

**THE EFFECT OF MILK VOLUME AND GROUP SIZE
ON THE GROWTH AND HEALTH OF DAIRY CALVES**

By

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Summary

THE INFLUENCE OF MILK VOLUME ON THE GROWTH AND HEALTH OF DAIRY CALVES

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The objective of the study was to investigate the effect of increased volumes of milk feeding as well as the effect different group sizes may have on the growth and health of Jersey calves. One hundred and twenty 3-day old heifer calves were randomly assigned to one of four treatment groups (30 calves each) and calves in groups one and two were assigned into four subgroups (15 calves each). Two groups received unrestricted volumes of milk (HMV), while two groups received restricted volumes of milk (RMV) during the preweaning period. The calves were weaned after 6 weeks. Feed intake, growth rates, health and cross-sucking behaviour of calves were monitored until all the calves in the trial reached at least 60 days of age. The effects of milk volume and group size on growth rates and the risks of diseases were evaluated using multiple linear- and logistic-regression models. During the milk-fed stage, the HMV calves drank 72% more milk than calves fed conventionally. Probably as a result of the much higher intake of milk, the HMV calves gained 154 g/d more weight than the RMV calves before weaning ($P < 0.001$), resulting in a 6.3 kg weight advantage on d 42. Birth weight of the HMV calves showed a strong linear relationship with milk intake (Pearson's $r = 0.696$, $P < 0.001$) and preweaning ADG (Pearson's $r = 0.426$, $P < 0.001$). Calves that were provided with more milk consumed less calf starter, reflecting effective substitution of milk with concentrate. However, after the calves were weaned, the difference in starter intakes disappeared. This resulted in no treatment differences in weight gains over the postweaning period, and on d 60 the HMV calves maintained an advantage in mean (\pm SD) body weight (67.6

± 7.9 kg vs. 60.8 ± 6.6 kg for the HMV vs. RMV calves). With the exception of keratoconjunctivitis, the incidence of disease in milk-fed calves was low and did not differ between HMV and RMV treatment groups. Days of treatment for keratoconjunctivitis (birth to d42) was significantly higher ($P < 0.05$) for calves in the large HMV group compared with calves in other groups. Smaller groups showed a higher incidence of diarrhoea during the preweaning period (OR = 3.23; $P < 0.01$). Over the whole trial period, the gain-to-feed ratio of HMV calves was 9.6% better than calves receiving restricted milk volumes. However, the cost per kg body mass gain was 12% higher for HMV calves. Cross-sucking observations showed that the incidence in the preweaning period differed greatly between the groups (1.7% vs. 75.5% for HMV vs. RMV groups; $P < 0.001$). During the last 10 days of the trial, this difference decreased, but was still significant (10.0% vs. 19.1% for HMV vs. RMV groups; $P < 0.001$). The conclusion was that the feeding of high volumes of milk to dairy calves will have a significant positive effect on growth rates, without compromising their health or the intake of solid food after weaning. Additionally it allows calves to be housed in groups with less problems of cross-sucking.

Table of Contents

Acknowledgements	I
Summary	Ii
Table of Contents	Iv
List of Figures	vii
List of Tables	Ix
List of Abbreviations	xi
Chapter 1 General Introduction	1
Chapter 2 Literature Review	3
2.1 Calf health in perspective	3
2.2 Colostrum and calf health	3
2.2.1 Importance of colostrum	4
2.2.2 The incidence of failure of passive transfer	4
2.2.3 Passive immunity and calf health	4
2.2.4 Measuring the level of passive immunity	5
2.3 Liquid feeds and feeding	6
2.3.1 Liquid feeds for calves	6
2.3.2 Calf growth and nutrient requirements	8
2.3.3 Effect of liquid feed volume on calf growth	9
2.3.4 Enhanced early nutrition programmes	10
2.3.5 Milk volume and calf health	11
2.3.6 Milk feeding to the calf with diarrhoea	12
2.3.7 Immune system responses to accelerated growth in calves	13
2.4 Rumen development and weaning	13
2.4.1 Normal rumen development	13
2.4.2 Rumen development in accelerated growth calves	15
2.4.3 Weaning and disease	15
2.5 Feed conversion and cost of calf raising	16
2.6 Long term effects of early life nutrition	17
2.6.1 Influence on successive growth	17
2.6.2 Effect on mammary development and milk production	18

2.7	Group size and calf health	20
2.7.1	Epidemiological aspects	21
2.7.2	Group size and disease	22
2.8	Cross-Sucking	23
2.9	Conclusion	23
Chapter 3	Research Questions	25
Chapter 4	Materials and Methods	26
4.1	Model system	26
4.2	Experimental design and project management	27
4.2.1	Experimental animals and staff	27
4.2.2	Sample size determination	27
4.2.3	Sampling and randomization	28
4.2.4	Calf management and housing	28
4.3	Experimental procedures and observations	29
4.3.1	Passive immunity	29
4.3.2	Feeding and feed intake	31
4.3.3	Measuring calf growth	33
4.3.4	Calf health assessment	34
4.3.5	Cross-sucking behaviour	36
4.4	Data analysis	37
4.5	Cost analysis	37
Chapter 5	Results	39
5.1	Passive immunity	39
5.2	Mortality	39
5.3	Milk intake and growth	39
5.3.1	Milk intake	39
5.3.2	Calf growth	41
5.4	Disease incidence and treatments	47
5.4.1	Keratoconjunctivitis	47
5.4.2	Diarrhoea	49
5.4.3	Other diseases	52



5.5	Dry feed and weaning	55
5.6	Feed conversion and cost	56
5.7	Cross-sucking	58
5.8	General observations	59
Chapter 6 Discussion		60
6.1	Feeding and feed intakes	60
6.1.1	Feeds and feeding schedules	60
6.1.2	Liquid feed intakes	62
6.1.3	Starter intake	63
6.2	Preweaning growth	63
6.3	Weaning	66
6.4	Postweaning growth	68
6.5	Effect of group size on calf growth	69
6.6	Calf health	70
6.6.1	Mortality and general calf health	70
6.6.2	Morbidity in preweaned calves	72
6.6.3	Morbidity in postweaned calves	76
6.7	Cross-sucking	76
6.8	Feed conversion, costing and long term effects	78
6.9	General observations and calf welfare	80
Chapter 7 Conclusion		81
References		84

List of Figures

Figure 4.1	Basic floor plan of calf paddocks used in the trial	29
Figure 4.2	Interpretation of test results of Quick Test Calf IgG Kit	30
Figure 4.3	Illustration of the Calf IgG test procedure	31
Figure 4.4	Calves receiving milk via plastic buckets and teats	32
Figure 4.5	Weighing of a calf in steel crate	34
Figure 4.6	A calf showing cross-sucking behaviour towards the belly of another calf	36
Figure 5.1	Mean daily milk intakes of calves in the RMV groups and two HMV groups	40
Figure 5.2	Mean BM of calves in different groups during the first 60 days of the trial	43
Figure 5.3	Scatter plot of average daily milk intake vs. birth mass of heifer calves receiving unlimited milk between day 4 and day 35 (Pearson's $r = 0.696$, $P < 0.001$)	45
Figure 5.4	Scatter plots to illustrate the association between birth mass and preweaning average daily gain of heifer calves receiving restricted milk volumes (Pearson's $r = 0.034$, $P = 0.797$) or receiving unlimited volumes of milk (Pearson's $r = 0.426$, $P < 0.001$)	45
Figure 5.5	Scatter plot of preweaning ADG vs. average daily milk intake of heifer calves receiving unlimited milk between day 4 and day 35 (Pearson's $r = 0.833$, $P < 0.001$)	45
Figure 5.6	Scatter plots to illustrate the association between day of birth and preweaning average daily gain of heifer calves receiving restricted milk volumes (Pearson's $r = 0.145$, $P = 0.270$) or receiving unlimited volumes of milk (Pearson's $r = 0.344$, $P < 0.01$)	46
Figure 5.7	The incidence (as a proportion of calves at risk) of keratoconjunctivitis in different groups during the trial	48



Figure 5.8	The incidence (as a proportion of calves at risk) of diarrhoea in different groups during the trial	50
Figure 5.9	Number of new cases of different calf diseases listed as “other” during the trial	53
Figure 5.10	The incidence (as a proportion of calves at risk) of diseases listed as “other” in different groups during the trial	53
Figure 5.11	Mean daily intake (kg/calf/day) of starter pellets of calves in different groups during the trial period	56

List of Tables

Table 2.1	Expected average growth rates for calves of various ages under different nutritional programmes (Drackley, 2008).	10
Table 2.2	Mean body mass for calves fed three levels of milk replacer (Macdonald and Penno, 1997)	18
Table 4.1	Time schedule and feeding of calves in high and standard volume groups during the preweaning period	31
Table 4.2	Composition of milk replacer and calf starter used during the trial	33
Table 4.3	Criteria for clinical diagnosis and therapeutic decisions used in clinical trial	35
Table 5.1	Mean daily milk intakes of calves in different groups during the trial	41
Table 5.2.	Means (\pm SD) of mass, wither height, average daily gain and wither height increase for calves in different groups during the trial	42
Table 5.3	Multiple regression models: effect of milk volume and group size on average daily gain (ADG) in dairy heifer calves, adjusted for birth mass, birth date, dam parity and sire	44
Table 5.4	Logistic regression models: effect of milk volume and group size on incidence of keratoconjunctivitis in dairy heifer calves, adjusted for birth date, dam parity and sire	48
Table 5.5	Median (interquartile range) treatment days for keratoconjunctivitis in dairy calves during the trial	49
Table 5.6	Logistic regression models: effect of milk volume and group size on incidence of diarrhoea in dairy heifer calves, adjusted for birth date, dam parity and sire	51
Table 5.7	Median (interquartile range) treatment days for diarrhoea in dairy calves during the trial.	52

Table 5.8	Logistic regression models: effect of milk volume and group size on incidence of diseases other than diarrhoea and keratoconjunctivitis in dairy heifer calves, adjusted for birth date, dam parity and sire	54
Table 5.9	Median (interquartile range) treatment days for diseases other than keratoconjunctivitis and diarrhoea in dairy calves during the trial.	55
Table 5.10	Average gain-to-feed ratio and cost analysis of calves in different groups over the study period	57
Table 5.11	Weighted percentages of calves showing cross-sucking behaviour in different groups	58
Table 6.1	The expected ADP allowable gain (according to standards of NRC, 2001) of a 30 kg Jersey calf receiving different volumes of whole milk or milk replacer	65
Table 6.2	Age, live weight and wither height of calves in the current trial compared to targets, according to Hoffman (2007), for Jersey heifers to calve at 2 years of age	69



List of Abbreviations

AG	Accelerated growth
ADG	Average daily gain
ADP	Apparent digestible protein
APT	Adequate passive transfer of immunity
BM	Body mass
CP	Crude protein
DM	Dry matter
DMI	Dry matter intake
ELISA	Enzyme-linked immunosorbent assay
FPT	Failure of passive transfer
G:F	Gain-to-feed ratio
HMV	High milk volume
Ig	Immunoglobulins
LW	Live weight
ME	Metabolisable energy
MI	Milk intake
MR	Milk replacer
OR	Odds ratio
RMV	Restricted milk volume
SD	Standard deviation
VFA	Volatile fatty acid
WH	Wither height
WHI	Wither height increase

Chapter 1

GENERAL INTRODUCTION

Because of the economics of scale and world wide labour shortages, the current trend in cattle production is to move towards larger production units and simplified labour requirements (Heinrichs, 1993). Group housing systems seem to be economically viable due to less space and labour consumption, and in many ways also involve improvement of welfare by allowing full social interactions and greater access to space (Weary, 2002; Lidfors & Isberg, 2003; Babu et al., 2004). However, group raising does have specific disadvantages. Among these are a better environment for the spread of pathogens (Barrington et al., 2002) and behavioural problems such as cross-sucking (Appleby et al., 2001). In group raising systems provision must be made for minimising agonistic behaviour (licking, cross-sucking, etc.) and improving calf health, performance and social behaviour (Boe & Faerevik, 2003; Jensen, 2003).

Our fast growing, high consuming and high producing cows may need a better start to life to be able to cope with modern production demands. Selection for high-appetite cows has lead to high-appetite calves. Some studies have found that calves will grow better and be healthier if fed according to appetite (Weary 2002, Hammon et al., 2002). This makes group raising of calves, where an unlimited volume of milk is fed to the calves once or twice a day (e.g. calfeteria system), an excellent option for large dairy farms today (Macdonald, 1999). However, unrestricted volumes of milk may also decrease starter intake and increase the total cost of calf raising (Jasper & Weary, 2002). There is also a perception among farmers and veterinarians that high milk volumes have a negative effect on calf health (Van Amburgh, 2003). It is therefore important that scientific based guidelines about health and behavioural problems in these systems must be in place.

The aim of the trial was to test the hypothesis that the feeding of high volumes of milk will have a significant effect on growth rate and cross-sucking behaviour of calves without compromising their health or the weaning process. The hypothesis also tested possible confounding influences of two different group sizes.

Specifically, the study objectives were to demonstrate the influence of an enhanced early nutrition programme due to the feeding of an increased volume of milk and milk replacer as well as the effect of group size on:

- Calf health indicators namely disease incidence, days of treatment and mortality rate.
- Calf growth indicators namely average daily gain (ADG) and wither height changes before (0 to 42 d) and after (42 to 60 d) weaning.
- Calf behaviour and more specifically the proportion of calves showing cross-sucking behaviour.
- The cost of calf raising as well as feed conversion rate.

The study will help to provide guidelines to commercial dairy farmers regarding the use of increased milk volumes under different systems of group raising. Additionally, the study will also lend itself towards follow-up studies to determine the long term effects of enhanced early nutrition on later growth, conception rates of heifers and milk production of first lactation cows. Such studies will bring into perspective the long term economic benefits (or drawbacks) of enhanced early nutrition in dairy calves.

Chapter 2

LITERATURE REVIEW

2.1 Calf health in perspective

There is no single best way to milk-rear calves as all sorts of combinations of feeding, housing and husbandry can be successful in the right hands and on the right farm (Moran, 1997). Mainly in an effort to improve cost efficiency, rearing systems have changed markedly in the last 30 years. Since the 1980's, there has been a move towards reduced milk and increased concentrates consumption in an effort to reduce labour requirements while promoting early rumen development (Macdonald, 1999).

The influence of the restriction of milk intake on calf health is still uncertain. Neonatal calf morbidity and mortality have been a problem for decades and are still a huge problem in the dairy industry. According to Lofstedt et al. (1999), the mortality risk of live-born neonatal calves at one month of age has been reported to range from 15 to 30%. Another survey reports average mortality rates of 6-13% for dairy calves (Losinger & Heinrichs, 1997). Over the past 10 years these figures have not improved although it is clear that some dairy producers do achieve much lower calf mortality and morbidity. Surveillance data of the National Animal Health Monitoring System in the USA showed that there was essentially no change from 1995 to 2001 in the overall mortality of pre-weaned calves (USDA, 2002).

Calf health is mostly at risk during the milk feeding period (Quigley, 1997). The majority of deaths are attributable to infectious diseases, with diarrhoea, pneumonia, and septicaemia being the most common. Neonatal calf diarrhoea is a multifactorial disease which, despite decades of research on the topic, remains the most common cause of death in young calves (Lorenz, 2006). Even though major risk factors have long been identified, the numbers of calf losses due to diarrhoea are not declining. Earlier studies in the USA found that enteric pathogens are associated with the death of up to 25% of the US calf crop annually (Hunt, 1985). Surveillance studies on dairies in Southern Germany showed that the incidence of diarrhoea in young calves was between 15.4%, and 28.4% when data were based on questionnaires filled in by the farmers (Kataridis, 2000; Biewer, 2001), and 47.8% when calves were examined by a veterinarian daily up to three weeks of age (Girnus, 2004).

2.2 Colostrum and calf health

2.2.1 Importance of Colostrum

Calves are born agammaglobulinemic, rendering ingestion and absorption of adequate amounts of colostral immunoglobulins (Ig) essential for establishing passive immunity. The transfer of immunoglobulins from the dam to the neonate, termed passive transfer, is important in the protection of neonates from infectious diseases. The primary immunoglobulin in bovine colostrum is IgG1, which is derived from maternal serum IgG1. Transport of immunoglobulins from the serum to the mammary gland (colostrogenesis) begins several weeks before parturition and reaches a peak one to three days before parturition in the cow (Barrington & Parish, 2001). Not only does colostrum provide vital antibodies (Ig), but it also provides significant amounts of non-immunoglobulin immune factors, e.g. leucocytes and cytokines, as well as nutrients that will support the calf during the first few days of life (Quigley & Drewry, 1998).

2.2.2 The incidence of failure of passive transfer

Failure of passive transfer (FPT) is not a disease, but a condition that predisposes the neonate to the development of disease. A number of studies showed that a high proportion of calves on calf ranches and dairies are colostrum-deprived (Gay et al., 1983; Fallon et al., 1987; Wilson et al., 2000), with as many as 35% of dairy calves suffering from FPT (Stott et al., 1979; Brignole et al., 1980). In the US, the National Dairy Heifer Evaluation Project (Wells et al., 1996) reported that more than 40% of all calves sampled between 24 and 48 h had IgG concentrations below the recommended level of 10 g/L and more than 25% of calves had levels less than 6.2 g/L. A New Zealand study showed that only 50% of calves have had sufficient colostrum within the critical first 24 h (Wesselink et al., 1999).

2.2.3 Passive immunity and calf health

The importance of adequate passive transfer (APT) for minimizing morbidity and mortality has been demonstrated in several studies (Quigley et al., 1997; Donovan et al., 1998; Weaver et al., 2000; Berge et al., 2005). Calves with inadequate passive transfer of immunity have an increased risk of death until at least 10 weeks of age

(Tyler et al., 1998). In an extensive study of USA dairy herds in 1992, it was found that over half of the death loss of calves can be attributed to FPT (NAHMS, 1992). Circulating IgG level has also been related to preweaning growth (Nocek et al., 1984) as well as to long-term performance of calves (Wittum & Perino, 1995).

2.2.4 Measuring the level of passive immunity

Several methods are available to measure Ig concentration in calf blood after absorption from colostrum. A serum IgG concentration of 10 mg/mL at 48 h of age can be used as the objective value for defining the threshold between APT and FPT (Gay, 1983). Blood samples can be taken from 24 h to about 7 d of age, depending on the type of test. The single radial immunodiffusion (currently the gold standard) and the enzyme-linked immunosorbent assay (ELISA) tests are the only ones that directly measure serum IgG concentration. Other tests, including zinc sulphate turbidity, sodium sulphite precipitation, whole blood glutaraldehyde coagulation, total serum solids by refractometry and gamma-glutamyl transferase activity estimate serum IgG concentration based on total protein concentration which is statistically associated with that of IgG. Several articles have been published that have fine-tuned these various testing methods to provide more accurate values for defining Ig levels in the neonate (Hudgens et al., 1996; Parish et al., 1997; Tyler et al., 1996).

Recently, a quick ELISA test (Midland Bioproducts Inc.) has become available for use in calves. This test measures a semi-quantitative immunoglobulin concentration and is similar to radial immunodiffusion in accuracy. In preliminary testing, this test seemed to perform similarly to the 18% sodium sulphite turbidity test or refractometry procedures (Doug Hostetler, personal communication to Weaver et al., 2000). Results of a study of Dawes et al. (2002) suggest that the immunoassay is an excellent tool for evaluating failure of passive immunity in neonatal calves. They concluded that its accuracy compared well with refractometry, sodium sulphite turbidity assays, and radial immunodiffusion, with the additional convenience of on-site results. Compared to indirect ELISA, Jensen et al. (2004) classified 87% of the samples correctly with this test kit, which is in accordance with other similar quick tests.

2.3 Liquid feeds and feeding

The feeding patterns currently used by most dairy producers (once or twice daily) contrast with the feeding strategies used for pigs, lambs, or beef calves. Although dairy calves are raised in a wide diversity of environment and housing conditions, they are the only neonatal animals that are purposely restricted with respect to milk or milk replacer intake from day of birth. Intensively reared dairy calves are typically separated from the cow within 24 h of birth and fed milk at only 10% of their body weight/day, about half of their voluntary intake (Appleby et al., 2001). These calves often have free access to solid feed (calf starter), but calves consume very little solid food within the first month of life and are unable to use these solids to compensate for restricted intake of milk (Jasper & Weary, 2002). In reality the conventional practice of feeding restricted amounts of milk to young calves does not take into account the energy levels that they require for growth and development (Diaz et al., 2001; Van Amburgh & Drackley, 2005).

2.3.1 Liquid feeds for calves

Liquid feeds used on dairy farms include whole saleable milk, non-saleable milk (unpasteurised or pasteurised), and milk replacers. All can provide excellent results and the decision to use one or another largely comes down to economics and convenience. Saleable milk usually has higher value when sold than when fed to calves, and most commonly either non-saleable milk or milk replacer is fed instead. Many producers in South Africa successfully use a pool of all non-saleable milk (colostrum, transition milk and milk withheld after drug treatment) to feed calves.

Although whole milk is an excellent feed from a nutritional point of view, the risks for ingestion of potentially pathogenic organisms in unpasteurised waste milk have been well documented (Selim & Cullor, 1997). On-farm pasteurisation has been shown to result in acceptable growth and health of calves under field conditions (Godden et al., 2005). In fact calves fed conventional milk replacer had significant lower rates of gain and a higher risk of disease than calves fed pasteurised non-saleable milk (Godden et al., 2005). Another concern with feeding waste milk is the likelihood that antibiotics are present. Antibiotic contaminated milk may alter gut microflora of calves and result in digestive upsets. Selim & Cullor (1997) reported that *Escherichia coli* cultured from waste milk samples was resistant to antibiotics

with less than one third of the samples being sensitive to tetracycline or ampicillin. Wray (1990) reported that milk containing antibiotics was less palatable, and that calves fed antibiotic milk had reduced rates of gain.

High-quality milk replacers are excellent liquid feeds for young calves and are less expensive per unit of nutrient supplied than whole saleable milk. Although more expensive than surplus colostrum, transition milk, or pasteurised waste milk, milk replacers have advantages in consistency of product from day to day, ease and flexibility of storage, and disease control. Maintaining as much consistency as possible in the diet for young calves minimizes chances for digestive upsets. This consistency may be particularly important when calves are raised under conditions of increased stress, such as cold or wet weather or during outbreaks of disease. Reports of poor calf performance on milk replacers most often are attributable to selection of an inappropriate or poor-quality milk replacer, to underfeeding the calf, or to an underlying disease or sanitation problem (Drackley, 2008). Milk replacer nutrient content should be matched to desired calf growth rates. For calves fed on conventional restricted feeding programs, a crude protein (CP) content of 20% to 22% maximizes lean tissue growth (Bartlett et al., 2006). For calves on more aggressive liquid feeding programs designed to increase early growth rates, CP must be in the range of 26% to 28% (National Research Council, 2001; Van Amburgh & Drackley, 2005). Critical factors in protein quality include digestibility, amino-acid content and balance, and the presence of anti-nutritional factors. The major variable that results in differences in energy content of milk replacers is fat. Increasing fat content (and thus energy content of the milk replacer) increases daily gains but may decrease starter intake (Kuehn et al., 1994). In isocaloric feeds or feeding programs, dietary fat is preferentially and efficiently deposited as body fat (Tikofsky et al., 2001). Lactose is more readily used as an oxidative fuel to drive protein synthesis. Under thermoneutral conditions, a lower fat content of the milk replacer favours lean tissue growth and development of starter intake. Higher fat contents may be more desirable in cold feeding conditions (Drackley, 2008).

Despite its importance and recognition as the most critical nutrient, water nutrition is often the weakest link on farms. Calves must be provided with additional free water beyond what is consumed as part of the liquid diet. Empty body tissue in young calves, the component deposited in greatest amounts during growth, consists of almost

75% water (Bartlett et al., 2006). Development of starter intake clearly depends on water intake (Kertz et al., 1984). Water intake does not cause scouring in calves; rather, calves that scour voluntarily increase their water consumption if it is available (Kertz et al., 1984). Water ideally should be available at all times to young calves, but as a minimum warm water should be offered after feeding and midday in cold climates. Separating water and dry feed containers physically or with dividers keeps calves from slopping water into the dry feed.

2.3.2 Calf growth and nutrient requirements

Growth in young calves before weaning mainly occurs in the skeleton and muscle systems. Tissue growth is largely a function of protein deposition in bone and muscle, with corresponding mineralization of the protein matrix in bone. Some fat (primarily phospholipids) is deposited as part of normal tissue growth, with additional surplus energy deposited within adipose tissues as triacylglycerol. Rates of growth expressed as the percentage increase of body size (either as mass or height) are highest at birth and decline steadily thereafter (Kertz et al., 1998). Early nutrition thus centres on provision of adequate energy and protein, while ensuring that all required minerals and vitamins are consumed in appropriate amounts and ratios to overall energy intake.

The NRC system (National Research Council, 2001) establishes requirements for metabolisable energy (ME) and protein as a function of body mass (BM) and rate of gain. In this approach, needs for maintenance are met first, with nutrients in excess of those needed for maintenance being available to support growth. The system is based on energy-allowable growth, with protein requirements calculated to provide the amino acids necessary to support the amount of growth allowed by available energy. For calves to grow faster, they need to be fed more milk or milk replacer, or, in older calves, they must consume more starter. Energy requirements for calves less than 100 kg BM are established in units of ME, which is determined by subtracting losses of energy in faeces, digestive gasses (methane), and urine from total feed (or intake) energy. In young calves, loss of energy in methane is negligible and is ignored (Holmes & Davey, 1976). Because most milk replacers are lower in fat content than whole milk, they have less ME per unit of solids (19.3 - 19.7 MJ/kg). Only milk solids consumed above maintenance can be used for growth.

Like energy, protein is required for maintenance and growth as a source of amino acids. Unlike energy, however, the protein requirements for maintenance are small (about 22 g/d for a 30 kg calf) and are not believed to be substantially altered by cold or heat stress. Protein requirements are mostly determined by the rate of growth. On average 188 g of protein are deposited for every kg of BM gain in calves, which would require 250 to 280 g of CP intake from milk replacer (National Research Council, 2001). The practical outcome of these principles is that body deposition of protein in the growing calf is essentially a linear function of dietary protein intake over the range of protein intakes that would be encountered in practice. This effect is unrelated to energy intake of the calf as long as sufficient energy is available to use the additional protein to deposit body protein. CP content of the diet appears to approach a plateau at about 27% of the DM, which is similar to the CP content of whole milk solids (about 26% on a DM basis; Blome et al., 2003).

2.3.3 Effect of liquid feed volume on calf growth

A calf kept with its dam will suckle on average seven to ten times a day, and consumes much more milk and gains weight at several times the rate of conventionally reared calves (Metz, 1987; Albright & Arave, 1997; Flower & Weary, 2001). Another method of increasing milk intake is to provide milk for ad libitum (unrestricted) consumption through a teat. This system allows calves to express their natural sucking behaviour (Hammell et al., 1988), and may improve digestion (de Passille´ et al., 1992) and weight gain (Marshall & Smith, 1970). Several authors showed that during the first weeks of life, calves with this type of feeding consumed a lot more milk and gained weight at more than twice the rate of conventionally fed controls (Appleby et al., 2001; Jasper & Weary, 2002).

Wolf et al. (2005) showed that calves provided with unlimited milk for only 4 h/d (two feedings of two hours each) compensate by changing their milk feeding behaviour and achieve similar weight gains as animals fed milk continuously through the day. One disadvantage of ad libitum milk feeding to calves in groups is that there is great variation in growth (Tomkins, 1991), merely because larger and stronger calves tend to obtain more milk.

In conclusion, it is clear that during the early liquid feeding period, growth of calves fed milk or milk replacer is directly proportional to the amount of liquid provided

(Khouri & Pickering, 1968, Hodgson, 1971; Huber et al., 1984). In contrast, in restricted liquid feeding programs, growth rates are directly proportional to the amount of calf starter consumed (Kertz et al., 1979).

2.3.4 Enhanced early nutrition programmes

Programmes of so-called “accelerated growth” (AG) or “intensified nutrition” are outgrowths from research by the laboratory of Dr. Mike Van Amburgh at Cornell University (Diaz et al., 2001). In those experiments, calves were fed much larger (approximately twice the dry solids intakes) amounts of a specially designed, high-protein milk replacer to gain over 0.9 kg/day during the first few weeks of life. Drackley (2008) summarized the expected growth rates of calves under different nutritional programmes of accelerated growth (Table 2.1).

Table 2.1 Expected average growth rates for calves of various ages under different nutritional programmes (Drackley, 2008).

Program and stage	Expected growth rate (kg/d)	
	d 0-21	Overall
Conventional milk replacer, ad libitum starter, d 0–42	0.2 - 0.3	0.5 - 0.6
Accelerated milk replacer, ad libitum starter, d 0–42	0.5 - 0.6	0.6 - 0.8
Moderate milk replacer, ad libitum starter, d 0–42	0.4 - 0.5	0.55 - 0.65
Weaned calves, ad lib. starter, d 56–84	-	0.85 - 0.95

Research of Blome et al. (2003) showed that increasing crude protein in milk replacers from 16 to 26% and the corresponding increase in protein:energy ratio linearly increased growth rates of calves, even though total energy deposition remained unchanged. Increased average daily gains were shown to reflect increases in structural tissues and lean tissue deposition, not additional fat deposition. As growth rate increased, calves also grew larger at a more efficient rate and retained a greater proportion of ingested protein at the same metabolisable energy intake. These results indicate that manipulating milk replacer composition can markedly alter the characteristics of body growth in young dairy calves. Because this system of calf

raising is closer to the natural system of calf raising where the calf drinks much more milk from its dam, Drackley (2001) suggested that it should more properly be called intensified feeding or enhanced early nutrition.

Van Amburgh (2003) illustrates further that traditional milk replacer formulations were designed to be fed at close to labelled rates. Exceeding that level of intake in all cases except for milk replacers with crude protein (CP) percentages of 28% (or above), leads to a deficiency in protein allowable gain. The result is an accumulation of fat and a reduction in protein deposition and feed efficiency (Bartlett, 2001, Diaz et al., 2001). Fat levels of 15% to 20% appeared adequate for normal growth and development in Holstein milk fed calves (Tikofsky et al., 2001). Excess fat content of the liquid diet will also suppress intake of calf starter (Kertz et al., 1979; Kuehn et al., 1994).

Research at the Virginia State University (Mowrey, 2001; Bascom, 2002) showed that Jersey calves may require slightly higher levels of fat in milk replacer. Mowrey (2001) fed Jersey and Holstein calves MR (20% fat and 20% CP) reconstituted to 12.5% solids at a rate of 31% of metabolic BM. The diets were designed according to NRC (2001) standards to support 227 g of ADG and calves should have gained more than 8 kg BM over the duration of the experiment, the Jersey calves gained less than 5 kg BM. This indicates maintenance energy requirement of Jersey calves may have been higher per unit of metabolic BM than Holstein calves and that NRC (2001) equations for maintenance energy may not be appropriate for Jersey calves. Increasing the feeding rate and/or increasing the caloric content of the liquid diet may improve the growth of young calves and this may be particularly important in Jersey calves. Bascom (2002) concluded that it is advisable to include 25% fat in a MR for Jersey calves to provide additional energy for times of stress such as disease, environmental stress, or other stresses that would increase maintenance energy requirements.

2.3.5 Milk volume and calf health

Despite the greater growth rates obtained with increased liquid feeding, most producers continue to feed restricted quantities of milk to calves. This is largely because of the perception that increased milk intake leads to a higher incidence of diarrhoea, or that it leads to reduced intakes of solid feed, resulting in reduced weight gains after weaning. Earlier reports on the feeding of large amounts of milk to young

calves did show an increase in cases of diarrhoea (Khouri & Pickering, 1968; Grieve et al., 1972 ; Hodgen, 1971; Stiles et al., 1974; Bøe & Havrevoll, 1988), but the reason for this increase was not clear. Similar results were found with veal calves, which were fed ad libitum from an automatic milk feeder in groups of 40 to 50 calves (Tomkins, 1991). Other reports showed that merely feeding more milk or more of a high-quality milk replacer does not necessarily cause scouring (Mylrea, 1966; Marshall & Smith, 1970; Huber et al., 1984; Nocek & Braund, 1986; Vieira et al., 2008). Huber et al. (1984) found that scour scores were not different for calves receiving 6.7 kg milk per day vs. calves receiving 4.1 kg milk per day. However, rectal temperature and the number of days medicated were higher for the high milk intake group. Jasper & Weary (2002) observed no difference in diarrhoea (low incidence in both groups) between calves receiving ad libitum milk and calves receiving standard milk volumes. According to Drackley (2001), anecdotal evidence from producers that have implemented enhanced early nutrition programmes suggests that AG calves may be more resistant to early-life scours and respiratory disease. The calves that do become sick are also able to recover more quickly without major impacts on growth rates during illness. However, these improvements in health have not been documented through controlled research.

It seems that programmes of increased liquid feeding have resulted in variable effects on calf health. The level of management has a profound effect on calf morbidity and mortality (Curtis et al., 1985; Waltner-Toews et al., 1986a, 1986b), and the interaction of management and milk volume is still unclear. The occurrence of calf scours, unless a poor-quality milk replacer or contaminated milk is fed, depends more on the load of pathogenic micro organisms in the calf's environment (Roy, 1980a) and on the degree of environmental stress of calves (Bagley, 2001).

2.3.6 Milk feeding to the calf with diarrhoea

Traditionally, continued feeding of milk to diarrhoeic calves was thought to aggravate diarrhoea. The thought was that malabsorption would provide substrate to the intestinal flora which would result in fermentation of undigested nutrients and thus lead to osmotic diarrhoea (Bywater, 1980; Demigne et al., 1980). Consequently withdrawal of milk during the first days of diarrhoea was recommended. In later studies, secretory mechanisms were found to play the major role even in diarrhoea

caused by viruses or cryptosporidia (Doll, 1994). Evidence was produced that diarrhoeic calves have sufficient capacity to digest milk (Heath et al., 1989; Garthwaite et al., 1994). The ingestion of adequate amounts of milk has also no negative effect on the duration of diarrhoea (Deischl, 1992; Niemeyer, 1992; Doll, 1994; Lorenz, 2006).

2.3.7 Immune system responses to accelerated growth in calves

Enhanced early nutrition programmes may offer the possibility of improved health through better development or function of the immune system (Drackley, 2001). Evidence in the scientific literature to support this idea is limited, but is suggestive of possible benefit (Williams et al., 1981; Griebel et al., 1987; Pollock et al., 1993; Nonnecke et al., 2000; Foote et al., 2003). Other studies did not support this viewpoint. In a trial in the early 90's, Pollock et al (1994) showed that a high level of nutrition (approximately twice maintenance requirements) caused decreased serum antibody responses and decreased antigen titres. Nonnecke et al. (2003) showed that blood mononuclear leukocytes from calves on intensified diets produced less interferon- γ and more inducible nitric oxide, suggesting that increased dietary energy and protein affects specific aspects of leukocyte function associated with cell mediated immunity. In a later study, Foote et al. (2005) found that feeding calves an intensified milk replacer was associated with a decreased proliferation of certain cells of the immune system. In a subsequent study, Foote et al. (2007) found that higher growth rate was associated with decreased viability of T cell populations.

2.4 Rumens development and weaning

2.4.1 Normal rumen development

With respect to the nutrient requirements of the calf, three phases of development related to digestive function are recognised (Davis & Clark, 1981).

- Liquid feeding phase. Essentially all of the nutrient requirements are met by liquid feeding.
- Transition phase. Liquid diet and calf starter both contribute to nutrient requirements of the calf.

- Ruminant phase. Post weaning when all nutrients are derived from solid feed.

The primary stimulus for development of the ruminal absorptive epithelium into its characteristic papillae are the volatile fatty acids (VFA's) - particularly butyric acid and to a lesser extent propionic acid (Sander et al., 1959; Lyford, 1988; Heinrichs & Lesmeister, 2005). Therefore, rumen papillae development is primarily controlled by chemical, not physical means. Because grains provide fermentable carbohydrates that are fermented to propionate and butyrate, they are a good choice to ensure early rumen development. On the other hand, volume and musculature develop in response to physical bulk in the rumen and not fermentation products. The structural carbohydrate of forages tend to be fermented to a greater extent to acetate, which is less stimulatory to ruminal development. However, it does promote the growth of the muscular layer of the rumen and helps to maintain the health of the epithelium (Flatt et al., 1958; Tamate et al., 1962). As the papillae become functional and are able to absorb VFA, the pH of the rumen stabilises and begins to increase. Until the pH is stable at greater than 6.0, the ability of cellulolytic bacteria to thrive is limited (Drackley, 2008). The challenge from a nutritional standpoint is that the rumen and post-ruminal digestive tract must be sufficiently developed to use starches and other non-fibre carbohydrates and non-milk proteins to support nutrient needs for maintenance and growth after weaning. It appears that rumen epithelial development requires about three weeks, regardless of when the process is initiated (Pollard et al., 2003).

As calves begin to consume dry feed, the rumen develops in microbial population and absorptive function (Drackley, 2008). Whereas nearly all of liquid diets will by-pass the rumen after swallowing, essentially all solid feed will go to the rumen and be subjected to the normal fermentative processes. The source of nutrients begins to change from products absorbed directly from digestion of milk or MR to a combination of dietary ingredients and end products of microbial fermentation (VFA's, microbial protein). The efficiency of use of nutrients during this transition is not greatly different between calves consuming only liquid diets and those consuming both starter and milk or MR (Davis & Drackley, 1998; National Research Council, 2001). The only differences arise from the digestibility and metabolisability of dietary ingredients. Until calves are weaned the same principles of nutrient requirements can

be applied to calves during this transition period. Fermentation of dry feeds to the VFA butyrate and propionate is necessary to drive growth and differentiation of the ruminal absorptive epithelium (Heinrichs & Lesmeister, 2005). Increasing starter intake sustains a self-perpetuating feed-forward regulatory system that improves the ability of the calf to make use of the end products of the intake. It should be obvious that the key limiting factor here is getting calves to eat the dry feed at an early age, assuming that the starter is formulated with easily fermentable ingredients. Palatability and acceptability of the starter formulation to the calves therefore assume paramount importance.

2.4.2 Rumen development in accelerated growth calves

From the discussion above, it is reasonable to believe that, if high liquid feed intakes would lead to substitution of calf starter, rumen development would be delayed. A number of studies showed that high intakes of milk often lowers consumption of solid food during the milk feeding period (Hodgson, 1971; Leaver & Yarrow, 1972 ; Roy et al., 1971; Bøe & Havrevoll, 1988; Jasper & Weary, 2002). This may explain the lower postweaning gain of calves reared on high milk volumes compared to those fed less milk (Dallzell & Allen, 1970 ; Le Du et al., 1978a, 1978b). Church et al. (1980) concluded that calves fed lower levels of milk consume more starter and therefore, compensate for the lower nutrient supply from milk. Studies from Pollard et al. (2003) indicate that starter intake curves for AG calves are similar to those of early weaning controls, but are delayed by about two weeks. Kristensen (2007) compared rumen environment and development in calves with different milk allowances. They concluded that the ruminal environment of young calves fed a barley-based starter concentrate was characterized by a low ruminal pH and high VFA concentration regardless of the milk allowance. Lengths of ruminal papillae in the atrium and ventral ruminal sac were not affected by treatment.

2.4.3 Weaning and disease

Although weaning can sometimes be associated with an increase in incidence and severity of disease (Roy et al., 1971 ; Jenny et al., 1981), calves are normally less susceptible to disease after weaning (Quickley, 1997). The effects of weaning on disease incidence have been considered to be mediated by nutritional change (Pollock

et al., 1993; 1994) and stress-induced effects on the immune system (Kelley, 1980; Stinnett, 1983; Griffin, 1989).

2.5 Feed conversion and cost of calf raising

Acquiring healthy replacement heifers that calve between 22 and 24 mo of age represents a major expense to dairy operations. Because of the nature of replacement heifer management, a dairy operation must invest feed, labour, and capital for 22 to 24 mo without receiving any realized benefits. Heinrichs (1993) reports that heifer rearing represents the second largest expense on a dairy operation, approximately 20% of the total operation expenses, following only feed costs for the milking herd. Consequently, minimizing heifer rearing investments while maintaining the productive integrity of the replacement heifers should be the primary objective of replacement heifer management (Hoffman & Funk, 1992). Research by Lin et al. (1987) demonstrated the lifetime productive benefits of replacement heifers calving between 22 and 24 mo of age. Heifers calving at 23 mo acquired 107 more days of productive life and yield 1475 more kg of milk, than replacement heifers calving at 26 mo. Although earlier calving age has been proven beneficial (Lin et al., 1987), Clark et al. (1962) determined that mass at calving influences first lactation milk yield four times more than age at calving alone. It has been shown that optimum calving mass of a first calf Holstein heifer is between 544 and 567 kg to maximize first lactation milk yield (Keown & Everett, 1986). For replacement heifers to achieve optimum calving mass, an increase in average daily gain (ADG) is required. However, the temporal pattern and composition of increased growth rates in heifers may be critical (see paragraph 2.6).

Studies showed that proportional rates of increase in wither height (WH) and body mass (BM) are highest during the first two mo of life (Kertz et al., 1998) and that the feed cost per increase in wither height is lowest during this period. Efficiency of dietary protein use for body protein gain is also highest in young calves and decreases with body size (Gerrits et al., 1996). Furthermore, a number of studies showed that mass gain to feed intake ratios (G:F) were improved by increasing the rate of gain of milk-fed calves (Diaz et al., 2001; Bartlett, 2001). Therefore ad libitum or increased liquid feeding programs have resulted in greater growth rates and improved feed efficiency during the liquid feeding period (Khoury & Pickering, 1968, Hodgson,

1971; Huber et al., 1984; Nocek & Braund, 1986; Richard et al., 1988). It is, however, generally accepted that the feeding of ad libitum milk to calves will lead to higher total feed costs (Moran, 1997). This is because of the relatively high market value of milk compared to dry feed.

2.6 Long term effects of early life nutrition

The productivity of the dairy herd can be negatively impacted by impaired growth and health of calves. Decreased milk production of animals that experienced chronic illness as baby calves, spread of infectious diseases from calves to adult cows, increased veterinary costs and the limited opportunity for genetic selection due to high calf mortality may all play a role (Heinrichs, 1993; Cady & Smith, 1996).

2.6.1 Influence on successive growth

Studies indicate that underfeeding of calves during the first few weeks of life has a permanent adverse effect on the animals and that compensatory growth does not occur. Everett & Jury (1977) found that underfeeding of calves during the first 16 weeks of life will reduce mature body weights. Mac Donald & Penno (1997) showed that if calves are lighter at weaning because of a lowered feeding level, then they are unlikely to make up that deficit. Three groups of calves were offered allowances of either 396 g (Low), 445 g (Medium) or 605 g (High) milk replacer per calf per day plus ad libitum dry feed (Table 2.2). At 135 d of age, the difference was still 7.0 kg and 7.3 kg ($P < 0.05$). Compensatory mechanisms therefore failed to fill the difference. All heifers should reach minimum live weights before mating, as lighter animals have lower conception rates. Mating Friesians at less than 260 kg and Jerseys at less than 200 kg will lead to more calving difficulties (Moran, 1997). Higher feeding levels after mating often result in heavier calves at birth, overconditioned heifers, and more calving problems with little improvement in milk yield during the first lactation (Moran, 1997).

Table 2.2 Mean body mass for calves fed three levels of milk replacer (Macdonald & Penno, 1997).

Age of weighing	Milk Replacer allowance		
	High	Medium	Low
Day 65	69.8	66.2	66.3
Day 86	83.4	79.9	78.7
Day 135	108.2	100.9	101.2

For calves receiving higher volumes of milk, the greatest difference in growth rates will occur during the preweaning period. However, available research data suggest that the growth advantage can be maintained after weaning with a likelihood of a decrease in time to target breeding age (Riordan & Everett, 1972; Jasper & Weary, 2002).

2.6.2 Effect on mammary development and milk production

The effect of increased levels of prepubertal nutrition on subsequent milk production depends largely on the time of increased nutrition and on the composition of growth.

High growth rates in the middle and late prepubertal period.

The adverse effects of allowing heifers to become overconditioned has been known for some time. The period that is most negatively affected by an increased BM gain appears to be between 90 and 300 kg of BM (Sejrsen et al., 1982). Excess prepubertal energy intake can have negative effects on the development of the mammary parenchyma (ductular epithelial tissue) (Sejrsen, 1978, Sejrsin et al., 1982, 1998; Harrison et al., 1983). Other studies (Swanson, 1960; Gardner et al., 1977; Little & Kay, 1979) have indicated that when prepubertal growth rates of heifers increase, time to conception, age at first calving and milk yield during first lactation decrease. Swanson (1960), using Jerseys and Little & Kay (1979), using British Friesians demonstrated a 15 to 48% decrease in first lactation milk yield by heifers fed high energy diets for higher rates of BM gain. Research showed that heifer prepubertal

growth rates above 900 g/d sometimes resulted in a decrease in first lactation milk yield (Sejrsen et al., 1982, Van Amburgh et al., 1998). Other research (Waldo et al., 1986) has found no effect on first lactation milk yield with similar growth rates during the prepubertal period.

Much of the concern about pre-breeding BM gain stems from early research that suggested impairment of mammary epithelial development (measured as decreased DNA accumulation in mammary parenchymal tissue) and decreased milk production during first lactation when heifers grew too rapidly (Sjersen, 2005). This negative effect was associated with greater deposition of fat in the developing mammary gland, and interpreted as a competition for tissue establishment with potential epithelial tissue. It is logical to assume, however, that if fat is being deposited in the mammary gland it also is likely being deposited elsewhere throughout the body. The negative consequences of overconditioning in cows of any age are clearly documented and well accepted. Decreased milk production is therefore likely attributable to general over-fatness (National Research Council, 2001).

Recent studies (Meyer et al., 2006a, 2006b) at Cornell University have established that the rate of DNA accumulation in mammary parenchymal tissue is determined by chronologic age rather than rate of BM gain. Heifers were grown at rates of 650 g/d or 950 g/d and harvested at the same BM in 50 kg intervals. Heifers grown more rapidly reached the same BM at a younger chronologic age; for example, heifers grown more rapidly reached puberty approximately 108 days earlier than heifers grown more slowly. At the same BM, heifers grown at the higher ADG had less parenchymal DNA in the mammary glands, consistent with previous research. The rate of accumulation of DNA (mass per day) was similar between groups, however, and there was no impairment of parenchymal proliferation rates measured *in vivo*. The rates of parenchymal DNA accumulation in heifers are thus independent of plane of nutrition and are determined by chronologic age. These studies have effectively refuted the long-held dogma that higher growth rates before puberty are detrimental to future production by impairing mammary development. As long as diet formulation provides sufficient metabolisable protein to favour lean tissue gain and minimize overall body fattening, there is little basis for concern about target growth rates between 0.8 and 0.9 kg/d to breeding age.

High growth rates during the preweaning period

Several studies showed that mammary parenchyma growth was enhanced with increased feeding rates of milk fed calves (Sejrsen et al., 2000; Brown et al., 2002). This increase in mammary development was not observed once the calves were weaned. This indicates that the calf's mammary system is more sensitive to level of nutrition prior to weaning and that the enhanced mammary development cannot be "recovered" once the animal is weaned. Three studies showed that an increase in nutrient intake of calves prior to 56 d of life resulted in an increase in milk yield during the first lactation (Bar-Peled et al., 1997; Foldager & Krohn, 1994; Foldager et al., 1997). When compared to restricted fed calves (birth to 42 or 56 d of life), ad-libitum milk feeding of calves resulted in an additional 450 to 1360 kg of milk during the first lactation.

It is clear from the preceding discussion that although effects of preweaning and postweaning live weight (LW) gain have been controversial, the preponderance of data indicate that relatively high growth rates in dairy heifers are safe provided that metabolisable protein supply is adequate as predicted by National Research Council (2001). The important concept is that diet formulation must provide sufficient metabolisable protein to favour lean tissue gain and minimize overall body fattening.

2.7 Group size and calf health

In South-Africa and other southern hemisphere countries, group raising of calves without automatic feeders has become more popular, especially among larger producers. In the northern hemisphere, group pens equipped with automatic milk-feeding systems are increasingly being used (Svensson & Liberg, 2006). In Finland, the number of calves less than 8 weeks of age reared in groups is increasing, especially in beef production (Hepola et al., 2006). From a welfare perspective, group housing is in many ways preferable to housing in single pens. It enables the calves to have full social interactions with other calves, while the often larger accessible area per animal improves the calf's opportunities to satisfy the needs for motion and play (Webster et al., 1985; Jensen, 1999; Babu et al., 2004). According to the European Union's Animal Welfare law, calves must be raised in groups after 8 weeks of age (Hepola et al., 2006). Group housing also helps farmers rationalise livestock feeding and management. However, the preference for individual rearing stems from the idea

that individually housed calves have a lower disease incidence, a reduction in behavioural problems and higher weight gains (Weary, 2002).

2.7.1 Epidemiological aspects

The two important pillars of infectious biosecurity (Barrington et al., 2002) are:

1. Reducing the likelihood of introduction of an infectious agent into a group (external biosecurity) and
2. Reducing the likelihood of its transmission when present (internal biosecurity).

Most enteric agents are transmitted predominantly by the faecal-oral route from the faeces of infected animals to the mouths of susceptible animals and very efficiently so. Most calf pathogens, e.g. *Salmonella* spp., survive well under most environmental conditions, where they can be transmitted indirectly by contact with contaminated faeces, fomites such as equipment or mechanical vectors such as flies (Foster & Spector, 1995). All the common agents causing neonatal calf diarrhoea are often present to some degree in the calf's environment, so the collective strategy for minimizing exposure of calves to pathogens should be focused on decreasing exposure to faecal contamination (Barrington et al., 2002).

As a result of the increase in competition, calves in larger groups increase their drinking speed and milk intake when compared with calves in smaller groups (Barton & Broom, 1985; Jensen, 2004; Jensen & Budde, 2006). Hepola et al. (2006) found that group rearing may facilitate calves to start eating and ruminating earlier than individual housing. Group-housed calves started to eat hay at an earlier age and also consumed more hay than individually housed ones. Group-housed calves also start eating concentrates earlier than individually reared calves (Warnick et al., 1977). Social facilitation may have play a role in both hay and starter intakes. This earlier intake of dry feed led to group-housed calves starting to ruminate at an earlier age than calves in individual pens (Babu et al., 2004). However, any subsequent effect on growth rate of calves in larger groups may be confounded by impacts of group size on stress and disease.

There are two aspects of space that have to be considered for group-housed calves: space allowance per animal and total space available in the pen (Jensen & Kyhn, 2000). For larger group sizes, more shared space is available in the pen at a given space allowance per animal, and the effect of space allowance per animal has to be considered in relation to group size. Crowding of calves should be minimized to lessen the effect of neurogenic stress. Although limited research in this area has been undertaken in calves, it is logical to assume that calves will react similarly to other mammals under such stressful situations, with a resultant increase in plasma cortisol levels and subsequent immune suppression. Additionally, crowding will unquestionably also increase exposure to enteric pathogens (Barrington et al., 2002).

2.7.2 Group size and disease

The risk of infection is higher in groups, because the calves are in close contact with each other (Steenkamer, 1982). Evidence that members of larger groups are at increased risk of diarrhoea is contained in a study of Michigan dairies, which found that the incidence of calf diarrhoea was approximately proportional to herd size (Frank & Kaneene, 1993). Another disadvantage of large groups is that detection of illnesses may be delayed and the therapy must then be more intensive (van Putten, 1982). Heinrichs (1993) reported that stress factors related to calf housing environment have an impact on incidence of disease. This hypothesis was supported by the increased level of mortality that was observed in calves housed in groups before weaning (NAHMS, 1996). Calves fed in groups before weaning are more likely to transmit disease by calf-to-calf contact. These findings suggest that group sizes should be minimized as much as feasible. Nevertheless, not all research showed a negative relationship between group size and disease incidence, especially where computer controlled feeding is used (Kung et al., 1997; Hepola, 2003).

Respiratory tract disease is mostly caused by bacterial infections, and bacterial transmission by aerosol and direct contact is well documented. Once in the herd, bacterial infections are likely to spread to all calves within a shared air volume. Due to the close contact between many calves, group-raised neonatal calves are at a higher risk of transmission of respiratory disease (Callan & Garry, 2002; Svensson et al., 2003). Factors that contribute to transmission include the number of animals, relative animal density and housing facilities. Several studies showed that there is an increased

risk of exposure and respiratory disease where an increased number of calves are housed together (Losinger & Heinrichs, 1996; Willard et al., 1996; Svensson & Liberg, 2006). Svensson & Liberg (2006) concluded from their own and previous studies that housing calves in groups of under 10 calves is preferable from a health as well as a growth perspective. It must nevertheless be emphasized that most of these studies were done in indoor housing facilities in the northern hemisphere and conclusions are not necessarily relevant to calves in outdoor paddocks in South Africa.

2.8 Cross-Sucking

Cross-sucking is an abnormal behaviour defined as non-nutritive sucking directed toward another calf's head or body (Lidfors, 1993). Studies have shown that calves are very motivated to suck for 5-15 minutes after a milk meal and will suck anything available to satisfy this need (de Passillé, 1992; de Passillé et al., 2001, 2004; de Passillé & Rushen, 1997; Jensen, 2003). When calves are raised in groups, they will suck each other and this behaviour may be intensified as the calves grow older. Cross-sucking in calves is considered undesirable as it may eventually lead to so called intersucking in heifers and cows. The negative consequences of intersucking are urine drinking, decreased growth rates, milk stealing, mastitis, udder malformation and injury in the recipient heifer (Lidfors & Isberg, 2003). Intersucking is therefore classified as aberrant agnostic behaviour (McGlone, 1986).

According to de Passillé (2004), there is a growing body of evidence that indicates that milk stealing or intersucking are related to hunger during the weaning process. Heifers that perform intersucking are often underfed at weaning. Appleby et al. (2001) confirmed that hunger throughout the milk-fed stage would stimulate cross-sucking. They concluded that ad libitum feeding of calves from artificial teats allows calves to be housed in groups without the problem of cross-sucking.

2.9 Conclusion

As is evident from the preceding discussion, an abundance of research remains to be conducted on both biological and management issues associated with enhanced early nutrition programmes for heifer calves. There is currently still a lot of conflicting evidence regarding the effect of accelerated growth (AG) on calf health and immune

system development. Relationships among nutrition, growth and immune function seem to be fertile areas for future research. Interactions between AG and management practices that influence the calf's health through the load of pathogenic microorganisms in the environment or through the degree of environmental stress, are still unclear. Other unclear issues include the proper composition of milk replacers and starters to achieve and maintain early growth advantages and the feeding strategies for liquid and starter feeds to allow trouble-free weaning and rumen development. There is also a lot of uncertainty about short term costing versus long term economic benefit of these systems through its influences on subsequent health, growth rate, reproduction and milk production.

Chapter 3

RESEARCH QUESTIONS

The following research questions are relevant for dairy calves under typical South-African circumstances:

1. Does the feeding of unrestricted volumes of milk lead to more health problems?
2. Does the feeding of unrestricted volumes of milk lead to significant benefits in terms of increases in weight gain and wither height?
3. Will the feeding of unrestricted milk volumes have a negative effect on the weaning process because of a decrease in starter intake?
4. What will be the influence of the feeding of unrestricted milk volumes on behavioural problems like cross-sucking?
5. Does group size have a confounding influence on the effects of unrestricted milk volume feeding?
6. What will be the difference in cost effectiveness and feed conversion rate between calves receiving standard milk volumes and calves receiving unlimited milk volumes?

Chapter 4

MATERIALS AND METHODS

4.1 Model system

The target population for the trial was young heifer dairy calves housed in groups. The study was done on a dairy farm in the Southern Cape area of South Africa. The Weideland farm operates a seasonal Jersey herd with the main calving season in January and February each year. This is normally a dry time of the year with healthy calving conditions. The calf raising team consists of four labourers and one supervisor, all of them women.

Calves on Weideland are born in outside paddocks in a relatively large, dry area. The dry and hot conditions during January help to ensure a clean and hygienic calving area. Calves are collected in the calving pen every 6 h. Just after birth all calves receive a plastic ear tag for identification. Colostrum is then hand-fed to all calves that do not show obvious physical signs of sufficient intake through natural sucking. At least 3 L of colostrum is fed to all calves within the first 24 h, with the first feeding (2 L) within 8 h after birth. Calves with a suckle reflex receive colostrum with a plastic bucket and teat. Otherwise colostrum is force-fed with a stomach tube. In general there is enough first day colostrum available to feed the calves for the first 2 to 3 d. All fresh colostrum is pooled together before usage. During the first 3 d, all calves are housed indoors in individual hutches while they are trained to drink milk via artificial teats. When calves are 3 d old, they are tattooed in both ears, thermally dehorned with an electric dehorner and supernumerary teats are removed with a pair of scissors. No vaccination is done on any calf during the first 3 mo of age.

The three day old calves are placed in groups in outside paddocks. Because of the seasonal calving pattern, no other calves had been raised in the paddocks during the previous 6 mo. All the paddocks are provided with water and shade. Special care is taken to provide clean milk or colostrum to the calves. All of the teats of colostrum cows are washed and dry wiped with a disposable paper towel before milking. Milk or reconstituted milk replacer (MR) is transported in 200 L drums before feeding to the calves. All milk feeding is done with 3 L plastic buckets with teats while calf starter is

fed in plastic troughs. During feeding times, each group of calves is taken to a central milk feeding area where 20 calves receive milk simultaneously.

4.2 Experimental design and project management

4.2.1 Experimental animals and staff

On the Weideland farm, approximately 250 heifer calves were expected during the 2008 calving season (sampling frame), with about 150 heifer calves expected before the end of January. The first 120 female calves born were used in the study. At two days old, calves were evaluated on clinical signs and appetite by the veterinarian in charge. Calves were excluded from the trial if they:

- showed any sign of clinical disease and/or
- were too weak to stand up, and/or
- did not drink at least 3 L of colostrum milk in a 24 h period.

Normal staff of Weideland farm were used in the trial, under supervision of the main researcher. The promoters, professors D.C. Lourens and P.N. Thompson also paid visits to the farm and were monitoring and advising the project.

4.2.2 Sample size determination

The number of calves per treatment group was determined through power analysis (Snedecor & Cochran, 1980) for the response variable of number of treatment days.

The assumptions for determining sample size were:

- Level of significance (Type I error, α) = 0.05
- Type II error rate (β) = 0.10
- Mean number of morbid days for high milk volume calves : 3
- Mean number of morbid days for standard milk volume calves: 5
- Sample Standard deviation = 2 d.

Using the equation given by Snedecor & Cochran (1980), the sample size (n) was calculated as:

$$n = 2((Z_{\alpha} - Z_{\beta})S)/(X_t - X_c)^2$$

Where $Z_{\alpha} = 1.96$ for $\alpha = 0.05$

$Z_{\beta} = -1.28$ for $\beta = 0.1$

$X_t =$ expected mean outcome in the treated group = 3

X_c = expected mean outcome in the control group = 5

S = estimated common standard deviation for the two groups = 2

Therefore, the estimated sample size was calculated as 21. Allowing for a 5% loss to follow up, 30 calves were allocated to each of the four blocks with a total of 120 calves in the trial.

NOTE: Although a further increase in group size would have led to an increase in the power of the statistical test, it would also have led to an increase in the age variation within the groups.

4.2.3 Sampling and randomization

This trial was designed as a parallel-group prospective field trial with two main treatment effects: feeding of high milk volumes and housing in large groups. The hallmarks of a clinical trial are randomization of subjects to the treatment groups and objective assessment of outcomes using blinding (Institute of Medicine, 2001). The intent of randomization is to eliminate selection bias and to minimize the possibility that unmeasured covariates bias or confound the study. Block randomization was used, whereby each calf in a block of eight (determined by order of calving, i.e. eight consecutively born calves), was randomly allocated to one of the four treatment groups, and calves in groups one and two into four subgroups. The following groups were therefore achieved:

- **Group HL:** High milk volume, large group size. One group of 30 calves.
- **Group HS:** High milk volume, small group size. Two subgroups of 15 calves each.
- **Group RL:** Restricted milk volume, large group size. One group of 30 calves.
- **Group RS:** Restricted milk volume, small group size. Two subgroups of 15 calves each.

4.2.4 Calf management and housing

As soon as calves were collected from their dams, they were weighed and their wither height was measured. A preliminary health survey was performed on all the calves on day three. Any calf that showed any sign of disease or a lack of appetite at this stage,

was not included in the trial (see exclusion criteria earlier). It is also at this time that blood samples were collected from calves to test for failure of passive transfer (FPT). At 4 d of age, calves were randomly allocated into outside paddocks in groups of 15 or 30. The surface area of each of the small paddocks was 400 m² while that of each large paddock was 800 m² (See Figure 4.1).

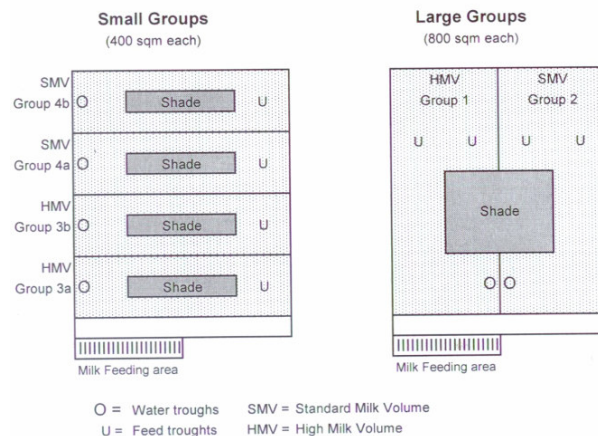


Figure 4.1 Basic floor plan of calf paddocks used in the trial.

4.3 Experimental procedures and observations

The first calf was born on the 22nd of December 2007, while calf no. 120 was born on the 24th of January 2008. Although the various groups did not start with the intended number of calves in a group, the proportion of calf numbers in the different groups was constant throughout the trial. Calves remained in different groups until the 26th of March, when all the calves had reached at least 60 d of age. All experimental procedures were performed under protocol number V066/07, as approved by the Animal Use and Care Committee of the University of Pretoria, and the Research Committee of the Faculty of Veterinary Science.

4.3.1 Passive immunity

It was important to measure the level of passive immunity of each calf in the trial in order to take into account the confounding effect of FPT on calf morbidity and mortality. Radial immunodiffusion is currently the gold standard for measurement of serum IgG concentration. Although this method is suitable for herd monitoring purposes, its use in this trial was compromised by the availability of a laboratory and

the extended time required for results to be available. Calves were therefore tested with the Quick Test Calf IgG Kit (Midland Bioproducts Inc, Boone, IA) between 48 and 72 h after birth (see earlier). The whole blood immunoassay kit consists of a 4-mm lateral flow membrane strip enclosed in a plastic test device. Blood was collected from the vena jugularis of each calf in a 4 ml Vacutainer[®] tube with EDTA anti-clotting agent. Each tube was marked with the number of the corresponding calf. Standard test procedures were done on blood samples of all the calves according to directions of manufacturers. During the procedure, 200 μ L of diluted blood was expressed into the sample well of the cassette. After 20 min the test results were interpreted. In a properly functioning test, a line appeared at the Control (C) position of the results window. If the sample IgG concentration was ≥ 10 mg/mL (1,000 mg/dL), a single red line developed at the “C” position. This was an indication of adequate passive transfer (APT). On the other hand, if the sample IgG concentration was < 10 mg/mL, two lines developed on the membrane strip; One at the “T” position and one at the “C” position. Regardless of the line intensity, a faint line at the “T” position was interpreted as an inadequate level of IgG, indicating FPT (see Figures 4.2 and 4.3).

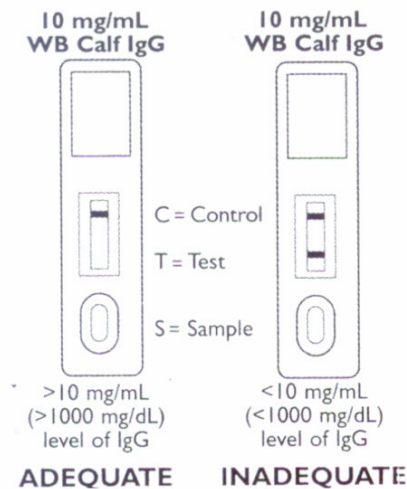


Figure 4.2. Interpretation of test results of Quick Test Calf IgG Kit.



Figure 4.3 Illustration of the Calf IgG test procedure.

4.3.2 Feeding and feed intake

Although all the calves were group housed, they received milk or milk replacer (MR) individually according to their block’s criteria and age. The liquid feeding schedule of the calves in the trial is illustrated in Table 4.1.

Table 4.1 Time schedule and feeding of calves in high and restricted volume groups during the preweaning period.

Time from birth	Restricted Milk Volume (Groups RL & RS)	High Milk Volume (Groups HL & HS)
< 8 h	2 L fresh day 1 Colostrum	
1-3 d	1 st day Colostrum: 2 L twice a day	
4–7 d	Colostrum* : 2 L twice a day	Colostrum* : Unlimited twice a day
8-21 d	Milk & MR: 2 L twice a day	Milk & MR: Unlimited twice a day
22-35 d	MR: 4 L once a day	MR: Unlimited once a day
36-42 d	MR: 2 L once a day	MR: 3 L once a day
42-60 d	Weaned with only calf starter and water available ad libitum to all the calves.	

* Day 2-3 colostrum pooled together.

Milk was fed via plastic buckets fitted with one teat each throughout the whole 42 d (Figure 4.4). The calves were fed from 05:00 in the morning and from 15:30 in the afternoon. Up to d 21, calves received milk twice a day. Calves in the restricted milk volume (RMV) groups (RL and RS) received 2 L of milk at feeding times, while calves in the high milk volume (HMV) groups (HL and HS) received an unlimited volume of milk during feeding time. Unlimited was defined as all the milk the calf was able to drink during milk feeding time plus another two minutes during which time no further milk was consumed. After 14 d, calves were gradually adapted from fresh milk to a commercially available milk replacer over a 3 d period (Table 4.2). From day 22 until weaning, milk was fed only once a day in the afternoon. From day 22 until day 35, the calves in RMV groups received 4 L of milk replacer once a day (in the afternoon), while calves in the HMV groups received an unlimited volume of milk replacer at feeding time (also only in the afternoon). From day 36 to day 42, calves in the RMV groups received 2 L of MR per day while those in the HMV groups received 3 L of MR per day. Dilution of MR was done in such a way to produce a powder-water ratio of 1:6 and therefore a 14.3% concentration of milk replacer.



Figure 4.4 Calves receiving milk via plastic buckets and rubber teats.

Calf starter pellets as well as fresh drinking water were available ad libitum to all the calves throughout the trial. The chemical composition of the milk replacer and calf starter used is shown in Table 4.2.

Table 4.2 Composition of milk replacer and calf starter used during the trial.

Ingredients	Milk Replacer ¹	Calf Starter ²
Dry Matter %	96	90
Protein %	25	18
Fat %	25	3
Calculated Metabolisable Energy (MJ/kg)	20	10
Calcium %	0.9	0.8
Phosphorus %	0.7	0.5
Additives	Lacalocid sodium Probiotic	Monensin

Meadow Milk Replacer[®] (25% Protein, 20% Fat)(V20041; Act 36/1947)
Meadow Complete Calf 18%[®] (V12012; Act 36/1947)

The intake of milk and/or MR of the individual calves was measured to the nearest 200 mL on a daily basis. Because of group housing, individual feed intakes of starter pellets were impossible to measure. However, the weight of calf starter consumed for each of the four groups was measured and recorded daily. From this it was possible to estimate the mean starter intake of calves in each group.

4.3.3 Measuring calf growth

All calves were weighed immediately after birth, at day 42 (weaning) and at day 60. All calves were also weighed on a weekly basis (every Wednesday) for the duration of the trial. Weighing was done at 09:00 in the morning, about 2 h after feeding was complete. Wither height (WH) was measured at the same time. When measuring the WH, the calf was put on a flat surface. Wither height was defined as the vertical distance from the standing surface to a horizontal line where the dorsal margin of the calf's scapula lies just below the skin. It was measured with a measuring tape to the nearest 5 mm. An electronic scale (Ruddweigh) with accuracy to the nearest 200 g

(<50 kg) or the nearest 500 g (>50 kg) was used. During a weighing session, each calf was put inside a crate with load bars connected to the floor and connected to the scale (Figure 4.5).



Figure 4.5 Weighing of a calf in a steel crate.

4.3.4 Calf health assessment

All calves received a recorded visual health appraisal twice daily by a veterinarian. Calf health was assessed visually using objective criteria of appetite, faecal consistency, hydration status, respiratory effort, and attitude (Table 4.3). Subsequent to these evaluations, calves were designated as "normal" or "to be treated". Treatments were administered by the veterinarian in charge of the study. Calves received treatment based on the health category strategy as described in Table 4.3. Complete records of all treatments and clinical signs were kept.

Calves were removed and censored from the study when their clinical status appeared critical and they were not expected to survive. These calves were quarantined in hutches elsewhere on the farm and treated with antibiotics and IV fluids according to the standard farm policy. The decision to remove an animal from the study was made by the veterinarian in charge and was done to ensure compliance with international animal welfare standards. Objective criteria were:

- o No appetite (compulsive liquid feed intake) for more than 24 h with no sucking reflex and/or

- o Calf unable to stand (very weak, unresponsive or comatose) for more than 24 h and/or

Table 4.3 Criteria for clinical diagnosis and therapeutic decisions used in clinical trial.

Health Criteria	Clinical Signs	Score	Treatment Choices
Faecal consistency	Formed	0	-
	Semi-formed	1	-
	Watery	2	Antibiotics ¹ Supportive care ²
	Watery with mucus	3	Antibiotics ¹ Supportive care ²
	Blood in faeces ⁴	4	Antibiotics ¹ Supportive care ²
Respiratory effort	Normal	0	-
	Unilateral cloudy discharge	1	-
	Repeated coughing	2	Antibiotics ¹ Supportive care ²
	Heavy breathing	3	Antibiotics ¹ Supportive care ²
Hydration Status	Normal	0	-
	Dehydration 2 – 7 %	1	Oral Fluid Therapy
	Dehydration > 8 %	2	IV Fluids
Attitude	Alert	0	
	Depressed	1	Flunixin
	Non-responsive	2	Flunixin, IV Fluids
Appetite	Normal	0	-
	Consuming < standard ³	1	Clinical examination
Navel cord	Normal	0	-
	Swelling/heat/pain (Omphalitis)	1	Iodine(Topical), Penicillin G
Signs of Septicaemia	No signs	0	-
	Swollen joints	1	Antibiotics ¹ Supportive care ²
	Depressed, Weak	2	Antibiotics ¹ Supportive care ²
	Meningitis, coma	3	Antibiotics ¹ IV Fluids
Eyes	Normal	0	-
	Tears in eyes.	1	Topical antibacterial cream
	Inflammatory eyes (Keratoconjunctivitis)	2	Subconjunctival antibiotic injection.

¹ **Systemic Antibiotics:**

- Intramuscular injections: Amoxicillin (Noroclav[®], Norbrook), Sulphadiazine (Norotrim 24[®], Norbrook) or Danofloxacin (Advocin[®], Pfizer AH).
- Sulphadimidine sodium (Sulfazine[®], Bayer AH) or Neomycin (Biosol 70%[®], Pfizer AH) per os if watery diarrhoea within first 3 days of life.

² **Supportive Care:**

- Oral Electrolytes (Meadow Electrolyte[®]) if appetite score 1;

- Flunixin if early morning rectal temperature > 39.4 °C;
- Activated charcoal if bloat with diarrhea
- ³ **Standard Milk Intake** :Any calf not drinking at least 4 litres of milk per day.
- ⁴ **Bloody Diarrhoea**: If symptoms of coccidiosis, use Diclazuril (Vecoxan[®], Bayer AH).
 - o Dehydration status of more than 8% with slow recovery (>12 h), indicated by enophthalmos > 4 mm, cervical skin-tent duration > 6 s and cool to cold extremities.

4.3.5 Cross-sucking behaviour

The cross-sucking behaviour of the calves was recorded at milk feeding time in the evenings by means of direct observations. Cross-sucking was defined as any sucking action of a calf directed toward another calf's head or body. The recordings of calves in a group began the minute the calves in the group finished drinking, and continued for another 30 min. Only the total number of calves in each group that showed cross-sucking behaviour was recorded. Further recording of cross-sucking was done at postweaning in the mornings for 30 min at a time.

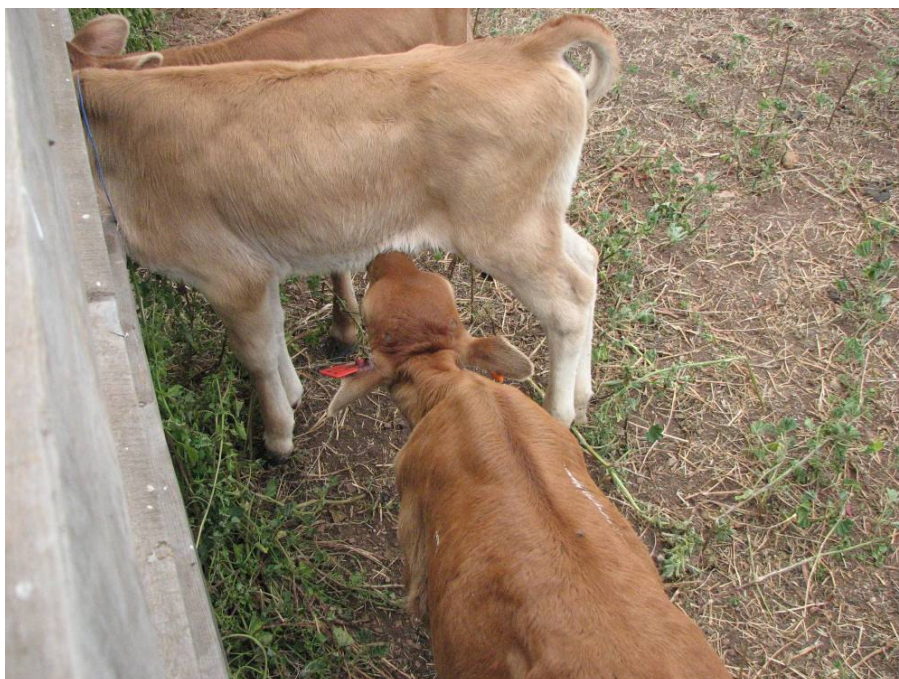


Figure 4.6 A calf showing cross-sucking behaviour towards the belly of another calf.

4.4 Data analysis

All data were recorded and entered into a spreadsheet program (Excel, Microsoft Corp., Redmond, WA) and analysed using a statistical software package (Stata 10.0, StataCorp, College Station, TX, USA). Hypothesis testing was done to compare data of different groups of animals. The level of confidence was set at 95%. Data from calves with FPT were removed from the analysis. The primary outcome measures were mortality, morbidity, survival, average daily mass gain (ADG), feed intake (liquid feed and calf starter) and cross-sucking behaviour. Initial bivariable tests were done to compare data between groups. One-way analysis of variance (ANOVA) was done to compare means of continuous data (weight measurements; milk intake). When comparing proportions (morbidity rates; cross-sucking), Fisher's exact test was used. These tests were followed by multiple regression to adjust for confounding. For each of the continuous outcomes (ADG, treatment days, feed intake), multiple linear regression was done with milk volume, group size, birth weight, birth date, dam parity and calf sire as predictors. For the binary outcomes (morbidity; cross-sucking), multiple logistic regression was used, with the same predictors as above.

A calf was considered diseased when it received an antibiotic treatment, irrespective of the route of administration. Calf health was evaluated using 2 outcomes, namely incidence of disease and the number of days of treatment. Three disease categories were used namely keratoconjunctivitis, diarrhoea and other diseases. In order to adjust for possible confounding of other independent variables, multiple logistic regression analysis was done on incidence data as described above. Non-parametric testing (Kruskal-Wallis one-way ANOVA on ranks) was done to test for equality of medians of treatment days between groups.

4.5 Cost analysis

A cost analysis spreadsheet was developed with the use of a spreadsheet program (Excel, Microsoft Corp., Redmond, WA). Costs were calculated on a per head basis over the whole trial period. Special emphasis was placed on cost per unit increase in bodyweight. Only variable costs were included in the economic analysis. Direct variable costs were feed costs and cost of treatment. Because of the relatively low mortalities, mortality costs were ignored, but other variable costs were spread over

surviving calves. Feed costs include cost of milk and starter pellets. Medicine costs were calculated at list drug prices for January 2008 (Carrington, 2007). The prices used in this analysis were as follows:

- Milk and MR at R3.00 per litre of milk or per litre of reconstituted MR
- Calf starter pellets at R3.00 per kg as fed
- Cost of treatment at R30 per treatment for diarrhoea and other diseases and R5 per treatment of keratoconjunctivitis.

Labour costs were not included in the model because of the assumption that no difference exists between labour costs of different groups. The extra labour for treatment of sick calves was included in the treatment costs.

Chapter 5

RESULTS

One hundred and twenty calves were enrolled in the study over a 13 week period. The first calf was born on the 22nd of December 2007 and the last measurements were taken on the 26th of March 2008. During the trial, the weather was dry except for 2 days of light rain. Night time temperatures ranged between 10 and 15°C, and daytime temperatures were between 25 and 40°C.

5.1 Passive immunity

The whole blood IgG level of each calf in the trial was measured in order to take into account the confounding effect of FPT on calf morbidity and mortality. Of the 120 calves tested with the Midland Test Kit, only two calves showed FPT, namely calf number 08 004 and calf number 08 029. Both calves were allocated into group HS. Therefore, in order to eliminate this potential confounding, the growth and morbidity data of these two calves were not included in the statistical analysis of the study.

5.2 Mortality

Of the 120 calves that were enrolled in the study, 114 calves finished the trial. Only one calf died during the preweaning period, due to foreign body pneumonia. During the postweaning period, one calf died and another four calves were removed from the study. All these calves were suffering from an outbreak of meningo-encephalitis (MEC). The mortality due to MEC was restricted to calves from the RMV groups.

5.3 Milk intake and growth

5.3.1 Milk intake

The temporal pattern of mean daily milk intake (MI) for the different groups is presented in Figure 5.1 and in Table 5.1. Daily milk consumption for the HMV calves increased gradually from 6.4 L on day four to 7.5 L/calf/d (HL group) and 7.8 L/calf/d (HS group) on day 20. The mean daily MI for the HMV calves was 7.3 L/calf/d during this period. As soon as the milk schedule was changed to once a day feeding (day 21), the average MI dropped by approximately 1 L/calf/day ($\pm 18\%$). This average slowly increased again to 7.1 L/calf/d (group HL) and 7.4

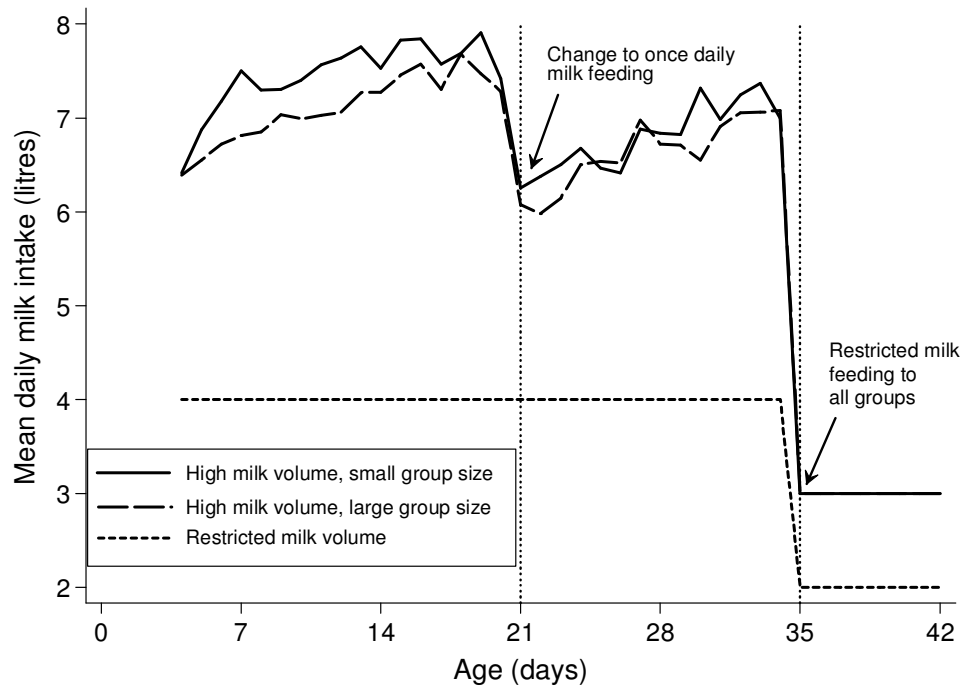


Figure 5.1 Mean daily milk intakes of calves in the RMV groups and two HMV groups.

L/calf/d (group HS) on day 34. The mean daily milk intake (HMV group) during this period was 6.7 L/calf/d. Over the whole 30 d period (d4-34), calves with unrestricted MI consumed about 3 L (or 75%) more milk per day than the calves that received restricted volumes. Within the HMV groups, milk consumption of calves in smaller group sizes was approximately 4% higher than that of calves in larger groups (7.16 vs. 6.89 L/calf/d). This difference of 0.27 L/calf/day did not achieve statistical significance. However, the variation in individual daily milk intakes of calves in the HMV groups was high. During the period of unrestricted milk feeding (d4-34), the minimum average daily intake was only 4.77 L/calf, while the maximum average daily intake was 9.22 L/calf. The HMV calves consumed on average 241 L of milk prior to weaning (237 and 246 L/calf for groups HL and HS), compared to 140 L for the RMV calves.

Table 5.1 Mean daily milk intakes of calves in different groups during the trial.

Parameter	High milk volume		Restricted milk volume
	Large group HL (n=29)	Small group HS (n=28)	Both groups RL,RS (n=60)
<i>Period of unrestricted milk feeding for HMV groups (d4-34)</i>			
Mean daily intake (L/calf/d)	6.89	7.16	4.0
Day to day variation (L/d/calf)			
- SD	0.43	0.49	
- Max mean intake/group/d	7.68	7.90	
- Min mean intake/group/d	5.98	6.26	
Calf to calf variation (L/calf/d)			
- SD	0.81	0.89	
- Max mean intake/calf/d	8.68	9.22	
- Min mean intake/calf/d	5.46	4.77	
<i>Period of twice a day feeding (d4-20)</i>			
Mean daily intake (L/calf/d)	7.12	7.45	4.00
<i>Period of once a day feeding (d21-34)</i>			
Mean daily intake (L/calf/d)	6.63	6.80	4.00
<i>Period of restricted milk feeding for all groups (d35-42)</i>			
Mean daily intake (L/calf/d)	3.00	3.00	2.00
<i>Total milk-fed period (d4-42)</i>			
Mean daily intake (L/calf/d)	6.24	6.47	3.68
Mean total milk intake (L/calf)	237	246	140

5.3.2 Calf growth

The effect of milk volume and group size on the growth of calves is illustrated in Table 5.2. During the preweaning period (d4-42), the ADG for calves in the HMV groups was significantly higher ($P < 0.01$) than the ADG for calves in the RMV groups (0.71 ± 0.10 kg/d and 0.75 ± 0.11 kg/d vs. 0.57 ± 0.06 kg/d and 0.59 ± 0.10 kg/d for the HL and HS groups vs. RL and RS groups). However, the greater

ADG of especially group HS was not reflected in the preweaning WH changes of the calves, although the preweaning wither height increase (WHI) of group HL was significant greater than the WHI of group RL ($P < 0.01$) and group RS ($P < 0.05$). There were no significant differences between the groups in the ADG or WH changes from weaning until day 60. However, the differences in preweaning growth resulted in significant differences in growth rate over the whole period from day 0-60 ($P < 0.05$).

Table 5.2. Means (\pm SD) of mass, wither height, average daily gain and wither height increase for calves in different groups during the trial.

Variable	High milk volume		Restricted milk volume	
	Large group HL (n=29)	Small group HS (n=28)	Large group RL (n=29)	Small group RS (n=26)
Live mass (kg)				
Birth	22.9 ^a \pm 3.8	25.4 ^a \pm 3.6	24.0 ^a \pm 3.7	23.8 ^a \pm 3.4
Wean (d42)	52.6 ^a \pm 6.2	57.1 ^b \pm 7.3	48.1 ^c \pm 4.1	48.5 ^c \pm 5.8
Day 60	64.9 ^a \pm 7.2	70.3 ^b \pm 7.7	60.6 ^a \pm 5.5	61.1 ^a \pm 7.7
Wither height (mm)				
Birth	644 \pm 33	658 \pm 32	653 \pm 31	657 \pm 21
Wean (d42)	770 \pm 32	778 \pm 30	762 \pm 24	767 \pm 28
Day 60	816 \pm 32	821 \pm 31	800 \pm 29	810 \pm 29
ADG (kg/d)				
Pre-wean (d0-42)	0.71 ^a \pm 0.10	0.75 ^a \pm 0.11	0.57 ^b \pm 0.06	0.59 ^b \pm 0.10
Post-wean (d43-60)	0.68 \pm 0.15	0.73 \pm 0.14	0.69 \pm 0.18	0.71 \pm 0.17
Total (d0-60)	0.70 ^a \pm 0.09	0.75 ^a \pm 0.09	0.61 ^b \pm 0.07	0.63 ^b \pm 0.11
WHI (mm/d)				
Pre-wean (d0-42)	3.06 ^a \pm 0.58	2.86 \pm 0.49	2.59 ^b \pm 0.49	2.62 ^b \pm 0.61
Post-wean (d43-60)	2.68 \pm 1.12	2.35 \pm 1.03	2.13 \pm 1.24	2.46 \pm 1.42
Total (d0-60)	2.88 ^a \pm 0.39	2.71 \pm 0.41	2.46 ^b \pm 0.38	2.60 \pm 0.51

^{a,b,c} Means within rows with no superscripts in common differ significantly ($P < 0.05$)

From the weekly body mass (BM) measurements (Figure 5.2), it is clear that the BM advantage of the high milk volume (HMV) groups (groups HL and HS) was maintained throughout the trial period, although it was less pronounced for group HL than for group HS. By day 60, the difference in preweaning gains still resulted in a significant 6.7 kg mass advantage for the HMV calves ($P < 0.05$).

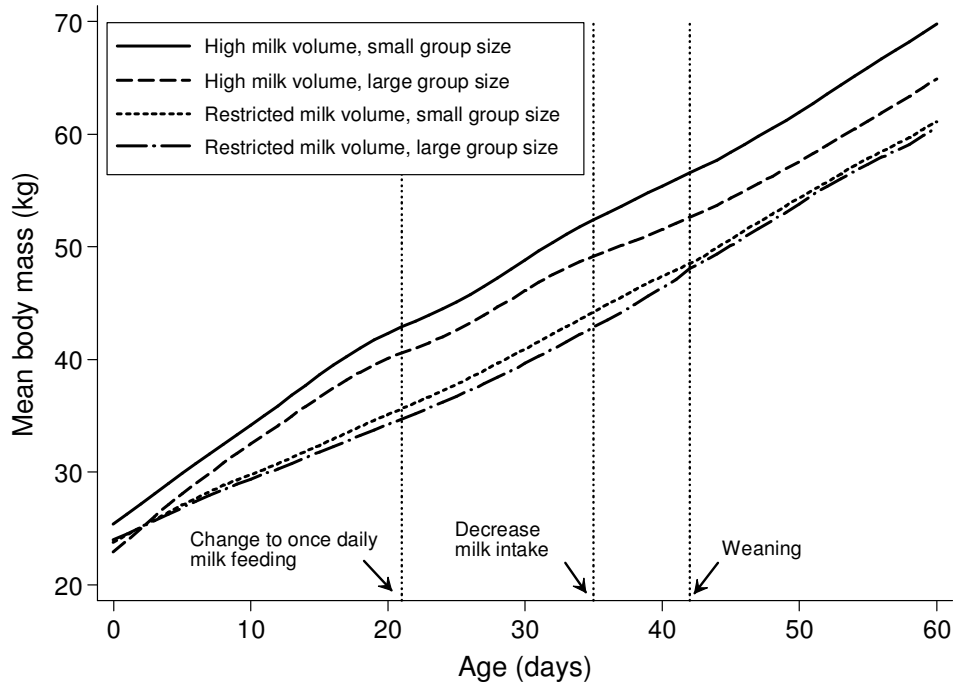


Figure 5.2 Mean BM of calves in different groups during the first 60 days of the trial.

Multiple regression analysis of the mass gain of the calves, adjusting for birth mass, birth date, dam parity and sire (Table 5.3), confirmed the significant differences in ADG (d0-42 and d0-60) between the HMV and RMV groups. On average, the feeding of high milk volumes increased ADG by 154 g from birth to weaning ($P < 0.001$) and by 104 g from birth to 60 d ($P < 0.001$). There was no significant difference in ADG from weaning to 60 d ($P = 0.944$). There was also no significant effect of group size on ADG.

Table 5.3 Multiple regression models: effect of milk volume and group size on average daily gain (ADG) in dairy heifer calves, adjusted for birth mass, birth date, dam parity and sire.

Outcome	Variable and level	<i>b</i>	S.E.(<i>b</i>)	95% confidence interval (<i>b</i>)	<i>P</i> -value
ADG from birth to weaning (42 d)	Milk volume				
	High	0.154	0.017	0.121, 0.187	<0.001
	Restricted	0 ^a	0	–	–
	Group size				
	Large	-0.020	0.017	-0.054, 0.013	0.237
	Small	0 ^a	0	–	–
ADG from weaning to 60 d	Milk volume				
	High	-0.002	0.030	-0.062, 0.058	0.944
	Restricted	0 ^a	0	–	–
	Group size				
	Large	-0.046	0.031	-0.107, 0.014	0.133
	Small	0 ^a	0	–	–
ADG from birth to 60 d	Milk volume				
	High	0.104	0.017	0.071, 0.137	<0.001
	Restricted	0 ^a	0	–	–
	Group size				
	Large	-0.027	0.017	-0.061, 0.006	0.109
	Small	0 ^a	0	–	–

^a Reference level

Figure 5.3 illustrates the strong linear relationship that existed between birth mass and mean daily MI (d4-34) for the groups with unrestricted milk consumption (Pearson's $r = 0.696$, $P < 0.001$).

A statistically significant association existed between birth mass and preweaning ADG of the HMV groups (Figure 5.4) (Pearson's $r = 0.426$, $P < 0.001$). No association existed between birth weight and ADG of the RMV group of calves.

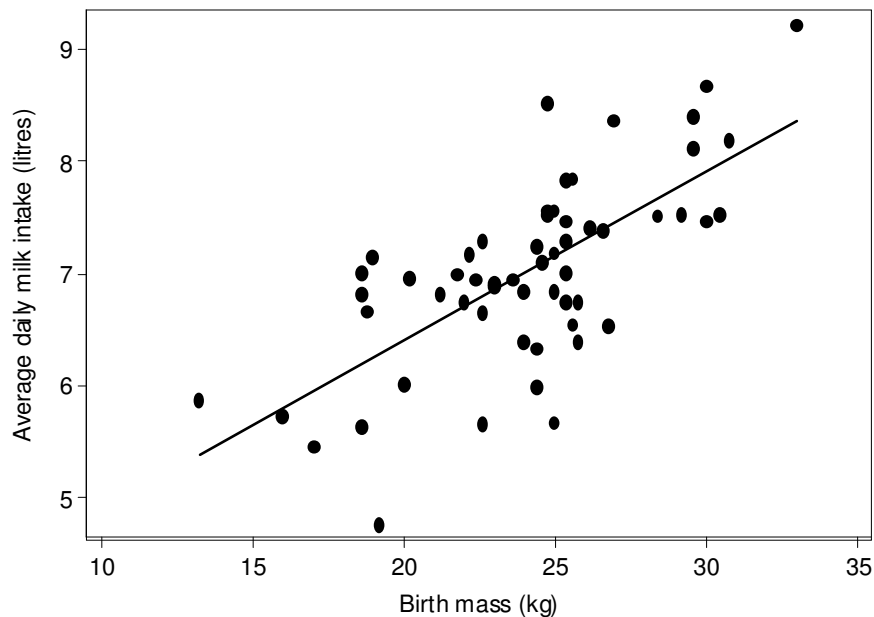


Figure 5.3 Scatter plot of average daily milk intake vs. birth mass of heifer calves receiving unlimited milk between day 4 and day 35 (Pearson's $r = 0.696$, $P < 0.001$).

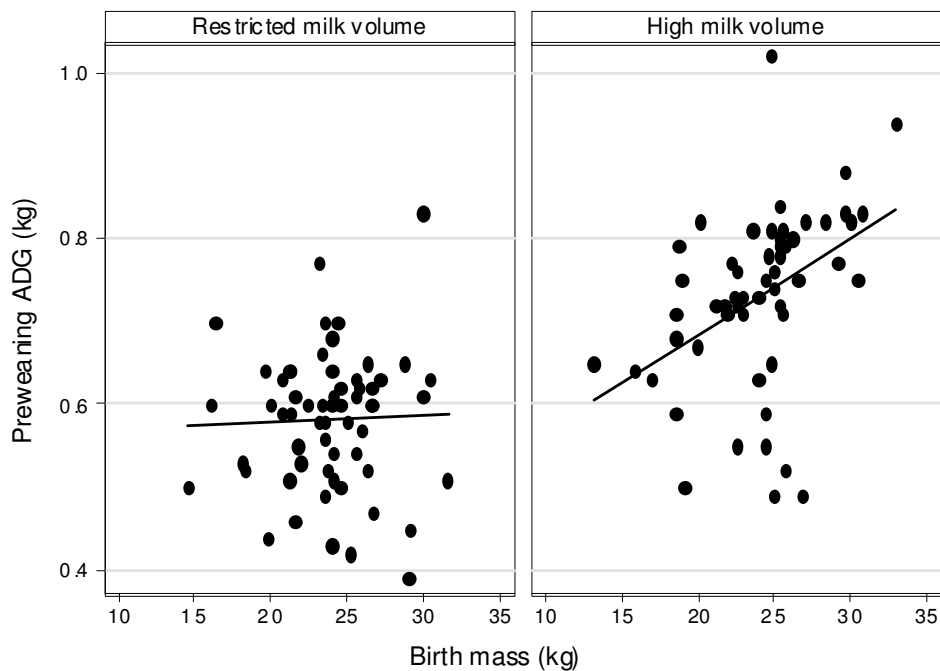


Figure 5.4 Scatter plots to illustrate the association between birth mass and preweaning average daily gain of heifer calves receiving restricted milk volumes (Pearson's $r = 0.034$, $P = 0.797$) or receiving unlimited volumes of milk (Pearson's $r = 0.426$, $P < 0.001$).

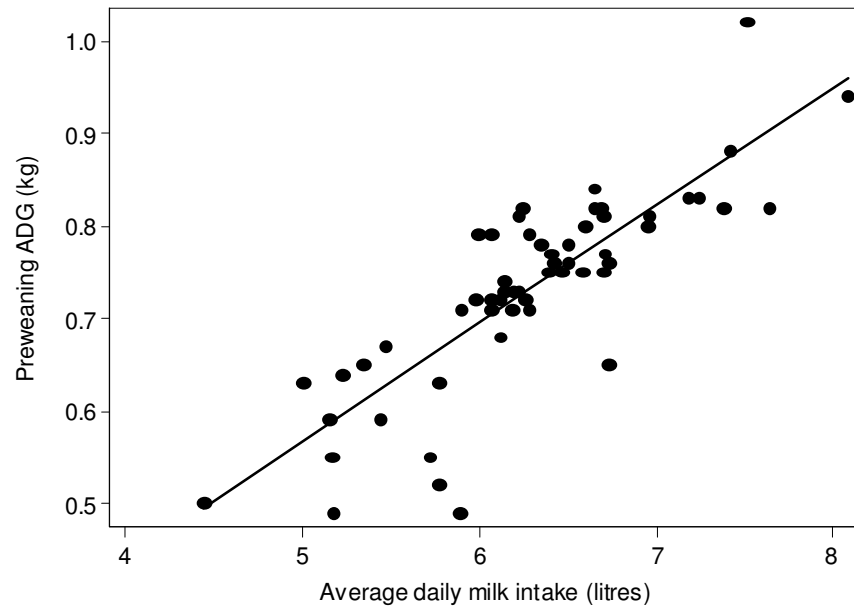


Figure 5.5 Scatter plot of pre-weaning ADG vs. average daily milk intake of heifer calves receiving unlimited milk between day 4 and day 35 (Pearson's $r = 0.833$, $P < 0.001$).

There was also a linear relationship between liquid feed intake (d4-35) for the HMV groups and preweaning ADG (Figure 5.5) (Pearson's $r = 0.833$, $P < 0.001$). No linear relationship existed between birth mass and postweaning ADG of either of the groups.

A statistically significant association existed between day of birth and preweaning ADG of the HMV groups (Pearson's $r = 0.344$, $P < 0.01$). This association was not found in the RMV group of calves (Figure 5.6).

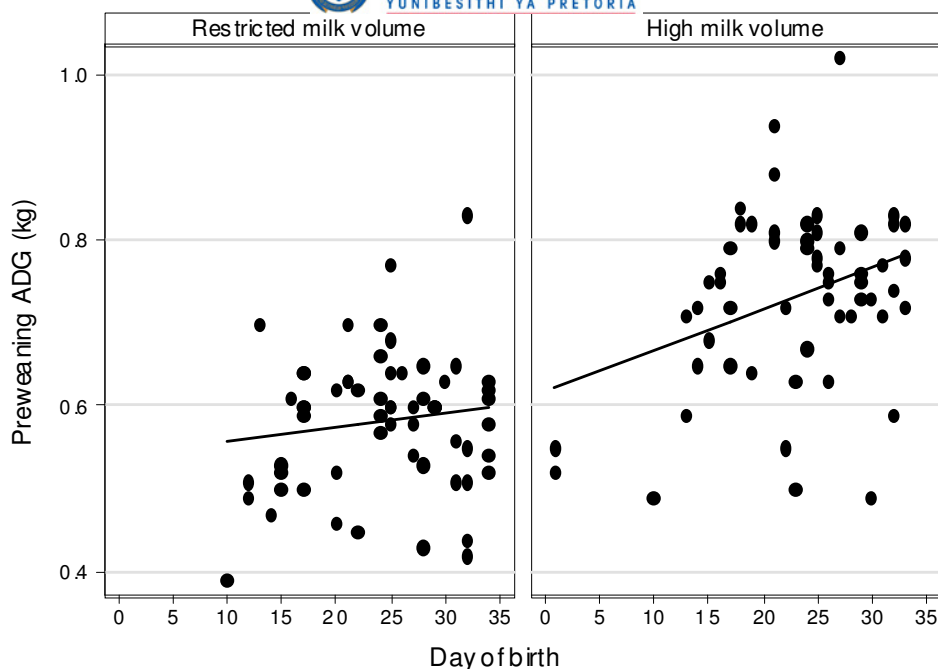


Figure 5.6 Scatter plots to illustrate the association between day of birth and preweaning average daily gain of heifer calves receiving restricted milk volumes (Pearson's $r = 0.145$, $P = 0.270$) or receiving unlimited volumes of milk (Pearson's $r = 0.344$, $P = 0.009$).

5.4 Disease incidence and treatments

5.4.1 Keratoconjunctivitis

The incidence of keratoconjunctivitis during the trial is illustrated in Figure 5.7. During the preweaning period, the highest incidence (0.90) occurred in group HL, and the lowest incidence (0.63) occurred in the RS group. Frequencies differed significantly ($P < 0.05$) between the HL group and other groups. There was no significant difference between the groups in the incidence of postweaning keratoconjunctivitis.

Table 5.4 shows logistic regression models of incidence data in different groups adjusted for independent variables of birth date, dam parity and sire. No significant influence of milk volume or group size was detected on the incidence of keratoconjunctivitis during any period of the trial. There was however a tendency towards higher odds of preweaning disease in the larger groups ($P = 0.072$).

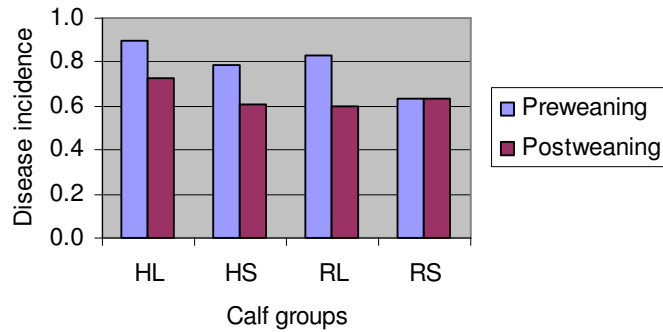


Figure 5.7 The incidence (as a proportion of calves at risk) of keratoconjunctivitis in different groups during the trial.

Table 5.4 Logistic regression models: effect of milk volume and group size on incidence of keratoconjunctivitis in dairy heifer calves, adjusted for birth date, dam parity and sire.

Outcome	Variable and level	Odds ratio	95% Confidence interval	P-value
Keratoconjunctivitis from birth to weaning (42 d)	Milk volume			
	High	2.00	0.71, 5.92	0.220
	Restricted	1 ^a	–	–
	Group size			
	Large	2.65	0.93, 8.17	0.072
	Small	1 ^a	–	–
Keratoconjunctivitis from weaning to 60 d	Milk volume			
	High	1.66	0.69, 4.10	0.299
	Restricted	1 ^a	–	–
	Group size			
	Large	1.26	0.52, 3.07	0.719
	Small	1 ^a	–	–
Keratoconjunctivitis from birth to 60 d	Milk volume			
	High	4.78	0.86, 50.14	0.084
	Restricted	1 ^a	–	–
	Group size			
	Large	2.95	0.57, 20.36	0.253
	Small	1 ^a	–	–

^a Reference level

Kruskal-Wallis one-way ANOVA of treatment days for keratoconjunctivitis showed significant inequality of medians of treatment days among groups (Table 5.5). The number of treatment days of keratoconjunctivitis from birth to weaning (42 d) was significantly ($P < 0.05$) higher in group HL than in group RS. From birth to 60 days, the number of treatment days was also significantly ($P < 0.05$) higher in group HL than in group RL.

Table 5.5 Median (interquartile range) treatment days for keratoconjunctivitis in dairy calves during the trial.

Variable	High milk volume		Restricted milk volume	
	Large group HL	Small group HS	Large group RL	Small group RS
Treatment days for keratoconjunctivitis				
Birth to weaning	2 ^a (2-3)	1 ^{ab} (1-2)	1 ^{ab} (1-2)	1 ^b (0-1)
Weaning to d 60	1 (0-2)	1 (0-2)	1 (0-2)	1 (0-3)
Birth to d 60	3 ^a (3-4)	2 ^{ab} (1.5-3)	2 ^b (1-3)	2 ^{ab} (1-4)

^{a,b} Medians within rows with no superscripts in common differ significantly ($P < 0.05$; Kruskal-Wallis one-way ANOVA on ranks)

5.4.2 Diarrhoea

During the preweaning period, the highest incidence of diarrhoea occurred in the smaller groups (Groups HS and RS) (Figure 5.8). This difference between small and large groups was significant ($P < 0.01$). Incidence of diarrhoea during the postweaning period was very low and there were no significant differences between groups.

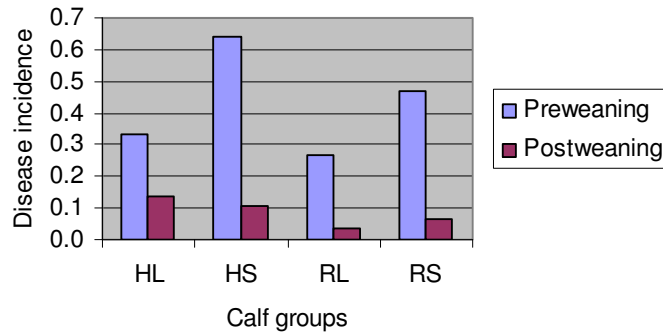


Figure 5.8 The incidence (as a proportion of calves at risk) of diarrhoea in different groups during the trial.

Logistic regression analysis (Table 5.6) confirms a statistically significant influence of group size on the incidence of diarrhoea during the preweaning period as well as during the period from birth to 60 d. The odds of a calf showing symptoms of diarrhoea during the period from birth to weaning was 3.23 times higher in the smaller groups than in the larger groups ($P = 0.008$). From birth to 60 days of age, the odds of a calf being diagnosed with diarrhoea was 2.56 times higher in the smaller groups than in larger groups ($P = 0.030$).

Table 5.6 Logistic regression models: effect of milk volume and group size on incidence of diarrhoea in dairy heifer calves, adjusted for birth date, dam parity and sire.

Outcome	Variable and level	Odds ratio	95% confidence interval	<i>P</i> -value
Diarrhoea from birth to weaning (42 d)	Milk volume			
	High	1.97	0.81, 4.90	0.147
	Restricted	1 ^a	–	–
	Group size			
	Large	0.31	0.12, 0.75	0.008
	Small	1 ^a	–	–
Diarrhoea from weaning to 60 d	Milk volume			
	High	2.19	0.43, 14.40	0.463
	Restricted	1 ^a	–	–
	Group size			
	Large	0.69	0.13, 3.39	0.840
	Small	1 ^a	–	–
Diarrhoea from birth to 60 d	Milk volume			
	High	1.98	0.83, 4.85	0.135
	Restricted	1 ^a	–	–
	Group size			
	Large	0.39	0.16, 0.93	0.030
	Small	1 ^a	–	–

^a Reference level

Non-parametric testing of treatment days (for diarrhoea) showed significant ($P < 0.05$) higher medians of the HS group compared to other groups of calves (Table 5.7). From birth to weaning, the median number of treatment days in the HS group differed significantly with those of both large groups (HL and RL). From birth until 60 d, this difference was only significant between the HS group and the RL group of calves.

Table 5.7 Median (interquartile range) treatment days for diarrhoea in dairy calves during the trial.

Variable	High milk volume		Restricted milk volume	
	Large group HL	Small group HS	Large group RL	Small group RS
Treatment days for diarrhoea				
Birth to weaning	0 ^b (0-1)	1 ^a (0-2)	0 ^b (0-1)	0 ^{ab} (0-1)
Weaning to d 60	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)
Birth to d 60	0 ^{ab} (0-1)	1 ^a (0-2.5)	0 ^b (0-1)	0.5 ^{ab} (0-1)

^{a,b} Medians within rows with no superscripts in common differ significantly ($P < 0.05$; Kruskal-Wallis one-way ANOVA on ranks)

5.4.3 Other diseases

Diseases listed as “other” were GIT disturbances other than diarrhoea, arthritis, septicaemia and pneumonia in the preweaning period, and meningo-encephalitis (MEC) in the postweaning period (Figure 5.9). In general the incidence of diseases other than keratoconjunctivitis and diarrhoea was low throughout the trial period. Calves in the HMV groups showed a marginally higher incidence of these diseases during the period from birth to weaning. However, the outbreak of MEC in the postweaning period was limited to calves from the RMV groups (Figure 5.10).

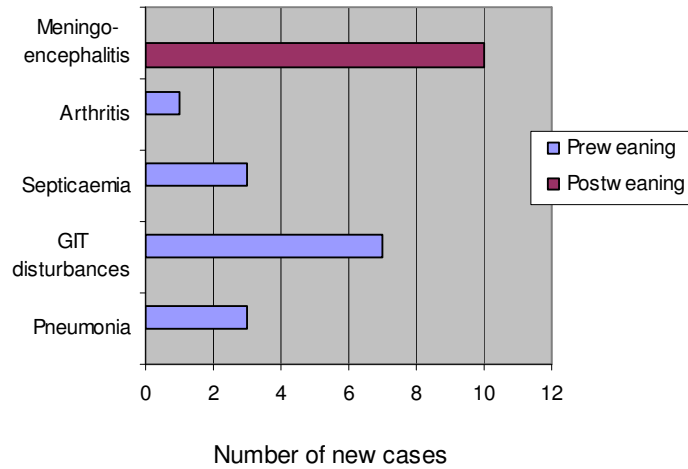


Figure 5.9 Number of new cases of different calf diseases listed as “other” during the trial.

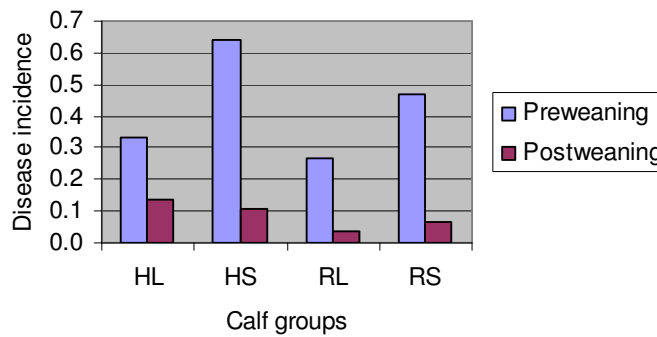


Figure 5.10 The incidence (as a proportion of calves at risk) of diseases listed as “other” in different groups during the trial.

Logistic regression analysis (Table 5.8) failed to show any association between milk volume or group size and other diseases from birth to weaning. However, during the postweaning period, milk volume had a statistically significant influence on the incidence of other diseases ($P = 0.025$). The odds of a calf being diagnosed with other diseases from weaning to 60 d was 14 times lower in the HMV groups than in the RMV groups (largely due to the outbreak of MEC in the RMV groups).

Table 5.8 Logistic regression models: effect of milk volume and group size on incidence of diseases other than diarrhoea and keratoconjunctivitis in dairy heifer calves, adjusted for birth date, dam parity and sire.

Outcome	Variable and level	Odds ratio	95% confidence interval	<i>P</i> -value
Other diseases from birth to weaning (42 d)	Milk volume			
	High	1.38	0.24, 8.06	0.940
	Restricted	1 ^a	–	–
	Group size			
	Large	0.66	0.11, 3.51	0.833
	Small	1 ^a	–	–
Other diseases from weaning to 60 d	Milk volume			
	High	0.07	0, 0.74	0.025
	Restricted	1 ^a	–	–
	Group size			
	Large	0.16	0.003, 1.74	0.177
	Small	1 ^a	–	–
Other diseases from birth to 60 d	Milk volume			
	High	0.44	0.08, 1.91	0.348
	Restricted	1 ^a	–	–
	Group size			
	Large	0.48	0.12, 1.67	0.311
	Small	1 ^a	–	–

^a Reference level

Non-parametric testing of treatment days (for other diseases) also showed significant ($P < 0.05$) differences in the medians of groups only during the period from weaning to 60 d (Table 5.9). The median number of treatment days in both of the HMV groups (HL and HS) was significantly lower than those of the RS group.

Table 5.9 Median (interquartile range) treatment days for diseases other than keratoconjunctivitis and diarrhoea in dairy calves during the trial.

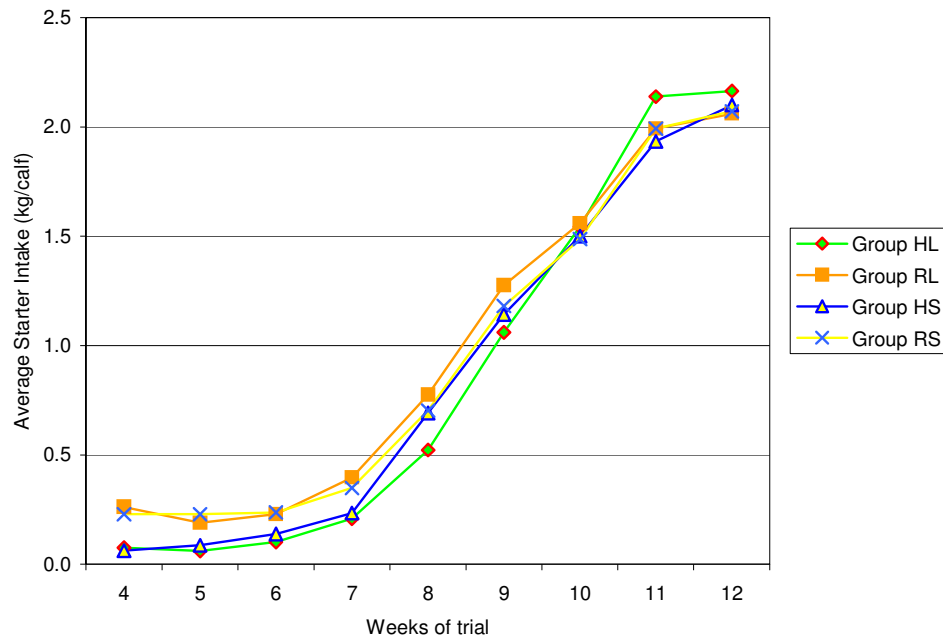
Variable	High milk volume		Restricted milk volume	
	Large group HL	Small group HS	Large group RL	Small group RS
Treatment days for other diseases.				
Birth to weaning	0 (0-0)	1 (0-0)	0 (0-0)	0 (0-0)
Weaning to d 60	0 ^b (0-0)	0 ^b (0-0)	0 ^{ab} (0-0)	0 ^a (0-0)
Birth to d 60	0 (0-0)	0 (0-0)	0 (0-0)	0.5 (0-1)

^{a,b} Medians within rows with no superscripts in common differ significantly ($P < 0.05$; Kruskal-Wallis one-way ANOVA on ranks)

5.5 Dry feed and weaning

The calculated average daily consumption of calf starter for calves in each of the four groups is illustrated in Figure 5.11. Solid food intake was negligible for all the treatment groups until the 4th week of the trial. Up to the 7th week of the trial, mean intake of starter pellets was more than 50% higher in the RMV groups than in the HMV groups. There was a rapid increase in consumption in all the groups of approximately 1.7 kg/calf/day between wk seven and wk 11 of the trial. During the last three wk of the trial, the differences in average consumption of solid food between the groups were less than 0.1 kg/calf/day. Nevertheless, over the whole trial period, the mean intake of starter pellets was still 5.85 kg/calf (61.00 kg vs. 55.15 kg) more for the RMV calves than for the HMV calves.

Figure 5.11 Mean daily intake (kg/calf/day) of starter pellets for calves in different groups during the trial period.



5.6 Feed conversion and cost

Average gain-to-feed ratio (G:F) and average cost of raising for calves in different groups over the whole trial period are given in Table 5.10. The G:F was calculated as average mass gained (in kg) per kg dry matter intake over the whole trial period. The dry matter (DM) content used in the calculations was 13% for milk and MR and 90% for starter pellets. It is clear from Table 5.10 that there was approximately a 10% better G:F of calves in HMV groups compared to calves in the RMV groups.

The results demonstrate that on average the feed and treatment cost for a calf from the HMV groups was about R250 (or almost 35%) more than for a calf from the RMV groups. Cost per kg of survival LW gain was on average just over 10% higher for a calf receiving unrestricted volumes of milk compared to a calf receiving restricted volumes of milk.

Table 5.10 Average gain-to-feed ratio and cost analysis of calves in different groups over the study period.

	High Milk Volume			Restricted Milk Volume		
	Large group HL	Small group HS	Mean	Large group RL	Small group RS	Mean
Intake per calf						
Milk and MR (L)	237	246	241	140	140	140
Starter (kg)	55.1	55.2	55.2	61.9	60.0	61.0
Total DM (kg)	80.4	81.6	81.0	73.9	72.2	73.1
Body mass per calf						
Birth (kg)	22.9	25.4	24.1	24.0	23.8	23.9
End of Trial (kg)	77.7	81.8	79.7	68.7	71.6	70.0
Total Gained (kg)	54.7	56.4	55.6	44.8	47.8	46.2
G:F (kg BM/kg DM)	0.68	0.69	0.69	0.61	0.66	0.63
Mortality %	3.33%	0%	1.67%	3.33%	13.33%	8.33%
Days of Treatment						
Keratoconjunctivitis	4.27	2.54	3.40	2.53	2.53	2.53
Diarrhoea	0.48	1.32	0.90	0.30	0.70	0.50
Other	0.53	0.18	0.36	0.43	1.07	0.75
Cost/calf						
Feed (R)	876.76	903.27	889.79	605.77	600.01	602.89
Treatment (R)	51.82	57.68	54.75	34.67	65.67	50.17
Total (R)	928.58	960.95	94.53	640.44	665.68	653.06
Cost/calf surviving						
Feed (R)	907.00	903.27	904.87	626.66	692.32	657.70
Treatment (R)	53.60	57.68	55.68	35.86	75.77	54.73
Total (R)	960.60	960.95	960.54	662.52	768.09	712.43
Cost/kg BM gain of surviving calves						
Feed (R)	16.57	16.03	16.28	14.00	14.48	14.24
Treatment (R)	0.98	1.02	1.00	0.80	1.58	1.19
Total (R)	17.55	17.05	17.28	14.80	16.07	15.43

5.7 Cross-sucking

The weighted percentages of calves that showed cross-sucking behaviour in each group are shown in Table 5.11. These are average percentages of calves showing cross-sucking during each period, weighted by the number of calves present in each group on each day. Persistent cross-sucking behaviour refers to cross-sucking during the last ten days of the study. During this time the percentages of calves with cross-sucking in the different groups did not change from day to day.

Table 5.11 Weighted percentages of calves showing cross-sucking behaviour in different groups.

Period	High Milk Volume			Restricted Milk Volume		
	Large group	Small group	Total	Large group	Small group	Total
Pre-weaning	1.1	2.2	1.7 ^a	75.3	75.6	75.5 ^b
Post-weaning	9.5	4.9	7.3 ^a	21.2	15.6	18.4 ^b
Persistent	13.3	6.7	10.0 ^a	20.0	18.1	19.1 ^b

^{a,b}Totals within rows with differing superscripts differ significantly ($P < 0.001$; Fisher exact test)

It is clear from the results that the incidence of cross-sucking in the preweaning period differed greatly between the two groups ($P < 0.001$). While less than 2% of the calves in the high milk volume groups (groups HL and HS) showed signs of intersucking, 75% of calves in the restricted milk volume groups (groups RL and RS) showed intersucking. During the postweaning period, the proportion of calves with cross-sucking behaviour increased to 7.3% in the high milk volume groups while it decreased to 18.4% in the restricted milk volume groups. During the last ten days of the study, the percentage of calves with cross-sucking behaviour stabilised to between 10 and 20%. The weighted percentage of calves with persistent intersucking was still almost double in the restricted milk volume groups compared to the high milk volume groups ($P < 0.001$).

5.9 General Observations

During the period of unrestricted milk consumption (d4-35 for HMV calves), it was clear that the competition for milk was higher among calves in RMV groups compared with calves in HMV groups. Firstly, the rate of ingesting milk was higher in RMV calves. Secondly, butting during milk feeding was much more aggressive in the RMV calves. Thirdly, calves in RMV groups made more attempts to steal milk from other calves' teats the moment their own buckets were empty.

Another general observation was that calves in the HMV groups spent much more time in social behaviour, including play such as pushing and butting each other and running around in the paddocks (locomotor play). This was especially noticeable in the 30 minutes after milk feeding, whereas calves in the RMV groups were largely busy with cross-sucking. A direct result of this behaviour was that during the last few weeks of the trial, the surface area in the HMV paddocks appeared much more trampled and bare than that of the RMV paddocks. Although some competition was observed at the feeding troughs, all calves in the trial generally showed tolerant social behaviour in the paddocks.

Chapter 6

DISCUSSION

The hypothesis of the study was that the feeding of high volumes of milk would have a significant effect on growth rate and cross-sucking behaviour of calves without compromising their health or the weaning process. The influence of two different group sizes was also tested. Confounding bias was controlled in two ways. Firstly by the randomization, and secondly by the analysis which accounted for the principle potential confounder of birth weight.

As a scientific study, this parallel-group prospective field trial holds the middle ground between observational studies and laboratory experiments. The subjects (calves) were being raised under typical South African dairy farm conditions, with the investigator only controlling entry into the trial and allocation to different groups. The investigator did not control the environment or exposure to disease or risk. Because of the real-world setting, if properly done, this kind of trial is considered to give the best evidence to answer clinical questions (Sanderson, 2006). However, caution is required when comparing these results with those from other studies under very different circumstances.

6.1 Feeding and feed intakes

6.1.1 Feeds and feeding schedules

The study compared two liquid feeding programmes (Table 4.1) for group fed Jersey calves housed in open paddocks. After the initial colostrum feeding (first day colostrum for three days), the two high milk volume (HMV) groups received unrestricted volumes of milk, while the two restricted volume groups received 4 L of liquid feed up to d 35. All calves received restricted volumes of MR during the last week (d36-42) before weaning. The liquid feed consisted of d2-3 colostrum (d4-7), whole milk (d8-21) and finally a good quality 25% fat, 25% protein MR (d22-42). At day 21, milk schedule was changed from twice a day to once a day milk feeding. From a nutritional point of view, all the abovementioned liquid feeds are excellent choices in pre-ruminant calf nutrition (See paragraph 2.3.1). Clean, fresh water was available to all calves throughout the trial.

A good quality starter with an 18% protein content has been used in the trial (See Table 4.2) and was available ad libitum to all calves throughout the trial period. The importance of a well balanced, high protein calf starter in rumen development has been discussed earlier (See paragraph 2.4.1). The NRC (2001) lists the CP requirement for calf starters to be 18% of DM on an as-fed basis (about 20% of DM). Consistent with this recommendation, studies in which CP was titrated into calf starters showed responses of up to 18% CP but no further increases in growth of calves when starter CP exceeded 18% (Drackley, 2008). The main portion of energy in starters is derived from cereal grains, either corn, triticale or barley in South Africa. Studies that have examined various processing techniques for cereals have shown relatively small effects of extensive processing. Fat as an energy-rich feedstock might seem to be logical for improving energy intake and thus growth in young calves. Studies in which fat has been added incrementally to starter consistently showed decreased starter intake, and decreased or unchanged growth performance (Kuehn et al., 1994). Addition of fat to starters beyond a small amount (e.g. 1%) to aid in pellet formation or to decrease dustiness is therefore not recommended. Several compounds are approved for use in starters as coccidiostats (decoquinate, monensin, lasalocid). Monensin, the additive used in the starter of the current trial, prevents coccidiosis caused by *Eimeria zuernii* and *E. bovis*. Monensin has been demonstrated to improve nutrient absorption, growth rate and feed efficiency in growing ruminants (Hill et al., 2005). All starters should contain one of these compounds. Because effective dose as a coccidiostat depends on projected intake of starter DM, lower intakes than desired may make the compound ineffective in controlling coccidia infection and so coccidia control should begin in the liquid diet.

No long-stem forage was available to calves during the trial. This was mainly because of the complexity of measuring wastage when feed intake is monitored. Whether or not to feed forage to young calves during the milk-fed period has been controversial. Because of a low pH and a limited physical size in the young calf, cellulose digestion is very limited during the first 10 weeks of life. Accumulation of undigested forage material in the rumen also decreases voluntary intake of starter that could be fermented. On the other hand, some fibre may be needed to maintain an abrasion factor to prevent abnormal development of rumen papillae (See paragraph 2.4.1). The

starter used in the current trial contained some “long” particles, such as rolled oats or lucerne meal, so supplemental forage was not needed.

6.1.2 Liquid feed Intakes

Traditionally, all dairy calves in South Africa are fed limited amounts of milk or milk replacer (typically 8% to 10% of BM) with starter offered for ad libitum consumption from the first week of life. The amount of milk or MR provided to the conventionally fed (RMV) calves in the current trial changed according to age and was not fed as a percentage of BM (step-up program, Davis & Drackley, 1998). During the early neonatal period, the 4 L of milk corresponded to approximately 15% of BM, while at day 35 it was closer to 10% of BM. During the last week of the trial, the 2 L of MR represented between 4 and 5% of BM in preparation for weaning.

The average milk intake of between 6.9 and 7.2 L/calf/d (d4-34) of the HMV calves in the current trial, confirmed that growing calves have the capacity for much greater DMI during the preweaning period than provided by most dairy management programmes. Calves in the HMV groups consumed about 75% more milk during the milk-fed stage compared to the RMV groups. The mean milk intake of the HMV calves ranged between 22% and 23% of BM during twice a day feeding (d4-20) and between 14.5% and 15% of BM during once a day feeding (d21-34). This mean milk intake compares well with studies on ad libitum systems of calf rearing, especially during twice a day feeding. Consistent with findings of Wolf et al. (2005), it appears that the HMV calves changed their milk feeding behaviour in order to achieve milk intakes comparable to ad libitum intakes. Several studies have showed that ad libitum milk intake for dairy calves was approximately 16% to 20% of BM, or 2% to 2.5% of BM as dry solids (Khouri & Pickering, 1968; Roy, 1980b; Diaz et al., 2001; Drackley, 2008). This is much higher than standard guidelines of restricted milk allowances of between 8% and 10% of BM or 1% to 1.5% of BM as dry matter. The considerable between-calf variation in daily milk intake among HMV calves is consistent with reports from Tomkins (1991) and Appleby et al. (2001). However, it is notable that even the lowest mean intake (4.77 L/d) by calves fed unrestricted milk volumes, still exceeded the daily milk allowance of calves in the RMV groups. Even with once a day feeding (d21-35), the HMV calves still consumed 68% (Table 5.1) more milk per day than the calves in the restricted groups.

6.1.3 Starter intake

As expected, the results showed that calves that were provided with more milk consumed less calf starter, reflecting effective substitution of concentrate with milk. Even though differences in starter intake between the groups disappeared during the last three wk of the trial, the higher starter intakes of the RMV calves in the early stages of the trial resulted in a 10% (5.85 kg/calf) higher starter intake over the whole trial period. The observed effects of milk allowance on concentrate intake are in agreement with previous studies (Khalili et al., 1992; Jasper & Weary, 2002; Brown et al., 2005; Von Keyserlingk et al., 2006; Kristenson, 2007). However, the current trial found no evidence that this reduced intake before weaning led to reduced intakes after weaning. Although individual starter intake was not measured, average intake of starter in the different groups did not differ during the last three weeks of the trial (Figure 5.11). During the last week of the trial, an average starter intake of more than 2 kg/calf/day (more than 2.5% of BM) was measured in all the groups. The similar post-wean starter intake in the different groups is also confirmed by the equality in post-wean ADG and WHI among groups (See later).

6.2 Prewaning growth

The faster preweaning growth of the HVM calves compared to the RMV calves was expected and primarily caused by the increase in milk intake. This was reflected in the 25% higher ADG and a 13% higher WHI of the HVM groups compared to the RMV groups. Multiple regression models confirmed that the feeding of unrestricted milk volumes led to a 154 g per day increase in preweaning ADG, compared to RMV feeding. The increases in stature measurements of the HVM calves demonstrate that increases in LW and ADG were also increases in frame size, and not just gain of gut fill or body fat. The relatively larger increase in WH than in BM of the HL group can possibly be explained by the increase in activity of calves in the larger paddocks. Although the average calf density was the same for calves in the large and small paddocks, each calf in the large paddocks had a larger available area for locomotor play. This increase in activity could have led to less body fat in these calves.

The ADG of the HVM calves (0.71 kg/d and 0.75 kg/d for the large and small groups respectively) compared well with expected growth rates in Holstein calves on

enhanced early nutrition programmes of between 0.6 and 0.8 kg/d (See Table 2.1, Drackley, 2008). This was surprising as smaller weight gains were expected with the Jersey calves in the current trial. It is possible that the high milk intake (as percentage of BM) and lower maintenance requirements compensated for any genetic disadvantage in growth rate of the Jersey calves. It also contradicts findings of Bascom (2002) that Jersey calves raised on 'intensified' milk replacer programs would attain growth rates of no more than 500g/day and that maintenance energy requirements of Jersey calves may be higher per unit of metabolic BM than that of Holstein calves.

Treatment effects on preweaning ADG (0.73 kg/day vs. 0.58 kg/day) were relatively small compared with some previous studies. Work on calves of similar ages showed larger differences in rates of gain for ad libitum versus calves fed restricted milk volumes: 0.85 kg/day vs. 0.36 kg/day (Appleby et al., 2001); 0.78 kg/day vs. 0.48 kg/day (Jasper & Weary, 2002) and 0.53 kg/day vs. 0.11 kg/day (Vieira et al., 2008). This might partly be explained by larger milk allowances (more than 10% of BM) to the RMV calves in the present study, the relatively short period (d4-35) of unlimited milk allowance, a change to once a day feeding at d 21, and the fact that in some studies, milk was offered ad libitum throughout the day with no concentrate consumption or availability.

Mean birth mass of calves in all the groups was about 3 kg lower than the target birth weight set by Hoffman (2007) (See Table 6.2). The reason for this is probably that only long stem hay and silage (no concentrates) were fed to late pregnant cows on the Weideland farm (see Nocek et al., 1983). Nevertheless, BM and stature measurements at birth did not differ significantly among treatment groups. This was important, taking into account the strong linear relationship between birth mass and average daily milk intake for calves in the HMV groups (Figure 5.3). It appears that the higher milk intakes of larger calves was largely responsible for the association between BM and preweaning ADG (Figure 5.4). These results confirmed that the growth of milk-fed calves is directly proportional to the amount of milk or milk replacer provided (Khouri & Pickering, 1968, Hodgson, 1971; Huber et al., 1984). In contrast, in restricted liquid feeding programmes in the current trial, growth rates were not linearly related to birth mass (Figure 5.4) because larger calves were not allowed to consume more milk than smaller calves. The linear relationship between day of birth

and preweaning ADG of calves from the HMV groups (i.e. later-born calves showed higher preweaning ADG's) is more difficult to explain. One possible explanation is that calves in larger groups tend to increase their drinking speed and milk intake when compared with calves in smaller groups (Barton & Broom, 1985; Jensen, 2004; Jensen & Budde, 2006). This is because of social facilitation and an increase in competition in larger groups. Calves born later in the trial immediately found themselves in a larger group than calves born earlier in the trial. However, no association could be established between day of birth and milk intake. Another explanation is that unknown environmental factors, such as subtle weather changes, may have played a role.

For a two week old Jersey calf in the current trial with a BM of 30 kg, the ME requirement for maintenance under thermoneutral conditions is approximately 5.36 MJ/d (National Research Council, 2001). Whole milk contains about 22.5 MJ ME/kg of solids, which means that a 30 kg calf requires about 238 g of milk solids, or 1.9 kg of whole milk (about 2.0 L) just for maintenance. Lean body weight gain in the growing calf is essentially a linear function of dietary protein intake over the range of protein intakes that would be encountered in practice. This effect is unrelated to energy intake of the calf as long as sufficient energy is available to use the additional protein to deposit body protein (See 2.3.2). Table 6.1 illustrates the expected apparent digestible protein (ADP) allowable gain of a 30 kg calf for different volumes of milk or milk replacer (20% CP, 20% fat) based on the current NRC (2001) system. The expected ADP allowable gain for whole milk and the 25% CP: 25% fat milk replacer used in the trial does not differ substantially.

Table 6.1. The expected ADP allowable gain (according to standards of NRC, 2001) of a 30 kg Jersey calf receiving different volumes of whole milk or milk replacer.

Intake/day (kg)	ADP allowable gain	
	Whole milk ^a	Milk replacer ^b
3	0.30	0.22
4	0.41	0.30
5	0.54	0.40
6	0.66	0.50

^a Also for 25% CP : 25% fat MR

^b 20% CP: 20% fat

It is clear from Table 6.1 that the growth rates achieved during the trial (at 30 kg BM) were probably very similar to the expected growth rates according to NRC (2001) standards. From this exercise it becomes clear that if the 30 kg calf were to be fed the conventional (10% of BW) amount of 3 L/day, it would have gained weight at less than 0.3 kg/day. Even with some calf starter intake, the expected ADG would still be less than half of the ADG achieved by the HMV calves in the current trial. The current trial clearly illustrates that higher rates of lean weight gain were achieved through the feeding of increased volumes of milk or MR than what is usually observed in conventional early weaning systems. This higher rate is actually biologically normal growth, because it is closer to natural conditions in which calves would have ad libitum access to milk. However, the key issue is whether normalising early growth provides any short- or long-term advantages to the calf or to subsequent productive longevity in the dairy herd compared to conventional systems of calf raising.

6.3 Weaning

Nothing in the results of the current trial indicates that there was any difference in fluency of weaning between the groups. It is clear that the growth advantage of calves on enhanced early nutrition programmes can be maintained after weaning. Other studies have found similar results (Leaver & Yarrow, 1972; Riordan & Everett, 1972; Jasper & Weary, 2002). In their review, Weary et al. (2007) suggested that weaning distress can be reduced if the calves increase their intake of solid feed before weaning and thereby reduce their dependency on milk. In the current trial, weaning stress was minimised and calf starter intake was stimulated by two management procedures. Firstly, the change to once a day milk-feeding had a pronounced effect on the milk intake of the HMV calves and did stimulate starter intake in this group. Secondly, the reduction of milk offered to calves one week before weaning clearly stimulated starter intake and avoided the weaning distress normally associated with calves fed increasing amounts of milk (Quickly, 2005). Surprisingly, in all the treatment groups the ADG did not decrease during the week after weaning, indicating sufficient availability of energy (owing to high starter consumption) to maintain previous growth rates. Other studies found that the transition from MR or milk to solid feed may cause a lag in growth when the preweaning milk or MR allowance is high (Dallzell & Allen, 1970; Terré et al., 2006; Huuskonen & Khalili, 2008).

Conventional milk feeding systems normally consider the age of the calves as the sole criterion for milk allowance and weaning. Under natural conditions, the weaning process of a calf is completed at about 9–11 mo of age (Reinhardt & Reinhardt, 1981). In dairy calves, weaning can be gradual or abrupt, or it can be done according to calf starter intake (Roth et al., 2008). There are several possibilities in trying to reduce the MR intake of group-reared calves during the weaning period in ad libitum feeding systems. The intake can be reduced by gradually decreasing the milk amount given or gradually reducing the time the calves are allowed to drink (Jensen, 2006; Huuskonen & Khalili, 2008). Gradual weaning over 14 d has been shown to increase the concentrate intake of calves during the weaning period (Jensen, 2006; Nielsen et al., 2008a) and thereby ease the transition to a solid-based feed. Jasper et al. (2007) found that calves reacted very little behaviourally when weaned by diluting milk with water, and that they did increase their concentrate intake compared with non-weaned calves. Khan et al. (2007) also reported excellent pre- and postweaning performance in Holstein calves weaned from high milk rations by milk dilution (step-down method described by Khan et al. (2007)). However, Nielsen et al. (2008b) suggested that the preferable weaning method is weaning by volume reduction over a long period because of the higher concentrate intake during and after weaning and because of the lower activity shown by these calves during the weaning period.

In a concentrate-intake-dependant weaning method, Roth et al. (2008) reduced milk intake as soon as an individual calf consumed more than 700 g concentrate per day. As soon as the calf consumed more than 2000 g concentrate per day, all milk intake was ceased. Compared to a conventional weaning method, this concentrate-intake-dependent weaning method met the individual nutritional needs of dairy calves, reduced the number of calves exhibiting cross-sucking (occurring independently of milk intake) and improved weight gain, particularly after milk provision was stopped. While this weaning method may be an excellent option in some high milk volume systems of calf rearing, it is however very difficult to implement under circumstances of group raising without the luxury of automatic feeders. In the current trial, it appeared that the one week of reduced milk intake was sufficient to stimulate starter intake. While this reduction in MR intake was only 50% for the RMV calves, it was almost 60% for the H MV calves.

6.4 Postweaning growth

The average postweaning ADG in all the groups was in the range of 0.68 to 0.73 kg/calf/day. There were no significant differences between the groups in the weight gain or WH changes from weaning until day 60. The BM advantage of the HMV groups at weaning was therefore maintained for the remainder of the trial period, resulting in a 6.7 kg average BM advantage for the HMV calves at the end of the trial. As postweaning growth is mainly determined by starter intake (National Research Council, 2001), this observation confirmed that the gradual weaning method in the HMV calves was effective in stimulating sufficient starter intake in these calves. The abrupt weaning technique used in other studies (Dallzell & Allen, 1970 ; Le Du et al., 1978a, 1978b) was probably responsible for the lower postweaning gain of calves reared on high milk volumes compared to those fed less milk.

Although the NRC (2001) does not have specific recommendations on postweaning growth rates, diets should be formulated to allow heifers to reach breeding age as quickly as possible without fattening. The target BM at first breeding is 55% of mature BM, with heifers calving for the first time at 82% of mature BM (National Research Council, 2001). For Jersey heifers breeding at 13 months at a target breeding BM of 220 kg, the target BM gain pre-breeding is therefore 0.51 kg/d. Hoffman (2007) also used percentage of mature BW as the basis for the current benchmarks for growing heifers (See Table 6.2). The growth indicators (BM and WH) of the calves in both the HMV and RMV groups were higher at 42 days and at 60 days than the targets (according to Hoffman, 2007) set for Jersey calves. The growth rate of all the calves in the trial was therefore sufficient at this early stage and on target for heifers to calve at 2 years of age.

Table 6.2 Age, live weight and wither height of calves in the current trial compared to targets, according to Hoffman (2007), for Jersey heifers to calve at 2 years of age.

Age(d)	Trial growth results				Growth targets (ADG = 0.51kg/day)	
	High milk volume		Restricted milk volume		LW (kg)	WH(mm)
	LW (kg)	WH(mm)	LW (kg)	WH(mm)	LW (kg)	WH(mm)
0	24	651	24	655	27	660
42	55	774	48	765	47 ^a	730 ^a
60	68	819	61	805	55	760
120	110 ^a	970 ^a	103 ^a	943 ^a	75	815

^a Projected values

6.5 Effect of group size on calf growth

The results of the present study were not able to demonstrate any significant association between group size and ADG. There was however a tendency towards a higher ADG in the smaller groups (0.75 vs. 0.70 kg/d and 0.63 vs. 0.61 kg/d for small groups vs. large groups). This tendency was in both pre- and postweaning periods. Although other studies (Willard et al., 1996; Svensson & Liberg, 2006) had shown that reduced group size is associated with an increased growth rate, these studies were done in indoor facilities in the northern hemisphere. In these studies, the confounding influence of respiratory disease in larger groups was shown to be principally responsible for the influence of group size on ADG.

The larger area of total space available per calf in the large paddocks probably led to an increase in activity of these calves. This increase in activity may possibly explain the slight tendency toward a better G:F in the smaller groups during the trial (Table 5.10). The increase in activity was more apparent in H MV calves and may also explain the relative larger increase in WH than in BM of the HL group during the whole trial period. This increase in activity could have led to less body fat in these calves. This observation is consistent with Norwegian research (Færevik et al., 2007) that showed that calves in larger groups were more active, competed less for feed and spent more time resting than calves in smaller groups.

In general the results of the current trial showed that larger group sizes (up to at least 30 calves per group) do not have a negative influence on the growth of young dairy calves housed in outside paddocks, irrespective of the level of liquid feeding.

6.6 Calf health

6.6.1 Mortality and general calf health

The mortality of calves in the trial was very low, with less than 1% deaths in the preweaning period. Surveys showed that the mortality risk of neonatal calves because of disease has been reported to range from 15 to 30% (Lofstedt et al., 1999; USDA, 2002). Although reported mortality rates vary greatly due to age, passive transfer status, type of operation, housing, season and management, enteritis and pneumonia emerge as the most common reasons for disease-related deaths among dairy calves and heifers (McGuirk, 2008). Together, pneumonia and diarrhoea are responsible for more than 80% of mortalities in unweaned calves and respiratory disease is the most important clinical problem in the postweaning period. These are complex, multifactorial diseases that are influenced by numerous host, pathogen and environmental factors. Mixed infections are frequently present in diseased calves. With the exception of bovine viral diarrhoea virus, some *Salmonella* species, some *Mycoplasma* species and some specific strains of *E. coli*, the pathogens responsible for most calfhood disease are ubiquitous and are present in a proportion of apparently healthy cattle on most dairy operations. Disease occurs when the right combination of factors interacts to upset the balance between pathogen virulence, exposure level and host resistance (Maunsell & Donovan, 2008).

Good management practices on the Weideland farm were most probably responsible for the low incidence of important diseases and the consequent low mortality rate. Among these are the following:

- Healthy calving areas and early separation from the dam. Management of the calf and cow at birth have profound effects on the risk of neonatal disease (Mee, 2008). In many cases, calves become infected with enteric or respiratory pathogens within the first few days of life. Asymptomatic and subclinically infected cattle shed these pathogens in faeces or respiratory secretions and large numbers may be shed by periparturient cows. The length of time after birth that calves remain with their dams affects the risk for pathogen exposure and therefore the risk for neonatal disease. Maternity areas that are dirty, wet or dusty increase the risk for calf disease and the risk for periparturient

infections in cows. The large calving area, the dry conditions during January as well as frequent collection of calves helped to decrease risk of neonatal infections.

- Excellent colostrum management. The importance of early colostrum intake has been discussed earlier (paragraph 2.2.3), but the volume, quality, and timing of colostrum feeding are vital for successful passive transfer (Davis & Drackley, 1998). The FPT rate of less than 2% during the trial was much lower than the range of between 40% and 50% reported from studies in the USA (Wells et al., 1996) and New Zealand (Wesselink et al., 1999) respectively.
- Hygienic handling of colostrum and milk. Poor hygiene associated with the collection, storage, or feeding of colostrum or milk can increase pathogen exposure and can negatively impact the acquisition of passive immunity (Barrington & Parish, 2001). Milk or colostrum can be contaminated with enteric pathogens if milking hygiene is inadequate, and some agents (e.g. *Salmonella*, *Mycoplasma* spp.) are shed in milk from infected cows (Maunsell & Donovan, 2008). Although the feeding of unpasteurised milk is a high-risk practice and should be avoided from a biocontainment perspective, special care was taken to provide uncontaminated milk and colostrum to the calves. Udders were always washed before milking and milk-handling equipment and buckets were cleaned and disinfected daily.
- Provision of clean water and feed. Contaminated feed and water sources can be important in pathogen transmission (Maunsell & Donovan, 2008). In a study of calves in New York dairies, herds where water was obtained from sources other than a well had higher rates of *Cryptosporidium* shedding than herds that used well water (Starkey et al., 2006).
- Outdoor housing facilities with low calf density. The type of housing (hutches, individual pens in a barn, group housing), temperature and humidity, bedding substrate (organic, inorganic, pH, moisture content), stocking density, cleaning practices, and manure management all influence the accumulation of pathogens in the housing environment and the survival and replication of pathogens on contaminated surfaces and bedding. The amount of exposure to direct sunlight greatly influences pathogen survival. In general, appropriately

spaced individual calf hutches that are cleaned, disinfected and moved between successive calves offer the best opportunity for limiting accumulation and calf-to-calf transmission of pathogens (Maunsell & Donovan, 2008).

- Early recognition and effective treatment of sick calves. All calves received a recorded visual health appraisal twice daily. The consequential early diagnosis and treatment of sick calves during the trial may have contributed to reduced mortality and a better response to treatment (McQuirk, 2008).

6.6.2 Morbidity in preweaned calves

In general the incidence of the most important calf diseases such as diarrhoea, pneumonia and septicaemia was low throughout the trial period. Results under circumstances that will lead to a higher incidence of diseases such as diarrhoea or pneumonia may differ dramatically from results in the current trial. The conclusions from morbidity results in the trial must therefore be interpreted with caution.

Keratoconjunctivitis

The incidence of keratoconjunctivitis was high throughout the trial with calves in the HL group showing the highest incidence (90%) as well as the greatest number of treatment days. A survey done on the Weideland farm during the summer of 2007/08 showed that the primary aetiological agents of infectious bovine keratoconjunctivitis on the farm are *Moraxella bovis* and *M. bovoculi* (Erasmus, 2008). Distinct serovars and pilus types of *Moraxella* exist, and new strains can be introduced by exposure to cattle from other herds. The reservoir of infection is asymptomatic carrier cattle that intermittently shed bacteria in respiratory and ocular secretions (Brown et al., 1998). The bacteria is highly contagious and transmission occurs by direct contact or, importantly, through mechanical transmission by flies (*Musca autumnalis*, *M. domestica*, and *Stomoxys calcitrans*) (McCluskey, 2002). A large number of risk factors for clinical disease have been identified, including environmental factors (e.g. dusty conditions and the amount of ultraviolet light exposure), season, the number of flies that visit the eyes of affected cattle, concurrent pathogens, the host immune status (e.g. stress such as transportation can precipitate disease outbreaks), and the virulence of the infecting strain (Brown et al., 1998). The disease is most common in summer and autumn and reaches epizootic proportions, especially among young

animals, when flies and dust are abundant (Blood & Radostits, 1989). The high incidence (more than 60%) of keratoconjunctivitis during the trial was therefore not surprising. It must be emphasized that, almost without exception, the diagnosis of the disease was made in the early stages of development. Oedema of the conjunctiva, hyperaemia of the corneal vessels and a copious watery lacrimation were the most common signs. Intense observation and early intra-ocular antibiotic treatment prevented further development into blepharospasm, photophobia and ulceration. Results from birth to d42 showed significant differences in incidence and days of treatment for keratoconjunctivitis in the HL group compared to one or more of the other groups. The reason for this observation is unclear. One possible explanation is that the calves in the HL group were probably also the most active calves (see paragraph 6.5) because of the combination of high milk intakes and a large available area per calf. Increased activity would have led to more dust in the paddock, one of the risk factors in keratoconjunctivitis.

Diarrhoea

Results showed that during the preweaning period, the incidence of diarrhoea ranged between 27% (group RL) and 64% (group HS). Smaller groups showed a significantly higher incidence than larger groups (OR = 3.23; $P < 0.01$). Incidence of diarrhoea during the postweaning period was very low and there were no significant differences between groups. Milk volume did not show any significant influence on the incidence or on the number of treatment days of diarrhoea. Not one case of diarrhoea during the trial led to mortality or to elimination from the trial.

Although the aetiological agents responsible for diarrhoea during the trial are unknown, most calf diarrhea problems are caused by a combination of factors, not all of which are infectious. Infections are mostly mixed and the agents may change over time, depending on season of the year and population dynamics within the environmental site of exposure (McGuirk, 2008). The major infectious causes of neonatal calf diarrhoea include rotavirus, coronavirus, cryptosporidia, coccidia, various strains of *Escherichia coli*, and *Salmonella* spp. (Maunsell & Donovan, 2008). Studies in different European countries revealed rotavirus and cryptosporidia as major pathogens to be found in faecal samples of diarrhoeic calves, and a low prevalence of coronavirus and enterotoxigenic *E. coli*. Because of the large numbers of oocysts excreted

even by asymptomatic calves together with a strong resistance to environmental conditions and disinfectants, the emphasis of prevention of cryptosporidiosis lies in good management practices (Lorenz, 2006).

Colostrum management, as discussed previously, is the most effective way to transfer immunity to the specific enteric pathogens of enterotoxigenic *E. coli*, coronavirus, rotavirus and *Clostridium perfringens* types C and D to newborn calves. Because most calf diarrhea problems occur within the first three weeks of life, good quality colostrum may be the only effective way to protect young calves (McQuirk 2008). The other good management practices on the farm (paragraph 6.3.1) most probably played a role in reducing risk factors for calf diarrhoea. These factors can be divided into those that reduce the ability of the calf to resist disease at a given level of pathogen exposure (e.g. failure of passive transfer of maternal antibodies, poor nutritional status, stresses and mixed infections) and those factors that increase the level of pathogen exposure (e.g. poor environmental hygiene, high stocking density, and exposure to other groups of cattle) (Maunsell & Donovan, 2008).

Both the incidence of diarrhoea and the response to treatment compared well to general observations on dairy farms (Kataridis, 2000; Girnus, 2004). Although diarrhoea accounted for between 21% (USDA, 2005) and 62% of calf losses in the USA (USDA, 2002), not one case of diarrhoea during the trial led to mortality or to elimination. The present results did not demonstrate any relationship between milk volume and the incidence of diarrhoea of preweaned calves. This is consistent with research reports that merely feeding more milk or MR does not necessarily cause scouring (Mylrea, 1966; Marshall & Smith, 1970; Huber et al., 1984; Nocek & Braund, 1986; Jasper & Weary, 2002). In the current trial, it seems that group size had a larger impact on diarrhoea than volume of milk. The higher incidence of preweaning diarrhoea in the smaller groups contradicts findings of Frank & Kaneene (1993), who suggested that group sizes should be minimized as much as possible. Treatment days analysis showed that it was especially the HS group that differed significantly from the two large groups. Spatial density of calves in different groups was identical and overcrowding was not a problem. The index case of diarrhoea occurred in the smaller paddocks (group HS) on the 18th of January, while the first case in the larger paddocks only occurred 10 days later, when there were also three new cases in group HS. Calves with clinical disease typically shed the highest numbers of pathogens and are

therefore likely to be the most important reservoirs of infection within the calf facility (Barrington et al., 2002). It is therefore possible that there was more of a build up of pathogens in the environment of the smaller paddocks during the early phases of the trial, leading to more clinical disease.

One can hypothesise that increased milk volume may increase the incidence of diarrhoea if the level of infection is high. Feeding increased volumes of milk will lead to increased amounts of faeces. The pathogens that cause neonatal diarrhoea are transmitted predominantly by direct or indirect contact with infected faeces. Most of these agents survive well in the environment, allowing for efficient indirect transmission. Increased volumes of milk can therefore easily lead to an increase in pathogen exposure, especially under circumstances of poor hygiene or high stocking rates.

Other Diseases

The incidence of diseases other than diarrhoea and keratoconjunctivitis was very low in all the groups with no statistically significant differences between the groups. The low incidence of FPT together with favourable environmental conditions, probably had a major influence on the occurrence of these diseases. The low incidence of septicaemia (three cases) in the neonatal period is an indication of the hygienic calving conditions on the farm.

The one case of foreign body pneumonia was probably caused by milk choking from a teat with an overstretched opening. Otherwise only two cases of pneumonia were diagnosed. This is in contrast with the general trend in the USA, where pneumonia is responsible for 21.3% and 50.4% of preweaned and weaned heifer deaths, respectively (USDA, 2002). The major infectious causes of respiratory disease in calves are bacterial and include various *Mycoplasma* species, *Pasteurella multocida*, and less often *Mannheimia haemolytica* and *Histophilus somni*. Bovine respiratory syncytial virus has been associated with outbreaks of dairy calf pneumonia, but other viral respiratory pathogens seem to play a minor role in respiratory disease in modern calf husbandry systems (Maunsell & Donovan, 2008). Although good management practices during the trial may have contributed to the extremely low incidence of pneumonia, environmental factors (outside paddocks and warm weather) probably played the most important role. Factors that influence airborne bacterial counts, such

as ventilation and stocking density, may affect transmission rates (Ames 1997). Independent of effects on bacterial load, poor air quality compromises respiratory defences, which may increase the risk for disease. Additionally, cold weather with increased humidity is an important factor affecting calf health (Ames 1997).

6.6.3 Morbidity in postweaned calves

In general, disease incidence was low during the postweaning period with little or no differences in morbidity between the groups. The only exception involved the incidence of diseases listed as “other”. The outbreak of meningo-encephalitis in the RMV groups was also the only reason for the dissimilarity between the groups. It is possible that the current system of increased milk feeding offered the possibility of improved health through enhanced development or function of the immune system. One way in which improved growth and nutritional status might be linked to an enhanced immune system is via growth hormone and the insulin-like growth factors (IGF). In addition to stimulating growth in young animals, these hormones play a direct role in integrating the growth, maintenance, repair and function of the immune system. Consequently, increased concentrations of IGF-I resulting from improved nutrition might be expected to enhance immune function in calves (Drackley, 2001).

6.7 Cross-sucking

During the 30 minutes immediately after milk feeding, when the behavioural recordings were made, most cross-sucking was directed to the belly of other calves, although cross-sucking towards the head and around the muzzle was also observed. There are many inconsistent reports in the literature regarding the direction of cross-sucking. Although Loberg & Lidfors (2001) also reported that cross-sucking was mostly directed at the belly, other reports showed that most of the cross-sucking in group housing was directed towards the mouth and ears (Lidfors, 1993; Margerison et al., 2003; Fröberg et al., 2008). The sucking under the belly and especially on the udder observed in this trial is of special concern. It may result in intersucking in heifers and cows, with subsequent negative effects on udder health and production (Lidfors & Isberg, 2003; Keil & Langhans, 2001).

The current cross-sucking results showed huge disparities in preweaning cross-sucking behaviour between HMV calves (1.7%) and RMV calves (75.5%). These

results confirmed those of Appleby et al. (2001) that hunger throughout the milk-fed stage would stimulate this behaviour. Calves fed restricted quantities of milk were more likely to have consumed their entire milk ration before negative feedback mechanisms associated with satiety took effect, so the cross-sucking performed immediately after a milk meal is likely related to hunger (Rushen & de Passillé, 1995; Vieira et al., 2008). On the other hand, because milk consumption was according to appetite, less than 2% of the HMV calves showed signs of cross-sucking during the preweaning stage. Keil & Langhans (2001) and Nielsen et al. (2008a) hypothesised that the development of cross-sucking is related to a low energy intake and the sensation of hunger. Apparently, the RMV calves were not able to fulfil their daily energy requirement through milk and concentrate intake in order to sufficiently suppress hunger, even though they were consuming more concentrate than the HMV calves.

Results of the HMV calves around weaning showed that the hunger during the last week of the milk-fed stage (restricted milk volumes) and after weaning did stimulate between 3 and 9% more of these calves to start with cross-sucking. This is in accordance with findings of de Passillé (2004) that heifers that perform intersucking are often underfed at weaning. It may be possible that more gradual weaning could have prevented the increase in cross-sucking behaviour of the HMV calves (as shown by Nielsen et al., 2008a). Stimulation of concentrate intake during the last part of the milk feeding period may provide more energy to these calves and therefore lower the risk of cross-sucking.

The result of total cross-sucking in the RMV calves is in line with other studies, where sucking behaviour decreased with increasing age of the calves (e.g. Reinhardt & Reinhardt, 1981; Lidfors, 1993; Keil & Langhans, 2001; Roth et al., 2008). An increase in energy intake can nevertheless not explain the dramatic decrease by 57 % in cross-sucking behaviour of the RMV calves just after weaning. This observation is better explained by the fact that there was no stimulation by the ingestion of milk anymore and consequently no redirection of the natural sucking behaviour (de Passillé & Rushen, 1997). Furthermore, the increased intake of solid feeds after weaning also decreased cross-sucking behaviours (Keil & Langhans, 2001; Terré et al., 2006). During the early postweaning period, it appeared that the hunger stimulus was more important in the HMV group while the lack of milk stimulus played the leading role in

the RMV group of calves. Throughout the trial it appeared that social facilitation also played a big role in cross-sucking behaviour. When one animal performed cross-sucking towards another calf, the likelihood that other calves around them would start performing intersucking increased. Nevertheless the results showed that unrestricted milk feeding allows calves to be housed in groups with only slight problems of cross-sucking.

It is important to notice that in the current trial, cross-sucking observations were only done during and shortly after milk-feeding. However, cross-sucking also occurs in the absence of close temporal association with milk intake, as has been found in several studies with prolonged observations after milk consumption. (e.g. Veissier et al., 1998; Keil & Langhans, 2001; Weber & Wechsler, 2001, Roth et al., 2008). It is assumed that milk-independent cross-sucking is triggered by both milk intake as well as by other motivational mechanisms, one of them likely being hunger (Roth et al., 2008).

Apart from the feeding of higher volumes of milk, there are also other ways in which cross-sucking can be reduced in group-fed calves. Cross-sucking is more common in bucket-fed calves than in calves fed the same MR through a teat (Hammell et al., 1988). The usefulness of a self-enclosing mechanism allowing the calves to engage in non-nutritive sucking at a soft rubber teat in reducing milk-dependent cross-sucking has been shown by Weber & Wechsler (2001). Other research (Margerison et al., 2004; Fröberg et al., 2008) showed that providing brief access to the teats of a cow post-milking can similarly reduce cross-sucking.

6.8 Feed conversion, costing and long term effects

Results from this study showed a moderate improvement (9.6%) in the G:F of calves receiving higher volumes of milk. This is consistent with previous research that showed better feed conversion rates of HMV calves (Khouri & Pickering, 1968; Diaz et al., 2001; Bartlett, 2001). These studies observed feed to LW efficiencies of 0.75 to 0.80 for preruminant calves fed for ad libitum consumption, which is marginally better than the FCR found in the current study (0.69) for calves assigned to the HMV groups. However, the mean feed intake of calves in the current study was lower (unrestricted feeding vs. ad libitum feeding for current study vs. previous studies) and feed conversion also involved the post weaning period. Feed conversion efficiencies

are expected to be poorer during the postweaning period because of lower DM intakes (Davis & Drackley, 1998). The slight tendency toward a better G:F in the smaller groups during the trial can perhaps be explained by less activity in the smaller paddocks. Restricted rates of liquid feeding result in considerably lower feed conversion efficiencies for young dairy calves compared with feeding practices for the young of other domestic species such as lambs and pigs (Greenwood et al., 1998; Harrell, 1998). The reason for this is that lower feed intakes lead to lower rates of gain and a smaller dilution of maintenance costs. Pigs, lambs and beef calves are raised in such a manner that frequent suckling is possible and milk intakes are close to ad libitum. This greater intake provides a much greater supply of nutrients above maintenance and allows a much higher rate of gain, which in turn decreases the amount of feed required per unit of gain. A calf fed liquid feed at 8 to 10% BM consumes approximately 2.7 units of feed DM per unit of gain but lambs and piglets allowed ad lib intake of milk often achieve feed efficiencies of less than 1.5 units of feed per unit of gain. Theoretically, calves can gain at similar levels of feed efficiency when fed similar levels of DM per unit of metabolic BM (Davis & Drackley, 1998). The feed efficiency of calves fed milk ad libitum compares well with data for lambs and pigs (Khouri & Pickering, 1968).

The 35% higher cost of raising of HMV calves can be largely attributed to the 72% higher milk consumption of these calves. The bottom line question is whether the superior BM of these calves at weaning is worth the extra cost of milk consumption. Even the cost per kg BM gain was 12% higher for the HMV calves compared to conventionally fed calves. Unfortunately the current trial is not entirely able to answer this question, because of potential long term effects of higher milk volume feeding. Previous work has shown that early weight advantages can be maintained far beyond the scope of the increased feeding (Riordan & Everett, 1972), resulting in a lower age at first calving, a reduction in the costs of production (Cady & Smith, 1996) and an increased mature body weight (Everett & Jury, 1977). Heifers that grow faster reach puberty at a younger age and can become productive sooner. Tozer & Heinrichs (2001) estimated that reducing age at first calving by 1mo decreases the cost of heifer rearing by 4.3%. High growth rates for calves in early life may also improve mammary development and first lactation milk production (see paragraph 2.6.2). It appears that the biology of the calf allows for rapid growth during the first few weeks

of life. If this early opportunity for rapid gains is not met, high levels of intake later in life may not allow for compensatory growth. From a biological perspective it would be difficult to argue that improving nutritional status of the young calf during the first few weeks of life should be anything but positive for subsequent productivity and longevity. Therefore a complete picture of the cost effectiveness of the current system of enhanced early nutrition can only be determined by longer term studies.

6.9 General observations and calf welfare

General observations showed less competition for milk and more social interaction of calves receiving increased volumes of milk. Satisfactory environments for newborn and growing dairy calves provide for thermal, physical, psychological and behavioural comfort. Each of these areas may be a source of stress for calves, which subsequently may predispose calves to compromised immune responses, growth rates, disease resistance and well-being. Psychological and behavioural needs in an environment include the absence of frustration, the sense of safety and freedom from injury and appropriate social herd behaviour and caretaker interactions (Stull & Reynolds, 2008).

The intensified competition for milk in the RMV calves is in agreement with other research (Jensen & Budde, 2006; Vieira et al., 2008). When housed in a group, calves compete for the milk, and they have a natural tendency to switch from one teat to another when the milk flow is low or stops (de Passille & Rushen, 2006; Nielsen et al., 2008). Therefore, when milk is fed restrictively, it is essential that milk stealing is limited to ensure minimal variation in milk intake within the group. Group raising systems that do not allow for individual milk feeding, for example calfeteria systems (Macdonald, 1999) or shared-teat-bar systems (Nielsen et al., 2008b), should rather allow for unrestricted milk consumption.

Group housing of calves is based on the principle that dairy cattle are herd animals and group housing allows for the development of social herd behaviour and interactions. Calves on pasture increase their time spent in social contact with other calves rapidly from birth until 6 weeks of age. In free living populations of cattle, group size may vary between 20 and 100 individuals, in which calves form subgroups up to 25 individuals, depending on environmental conditions and time of the day

(Færevik et al., 2007). It also allows opportunity for exercise and play among calves within the group. Group housing of neonatal calves may provide more calf-to-calf contact and enrichment stimulus compared with individual housing (Jensen et al., 1998; Hepola, 2003; Babu et al., 2004). Juveniles play when their primary needs are met. Play behaviour has consequently been suggested to be an indicator of good welfare in captive juveniles and calves (Lawrence, 1987; Jensen & Kyhn, 2000). The higher motivation to perform locomotor play in the HMV calves may therefore be an indication of better welfare conditions of calves receiving higher milk volumes. In order to satisfy calves' motivation for social contact, group housing of calves older than 8 weeks is now compulsory in the European Union (Council Directive 97/2/EEC). In order to allow farmed animals to synchronize their behaviour, the EU-regulations require that group housed animals should have the possibility to lie simultaneously (Council Directive 98/58/EC). Calves should have access to a comfortable lying area with a minimum space allowance of 1.5 m² for each calf with a live weight of less than 150 kg (Council Directive 97/2/EC). The regulations are in accordance with studies showing that a space allowance below 1.5 m² decreases group-housed calves' possibility to perform natural behaviour (Le Neindre, 1993). These standards are however not applicable to housing in outside paddocks in South Africa where no bedding is used. Average space allowance to calves in the current trial was more than 25 m² per calf.

Apart from competition in the milk-fed areas, displacements from the feed trough to get access to the starter was the most common aggressive interaction in the current trial, whereas butting and mounting were rarely seen. The facilities and management during the current trial may have played a role in the tolerant social behaviour observed in all the groups. Among these are the distribution and accessibility of food and resting areas, group composition, group size and space allowance which all may have affected this behaviour (e.g. Jensen & Kyhn, 2000; Jensen, 2004). Calves younger than three months are not found to show a clear dominance hierarchy (Webster, 1983). However, keeping young calves in different group sizes may still affect feed intake, resting patterns and the extent to which some individuals monopolise feeding space and attractive resting areas.

Chapter 7

CONCLUSION

The results of the experiment describe responses of young Jersey calves to increased volumes of milk. The general principles of growth and nutrients required are no different for young dairy calves than for young beef calves, pigs or any other species. Additional complexity is introduced, however, by the need to transition the young preruminant to a functioning ruminant at a very young age. The nutritional and digestive physiology of dairy calves as future ruminants needs to be the governing factor in designing practical feeding systems to meet nutrient requirements. Several strategies are available for raising young calves, ranging from restricted intakes of milk or milk replacer to more natural milk intakes that allow greater early growth but slightly delay development of solid feed intake. Growth and health are intimately interrelated in young calves, and evaluation of existing or potential programmes should be on an evidence-derived, results-oriented basis. Under the current experimental conditions, the results of this study showed that when compared to restricted milk volumes, calves that are fed unrestricted volumes of milk, consume much more milk, gain weight much more rapidly and remain healthy before and after weaning. These calves consume less solid food before weaning, but with gradual reduction in milk availability, weaning stress should not be a problem. The weight advantage of high milk volume calves can consequently be maintained for at least several weeks after weaning. Results also showed that larger group sizes do not necessarily have a negative influence on the growth or health of young dairy calves housed in outside paddocks. Because of lower relative maintenance requirements for calves receiving unlimited milk volumes, efficiency of feed conversion to growth should be better than for calves receiving restricted volumes. The higher growth rates of these calves does however not compensate for the extra cost of milk consumption resulting in a higher cost per kg BM gain. Finally, the feeding of higher volumes of milk from a teat reduces calf motivation to cross-suck during the milk-fed stage. This also leads to fewer calves cross-sucking in the postweaning period, thus facilitating group raising of calves.

Successful calf rearing requires that we protect the health and welfare of the young calf while profiting from the calves' growth potential. This trial showed that under typical South African circumstances, this can be achieved by feeding higher volumes of milk or milk replacer in either small or large groups. However, the cost efficiency of these systems will only become apparent with follow-up studies and may still be the most important reason why enhanced early growth cannot be a general recommendation. As more is learned about the effects of early nutrition and growth on long-term health and productivity, it is likely that recommendations will continue to be modified to help ensure animal well-being and improve farm profitability. The solution may lie in programmes that are intermediate in nature and which allow liquid intakes between conventional and accelerated programmes, while still providing improved nutritional status during the critical first two to three weeks.

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