development of the reticulo-rumen as early as 4 weeks of age in calves receiving a diet of milk, concentrate and hay.

A

Oesophagus

Rumen
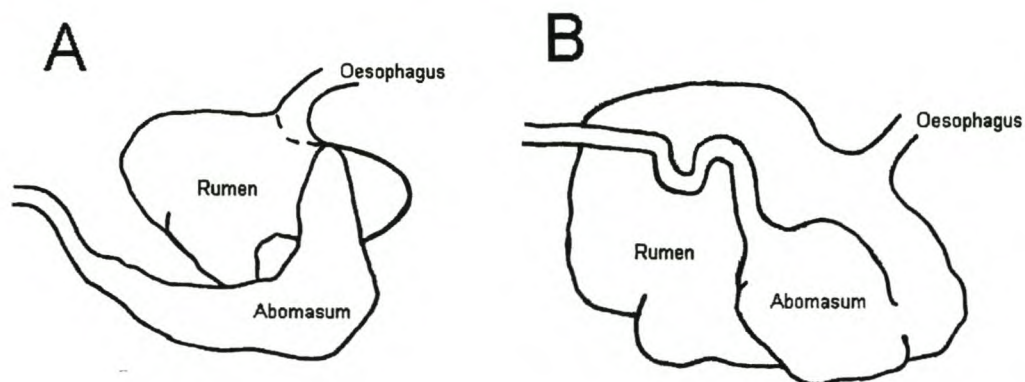
Abomasum

B

Oesophagus

Rumen

Abomasum

FIGURE 1.   The four-part stomach of a young calf (A) and a mature cow (B) showing the difference in the proportions of the rumen and abomasum (Ørskov, 1992).

In the adult ruminant the abomasum constitutes only 8 % of the total capacity whereas the volume of the reticulo-rumen represents 80 % of the total stomach capacity (Roy, 1980).  Calves at the age of 12 weeks, that had been weaned at 5 weeks of age onto a combination of concentrates and *ad lib.* hay diets, had a reticulo-rumen representing 84 – 87 % and an abomasum representing 11 – 13 % of the volume of their stomachs (Stobo *et al.*, 1966a).  In another experiment with 10 – 13-week-old calves on various types of roughage diets, Hodgson (1973) found 79 – 92 % of the wet digesta in the reticulo-rumen, 3.4 – 11.3 % in the omasum, and 1.9 – 10.6 % in the abomasum.

Rumen fluid volume increases with age and is significantly higher by 13 weeks of age compared to 7 and 9 weeks of age.  Rumen volume, expressed as a percentage of body weight, increase from 10.5 % at 7 weeks of age to 16.9 % at 13 weeks of age (Vazques-Anon *et al.*, 1993a).

## 2.1.2  Papillary development

Age alone has little effect on ruminal papillary development (Stobo *et al.*, 1966a; Tamate *et al.*, 1962), but is closely related to rumen function (Ralston, 1975).  The papillary development in the rumen of the newborn is quite infantile (1mm in height) and on an all-liquid diet minimal growth takes place (Tamate *et al.*, 1962).  In one study, regression in size and number of rumen papillae were demonstrated when

animals were changed back from a grain/hay diet to a milk diet (Harrison *et al.*, 1960). The addition of dry matter to the diet results in noticeable growth at 4 weeks in calves (Ralston, 1975) and complete development is reached at 7 – 8 weeks of age (Tamate *et al.*, 1962).

The inclusion of dry feed in the diet of a young ruminant, besides increasing the capacity of the reticulo-rumen, also increases the weight of tissue (Stobo *et al.*, 1966a). Only a relatively small increase occurs in the thickness of the muscular wall, but there is a considerable increase in thickness of the mucosa, due to the development of rumen papillae (Roy, 1980). The papillae increase the surface area of the rumen walls and thus the area through which nutrients can be absorbed (Elliot & O'Hagan, 1998). The fact that papillae development is stimulated by the end products of rumen fermentation, and not merely by the fibrous nature of the feed, is very well documented (Sutton *et al.*, 1963a; Stobo *et al.*, 1966a; Otterby & Linn, 1981; Ørskov, 1992). The end products of readily fermentable carbohydrates stimulate papillary growth in the order butyrate > propionate > acetate (Tamate *et al.*, 1962). Since the development of rumen papillae are dependent on VFA production, it would mean that diets which allow for a high rate of fermentation together with a rapid removal of digestible feed particles are those which allow for the greatest rate of development (Ørskov, 1992).

Concentrates that contains a high amount of fermentable carbohydrates stimulates papillary development in early life to a great degree, but physical stimulation by roughage also play an important role in the normal development of rumen papillae (Flatt *et al.*, 1958; Sander *et al.*, 1959). Feed texture (particle size) has been reported to affect papillae development (Hinders & Owen, 1965). Papillae length decreases linearly as particle size (or abrasion value) increases (Greenwood et al., 1997). Calves fed the fine diet had longer papillae than did calves fed the intermediate diet, which in turn had longer papillae than did those fed the coarse diet. Papillae width was not different among calves fed the three diets. As ruminal contractions mix digesta, fine particles adhere to the ruminal wall between papillae and larger particles slide across the surface and cause abrasion (Greenwood *et al.*, 1997). Greenwood *et al.* (1997) reported an increase in the degree of branching per papillae as the percentage of the epithelium composed of keratin increased.

Excessive papillary development may lead to rumen parakeratosis (Garrett *et al.*, 1961; Gilliland *et al.*, 1962; Bull *et al.*, 1965). In this condition there is an increase in the length and width of the papillae, clumping of the papillae with rumen contents and encrusting of the tips of the papillae with dark keratinized material. The condition occurs with high-concentrate diets, or mixed diets in which the hay has been pelleted, rather than wafered or given in long form. The low rumen pH on such diets, together with an increase in production of propionic acid relative to acetic acid and lack of muscle tone, have all been associated with the condition of parakeratosis (Roy, 1980). Beharka *et al.* (1998) on the other hand reported minor parakeratosis in papillae and no higher amount of incidences were associated with the finer diet. Coarse feed particles, which tend to float and form a hay mat, provide more physical stimulation in the dorsal sac than in the cranial or ventral sacs (Evans *et al.*, 1973).

## 2.2    Physiological development

### 2.2.1  Rumen microbial population

Amino acids that are available for absorption from the small intestine of the mature ruminant are derived from feed protein escaping ruminal degradation, microbial protein synthesised in the reticulo-rumen and endogenous protein in the form of abomasal secretions and desquamated epithelial cells. The former two is dependent on size and activity of microbial populations in the rumen (Quigley *et al.*, 1985).

The reticulo-rumen provides a continuous culture system for anaerobic bacteria, protozoa and fungi (McDonald *et al.*, 1988). Bacteria become established in the rumen of young animals at an early age whether they are isolated, kept with other young animals, or left with their dam (Church, 1975). In contrast to the situation with rumen bacteria, establishment of rumen ciliate populations in the young ruminant requires contact with older animals with a protozoan population (Bryant *et al.*, 1958; Borhami *et al.*, 1967; Anderson *et al.*, 1987b; Beharka *et al.*, 1998).

The abomasum of the very young calf supports a large and diverse population of lactobacilli and it is possible that a back flow of milk from the abomasum to the rumen after feeding may help to inoculate the rumen (Mann *et al.*, 1954). A large population of lactobacilli develops within a week of age. The numbers tend to

decline after 3 weeks of age, reaching adult levels by 3 – 4 months of age (Bryant *et al.*, 1958; Lengemann & Allen, 1959). The typical rumen amylolytic streptococci of the adult animal do not become properly established until the rumen pH is stabilised near neutrality, although in the very young calf a different amylolytic streptococcus is found which is more tolerant of a lower pH value. Cellulolytic bacteria are sensitive to a low pH in the rumen (Russel & Dombrowski, 1990). Iso-butyrate and iso-valerate are growth factors for cellulolytic bacteria in the rumen (Gorosito *et al.*, 1985). The decline of these acids may indicate increased cellulolytic activity as calves age (Anderson *et al.*, 1987b).

The protozoan population can also become established only once the pH is stabilised near neutrality at about 8 weeks of age (Mann *et al.*, 1954), because protozoa are especially sensitive at a pH lower than 5.5 (Mackie *et al.*, 1978).

Adequate bacterial populations appear to be present in the rumen of calves at 3 weeks of age (Vazques-Anon *et al.*, 1993b). Early consumption of dry feed leads to early development of ruminal flora (Anderson *et al.*, 1987b). The total number of bacteria and relative population of individual species vary with the animal's diet (Bryant *et al.*, 1958; Stobo *et al.*, 1967a). Protozoa are stimulated by high-roughage diets, while lactobacilli tend to be stimulated by high concentrate diets (Roy, 1980). Pounden & Hibbs (1948) reported that the types of bacteria associated with the digestion of hay disappear when the proportion of concentrates to hay in a ration exceeds a ratio of about 3:1.

Although populations of ruminal bacteria change in response to increasing starter intake prior to and immediately following weaning (Lengemann & Allen, 1959), these changes do not appear to affect amino acid composition of the total bacterial pool. The pattern of essential amino acids in bacterial cells of the rumen are not affected by age, weaning age (Quigley *et al.*, 1985) or ration (Bergen *et al.*, 1968; Ibrahim *et al.*, 1970), and is similar to that of mature ruminants (Meyer *et al.*, 1967; Leibholz, 1975; Stern *et al.*, 1983).

## 2.2.2 Volatile fatty acids

VFA's, primarily butyrate, are necessary to initiate the stomach modifications that change the calf from essentially a monogastric animal to a ruminating animal (Tamate *et al.*, 1962). VFA concentrations in the rumen increase with age (McCarthy & Kesler, 1956; Anderson *et al.*, 1987b; Beharka *et al.*, 1998) and reach constant levels at about 5 – 8 weeks of age (Conrad *et al.*, 1954; Hibbs *et al.*, 1956; Lengemann & Allen, 1959; Godfrey, 1961b; Agabawi *et al.*, 1968; Quigley *et al.*, 1985). The total VFA concentration varies widely according to the animal's diet and the time that has elapsed since the previous meal, but is normally in the range of 70 – 150 mg/L. Much of the acid produced is absorbed directly from the rumen, reticulum and omasum. The relative concentrations of the individual VFA's are often assumed to represent their relative rates of production, but this may be misleading if individual VFA's are absorbed at different rates (McDonald *et al.*, 1988).

In the developing rumen the proportion of acetic acid has been found to be lower than in adult cows and did not differ between calves given hay or concentrates (Stobo *et al.*, 1966b). The proportion of butyric acid increase rapidly from 10 % at 4 weeks of age to 20 – 30 % thereafter (Stobo *et al.*, 1966b). In the absence of protozoa the molar proportion of butyrate is low (Nagaraja *et al.*, 1986). Anderson *et al.* (1987b) found a higher proportion of butyrate between 3 and 7 weeks of age in early-weaned calves and a subsequent decrease as the calves approached 12 weeks of age. This coincided with a lower ruminal pH during week 3 – 7 and a decline of ruminal lactate thereafter, until 12 weeks of age. The high concentration of ruminal propionate in calves receiving high cereal grains is a result of a more rapid VFA production or impaired VFA absorption relative to calves receiving diets based on roughage (Eadie *et al.*, 1967). The acetate to propionate ratio decreases as calves ages, regardless of whether they are weaned at 4 or 6 weeks of age (Anderson *et al.*, 1987b).

Calves fed diets that are finely ground tend to have higher total concentrations of VFA's (Beharka *et al.*, 1998). Molar proportions of VFA's in rumen fluid are, however, not affected by the abrasive nature, in other words the particle size, of the diet (Greenwood *et al.*, 1997).

## 2.2.3 Ammonia-nitrogen

The amount of ammonia found in the rumen is largely a reflection of the N content of the feed, solubility of the diet and the rate at which N-containing compounds are degraded. Levels of rumen ammonia are extremely low at birth. In the first 4 – 5 weeks after birth the level rises rapidly and then decreases steadily until 17 weeks of age (Godfrey, 1961b; Anderson *et al.*, 1987b).

Vazques-Anon *et al.* (1993a) reported higher ammonia-nitrogen ($NH_3$-N) concentrations at 9 weeks of age than at 7 weeks of age, when calves were weaned at 5 weeks of age. This result is in agreement with other studies that suggest that $NH_3$ absorption and its utilisation in the rumen are low during the first 3 weeks after weaning (Leibholz, 1975). A decrease in ruminal $NH_3$-N is thus indicative of increased $NH_3$ utilisation by rumen microorganisms (Bryant & Robinson, 1963; Vazques-Anon *et al.*, 1993a), an increased ability of the rumen to absorb $NH_3$ (Lewis, 1955) and a dilution effect from a larger total rumen volume (Vazques-Anon *et al.*, 1993a).

## 2.2.4  pH

Rumen pH level increase from about 5 at birth to about 6.5 at 17 weeks of age (Godfrey, 1961b). The low pH at an early age may be due to a high production of lactic acid at a young age or to a low level of saliva production (Roy, 1980). The subsequent increase in ruminal pH as calves approach 10 weeks of age may be due in part to an increased absorption of VFA's as the rumen matures (Otterby & Linn, 1981) and possibly to an increased salivary secretion (Anderson *et al.*, 1987b). Beharka *et al.* (1998) reported a decline in rumen pH after 2 weeks of age and an increase at 10 weeks of age. Anderson *et al.* (1987a,b) also reported a quadratic change in the relationship between pH and age of the calf. Vazques-Anon *et al.* (1993a) suggested that pH increases toward more optimal conditions for microbial proteolysis (from 5.7 to 6.0) at 4 – 8 weeks after weaning. Calves receiving a coarse diet have higher rumen pH values than calves receiving a fine diet (Greenwood *et al.*, 1997; Beharka *et al.*, 1998).

## 2.3     Metabolic development

Performance of calves during and after weaning depends on the gradual development of the physical as well as metabolic functions of the rumen (Godfrey, 1961a,b).   Development of ruminal function in young calves causes fundamental changes in metabolites available for maintenance and growth (Quigley *et al.*, 1985; Quigley *et al.*, 1991).   Absorption of VFA's from the rumen depends on development of metabolic activity of ruminal mucosa (Sutton *et al.*, 1963a; Sutton *et al.*, 1963b), which in turn is dependent upon intake of dry feed and production of ruminal VFA's (Flatt *et al.*, 1958; Sander *et al.*, 1959; Quigley *et al.*, 1985; Anderson *et al.*, 1987a).

Sutton *et al.* (1963a) reported that the ability of the rumen to absorb large quantities of acetic acid was not inherent and did not develop in calves on a diet of milk alone. Also, the metabolism of VFA's by the rumen mucosa was low at birth, and this was stimulated by the intake of dry feed (Sutton *et al.*, 1963b).   Others (Martin *et al.*, 1959; Young *et al.*, 1965) have indicated that calves appear to be capable of utilising VFA's even prior to weaning and intake of solid feed.   Thus, it appears that production of ruminal VFA's and absorption of VFA's from the rumen mediate transition to the ruminant state (Quigley *et al.*, 1991).

Absorption of VFA's increases as the calf matures (Beharka *et al.*, 1998).   Quigley *et al.* (1991) reported that the plasma concentration of total VFA's in calves weaned at 4 weeks of age were low until 7 weeks of age and thereafter increases rapidly.   A lower pH appears to favour VFA absorption (Beharka *et al.*, 1998).   A ruminal pH of less than 6 has been associated with reduced cellulolysis, inhibition of growth of certain ruminal bacteria (Hoover, 1986) and ruminal protozoa (Purser & Moir, 1959) and a shift in ruminal fermentation away form acetate toward propionate and butyrate.   Murdock & Wallenius (1980) suggested that feeding calves rations to promote elevated concentration of ruminal butyrate would increase rate of ruminal maturation because butyrate influences metabolic activity of ruminal epithelium.

Metabolic activity typical of mature ruminants was observed by 3 weeks of age (Sutton *et al.*, 1963b; Quigley *et al.*, 1991).   The increase in contribution of microbial N to total N in the small intestine is evidence of gradual development of the rumen (Leibholz, 1975; Quigley *et al.*, 1985).   Contribution of bacterial N in calves weaned

at 4 and 8 weeks of age was similar to that of mature animals (exceeding 40 – 50 % of abomasal protein) at approximately 5 and 6 – 7 weeks of age, respectively (Quigley *et al.*, 1985; Funabe *et al.*, 1997). An increase in dry matter digestion in the rumen as calves increase in age is also indicative of gradual metabolic development. Leibholz (1978) reported an increase in dry matter digestion in the rumen from 26 % at 1 week after weaning to 40 and 51 % by 2 and 6 weeks after weaning, respectively.

## 2.4 Factors influencing rumen development

Normal development of the stomach is an orderly process. At a given age and weight and when an animal is on a typical diet, the approximate relative development of the stomach compartments can be predicted with reasonable accuracy. The intra-uterine environment is, presumably, rather constant and therefore the fetal development of the stomach is expected to be relatively uniform within a species. Existing data are not sufficient to demonstrate any effect of breed, size, plane of nutrition or general health of the dam on the development of the fetal stomach (Morrill, 1991). In addition to species differences, age and weight, feeding is considered to be the most important factor affecting stomach development.

Another factor, closely related to feeding, is weaning age. The feeding regime differs quite substantially before and after weaning and this causes fundamental changes in nutrients available to ruminants. After weaning, energy is derived primarily from ruminal fermentation and protein absorbed from the intestine consists of ruminally undegraded protein and microbial protein (Funabe *et al.*, 1994).

### 2.4.1 Dry feed consumption

The development of the rumen has been known to depend on the intake of dry feed (Savage & McCay, 1942; Leibholz, 1975; Roy, 1980). Tamate *et al.* (1962) reported a decrease in the rate of rumen development when calves received only liquids. The reticulo-rumen of animals receiving only milk or a milk replacer will usually be smaller than normal for their age. It will have thinner walls, have a lower capacity and will lack the normal development and coloration of papillae usually found in these compartments (Smith, 1961; Tamate *et al.*, 1962; Stobo *et al.*, 1966a; Oh *et al.*, 1972). Prolonged milk feeding delays the onset of typical ruminal microflora

(Lengemann & Allen, 1959). Dry feed consumption accelerates muscle development (Harrison *et al.*, 1960), VFA production (Quigley *et al.*, 1985), VFA absorption (Sutton *et al.*, 1963a), papillary development and establishment of bacteria, protozoa and other microorganisms (Morrill, 1991).

The calf may not eat much dry starter feed during the first week of life, but it triggers the start of rumen development. The fact that this process is rapid, is underlined by the fact that 28 day weaning for calves is now commonplace (Elliot & O'Hagan, 1998). The rate at which the reticulo-rumen increases can be influenced by nutritional means and thus the time at which the animals become dependent on rumen microorganisms as the main source of protein (Ørskov, 1992). Weaning was possible at 2 – 4 weeks of age, compared to the more conventional 5 – 11 weeks, in an early weaning program where calves received a highly palatable pre-starter diet to stimulate dry feed consumption at a younger age (Morrill *et al.*, 1984).

### 2.4.1.1 Roughage vs. concentrate

The type of dry feed plays an important role in the different aspects of rumen development. The fibre content of the diet has a major effect on the development of rumen motility, rumination, rumen size, and muscular development (Vazques-Anon *et al.*, 1993a). Dry feed must supply sufficient bulk and fibres to support increase in rumen capacity (Tamate *et al.*, 1962) and enough coarsely textured feed to maintain normal papillae shape. High concentrate diet enhances microbial development (Anderson *et al.*, 1987b) and increases rumen metabolic activity by increasing VFA production (Vazques-Anon *et al.*, 1993a) and $NH_3$-N concentration (Preston *et al.*, 1963).

Rapid ruminal fermentation of soluble carbohydrate in high grain diets causes reduced ruminal pH, which can alter proportions of VFA's produced in the rumen and induce a shift in types and proportions of ruminal microflora (Quigley *et al.*, 1992). Mature fibrous forages give rise to VFA mixtures containing a high proportion (70%) of acetic acid. Diets high in concentrate increase proportion of propionic acid at the expense of acetic acid. With all concentrate diets the proportion of propionic acid may even exceed that of acetic acid (McDonald *et al.*, 1988).

## 2.4.1.2    Texture of diet

Greenwood *et al.* (1997) reported a larger reticulo-rumen for calves receiving a coarse diet and a larger omasum for calves receiving a fine diet.    Beharka *et al.* (1998) also reported heavier empty and full omasal weights for calves receiving a grounded diet compared to those of calves receiving an ungrounded diet.    The increased omasal weight might have been due to increased flow of particles out of the rumen into the omasum, possibly stimulating omasal development.    In the same study the physical form of the diet (grounded or ungrounded) did, however, not affect the empty or full weights of the reticulo-rumen and abomasum.    The physical form of the diet affected papillary size and shape, but not the outer superficial or inner deep (circular) muscle thickness (Beharka *et al.*, 1998).

The physical form of the diet influences ruminal pH.    Ruminal pH was lower at 4 and 6 weeks of age for calves receiving a ground diet than for calves receiving an ungrounded diet (Beharka *et al.*, 1998).    Thomas & Hinks (1982) reported that calves receiving a pelleted diet have higher rumen pH levels than calves receiving a pelleted basal diet supplemented with long or chopped straw.    In the same study calves receiving the pelleted diet had lower VFA concentrations than calves supplemented with long or chopped straw.    Beharka *et al.* (1998) on the other hand, reported no change in the molar concentrations of VFA's or the acetate to propionate ratio due to the physical form of the diet.

## 2.4.2    Weaning age

Weaning of young ruminants accelerates rumen development by increasing dry matter intake (Godfrey, 1961a; Leibholz, 1975) and is considered to be a critical period in calf growth.    At weaning, calves become heavily dependent upon the products of rumen fermentation for maintenance requirements and for growth.

Ruminal metabolic development is faster in calves weaned early (4 weeks of age) than in calves weaned conventionally (6 weeks of age) as assessed by ruminal VFA concentrations (Agabawi *et al.*, 1968; Morrill *et al.*, 1984; Anderson *et al.*, 1987a; Klein *et al.*, 1987).    Calves weaned early have higher total rumen VFA (Anderson *et al.*, 1987a) and lactate (Anderson *et al.*, 1987b) concentrations compared to calves weaned conventionally.    Other researchers have also noted higher VFA

concentrations for early-weaned calves (Morrill *et al.*, 1984). Anderson *et al.* (1987a) reported higher molar proportions of butyrate in early-weaned calves and attributed it to the stimulation of butyrate production from lactate fermentation.

Calves weaned early have lower rumen pH levels compared to calves weaned conventionally (Anderson *et al.*, 1987a). Milk intake tends to increase rumen $NH_3$-N concentration and unweaned calves generally have higher ruminal $NH_3$ than weaned calves (Godfrey, 1961b). Anderson *et al.* (1987a), however, reported no difference in ruminal $NH_3$-N concentrations due to the weaning program.

In general the most significant changes in bacterial populations and metabolic activity in both early- and conventionally weaned calves occur between 4 and 6 weeks of age. Calves in the early-weaning program tended to have higher ruminal microbial activity during the fourth to sixth week of age, after the early-weaned calves were weaned and before the weaning of the conventionally weaned calves. Calves weaned early had more amylolytic and lactate-utilising bacteria than calves weaned conventionally. Amylolytic, proteolytic, lactobacilli, lactate-utilizers, cellulolytic and methanogenic bacterial populations increased progressively in both groups. Cellulolytic and methanogenic bacteria were present in both groups at 3 days of age (Anderson *et al.*, 1987b).

## 3.     Protein metabolism

Prior to rumen development and intake of solid food the digestive system of the calf is very similar to that of monogastric animals (Van Soest, 1987). In the preweaning period the young animal is dependent on enzymes in the abomasum and lower intestine for protein digestion. The age at which transition to the ruminant method of digestion occurs is largely dependent on the diet that a calf receives (Roy, 1980). The calf possesses the same ability, though not necessarily an equal capacity, to degrade protein in the rumen as mature ruminants at a fairly early age. For the purpose of this study the discussion on protein metabolism will be limited to the symbiotic relationship between the calf and rumen microorganisms.

Figure 2 gives a clear picture of the fate of dietary crude protein (CP) in the ruminant animal. Both bacteria and protozoa degrade dietary proteins that are available for degradation in the rumen. This degradation process involves basically two steps: 1) the hydrolysis of the peptide bond (proteolysis) to produce peptides and amino acids and 2) the deamination and degradation of amino acids (Tamminga, 1979). Following proteolysis, liberated peptides and amino acids can be utilised by the rumen microorganisms to synthesise microbial protein, leave the reticulo-rumen or be degraded to ammonia and fatty acids. Amino acids are rapidly degraded in the rumen and therefore only small quantities of free amino acids would be available for absorption or passage from the reticulo-rumen (Bull *et al.*, 1985). The rumen microorganisms are carried through to the abomasum and small intestine where their cell proteins are digested by enzymes and absorbed (McDonald *et al.*, 1988).

Rumen microorganisms can also convert non-protein nitrogenous compounds, like amino acids, amides, amines and nitrates to protein, but it might not result in the optimum yield and growth rate (Maeng *et al.*, 1976). Urea is a non-protein substance that is often used in ruminant diets (McDonald *et al.*, 1988). Urea is rapidly hydrolysed to ammonia by bacterial urease in the rumen and care should be taken to provide a source of readily fermentable carbohydrates to ensure readily available energy for the microorganisms for protein synthesis. The inclusion of too high levels of urea can cause toxic levels of ammonia in the blood if it is not efficiently incorporated into microbial protein in the rumen.

The ammonia in rumen fluid is the key intermediate in the microbial degradation and synthesis of protein. If the diet is deficient in protein, or if the protein resist degradation, the concentration of rumen ammonia will be low (50 mg/L) and the growth of rumen organisms will be slow and as a result the breakdown of carbohydrate will be retarded.

On the other hand if protein degradation proceeds more rapidly than synthesis, ammonia will accumulate in rumen liquor and the optimum concentration will be exceeded. When this happens, ammonia is absorbed into the blood, carried to the liver and converted to urea.

Some of this urea may be returned to the rumen via saliva, and also directly through the rumen wall, but the greater part is excreted in the urine and thus wasted (McDonald *et al.*, 1988).
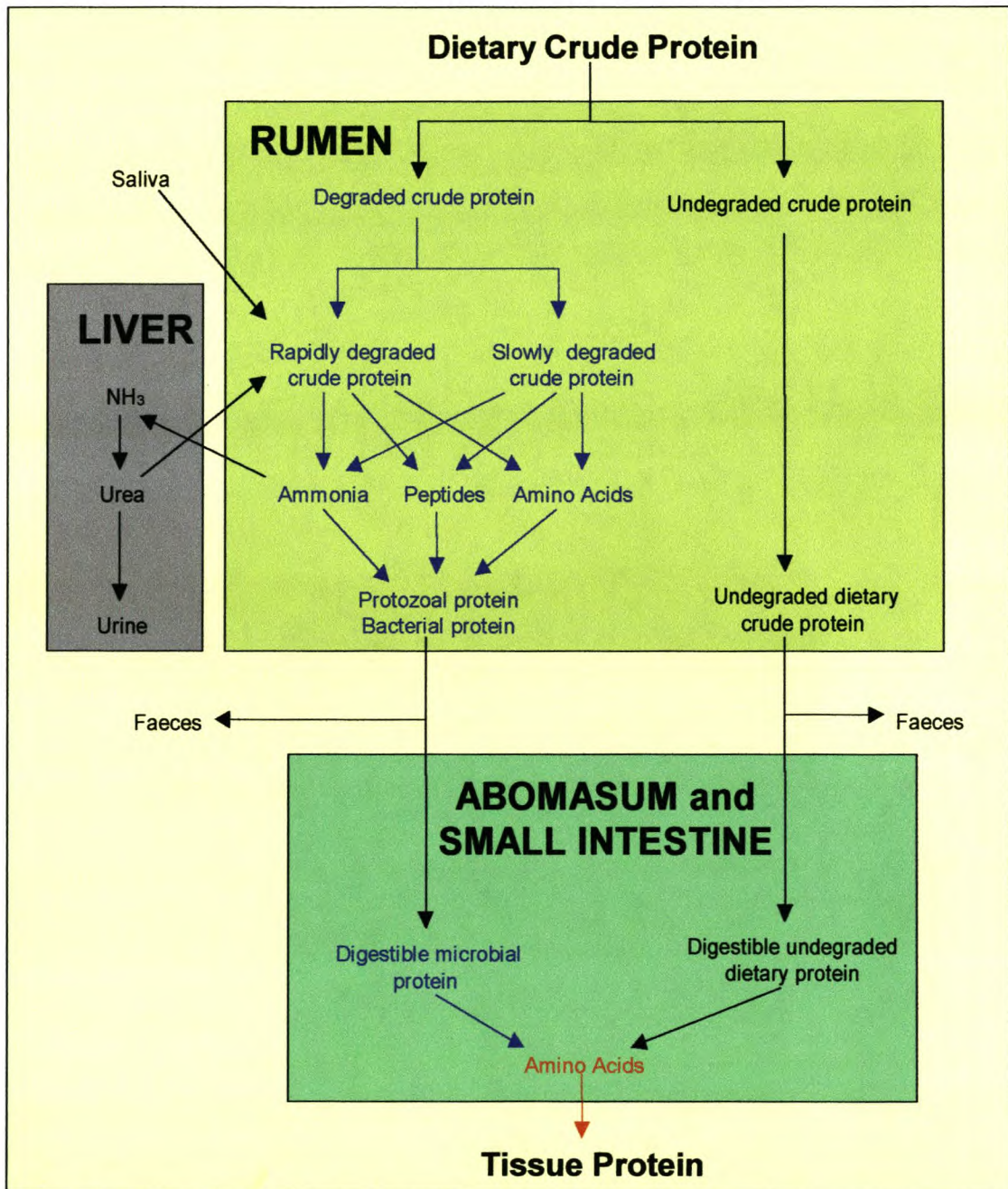


FIGURE 2. The metabolism of dietary protein in the ruminant (McDonald et al., 1988).

If food is poorly supplied with protein and the concentration of ammonia in rumen liquor is low, the quantity of N returned to the rumen as urea from the blood may exceed that absorbed from the rumen as ammonia.  This net gain in recycled N is converted to microbial protein, which means that the quantity reaching the intestine may be greater than that in the food.  In this way the ruminant is able to conserve N by returning to the rumen urea that would otherwise be excreted in urine.

An important feature of the digestive processes in ruminants is the production of microbial cells and hence the synthesis of microbial protein.  If this synthesis is for any reason inefficient, food protein will be wasted and the host animal will subsequently be presented with a mixture of digestible nutrients that is unbalanced with respect to protein.  In practice the rumen microorganisms synthesise protein in proportion to the quantities of nutrients that they ferment.

## 4.     Nutrient deposition

Early growth in calves involves primarily deposition of calcium, phosphorus, protein and water (Jacobson, 1969).  In the production of the best quality veal the carcass must be extremely well fleshed (Roy, 1980) and rapid weight gain is essential (Jacobson, 1969).  This necessitates the use of a breed with a high muscle to bone ratio.  The most favoured breed for the production of veal is a calf of large birth weight and a high muscle to bone ratio, like the Holstein-Friesian calf (Roy, 1980; Pretorius, 1994).  Emphasis in meat production has shifted from obtaining maximum growth of animals to production of lean meat and increasing the efficiency of N utilisation.  Weight gain should therefore not merely consist of the extra deposition of fat, but rather of protein deposition. There are many factors that affect the capacity of the young ruminant to synthesise tissue protein.  The most important of these factors are undoubtedly the genetic potential and the sex of the animal, the level of energy input and the stage of maturity (Ørskov, 1976).

Growth in young animals is almost invariably associated with a high rate of protein deposition in relation to the intake of available energy (Ørskov, 1976).  In an attempt to quantify the protein and fat deposition rates in veal calves, Gerrits et al. (1996) indicated a rather low priority for protein deposition in Holstein Friesian x Dutch

Friesian veal calves in the weight range of 80 – 240 kg. Furthermore, no protein- and energy-dependent phases were detected. At low protein intakes, protein deposition rate was affected by protein-free energy intake (Gerrits et al., 1996). Donnelly & Hutton (1976) also reported this effect for preruminant Holstein calves weighing between 40 and 70 kg. At low levels of protein intake, fat deposition increases as protein intake increases, but as protein intake increases further, fat deposition rate decreases (Donnelly & Hutton, 1976; Gerrits et al., 1996). Protein deposition increases with increasing digestible protein intake (Gerrits et al., 1996).

Calves use a large part of extra ingested protein for purposes other than for protein deposition for reasons that are not quite clear (Gerrits et al., 1996). In the experiments of Gerrits et al. (1996) only milk proteins, which is known to have a true digestibility of close to 100 % (Tolman & Beelen, 1995), were used and marginal efficiency of protein utilisation is therefore ruled out. Another possible explanation is the need for gluconeogenesis from amino acids in ruminants. It is possible that gluconeogenesis from amino acids, as an inevitable consequence of the operation of mechanisms controlling the degradation of amino acids in (potential) ruminants, continues even when glucose supply from the diet is abundant (Gerrits et al., 1996).

The rate of protein deposition by the young ruminant is most appropriately expressed as N retained per unit of energy digested since the microbial protein formed tends to be proportional to the amount of organic matter fermented. The attainable rate of protein deposition per unit of energy digested increases with level of feeding and decreases with stage of maturity (Ørskov, 1976). The quantity of microbial N synthesised per 100 g organic matter digested in the rumen is constant from 2 weeks after weaning (Leibholz, 1978). Leibholz (1976) reported that 2.4 g of microbial N was synthesised for every 100 g of organic matter digested in the stomach and in another study (Leibholz, 1978) a value of 2.7 g/100 g organic matter digested was reported.

The amount of N stored for each kilogram weight gained is generally between 26 and 34 g (Brisson et al., 1957; Roy et al., 1964; Stobo et al., 1967a), but appears to be higher for calves receiving a diet containing a high concentration of protein and gaining weight very rapidly (Roy, 1980).

## 5.     Protein Requirements

According to Ørskov (1992) young growing calves have a relatively higher need for protein than for energy. Several researchers have over the years conducted studies to establish the optimum level of protein in calf diets. Recommendations range from 12 (Brown *et al.*, 1958; Morrill & Melton, 1973) to 20 % CP (Bartley, 1973). The optimum protein level in starter diets has caused more controversy in the commercial milling industry than any other parameter (Elliot & O'Hagan, 1998). Veira *et al.* (1980) suggested that efficiency of rumen N metabolism can be assessed from the relationship between dietary N input and the rumen output of non-ammonia N (NAN). When abomasal flow of NAN is greater than or equal to N intake, there is efficient use of dietary N. However when rumen output of NAN is less than N input, the converse is true. Calves, age 12 – 14 weeks, receiving corn-based diets supplemented with soybean meal showed inefficient utilisation of dietary N in the rumen at protein levels above 12 % (Veira *et al.*, 1980). Akayezu *et al.* (1994) examined growth rates in calves over the period 4 – 53 days of age. The calves received starter diets ranging in protein level from 15 – 22 % (dry basis). The diet with 19.6 % CP resulted in the best growth rate. This is in agreement with Phelps (1990) who suggests that the current NRC (1989) recommendation of 18 % (dry basis) protein in calf starter diets is adequate for maximum growth.

The protein requirement of the ruminant is a combination of the needs of the rumen microorganisms and the host animal itself. Even if the microbial and the undegraded dietary protein is in excess of the need of the animal, the microbial requirement must be met to ensure maximum intake. In many systems of ruminant production, feed intake is the most limiting factor. The concentration of protein necessary to ensure maximum intake and production will remain relatively constant after the stage has been reached at which the potential protein utilisation is met from microbial and basal protein (Ørskov, 1976).

As the calf ages, protein entering the small intestine is derived increasingly from microorganisms in the rumen. Contribution of bacterial N to total N in abomasal contents was similar to that of mature ruminants by 5 and 7 weeks of age for calves weaned at 4 and 8 weeks of age, respectively (Quigley *et al.*, 1985). Several authors have, nonetheless, suggested that microbial protein production cannot meet

the needs of the host animal for rapid growth (Chalupa, 1975; Ørskov, 1977). The aim of protein supplementation is to provide sufficient amino acids in the small intestine of the host animal to promote maximal growth rate (Fiems et al., 1987). When the postruminal supply of limiting amino acids are adequate to fill the requirements for net tissue synthesis, no further growth of performance response to added protein would be expected (Zinn & Owens, 1993).

Different feeding strategies have been suggested to ensure the required supply of protein at the duodenum. One way of achieving this is to supply a high quantity of protein in the diet (Fiems et al., 1987). High levels of dietary crude protein may promote rapid body weight gains, but the protein may not be utilised efficiently because of partial degradation in the rumen (Chalupa, 1975).

Another way to enhance the availability of protein to the host animal is the use of lower levels of degradable protein and thus higher levels of protein that will bypass rumen degradation (Chalupa; 1975; Ørskov; 1976; Fiems et al., 1987). As mentioned earlier, microbial protein synthesis may not be adequate for maximum growth in the early-weaned ruminant and these animals should respond to increased dietary escape protein provided the amino acid composition of the protein is of high quality (Zerbini & Polan, 1985; Amos, 1986). The main role of the supplementary bypass protein sources must be to fill the gap between the post-ruminal amino acid pool in the basic diet and the requirements for post-ruminal amino acids of the particular class of ruminating animal (Drevjany, 1991). It is essential to know the animal's attainable rate of protein deposition in order to assess the effect of protection of protein from rumen degradation. Protection will only be advantageous if their potential for N deposition is greater than the quantity supplied by microbial and basal protein (Ørskov, 1976).

Ruminal escape protein may not be of the same amino acid composition as the original feedstuff and the absorbed amino acid profile may differ from both the microbial and dietary profiles. Early research in this area (Little et al., 1968) indicated that the dietary protein source could affect abomasal N flow. Regardless of the source of protein it is the amino acid profile reaching the small intestine that will supply the amino acids for the host animal (Koeln & Paterson, 1986).

Ruminants also possess the unique capacity by means of their rumen microbial population, to transform non-protein N sources such as urea into animal protein (Maeng *et al.*, 1976). Urea can be used to replace a part of the N from protein in calf starters, especially when urea is added to starters containing less than 12 % dietary protein (Brown *et al.*, 1956; Stobo *et al.*, 1967b). Utilisation of urea sometimes is less efficient at higher levels of crude protein (Kay *et al.*, 1967; Miron *et al.*, 1968; Stobo *et al.*, 1967b).

Urea supplementation of calf starters produced variable results that were dependent on urea concentration, CP content of starter, natural protein source used and other dietary ingredients, especially starch (Brown *et al.*, 1956; Kay *et al.*, 1967; Miron *et al.*, 1968; Leibholz & Naylor, 1971; Winter, 1973). Leibholz & Naylor (1971) reported that urea would not reduce weight gain of calves 5 – 11 weeks of age if urea was limited to 39 % of the dietary protein. According to Morrill & Dayton (1978) one can, to a limited extent, use urea successfully in feeds for both preweaned and weaned calves, providing that the ration is palatable. Sulphur supplementation, as inorganic sulphur, may be beneficial if rations fed to weaned calves contain urea and then no more than 0.2 % sulphur should be supplemented (Morrill & Dayton, 1978). Urea appeared to be efficiently utilised as a source of dietary N from 2 weeks after weaning (Leibholz, 1978). If a daily gain of more than 0.7 kg is expected, urea cannot be recommended as the sole supplementary N source for calves between 0 and 20 weeks, because of the significant negative effects on ADG, feed intake and feed conversion (Fiems *et al.*, 1987).

Urea supplementation can reduce the cost of protein supplementation without deleterious effects on growth if such supplementation is considered to be part of an integrated approach that takes into account dietary protein and carbohydrate fractions and their ruminal availabilities (Abdelgadir *et al.*, 1996a). Reasons for the lower animal performance obtained with urea-containing starters include an insufficient energy supply, a smaller extent of microbial protein synthesis despite a high ruminal ammonia concentration and harmful effects of high urea doses (Fiems *et al.*, 1987).

## 6.    Undegradable dietary protein and calf performance

Several factors could cause calves to respond differently to protein supplementation. Among them are differences in growth rates, methods of feeding (*ad lib*. versus restricted), digestible energy content of ration, solubility of protein, palatability of the diet, balance of the nutrients and amount of milk consumed (Morrill & Dayton, 1978). Fiems *et al.* (1987) also suggested that factors such as basal diet, feeding level and frequency, and physical form of the diet could be responsible for the variable effect that the level of undegradable dietary protein (UDP) has on animal performance. High feeding frequency, which is known to optimise efficiency of microbial protein synthesis, may lead to a lack in response to higher levels of UDP (Van Bruchem *et al.*, 1985).

Veen & Vahl (1984) reported higher daily weight gains and better feed efficiency from increasing levels of UDP for early-weaned calves. Other studies, however, indicated no advantage in increased levels of UDP to supply the protein needs of growing calves (Miller *et al.*, 1983; Firkins *et al.*, 1986; Mantysaari *et al.*, 1989; Hussein & Jordan, 1991; Swartz *et al.*, 1991). Cummins *et al.* (1982) reported more efficient N utilisation in calves (8 – 20 weeks of age) receiving diets with 30 % rumen degradable N compared to calves receiving diets with 60 % rumen degradable N.

A balance in the rates of N and energy-yielding substrates supply with the ruminal microbial population will maximise the capture of rumen degradable protein (RDP) and optimise microbial growth and efficiency (Johnson, 1976, Sinclair *et al.*, 1993). A more efficient capture of RDP would reduce requirements for more expensive UDP sources and also reduce excretion of urinary N into the environment (Abdelgadir *et al.*, 1996a).

In one study Abdelgadir *et al.* (1996a) reported similar performances for calves receiving starter diets containing ruminally synchronous and asynchronous CP and starch sources.   Yet in another study Abdelgadir *et al.* (1996b) reported that interactions between carbohydrate and protein sources in calf starters are important and that synchronising the carbohydrate and protein ruminal availabilities may improve efficiency of utilisation of calf starters.   Several other researchers also observed better utilisation of nutrients in the rumen and better performances from

synchronous utilisation of ruminally degradable carbohydrates and CP by ruminants (Russel & Hespell, 1981; Stern *et al.*, 1985; Herrera-Saldana & Huber, 1989; Maiga *et al.*, 1994).

## 7.    Measuring protein degradability

Considerable degradation and synthesis of protein occur in the rumen and the material that finally becomes available for digestion by the animal may differ considerably from that originally present in the diet.  These processes are of major importance in the N economy of the host animal since they determine the nature of the amino acid profile made available for protein synthesis at tissue level.  Satisfying the demands of the rumen microorganisms for readily available N is a major function of the diet and to this end a certain proportion of the N fraction must be degradable by the rumen microorganisms (McDonald *et al.*, 1988).

Protein fractions within the diet vary from immediately degradable to undegradable. Measuring protein degradation by rumen microorganisms is a difficult task.  There can be wide variation in protein degradation within and among feedstuffs as well as among animals.  Even the rate of passage which is influenced by the level of feed intake affects the actual extent of protein degradation in the rumen (Ørskov & McDonald, 1979; Tamminga, 1979).

Estimating rumen protein degradability has been a problem and the task is to devise methods for predicting with assurance the quantity of ruminally degradable as well as bypass protein (Cummins *et al.*, 1982).   Protein solubility in different aqueous solutions has been used as an indicator of protein degradability (Wohlt *et al.*, 1973; Crawford *et al.*, 1978), but relating to what occurs in the rumen environment this approach is questionable (Nocek *et al.*, 1979).  Claims have been made that the solubility of a protein is correlated with ease of breakdown but these do not survive critical examination.  Several authors stated that protein degradability was more accurate than solubility as an estimation of protein quality (Mahadevan *et al.*, 1980; Stern & Satter, 1984), but even protein degradability is not a standardised measurement (Evans & Cottrill, 1984).  In vitro incubations of feedstuffs with rumen contents (Broderick, 1978) and suspension in the rumen in non-degradable bags

(Mehrez & Ørskov, 1977) are two of the means of estimating rumen degradability of protein and dry matter. No single technique or experimental design is fully adequate at the present time (Bull *et al.*, 1985).

Properties of feedstuffs such as particle size influence rates of ruminal breakdown and passage into the abomasum. Furthermore, interactive properties of different feedstuffs must be evaluated. For example, how does the presence of hay influence the degradation or rate of bypass of dietary protein, especially protein from sources other than hay (Cummins *et al.*, 1982).

Amos (1986) noted that UDP sources should be selected with care because high acid detergent insoluble N levels, like that for corn gluten meal and distillers dried grain with solubles, can render a part of the UDP fractions unavailable for digestion in the small intestine. Protein may be rendered unavailable for rumen microorganisms by heat or chemical treatment (Beever *et al.*, 1976; Ahrat *et al.*, 1977; Yu, 1978), but heat processing of feedstuffs may also result in a decrease in protein digestibility (Koeln & Paterson, 1986).

## 8. Veal production potential in South Africa

The surplus bull calves in the dairy industry is mainly due to the widespread use of artificial insemination (Morrill, 1991). Only a few of the dairy bull calves born are used for breeding purposes, leaving many more that are available to be used for meat production (Albright, 1983). Dairy producers are often in doubt regarding the profitability of rearing bull calves (Cruywagen & Horn, 1985b) and therefore bull calves from commercial dairy herds are often sold a couple of days after birth as bobby veal or processed as carcass meal (Pretorius, 1994). Of the 540 000 milking cows in South Africa (Coetzee, 2000, South African Milk Producers Organisation, personal communication) approximately 60 % is Holstein Friesians. A calving percentage of 80 and an equal distribution of heifer and bull calves will result in 129 600 newborn Holstein Friesian bull calves per year. At an average carcass mass of 85 kg it would mean a potential production of 11 016 tons of veal.

The veal market in South Africa is presently too limited for white veal production (Cruywagen, 1993) and the pink veal market is not optimally utilised. Since the demand is for a darker meat, concentrates and hay can be included in veal calf diets. This would lower the cost of feeding and during periods of favourable meat prices it can be a viable option to market these as either veal or dairy steers. Calves should not be marketed later than 20 weeks of age, since they start cutting their first molars soon after this age and are then classified as beef (Pretorius, 1994).

Rearing calves on concentrate diets is proposed as an economically viable alternative to traditional methods of veal production. A veal calf raised on milk replacers to the age of 4½ months will consume 37 kg of the starter and 279 kg of the finisher milk replacer. At a cost of R 8.80/kg and R 10.76/kg for the starter and finisher milk replacer, respectively, the feed cost over the total period amounts to R 3 330.60/calf (Cruywagen, 2000, University of Stellenbosch, personal communication). In the current study (Chapter 2) the average feed cost over the 20 week period (milk plus concentrate) was R 592.75/calf. The expected carcass mass for the milk-fed veal calves is 100 kg and that for the grain-fed calves 85 kg. In the case of the milk-fed calves a price/kg carcass mass of R 33.31 is thus needed to break even, while the price for the grain-fed calves needs to be R 6.97. In South Africa no price differential currently exists between white and pink veal, and calf carcasses are priced at approximately R 10.00/kg.

The protein source in a calf diet contributes a considerable portion of the cost due to the high levels of protein included in these diets. Low degradable protein sources such as fishmeal is expensive and of variable quality. If comparable calf performance is possible by including high degradable protein sources, the rearing of calves on grain diets for veal can provide an economical viable option for surplus dairy bull calves in South Africa.

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# CHAPTER 2

# The Effect of Different Levels of Rumen Degradable Protein in Concentrate Diets on Veal Calf Performance

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## ABSTRACT

This study was conducted to investigate the effect of varying levels of rumen undegradable protein in calf starter and finisher diets on feed intake, weight gain, feed conversion efficiency and some carcass parameters. The objective was to obtain an indication of the level of undegradable dietary protein requirement for young calves intended for veal production. Two experiments were carried out with Holstein bull calves ($n_1$ = 24 and $n_2$ = 32) 3 – 10 days of age at the onset of the experiments and slaughtered at 20 weeks for veal. Both experiments were divided into a starter and finishing period. Calves received starter pellets for *ad lib*. consumption from 7 days of age. Diets were formulated to be iso-nitrogenous and iso-caloric, and differed only in undegradable dietary protein content within periods and within respective experiments. In Experiment 1 calves were randomly assigned to one of three treatments: low (LD), medium (MD) and high rumen degradable protein (HD). In Experiment 2 calves received a starter diet either high or low in rumen degradable protein. In the finishing period both the high and low groups were again divided into a low and high degradable group, resulting effectively in four treatments, viz. LL, LH, HL and HH. Calves were randomly assigned to one of the four treatments at the beginning of the experiment. In the starter period of both experiments there were no significant differences for feed intake, body weight gain or feed efficiency between treatments. In the finishing period (12 - 20 weeks) of Experiment 1 calves receiving the LD diet had significantly higher average daily gains than calves from the HD treatment. Calves receiving the MD diet had intermediate gains. The feed conversion ratio for the LD treatment was also

significantly better than for the other two treatments. In the finishing period (11 - 20 weeks) of Experiment 2 the feed conversion ratio tended (P = 0.098) to differ between treatments. Calves from the LL and HL treatments had a more favourable feed conversion ratio than calves from the LH treatment. The HH treatment had an intermediate feed conversion ratio, which did not differ from the LL, HL or LH treatment. The level of crude protein degradability appears to have no effect on calf performance in the starter period. It may however be beneficial to feed finisher diets with a lower crude protein degradability.

**(Key words: calves; nutrition; protein degradability; veal production)**

## INTRODUCTION

Protein nutrition and the protein requirements for young growing calves have been studied since at least 1920 (Spitzer & Carr, 1920). During the preruminant phase the supply of protein to the small intestine is primarily from the diet. The consumption of dry feed shifts the major source of protein to that of microbial protein. In the early 1960's Roy *et al.* (1964) already suggested that protein quality must be considered during the transition period from preruminant to ruminant when calves receive high concentrate diets *ad libitum*.

According to Ørskov (1977) microbial protein synthesis in the early weaned ruminant may not be adequate for maximum growth. These animals should respond to increased undegradable dietary protein (UDP), provided the amino acid composition of the protein is of high quality. During the transitional phase calves should therefore be supplied with dietary protein that would stimulate microbial protein synthesis, but also provide digestible UDP to optimize the amino acid profile of digesta in the small intestine (Vazques-Anon *et al.*, 1993).

Improved body weight gains have been reported for calves under the age of 12 weeks receiving diets high in UDP (Whitelaw *et al.*, 1961; Whitelaw *et al.*, 1963; Veen & Vahl, 1984). More recent results however showed no difference in average daily gain (ADG) due to varying UDP levels (Trotta *et al.*, 1984; Lalles & Poncet, 1990). Calves older than 12 weeks weighing up to 200 kg showed better body weight gain (Amos, 1986) and feed efficiency (Swartz *et al.*, 1991) with diets higher

in UDP. The NRC (1989) recommends UDP levels of 84.7, 69.5, 57.8 and 48.4 % for large breed growing male calves of 100, 150, 200 and 250 kg live weight, respectively. No recommendations exist for calves < 100 kg.

This study was conducted to investigate the effect of varying levels of UDP in calf starter and finisher diets on feed intake, weight gain, feed conversion efficiency and certain carcass parameters. The objective was to obtain an indication of the level of UDP required by young calves intended for veal production.

## MATERIALS AND METHODS

### Experiment 1

Twenty-four Holstein bull calves between 3 and 7 days of age were blocked according to arrival weight and the calves within each block were then randomly assigned to one of three treatments. The treatments were LD (low rumen degradable protein), MD (medium rumen degradable protein) and HD (high rumen degradable protein). The experiment was divided into two periods, namely the starter period (arrival – 11 weeks) and the finisher period (12 – 20 weeks). Diets in each period were formulated to be iso-nitrogenous and iso-caloric, but differed in dietary crude protein (CP) degradability. The ingredient composition of the diets is presented in Table 1 and the calculated CP degradability in Table 4.

TABLE 1. Ingredient composition (%) of starter and finisher diets for veal calves on an air dry basis.[1]

| Ingredient | Starter diet | | | Finisher diet | | |
|---|---|---|---|---|---|---|
| | LD | MD | HD | LD | MD | HD |
| Maize meal | 60.8 | 55.7 | 50.6 | 73.2 | 71.2 | 69.2 |
| Fish meal | 6.0 | 3.0 | - | 3.0 | 1.5 | - |
| Maize gluten meal (60) | 7.0 | 3.5 | - | 3.0 | 1.5 | - |
| Sunflower oilcake | - | 11.7 | 23.3 | - | 5.0 | 10.0 |
| Molasses | 5.1 | 5.1 | 5.1 | 5.0 | 5.0 | 5.0 |
| Chopped lucerne hay | 15.2 | 17.7 | 20.2 | 15.0 | 15.0 | 15.0 |
| Oat hulls | 5.1 | 2.5 | - | - | - | - |
| Salt | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Mineral premix | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |

[1] Diets formulated to our specification and supplied by Meadow Feed Mills Cape (Paarl, South Africa).

Each calf received 2 L of a commercial electrolyte solution (All-Lyte, Alltech, South Africa) for the first two feedings after arrival. The electrolyte solution was prepared by dissolving one sachet (100 g) in 4 L water (~ 40ºC). The ingredient and chemical composition of the electrolyte powder is shown in Table 2. The third feeding consisted of 1 L of fresh milk. Thereafter calves received 2 L of fresh milk twice daily for three weeks and then 2 L of fresh milk once daily until weaning one week later. Calves were offered starter pellets *ad lib*. from day 7 through week 11 and finisher pellets *ad lib*. from week 12 through week 20.

TABLE 2. Ingredient and chemical composition per 100 g sachet of All-Lyte powder[1].

Ingredients

Sodium chloride, Potassium chloride, Citric acid, Potassium citrate, Glycine, Gelatine, Sodium bicarbonate, Dextrose, Dried *Aspergillus niger* fermentation extract, Dried *Lactobacillus acidophilus* fermentation product, Dried *Streptococcus faecium* fermentation product

Chemical composition

| | |
|---|---|
| Sodium | Min. 9 % ; Max. 11% |
| Potassium | Min. 5% |
| *Lactobacillus acidophilus* (NCL84) | Min. 100 Million CFU |
| *Streptococcus faecium* (NCS97) | Min. 100 Million CFU |

[1] Alltech (Somerset West, South Africa).

Calves were housed individually in elevated pens (115 x 340 cm) with slatted wooden floors. Oat straw was used as bedding and replaced as often as needed to ensure dry bedding at all times. The pens were in a semi-closed barn with natural ventilation. Calves had free access to fresh water throughout the experiment. Feed intake and body weight were recorded weekly. At the end of week 20 the calves were slaughtered for veal at a commercial abattoir. Cold carcass mass was used to determine dressing percentage.

Two cannulated lactating Holstein cows were used to determine 12 h *in sacco* dry matter (DM) and CP degradabilities of the six diets. Diets were hammer-milled through a 2 mm screen and weighed into dacron bags, 100 x 180 mm, with pore size 53 ± 2 μm. Approximately 5 g DM were accurately weighed into each bag, providing a sample to surface ratio of ca. 14 mg/cm² to comply with standard procedures (Vanzant *et al*., 1998). Samples were prepared in triplicate for each diet and each cow. Bags were soaked in water (39 ºC) for 15 minutes before rumen incubation

and then placed inside a woven nylon bag to ensure easy retrieval of all the bags. Bags were removed after 12 h incubation, placed in ice water to terminate fermentation, rinsed under slow running tap water and then machine-washed three times on a gentle cycle. Bags were dried at 55 °C for 24 h and the residue analysed for CP content (AOAC, 1998).

## Experiment 2

Thirty-two Holstein bull calves between 3 and 10 days of age were used in the second experiment. The calves were purchased from a single farm (Grootte Post, Darling, South Africa). They arrived in four groups of eight each over a period of 5 weeks and were weighed upon arrival. Calves were blocked according to arrival date. Each group of eight were subdivided into two groups according to birth date and calves within an age subgroup were randomly assigned to one of four treatments.

Treatments were HH (starter and finisher diet with high RDP), HL (starter diet with high RDP and finisher diet with low RDP), LH (starter diet with low RDP and finisher diet with high RDP) and LL (starter and finisher diet with low RDP). The experiment was divided into two periods of 10 weeks each. Experimental diets within each period were formulated to be iso-nitrogenous and iso-caloric with the largest possible difference in rumen degradable protein (RDP) content, given the available feedstuffs. To obtain a maximum difference in RDP content in the starter diets, the diets were formulated with a CP content of 3 percent higher (compare Tables 4 and 6) than that of the starter diets in Experiment 1. The ingredient composition of the diets is presented in Table 3.

Housing and feeding management were the same as for Experiment 1. Feed intake and body weight were recorded weekly. Feed samples were collected weekly throughout the trial and composited for chemical analysis. Dry matter, ash, crude protein, ether extract and crude fibre were determined according to AOAC (1998) and ADF and NDF according to Van Soest & Robertson (1985). At the end of week 20 calves were slaughtered for veal at a commercial abattoir. Cold carcass mass was used to determine dressing percentage.

TABLE 3. Ingredient composition (%) of starter and finisher diets for veal calves on an air dry basis.[1]

| Ingredient | Starter diet | | Finisher diet | |
|---|---|---|---|---|
| | L | H | L | H |
| Maize | 55.1 | 48.2 | 72.0 | 68.0 |
| Barley | 1.7 | 5.0 | - | - |
| Wheaten bran | - | 2.4 | - | - |
| Chopped lucerne hay | 21.9 | 15.0 | 10.0 | 15.0 |
| NaOH-treated wheat straw | - | - | 5.0 | - |
| Fishmeal | 6.8 | - | 3.0 | - |
| Sunflower oilcake | - | 3.5 | - | 10.0 |
| Groundnut oilcake | - | 7.5 | - | - |
| Soybean oilcake | - | 10.0 | - | - |
| Maize gluten meal (60) | 5.8 | - | 3.0 | - |
| Bloodmeal | 0.4 | - | - | - |
| Molasses | 5.0 | 5.0 | 5.0 | 5.0 |
| Limestone | - | - | 1.1 | 1.1 |
| Mono-Calcium Phosphate | 1.6 | 1.8 | - | - |
| Salt | 1.2 | 1.1 | 0.4 | 0.4 |
| Vitamin & Mineral premix | 0.5 | 0.5 | 0.5 | 0.5 |

[1] Diets formulated to our specification and supplied by Meadow Feed Mills Cape (Paarl, South Africa).

## Statistical analysis

Body weight gain, feed intake and feed conversion efficiency data for the preweaning, starter, finishing and total experimental period were analysed as a randomised block design using the GLM procedure of SAS (1996). Significance was declared at $P \leq 0.05$ unless otherwise indicated. Least square means were separated using the PDIFF option when $P \leq 0.05$.

## RESULTS AND DISCUSSION

### Experiment 1

The chemical composition, calculated RDP and 12 h *in sacco* degradability values of the six diets used in the experiment are presented in Table 4. The three diets in the starter period were comparable in CP and metabolizable energy (ME) content. The slight difference in ME content between the diets was probably due to the difference in fat content. In order to obtain as large a difference as possible in RDP content, the HD starter diet had a large amount of sunflower oilcake with a much higher RDP

content than those of fish meal and maize gluten meal, viz. 86 % vs 40 and 31 % (Erasmus & Prinsloo, 1988). The high sunflower oilcake content caused the crude fibre content of the HD diet to be appreciably higher than those of the MD and LD diets.

The CP degradability values determined by the *in sacco* procedure are much lower than the calculated values. This is due to the fact that the calculated values were based on average effective degradabilities of the individual ingredients (literature values), while the *in sacco* values were 12 h degradability values of the specific diets. The CP and DM degradabilities do however confirm that the diets were indeed low, medium and high in degradable CP content.

TABLE 4. Chemical composition[1] (% of DM), calculated RDP and 12 h *in sacco* degradability values of starter and finisher diets for veal calves.

| | Starter diet | | | Finisher diet | | |
|---|---|---|---|---|---|---|
| Item | LD | MD | HD | LD | MD | HD |
| DM | 95.6 | 95.4 | 95.1 | 89.6 | 89.6 | 89.6 |
| CP | 16.3 | 16.5 | 16.7 | 13.3 | 13.6 | 13.1 |
| CF | 8.3 | 10.2 | 12.1 | 6.5 | 8.0 | 8.1 |
| Fat | 3.5 | 3.1 | 2.7 | 3.6 | 3.1 | 3.1 |
| Ca | 0.4 | 0.4 | 0.4 | 0.5 | 0.4 | 0.4 |
| Na | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| P | 0.4 | 0.4 | 0.5 | 0.3 | 0.4 | 0.4 |
| ME (MJ/kg) | 11.4 | 11.3 | 11.1 | 12.8 | 12.4 | 12.6 |
| UDP | 7.2 | 6.2 | 5.1 | 6.3 | 5.7 | 4.8 |
| RDP (% of CP) | 55.9 | 62.6 | 69.1 | 53.0 | 57.9 | 63.7 |
| 12 h *in sacco* degradability | | | | | | |
| DM ± SD | 45.6 ± 5.0 | 51.1 ± 11.0 | 57.1 ± 10.6 | 42.4 ± 2.5 | 46.5 ± 5.4 | 47.6 ± 10.4 |
| CP ± SD | 30.7 ± 4.7 | 40.6 ± 12.3 | 54.3 ± 8.9 | 28.5 ± 3.7 | 44.0 ± 0.3 | 44.3 ± 1.6 |

[1] Chemical composition as calculated (except where indicated otherwise) by Meadow Feed Mills Cape (Paarl, South Africa) according to laboratory-determined values for the batches of the feedstuffs used to prepare the experimental diets.

The finisher diets were similar in CP and ME content, but the crude fibre content of the LD diet was lower than those of the other two diets due to the absence of sunflower oilcake meal in the former. The difference was smaller compared to the starter diets because of the lower sunflower oilcake content in the HD finisher diet.

The calculated RDP content (Table 4) indicates moderate differences between the three finisher diets. Feedstuffs in the Western Cape limited the possibility to formulate finisher diets with a greater difference in RDP content. The *in sacco*

determined RDP content of all three diets was lower than the calculated values. There was no real difference between the MD and HD diets in DM or CP degradability. The reason for these discrepancies can be partly attributed to the high level of variance as seen in the large standard deviations, especially in the case of the DM degradability of the HD diet  (Table 4).  Another reason may be the use of average RDP values for feedstuffs while formulating the diets, which can differ quite substantially between different batches of the same feedstuff (Erasmus & Prinsloo, 1988).

Results on body weight, feed intake and carcass parameters for individual periods and the total experimental period are presented in Table 5.  Feed intake, body weight gain and feed efficiency did not differ between treatments in the preweaning period (0 – 4 weeks).  Feed intake and body weight gain during the starter period (0 – 11 weeks) followed the same trend between treatments as observed in the preweaning period.

Bouchard *et al.* (1980) replaced soybean meal (SBM) for meat and bone meal (MBM) in concentrates for veal calves and reported no significant difference in concentrate intake or feed conversion ratio (FCR) between treatments.  Fiems *et al.* (1987) found no favourable effect when replacing SBM with formaldehyde-treated SBM as the sole nitrogen source in starter diets for calves weighing less than 150 kg. The nitrogen degradability of the SBM diet was 89.9 % and that of the treated SBM diet was 68.0 %.  The treated SBM slightly improved ADG, but feed intake also increased causing similar FCR's for the two treatments.

Treatment had no effect on feed intake during the finishing period (12 - 20 weeks). Total gain and ADG for calves receiving the LD treatment was significantly higher than for those in the HD treatment (P = 0.0305).  Body weight gain for the MD calves was intermediate, but it did not differ significantly from either the LD (P = 0.0961) or HD (P = 0.6170) treatment.  The FCR of calves in the LD treatment was significantly better than for those of the MD and HD treatments.  The more efficient FCR resulted from the higher body weight gain of calves in the LD treatment.

In a trial with 4-month-old Holstein heifers, Amos (1986) found that an increase in UDP increased ADG, with no difference in feed intake or FCR.  Swartz *et al.* (1991)

reported lower daily DM intakes for high (37.9 %) and low (29.7 %) UDP levels as compared to an intermediate level (33.8%) for calves 14 - 25 weeks of age. In the same experiment FCR improved with increasing UDP content, but no difference in ADG was observed between treatments.

TABLE 5.  Feed intake, body weight gain, feed conversion and carcass parameters for veal calves receiving diets varying in RDP content.

| Item | Treatment | | | SEM | P |
|---|---|---|---|---|---|
| | LD | MD | HD | | |
| **0 - 4 weeks:** | | | | | |
| Total intake[1] (kg) | 20.80 | 21.00 | 20.43 | 1.0075 | 0.9213 |
| Dry matter intake (kg/day) | 0.74 | 0.75 | 0.73 | 0.0360 | 0.9213 |
| Total gain (kg) | 10.88 | 12.30 | 11.53 | 1.5470 | 0.8121 |
| Average daily gain (kg/day) | 0.39 | 0.44 | 0.41 | 0.0552 | 0.8121 |
| FCR (kg intake/kg gain) | 2.02 | 2.03 | 1.90 | 0.2694 | 0.9363 |
| **0 – 11 weeks:** | | | | | |
| Total intake[1] (kg) | 110.06 | 117.94 | 115.96 | 5.5303 | 0.5953 |
| Dry matter intake (kg/day) | 1.43 | 1.53 | 1.51 | 0.0718 | 0.5953 |
| Total gain (kg) | 49.46 | 55.51 | 49.77 | 3.4929 | 0.4412 |
| Average daily gain (kg/day) | 0.64 | 0.72 | 0.65 | 0.0454 | 0.4412 |
| FCR (kg intake/kg gain) | 2.27 | 2.14 | 2.34 | 0.0919 | 0.3648 |
| **12 - 20 weeks:** | | | | | |
| Total intake (kg) | 219.60 | 221.48 | 229.78 | 5.4842 | 0.3799 |
| Dry matter intake (kg/day) | 3.49 | 3.52 | 3.65 | 0.0855 | 0.3797 |
| Total gain (kg) | 73.18[a] | 65.30[ab] | 63.05[b] | 3.0209 | 0.0736 |
| Average daily gain (kg/day) | 1.16[a] | 1.04[ab] | 1.00[b] | 0.0480 | 0.0736 |
| FCR (kg intake/kg gain) | 3.03[a] | 3.45[b] | 3.70[b] | 0.1500 | 0.0205 |
| **0 - 20 weeks:** | | | | | |
| Total intake[1] (kg) | 323.44 | 334.20 | 339.65 | 9.7120 | 0.4908 |
| Dry matter intake (kg/day) | 2.31 | 2.39 | 2.43 | 0.0694 | 0.4908 |
| Total gain (kg) | 122.64 | 120.81 | 112.82 | 4.7528 | 0.3199 |
| Average daily gain (kg/day) | 0.88 | 0.86 | 0.81 | 0.0340 | 0.3200 |
| FCR (kg intake/kg gain) | 2.65[a] | 2.78[a] | 3.03[b] | 0.0602 | 0.0020 |
| Carcass mass | 85.63 | 82.76 | 79.75 | 2.3447 | 0.2308 |
| Dressing percentage | 49.38 | 49.11 | 48.69 | 0.6483 | 0.7422 |

[1] Total intake includes dry matter milk intake.
[a,b] Means within a row without common superscripts differ significantly (P < 0.05).
[*] HD and LD differ significantly at P < 0.001.

Feed intake and body weight gain over the total experimental period followed the same trend as during the finishing period.  For the overall period only the FCR differed significantly between treatments.  Both the LD and MD treatment resulted in a better FCR than the HD treatment.  Carcass mass and dressing percentage did not differ between treatments.

**Experiment 2**

The chemical composition for the diets used in Experiment 2 is presented in Table 6. The only difference in chemical composition between the diets was in terms of RDP content. The 24 h *in sacco* degradability values (Table 6) confirmed that the diets were either low or high in RDP.

TABLE 6. Chemical composition (% of DM) and 24 h *in sacco* degradability of starter and finisher diets for veal calves.

| Item | | Starter diet | | Finisher diet | |
|---|---|---|---|---|---|
| | | L | H | L | H |
| Determined: | DM | 90.7 | 91.1 | 89.2 | 89.0 |
| | Ash | 7.4 | 7.0 | 7.0 | 6.8 |
| | CP | 19.2 | 19.3 | 13.1 | 13.4 |
| | CF | 6.9 | 6.8 | 7.3 | 9.0 |
| | NDF | 24.9 | 22.0 | 22.3 | 22.8 |
| | ADF | 10.7 | 9.7 | 12.2 | 14.1 |
| | Ether extract | 3.8 | 3.4 | 3.7 | 3.5 |
| Calculated:[1] | Ca | 1.1 | 0.9 | 0.9 | 0.9 |
| | Na | 0.4 | 0.3 | 0.4 | 0.3 |
| | P | 0.7 | 0.8 | 0.4 | 0.4 |
| | ME (MJ/kg) | 12.2 | 12.2 | 12.9 | 12.7 |
| | UDP | 9.2 | 6.6 | 5.8 | 4.2 |
| | RDP (% of CP) | 52.0 | 65.6 | 55.7 | 68.4 |
| 24 h *in sacco* degradability | | | | | |
| DM ± SD | | 83.1 ± 1.0 | 90.9 ± 0.3 | 82.0 ± 1.4 | 85.2 ± 1.1 |
| CP ± SD | | 68.6 ± 1.3 | 94.7 ± 0.8 | 73.7 ± 1.0 | 90.5 ± 1.6 |

[1] Chemical composition as calculated by Meadow Feed Mills Cape (Paarl, South Africa) according to laboratory determined values for the batches of feedstuffs used to prepare the experimental diets.

Results on body weight, feed intake and carcass parameters for the different experimental periods are presented in Table 7. Treatment had no effect on feed intake, weight gain or feed conversion efficiency in the preweaning period (0 – 4 weeks). Feed intake and body weight gain results for the starter period (0 – 10 weeks) followed the same trends as those for the preweaning period.

TABLE 7.  Feed intake, weight gain, feed conversion efficiency and carcass parameters for veal calves receiving diets differing in RDP content.

| Item | Treatment | | | |
|---|---|---|---|---|
| | L | H | SEM | P |
| **0 - 4 weeks:** | | | | |
| Total intake[1] (kg) | 20.27 | 19.22 | 0.9323 | 0.4368 |
| Dry matter intake (kg/day) | 0.72 | 0.69 | 0.0333 | 0.4369 |
| Total gain (kg) | 10.03 | 9.09 | 1.1431 | 0.5676 |
| Average daily gain (kg/day) | 0.36 | 0.32 | 0.0408 | 0.5675 |
| FCR (kg intake/kg gain) | 2.26 | 2.81 | 0.3410 | 0.2668 |
| **0 - 10 weeks:** | | | | |
| Total intake[1] (kg) | 105.13 | 102.63 | 4.0763 | 0.6695 |
| Dry matter intake (kg/day) | 1.50 | 1.47 | 0.0582 | 0.6694 |
| Total gain (kg) | 47.25 | 44.66 | 2.0321 | 0.3761 |
| Average daily gain (kg/day) | 0.67 | 0.64 | 0.0290 | 0.3761 |
| FCR (kg intake/kg gain) | 2.24 | 2.33 | 0.0534 | 0.2518 |

| Item | LL | LH | HL | HH | SEM | P |
|---|---|---|---|---|---|---|
| **11 - 20 weeks:** | | | | | | |
| Total intake (kg) | 295.11 | 302.63 | 298.36 | 290.64 | 11.1340 | 0.8901 |
| Dry matter intake (kg/day) | 4.22 | 4.32 | 4.26 | 4.15 | 0.1591 | 0.8901 |
| Total gain (kg) | 90.00 | 84.56 | 91.44 | 88.13 | 2.9246 | 0.3980 |
| Average daily gain (kg/day) | 1.29 | 1.21 | 1.31 | 1.26 | 0.0418 | 0.3980 |
| FCR (kg intake/kg gain) | 3.29[a] | 3.61[b] | 3.27[a] | 3.31[ab] | 0.1040 | 0.0984 |
| **0 - 20 weeks:** | | | | | | |
| Total intake[1] (kg) | 400.13 | 405.36 | 398.11 | 393.42 | 16.2566 | 0.9633 |
| Dry matter intake (kg/day) | 2.86 | 2.90 | 2.84 | 2.81 | 0.1161 | 0.9633 |
| Total gain (kg) | 138.31 | 130.75 | 135.31 | 133.56 | 5.2347 | 0.7778 |
| Average daily gain (kg/day) | 0.99 | 0.93 | 0.97 | 0.95 | 0.0374 | 0.7778 |
| FCR (kg intake/kg gain) | 2.90[a] | 3.11[b] | 2.95[ab] | 2.96[ab] | 0.0699 | 0.1818 |
| Carcass mass | 92.94 | 90.31 | 93.69 | 91.44 | 2.8147 | 0.8332 |
| Dressing percentage | 51.33 | 51.36 | 51.92 | 51.74 | 0.4919 | 0.7874 |

[1] Total intake includes dry matter milk intake.
[a,b] Means within a row without common superscripts differ significantly ($P < 0.05$).

These results confirm the observation in Experiment 1 that no significant advantage appears to be gained from feeding a diet low in degradable protein to calves under 10 weeks of age.  In a trial with Holstein calves receiving one of three diets differing in UDP content, Swartz *et al.* (1991) also found no differences in feed intake, ADG and FCR during the first 12 weeks of age.  They attributed the lack of difference in growth due to varying levels of undegradable dietary protein, to the fact that feed was offered *ad lib.*, which allowed calves to consume additional protein and energy above NRC (1989) recommendations.  Veen & Vahl (1984) did however find significant differences in FCR's of calves receiving diets with either slowly or rapidly

degradable protein. The 12 h *in sacco* nitrogen degradability of the slowly degradable diet was 35 % (% of CP) and that of the rapid degradable diet 62 %. According to these authors, in two of the three trials the slowly degradable diet had a more favourable FCR for calves 3 – 7 weeks of age. Live weight gains were slightly higher for the slowly degradable diet, but only significantly so in one trial for the period 7 – 12 weeks of age. They concluded, contrary to observations from the current experiment, that growth of young calves can be improved if a higher than average portion of the ration protein is not degraded in the rumen.

Feed intake and body weight gain in the finishing period did not differ between treatments. In a trial with Holstein bull calves (8 – 20 weeks of age) receiving diets varying in nitrogen degradability and physical form, Cummins *et al.* (1982) found that nitrogen degradability level had no effect on feed intake, ADG or feed efficiency. During the finishing period of the current experiment the FCR tended to differ due to treatment. Calves receiving the LL and HL treatment had more favourable FCR's than calves receiving the LH treatment (P = 0.042 and P = 0.031 respectively). Calves receiving the HH treatment had a FCR comparable to the HL and LL treatment, and tended to be more favourable than that of the LH treatment (P = 0.056). Cummins *et al.* (1982) suggested that either high bypass of dietary protein or high degradability of nitrogen - and thus possibly greater microbial protein synthesis - results in the delivery of higher quality protein to the small intestine. According to Tamminga (1979) an inadequate supply of degradable protein in the rumen could decrease microbial efficiency and impact negatively on feed efficiency. A combination of the greater microbial protein synthesis in the HH treatment and a possible lower microbial efficiency in the LL and HL treatments could explain the lack of difference in FCR between these treatments.

It is not clear why the FCR of the LH treatment was less favourable compared to the other three treatments during the finishing period of Experiment 2. Swartz *et al.* (1991) suggested that protein sources that are low degradable might not allow an adequate supply of nitrogen in the rumen for maximum microbial growth. It could be possible that calves that have received the low degradable diet during the starter period did not have the same rumen microbe population (qualitatively and quantitatively) than calves receiving the high degradable starter diet. Calves that received the high degradable finisher diet therefore may have needed a period for

the rumen microbe population to increase.  It is, however, unlikely that this adaptation period could last longer than two weeks.  It is also unlikely that the first two weeks of the finishing period could have had such an effect on the whole 10 week period.

Results on feed intake and body weight gain for the whole experimental period followed the same trend as those for the finishing period.  The FCR for calves receiving the LL treatment was significantly better than that for calves receiving the LH treatment (P = 0.040), but were comparable to those of the HL and HH treatments.  As in Experiment 1, the carcass mass and dressing percentage were similar for all treatments.

The results from Experiment 2 confirmed those of Experiment 1 that a diet relatively high in RDP seems adequate for calves in the starter period.  The benefit of supplying protein sources higher in UDP could only be observed in the finishing period.

## CONCLUSION

Results from these two experiments suggest that the level of CP degradability in starter diets have no effect on preweaning calf performance.  According to Veen & Vahl (1984) the degree of protein degradability does not become a factor until the rumen function is sufficiently developed.  Some reports suggested that ruminal function is rapidly developed by early weaning (Quigley *et al.*, 1985; Anderson *et al.*, 1987a,b) and that rumen ammonia nitrogen concentration, total volatile fatty acids and the contribution of microbial nitrogen to total nitrogen in abomasal contents resemble that of mature ruminants as soon as a week after early weaning.  However, Funaba *et al.* (1994) suggested that it is not sufficient to report only on the metabolic products in the rumen, but that the digestion of solid feed in the rumen might not fully meet nutrient demands of calves because of immature size of the rumen.

Results from our experiments suggest that young calves up to 10 weeks of age may not utilize RDP in the same way as mature ruminants, which could possibly be due to the difference in rumen capacity and flow rates.  In calves with live weight > 200 kg

the rumen is developed to such a degree as to provide the lower intestine with sufficient amino acids solely from microbial protein, given that the diet provides enough energy for microbial protein synthesis (Oldham & Smith, 1982). Calves with live weight < 100 kg may still have underdeveloped rumen functions and it seems possible for high degradable protein to escape from the rumen intact. Provided therefore that calves are allowed to consume starter diets *ad lib.* and that the CP content of starter diets meets generally accepted recommendations, it seems possible for them to consume enough dry matter to supply their needs for rapid growth from highly degradable protein sources.

According to our results CP degradability however appears to have an effect on feed conversion ratio in the finishing period. The period from 11 – 20 weeks of age (bodyweight of ± 100 kg to ± 200 kg) appears to be the time when supplying additional UDP may be warranted.

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# CHAPTER 3

## The Effect of Age on Dry Matter and Crude Protein Degradability of Concentrate Diets for Veal Calves and Selected Rumen Physiological and Metabolic Characteristics

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## ABSTRACT

This study was conducted to examine the dry matter and crude protein degradabilities of diets used in a previous experiment with veal calves and to compare it with degradability values in mature cows. Selected rumen physiological and metabolic characteristics were measured and compared with literature values for mature ruminants to evaluate the level of rumen maturity of growing calves. Five Holstein bull calves were ruminally cannulated at 6 weeks of age and were used in consecutive weekly 24 h trials from 8 – 20 weeks of age. Dry matter and crude protein degradability values were determined after 24 h *in sacco* incubation of two starter and two finisher veal calf diets. In both cases, diets that were high and low in rumen degradable protein were used. Rumen pH, volatile fatty acid and ammonia-nitrogen concentrations were determined weekly. Three ruminally cannulated Holstein cows were used to evaluate dry matter and crude protein degradabilities of the same four diets. Dry matter degradability in the calves differed significantly between the low and high degradable diets within every week. Over time dry matter degradability differed between the starter and finisher diets (week 10 and 11) and remained fairly constant from week 11 – 20. Crude protein degradability in the calves also differed significantly between the low and high degradable diets within every week. Crude protein degradability increased up to week 12 and then remained constant to week 20. Both the dry matter and crude protein degradability values of the starter diets were lower than the corresponding values obtained with cows, while the values of the finisher diets were similar. No clear linear or non-linear relationships were noted for

rumen pH, volatile fatty acid concentrations and ratios, or rumen ammonia-nitrogen concentrations. These values showed some degree of fluctuation between weeks and were similar to literature values for mature ruminants.

**(Key words: calves; protein degradability; rumen volatile fatty acids; rumen pH; rumen ammonia nitrogen)**


## INTRODUCTION

Three metabolizable protein systems that have been proposed to replace crude protein (CP) or digestible protein to describe protein requirements for ruminants are dependent upon protein degradation values (Burroughs *et al.*, 1975; Vérité & Jarrige, 1979). Quantitative information on the extent of protein degradation in the rumen is therefore needed. Estimates on the amount of protein escaping degradation in the reticulo-rumen are extremely variable. Part of the variation is due to analytical error and part to variation in feedstuffs, the diets used, feed intake, the experimental animals employed, method of feeding and the physical nature of the diet (Bull *et al.*, 1985*). In vitro* incubations of feedstuffs with rumen contents (Broderick, 1978) and suspension in the rumen in non-degradable bags (Mehrez & Ørskov, 1977) are but two of the methods of estimating dry matter (DM) and protein degradability. No single technique or experimental design, however, is fully adequate at the present time (NRC, 1989).

The estimates on degradability presented by the NRC contains a limited amount of feedstuffs and were obtained by experiments with sheep and/or cattle (NRC, 1989). The question arises whether these values can be used when calculating the degradability of diets for young growing calves. The extent to which it will be applicable will, at least in part, depend on the state of maturity of the rumen at any given age. Adequate bacterial populations appear to be present very early in the rumen of calves and subsequent development is stimulated by an increase in dry feed consumption. The earlier dry feed is introduced into the rumen, the earlier microbial development occurs, resulting in higher ruminal metabolic activity (Anderson *et al.*, 1987b). Quigley *et al.* (1985) reported that ruminal functions in weaned calves at 4 weeks of age were not comparable to those in mature cattle. It may take several weeks for full

development of ruminal function, as evaluated by ruminal volatile fatty acid (VFA) concentrations (Quigley et al., 1985; Quigley et al., 1991; Quigley & Bernard, 1992) and ratio of microbial nitrogen to duodenal nitrogen (Leibholz, 1975; Quigley et al., 1985). Young calves have however been reported to possess mature ruminal function as early as 2 – 3 weeks after dry feed is first offered (Lalles & Poncet, 1990).

This study was conducted to examine the dry matter and crude protein degradability of four diets used in an earlier experiment with veal calves (Chapter 2 – Experiment 2). The degradability values for the calves were compared to degradability values obtained from a degradability experiment with mature cows. Selected rumen physiological and metabolic characteristics were measured and compared with literature values for mature ruminants.

## MATERIALS AND METHODS

Five Holstein bull calves and three ruminally cannulated Holstein cows were used in two degradability experiments. The five bull calves were between 3 and 7 days of age when purchased from the farm Welbeloond (Milnerton, South Africa). Feeding and housing management until weaning were the same as described in an earlier experiment with veal calves (Chapter 2). After weaning calves were moved to an open pen (10 m x 8 m) where they were kept until 16 weeks of age. During the last four weeks (week 16 – 20) of the experiment they were housed in a section of a freestall barn. Calves were rumen cannulated at the age of 6 weeks. Calves received starter pellets *ad lib.* from day 7 until week 10 of the experiment and finisher pellets *ad lib.* from week 11 through week 20. Both the starter and finisher diets consisted of a 50:50 mixture of the high (HD) and low degradable (LD) diets used in an earlier experiment with veal calves (Chapter 2).

Dacron bags were incubated once weekly from 8 through to 20 weeks of age to determine 24 h disappearance values. Diets were hammer-milled through a 2 mm screen and weighed into 100 x 140 mm bags with pore size 53 ± 2 µm. Approximately 4 g DM were accurately weighed into each bag, providing a sample to surface ratio of ca. 14 mg/cm² to comply with standard procedures (Vanzant et al., 1998). Four bags,

duplicates of both the high and low degradable diets, were incubated in each calf. Bags were soaked in water (39ºC) for 15 minutes before incubation. Bags were suspended individually on 50 cm nylon lines that were fixed to the screw-in plug of the cannula. The starter diets were used in week 8 through 10 and the finisher diets for the remainder of the experiment.

The three ruminally cannulated Holstein cows were adapted for a period of 2 weeks to a commercial total mixed ration for lactating dairy cows, supplemented with oat hay. Each cow received 10 kg of the total mixed ration and 4 kg of oat hay twice daily during the adaptation period, as well as during the degradation trial. Bags and diets were prepared in the same way as for the calves, the only differences being that starter and finisher diets were incubated simultaneously and suspended on 100 cm nylon strings. Eight bags per cow (2 LD starter, 2 HD starter, 2 LD finisher and 2 HD finisher) were incubated for 24 h once weekly for two consecutive weeks. After incubation bags were placed in ice water to terminate fermentation, rinsed under slow running tap water and then machine-washed three times on a gentle cycle. Bags were dried at 55 °C for 24 h and the residue analysed for CP content (AOAC, 1998).

Rumen content samples were taken from each calf before bags were inserted and after removal of the bags. The rumen content was strained through a double layer of cheesecloth and the pH of the strained rumen fluid measured immediately. Duplicate 9 ml rumen fluid samples were preserved with either 1 ml of a 50 % $H_2SO_4$ solution or 1 ml of a 10 % (m/v) NaOH solution for rumen ammonia-nitrogen ($NH_3$-N) and VFA analysis, respectively. Preserved rumen fluid samples were centrifuged at 4200 rps to remove feed particles. The supernatant fluid was kept at –20 °C until analysed.

**Statistical Analysis**

Data on DM and CP degradability in calves were analysed using the GLM procedure of SAS (1996) with repeated measurements. The PROFILE transformation was used to generate contrasts between degradability values of adjacent weeks. Degradability data for the cows were analysed using the GLM procedure. Linear regression functions were fitted on data of rumen VFA levels, pH and $NH_3$-N using the PROC REG procedure. In

the case of pH a quadratic regression function was also fitted. Significance was declared at $P \leq 0.05$ unless otherwise indicated.

## RESULTS AND DISCUSSION

### DM and CP degradability

Results on DM degradability are presented in Table 1 and illustrated in Figure 1.

TABLE 1. *In sacco* dry matter degradability of starter and finisher diets for veal calves determined in cannulated Holstein bull calves and Holstein cows.

| Week | LD | HD | SEM | P | P (contrast) |
|------|-------|-------|--------|--------|--------------|
| 8 | 74.47 | 81.83 | 0.2259 | 0.0001 | 0.3168 |
| 9 | 72.09 | 78.98 | 0.3348 | 0.0001 | 0.3466 |
| 10 | 74.24 | 81.72 | 0.0919 | 0.0001 | 0.0001 |
| 11 | 78.31 | 80.31 | 0.2835 | 0.0076 | 0.5036 |
| 12 | 79.49 | 81.90 | 0.1867 | 0.0008 | 0.1063 |
| 13 | 78.34 | 79.88 | 0.3537 | 0.0373 | 0.6099 |
| 14 | 79.52 | 81.46 | 0.3365 | 0.0152 | 0.5543 |
| 15 | 80.30 | 81.79 | 0.2772 | 0.0193 | 0.3533 |
| 16 | 80.61 | 82.67 | 0.3287 | 0.0115 | 0.4290 |
| 17 | 78.17 | 79.78 | 0.2110 | 0.0057 | 0.1358 |
| 18 | 79.43 | 82.08 | 0.3238 | 0.0044 | 0.6776 |
| 19 | 77.38 | 79.71 | 0.2828 | 0.0043 | 0.4003 |
| 20 | 78.13 | 80.83 | 0.1983 | 0.0007 | |
| Mean (8 – 10) | 73.60 | 80.84 | | | |
| Mean (11 – 20) | 78.99 | 81.04 | | | |
| Cow (Starter) | 83.06 | 90.87 | 0.4208 | 0.0001 | |
| Cow (Finisher) | 82.01 | 85.21 | 0.4208 | 0.0001 | |

LD = Low degradable diet; HD = High degradable diet; SEM = Standard error of LSmean.

The DM degradability differed significantly between the HD and LD diets for every week. The only difference in DM degradability over time occurred between week 10 and 11.

This could be due to the change in evaluating the starter diets to evaluating the finisher diets, which also coincided with a change in the basal diet from the starter to the finisher diet. It is not clear whether the difference between week 10 and 11 can be attributed to an increased ability of calves to degrade diets or simply as a result of the degradability of the diets per se. The difference between the DM degradability values in cows and the mean degradability value for week 8 – 10 in calves were 9.5 and 10.0 for the LD and HD starter diets, respectively. The differences for the finisher diets were smaller at 3.0 and 4.2 for the LD and HD diets, respectively. In both cases the values were higher in cows.
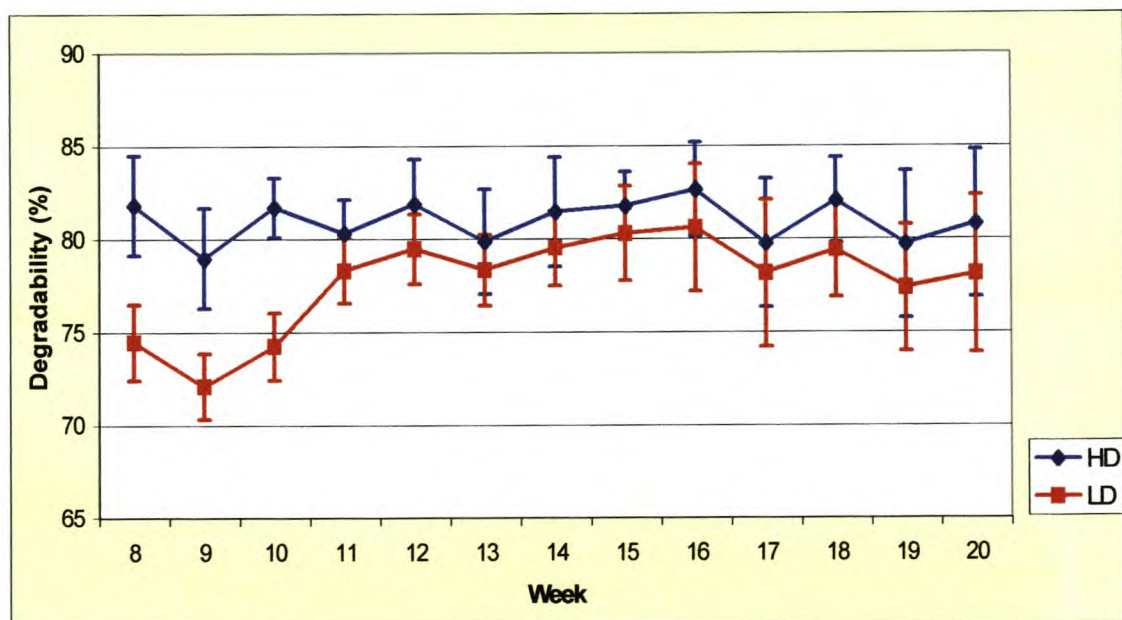


FIGURE 1. Dry matter degradability in veal calves from 8 to 20 weeks of age.

It appeared as though the DM degradability of the HD diet did not change over time (Figure 1), while that of the LD diet, on the other hand, appeared to increase during week 8 – 11 and then remained relatively constant until week 20.

Results on CP degradability are presented in Table 2 and illustrated in Figure 2. CP degradability for calves differed significantly between the LD and HD diets for all but one week. In week 19 the CP degradability of the LD diet tended to be lower. The standard error of the mean in week 19 was high compared to the other weeks and this probably led to the lack of significance for the difference in CP degradability between the diets.

TABLE 2. *In sacco* crude protein degradability of starter and finisher diets for veal calves determined in cannulated Holstein bull calves and Holstein cows.

| Week | LD | HD | SEM | P | P (contrast) |
|------|------|------|--------|--------|--------------|
| 8 | 59.25 | 84.23 | 0.8927 | 0.0001 | 0.0405 |
| 9 | 54.53 | 76.43 | 0.9172 | 0.0001 | 0.7734 |
| 10 | 60.71 | 82.98 | 0.1858 | 0.0001 | 0.0007 |
| 11 | 68.97 | 84.47 | 0.5801 | 0.0001 | 0.0678 |
| 12 | 76.16 | 89.66 | 0.2008 | 0.0001 | 0.5684 |
| 13 | 74.09 | 87.04 | 0.4843 | 0.0001 | 0.6416 |
| 14 | 77.35 | 89.89 | 0.1608 | 0.0001 | 0.6262 |
| 15 | 78.23 | 89.68 | 1.5668 | 0.0067 | 0.8486 |
| 16 | 81.08 | 91.92 | 1.3356 | 0.0046 | 0.1630 |
| 17 | 73.02 | 87.50 | 0.7918 | 0.0002 | 0.3974 |
| 18 | 77.72 | 89.48 | 1.7070 | 0.0082 | 0.9752 |
| 19 | 75.44 | 87.01 | 2.9790 | 0.0516 | 0.6895 |
| 20 | 75.12 | 88.23 | 0.8677 | 0.0004 | |
| Mean (8 – 10) | 58.16 | 81.21 | | | |
| Mean (12 – 20) | 76.47 | 88.93 | | | |
| Cow (Starter) | 68.64 | 94.74 | 0.3945 | 0.0001 | |
| Cow (Finisher) | 73.74 | 90.53 | 0.3945 | 0.0001 | |

LD = Low degradable diet; HD = High degradable diet; SEM = standard error of LSmean.

The difference between the CP degradability values in cows and the mean values for week 8 to 10 in calves were 10.5 and 13.5 for the LD and HD starter diets, respectively. The differences for the finisher diets were less at 2.7 and 1.6 for the LD and HD diets, respectively. The CP degradability value for week 11 was left out of the calculation because CP degradability appeared to increase until week 12. In the case of the LD diet the average CP degradability in calves were slightly higher than that in mature cows. Vazques-Anon *et al.* (1993b) reported similar rates of CP disappearance between cows and calves for distillers grains and corn gluten feed, but not so for soybean meal and heat treated soybean meal. This inconsistency in prediction among feedstuffs renders the cow *in situ* method not suitable for the prediction of rumen protein degradability of early weaned calves.
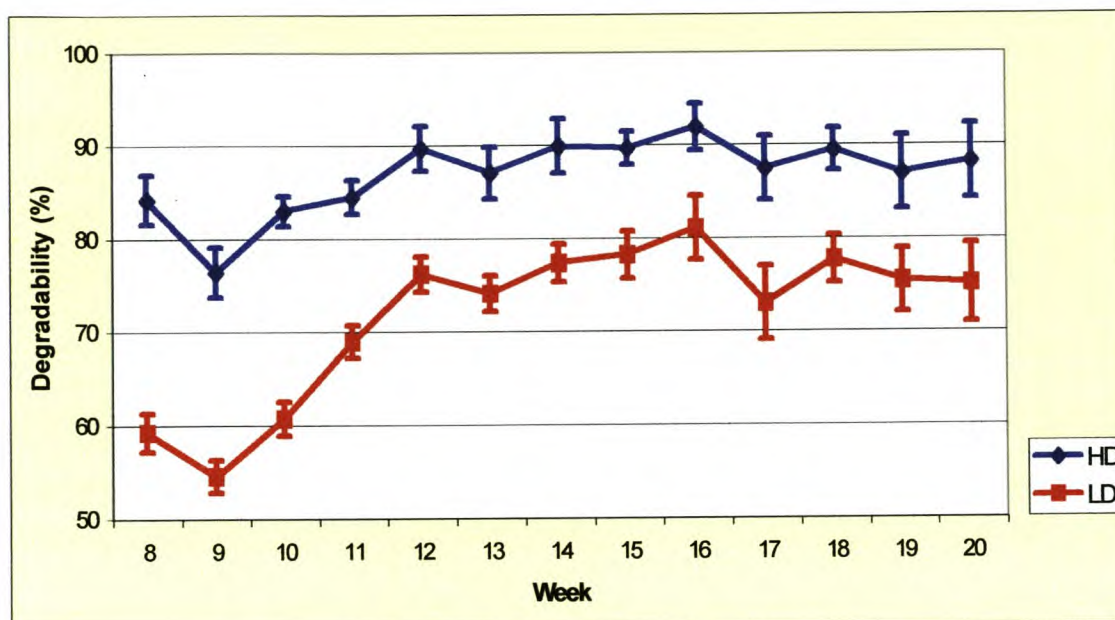
FIGURE 2.    Crude protein degradability in veal calves from 8 to 20 weeks.

Unlike the DM degradability there appeared to be an increase in CP degradability for both diets over at least part of the experimental period (Figure 2). The CP degradability increased until 12 weeks of age and then remained fairly constant until the end of the experiment at 20 weeks of age.

Both the DM and CP degradability resulted in time, time x calf and time x diet effects. This indicates a variation between calves in the development of their ability to degrade feed. The time x diet interaction is illustrated in Figures 1 & 2. The DM and CP degradability values of the HD diet appeared to change relatively little over time, whereas values for the LD diet appeared to increase up to the age of 12 weeks in the case of CP degradability.

In a degradability study with weaned calves, Vazques-Anon *et al.* (1993b) reported age, feed and feed x age interaction effects for the percentage of substrate remaining after 24 h from soybean meal, heat treated soybean meal, corn distillers grain and corn gluten feed. In contradiction with results from the present study, they reported no age effect on the rate of disappearance or on the percentage DM and CP remaining after

24 h of incubation for the low degradable feedstuffs. The rate of disappearance for high degradable feedstuffs increased with age and therefore the percentage remaining after 24 h of incubation for these feeds decreased with age after weaning.

**Volatile fatty acids**

Data on selected VFA concentrations and ratios are presented in Table 3 and illustrated in Figures 3 & 4. The acetate, propionate and butyrate concentrations expressed as a percentage of total VFA concentration, and VFA ratios did not differ significantly between calves. There were significant differences between weeks for all the parameters. These were expressed as significant differences between several individual sets of weeks.

TABLE 3. Selected volatile fatty acid concentrations and ratios for veal calves from 8 to 20 weeks of age.

| Week | Acetate | Propionate | Butyrate | A : P | A : B | P : B |
|------|---------|------------|----------|-------|-------|-------|
|      | (mol / 100 mol) | | | | | |
| 8    | 49.50   | 33.79      | 10.73    | 1.46  | 4.64  | 3.16  |
| 9    | 51.11   | 36.35      | 7.48     | 1.42  | 6.84  | 4.86  |
| 10   | 52.37   | 27.75      | 13.11    | 1.90  | 4.00  | 2.13  |
| 11   | 52.04   | 29.76      | 11.29    | 1.77  | 4.62  | 2.64  |
| 12   | 54.43   | 29.11      | 10.44    | 1.88  | 5.22  | 2.79  |
| 13   | 56.35   | 27.53      | 9.76     | 2.09  | 5.78  | 2.82  |
| 14   | 54.46   | 30.62      | 9.34     | 1.79  | 5.84  | 3.28  |
| 15   | 52.56   | 29.74      | 11.44    | 1.77  | 4.61  | 2.61  |
| 16   | 52.95   | 30.36      | 11.18    | 1.74  | 4.75  | 2.72  |
| 17   | 52.93   | 26.37      | 14.11    | 2.01  | 3.76  | 1.88  |
| 18   | 53.56   | 23.81      | 15.99    | 2.26  | 3.35  | 1.49  |
| 19   | 54.68   | 26.12      | 12.52    | 2.10  | 4.38  | 2.10  |
| 20   | 52.44   | 27.19      | 13.72    | 1.94  | 3.83  | 1.99  |
| SEM  | 0.7786  | 0.7925     | 0.1967   | 0.0797 | 0.1189 | 0.0928 |
| P (calf) | 0.3783 | 0.4001   | 0.1490   | 0.3197 | 0.2028 | 0.4078 |
| P (week) | 0.0001 | 0.0001   | 0.0001   | 0.0001 | 0.0001 | 0.0001 |

A : P = acetate to propionate ratio; A : B = acetate to butyrate ratio; P : B = propionate to butyrate ratio
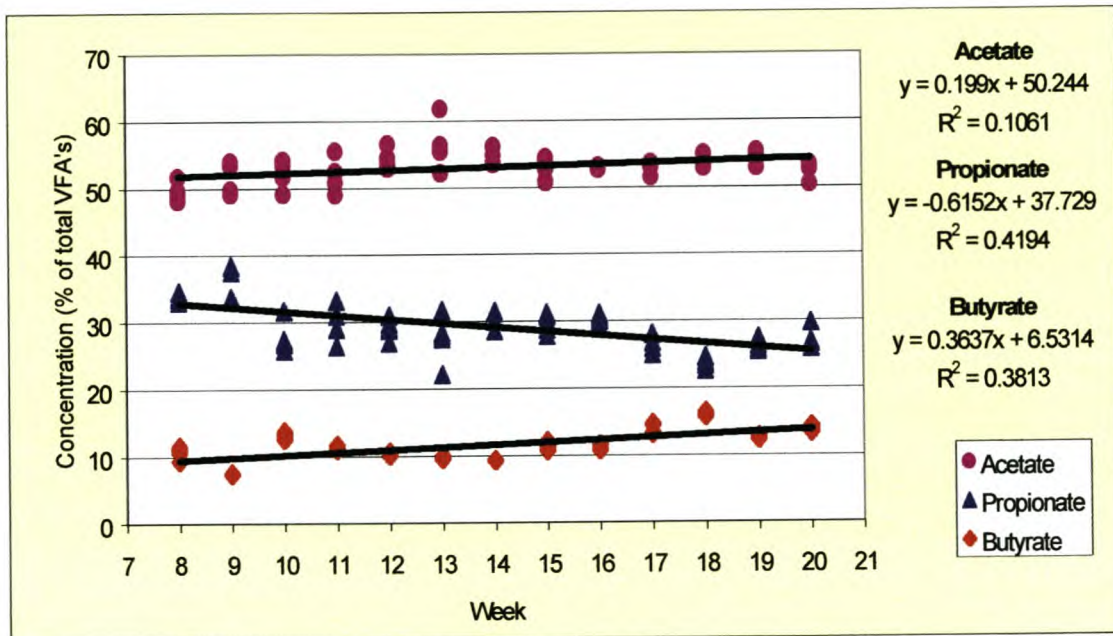
FIGURE 3. Volatile fatty acid concentrations in veal calves 8 to 20 weeks of age.

Acetate and butyrate concentrations appeared to increase slightly with age, while the propionate concentration appeared to decrease (Figure 3). This is in contradiction with Anderson *et al.* (1987a) who reported that the molar proportion of acetate decreased and that of propionate increased with age after weaning. The linear regression functions fitted to the data in the present study (Figure 3) did not show a high degree of goodness of fit as reflected in the low regression coefficients ($R^2$). No simple non-linear relationship for the selected VFA concentrations appeared evident.

Early research on VFA concentrations in the developing rumen of calves indicated an increase in total VFA concentrations with age, reaching constant levels at 6 (Lengemann & Allen, 1959) to 8 weeks of age (Hibbs *et al.*, 1956). Godfrey (1961) and Anderson *et al.* (1987a) reported constant levels of VFA concentrations for calves from 5 – 17 weeks of age, although a certain degree of fluctuation was noted. Quigley *et al.* (1985) also reported rumen VFA concentrations indicative of mature rumen function in calves at the age of 5 weeks. The molar proportions of acetate, propionate and butyrate were within the normal range for high concentrates. Mature fibrous forages result in VFA mixtures containing a high proportion (70 %) of acetic acid, while diets high in concentrate result

in an increase in the proportion of propionate at the expense of acetate (McDonald *et al.*, 1988).
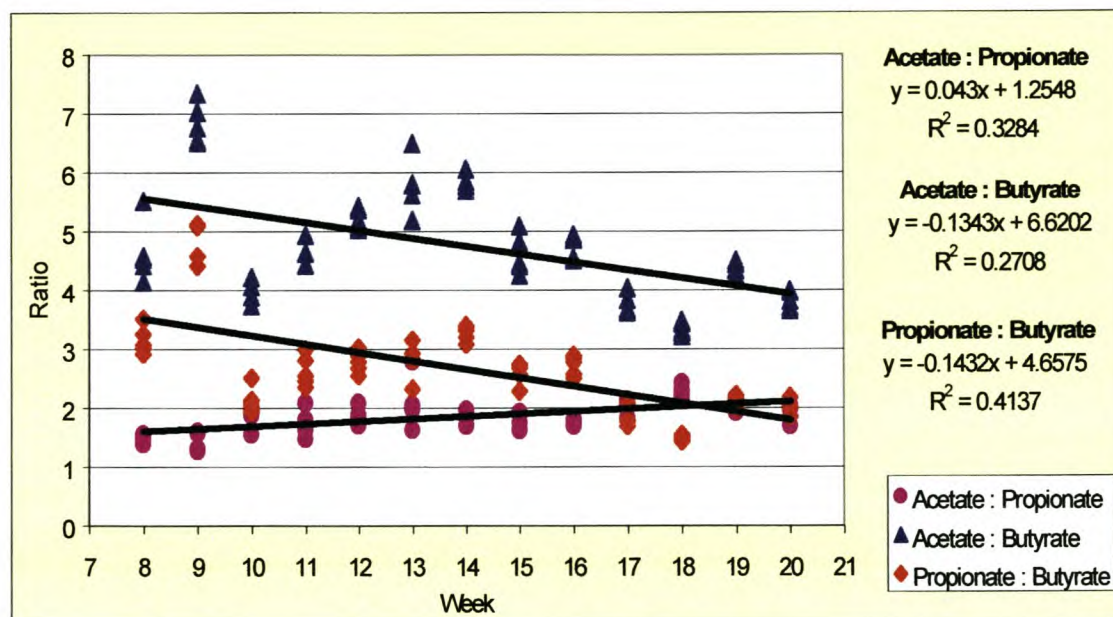


FIGURE 4.    Volatile fatty acid ratios for veal calves 8 to 20 weeks of age.

There appeared to be a decrease in the acetate:propionate and acetate:butyrate ratios and a slight increase in the butyrate:propionate ratio (Figure 4), but the low regression coefficients indicated a low degree of goodness of fit.  As in the case of the VFA concentrations, there appeared to be no simple non-linear relationship for any of the selected VFA ratios over time (Figure 4).  Anderson *et al.* (1987a) reported a decline in the acetate:propionate ratio as a result of the shift in the diet of calves from milk to fibre and starch.

**Rumen pH and ammonia-nitrogen concentration**

Data on rumen pH levels and $NH_3$-N concentrations are presented in Table 4 and illustrated in Figure 5.  There were no differences for rumen pH level or $NH_3$-N concentration between calves, but there were significant differences for both parameters between several individual sets of weeks.

TABLE 4. Rumen pH level and $NH_3$-N concentration in veal calves 8 to 20 weeks of age.

| Week | pH | $NH_3$-N (mM) |
|---|---|---|
| 8 | 5.06 | 0.33 |
| 9 | 5.07 | 2.97 |
| 10 | 5.04 | 3.98 |
| 11 | 5.47 | 1.98 |
| 12 | 6.60 | 2.97 |
| 13 | 6.55 | 2.06 |
| 14 | 5.91 | 2.18 |
| 15 | 6.15 | 2.77 |
| 16 | 6.21 | 3.93 |
| 17 | 5.75 | 1.51 |
| 18 | 6.01 | 2.57 |
| 19 | 5.86 | 2.16 |
| 20 | 5.60 | 2.53 |
| SEM | 0.1391 | 0.0519 |
| P (calf) | 0.9791 | 0.8280 |
| P (week) | 0.0001 | 0.0001 |

There appeared to be a quadratic response in the rumen pH level from 8 – 20 weeks (Figure 5). The moderate regression coefficient indicated that this relationship might be possible, but not necessarily definite. Godfrey (1961) reported a gradual increase in rumen pH from 5.2 at 1 week of age to 6.6 at 17 weeks of age. Vazques-Anon et al. (1993a) reported a similar increase of rumen pH to 6.0, which is more optimal for microbial proteolysis, by 17 weeks of age. An increase in the rumen pH level as the calves grew older may be due in part to an increased absorption of VFA as the rumen matured (Otterby & Linn, 1981), and possibly to increased salivary secretion (Anderson et al., 1987b).

No clear trend for rumen $NH_3$-N concentration over time was evident (Figure 5). There appeared to be a slight decrease in rumen $NH_3$-N from week 9 – 20, but the variation between weeks led to a very low linear regression coefficient (Figure 5). Godfrey (1961) reported a rapid increase in the rumen ammonia level up to 5 weeks of age and a subsequent gradual decrease until 17 weeks of age. Anderson et al. (1987b) and Vazques-Anon et al. (1993a) also reported a decrease in ammonia concentrations with an increase in age of calves. $NH_3$ absorption and its utilisation in the rumen are low during the first 3 weeks after weaning (Leibholz, 1975). The subsequent decrease in the

rumen $NH_3N$ concentration is possibly because of better utilisation of $NH_3$ by the micro-organisms and also because of the dilution effect from a larger total rumen volume (Vazques-Anon *et al.*, 1993a).



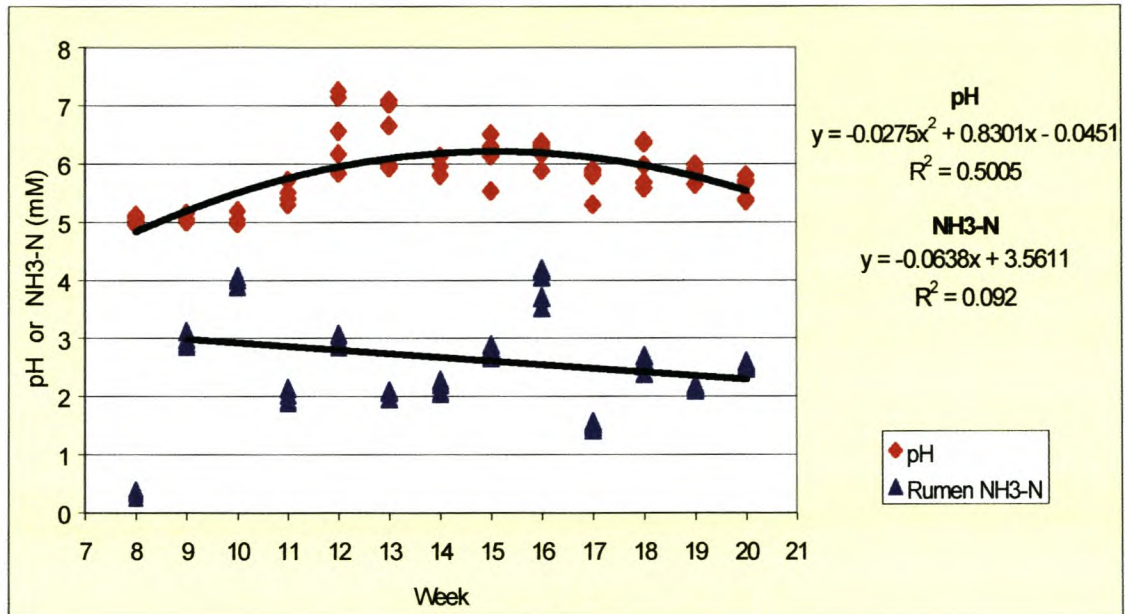FIGURE 5. Rumen pH level and $NH_3$-N concentration for calves 8 to 20 weeks of age.

## CONCLUSION

Results from this study suggest that DM and CP degradability values in calves up to the age of 11 – 12 weeks are not similar to that of mature cows. Thereafter the ability of calves to degrade feed approach that of mature cows. Degradability values obtained from experiments with mature cows should therefore not be used when calculating degradability parameters of diets for young calves. There is a need to establish a separate database of feedstuff degradability values for young calves.

Results on rumen pH levels, VFA and $NH_3$-N concentrations indicated that calves possess mature rumen metabolic function within 4 weeks after weaning. The fact that calves at this stage do not degrade diets to the same extent as mature cows, suggests that mature rumen metabolic function alone does not reflect a mature ability to degrade feedstuffs.

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# CHAPTER 4

# GENERAL CONCLUSION

The veal market in South Africa is not optimally utilised. The demand in South Africa is for darker meat and therefore it is not necessary to raise calves on expensive milk replacers for the entire period. Calves can be weaned at an early age and raised on high concentrate diets until 5 months of age for pink veal production. The quality of meat does not differ between liquid- and concentrate-fed calves. Since the concentrate diets are less expensive the only prerequisite would be that calf performance must be comparable to that obtained with liquid-fed calves.

Feeding diets high in undegraded dietary protein is believed to be necessary to provide the protein needs of the young growing calf in the preruminant and transition to ruminant stages. Results from the current study suggest that the level of crude protein degradability in starter diets have no effect on preweaning calf performance. In calves with live weights < 100 kg, the fact that the rumen may still be underdeveloped, could result in high degradable protein escaping from the rumen intact. Provided therefore that calves are allowed to consume starter diets *ad lib*. and that the crude protein content of starter diets meets generally accepted recommendations, it seems possible for them to consume enough dry matter to supply their needs for rapid growth from highly degradable protein sources.

According to our results crude protein degradability, however, appears to have an effect on feed conversion ratio in the finishing period. The period from 11 – 20 weeks of age (bodyweight of ± 100 kg to ± 200 kg) appears to be the time when supplying additional undegradable dietary protein may be warranted. The degree of protein degradability does not become a factor until the rumen function is sufficiently developed.

Results from the current degradability study suggest that dry matter degradability and crude protein degradability in calves to the age of 11 – 12 weeks are not similar to that of mature cows. Thereafter the ability of calves to degrade feed approach the capacity of mature cows. Degradability values obtained from experiments with mature cows should therefore not be used when calculating the degradability of diets for young calves.

Results on rumen pH levels, and volatile fatty acid and ammonia-nitrogen concentrations indicated that calves possess mature rumen metabolic function within 4 weeks after weaning. The fact that at this stage calves do not degrade diets to the same extent as mature cows, suggests that mature rumen metabolic function alone does not reflect a mature ability to degrade feedstuffs. The difference in rumen capacity and flow rates also plays a vital role.