Effect of differing forages on the early growth and behaviour development of dairy heifers during pre- and post weaning periods

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Abstract

Ullah (2017). Effect of differing forages on the early growth and behaviour development of dairy heifers during pre- and post weaning periods.

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The objective of this study was to evaluate the effects of different forage diets fed to young calves on early growth, behaviour development and long term milk performance. In experiment 1, 60 calves were randomly allocated to one of three diets, fed starter diet with no forage (PS), PS with additional moist alfalfa (PSA) or PS with additional pasture hay (PSH). In experiment 2, 108 calves were randomly allocated to one of three diets, PSH, PS with low (LF) or high (HF) moist alfalfa based total mixed rations. In Experiment 1, greater dry matter intake and liveweights were observed in PSH followed by PSA and then PS during the pre- and post-weaning periods. Longer time eating and ruminating behaviours were observed in PSA and PSH than PS during pre- and post-weaning periods. In Experiment 2, greater dry matter intake and liveweights were observed in PSH than LF and HF diets during the pre- and post-weaning periods. Greater numbers of incidents of allo-grooming were observed in the HF and PSH diets and calves spent longer time eating than LF calves. During post-weaning period, HF and PSH fed calves spent more time lying than LF fed calves. After turning out to pasture, no behaviour differences were observed among treatments in both experiments. While monitoring long term performance, no differences were observed in animals from Experiment 1 in terms of liveweight, milk yield, protein or fat production. From Experiment 2, greater liveweight gains were observed in HF and PSH fed animals than LF fed animals till first lactation. During first lactation, greater milk yield was observed in HF fed animals than PSH or LF fed animals. Greater fat production was observed in LF fed animals than HF or PSH fed animals during third lactation. The effects of diets on the long term performance of the animals should be repeated with sufficient animal numbers per treatment.

Declaration

This thesis contains no material that has been accepted for a degree or diploma by the University or any other institution. To the best of my knowledge no material previously published or written by another person has been used, except where due acknowledgement has been made in text.

This thesis has been written with chapters formatted as papers for publication. Therefore, there is some repetition of chapter introductions or methods, each chapter contains a full discussion, with the final general discussion chapter providing a succinct discussion of key findings of this thesis. Each chapter has been formatted for the Journal of Dairy Science and each has a complete list of references. For each of the chapters my input was the greatest with the appropriate assistance of my co-supervisors, I designed and carried out the research, analysed the data and wrote the main content of the chapters contained in this thesis.

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List of Abbreviations

ADF: Acid detergent fibre (%DM)

ADG: Average daily gain for animal at a given age (g or kg/day)

CP: Crude protein (%DM)

DE: Digestible energy (Mcal)

DIM: Days in milk

DM: Dry matter

DMI: Dry matter intake (kg/day)

FCE: Feed conversion efficiency

HF: High fibre

HH: Hip height

HW: Hip width

LF: Low fibre

LRG: Last rib girth

LWT: liveweight

ME: Metabolizable energy

MR: Milk replacer

MUEC: Massey University Ethics Committee

MW: Mature weight (kg)

NDF: Neutral detergent fibre (%DM)

PSH: Starter and pasture hay

PW: Production Worth

TDN: Total digestible nutrients (% DM)

TMR: Total mixed ration

WM: Whole milk

VFA: Volatile fatty acid

Chapter 1

General Introduction

1.1. Introduction

New Zealand has 4.92 million cows with an average annual production of 371 kg of milksolids (fat plus protein) and life span of 4.5 lactations (DairyNZ and LIC, 2016). The average replacement rate of New Zealand dairy cattle is 22-25% (DairyNZ and LIC, 2016), which is higher than the recommended replacement rate of 15-18% required to maintain greater genetic potential and profitability of a milking herd (Lopez-Villalobos et al., 2000). The main reason of this higher replacement rate is a high culling rate of 14% of heifers during the first lactation, which means that a high proportion of replacement heifers entering a milking herd do not survive their first lactation and only 80-85% enter second lactation (DairyNZ and LIC, 2016). The loss of young animals from the dairy herd represents a loss of investment in rearing costs and genetic improvement, as younger animals tend to have higher genetic merit, reflected in a consistent annual increase in breeding worth (approx. $10/year in last 5 years) according to national New Zealand Dairy Statistics (DairyNZ and LIC, 2016).

In New Zealand, the liveweight of dairy cattle at first calving is between 77 and 80% of their mature liveweight (McNaughton and Lopdell, 2013). Liveweight increases rapidly during the first lactation and continues to increase during subsequent lactations up to approximately five to six years of age (DairyNZ and LIC, 2016). An increase in the liveweight at first calving provides a good opportunity to reduce the likelihood of a high genetic merit heifer being culled, as well as increasing its longevity and performance (Khan et al., 2011; Soberon et al., 2012). This could be achieved by increasing early heifer health and growth rate during the milk feeding period, which occurs up to 12 weeks of age in New Zealand (Margerison et al., 2013). This would increase future milk yield (Khan et al., 2011; Soberon et al., 2012) as well as providing the opportunity to achieve maturity targets of mating at 15 months of age and calving at 24 to 25 months of age (Penno, 1998).

The growth rate of dairy heifers can be influenced by many factors; however, the most significant ones include genetics, nutrition and management (Khan et al., 2011; Bach, 2012). Nutritional and management factors, the level and type of pre-weaning feeding and housing have a long term effect on the growth and development of a dairy heifer (Khan et al., 2011; Soberon et al. 2012; Margerison et al., 2013). The New Zealand industry recommends weaning calves as they reach 90 kg for Friesian, 80 kg for Jersey and 85 kg for cross bred calves (DairyNZ and LIC, 2016). However recently, Roche et al. (2014) reported that heifers in New Zealand with very low liveweight gain during the pre-pubertal period do not reach puberty at their planned mating date, resulting in a delay in the date of their first calving as well as a reduced rate of pregnancy, and culling during first or second lactation (Archbold et al., 2012). Therefore, the level and type of pre-weaning diet is of great importance to determine the future growth rate (Moallem et al., 2010), age at mating and milk production of dairy heifers during first lactation (Davis Rincker et al., 2011, Khan et al., 2011, Soberon et al., 2012). Soberon et al. (2012) observed that heifers that had gained more liveweight during the pre-weaning period were likely to have increased milk production during their first lactation i.e., every kilogram of pre-weaning average daily gain (ADG) in heifers increased the milk yield by 1550 kg during the first lactation (Soberon and Van Amburgh, 2013).

Maize, wheat, rice, barley, oat and sorghum grains are commonly used cereals in calves' starter diets (Khan et al., 2007 a, b). These grains have differences in their starch concentrations, rate (Huntington, 1997) and site of fermentation (Philippeau et al., 1999). When smaller grains (barley, wheat or oats) are offered to calves as a sole diet, rapid fermentation occurs, with production of lactate in the rumen (Anderson et al., 1987; Barkema et al., 1998) that lowers rumen pH (Anderson et al., 1987; Barkema et al., 1998). This may cause parakeratosis, which in turn limits the voluntary feed intake in young calves (Barkema et al., 1998; Suarez et al., 2007). To avoid this problem, a coarse textured diets with greater feed particle size, or the addition of forage along with a cereal based starter diet is recommended, in order to increase chewing and saliva production, which buffers the pH in the rumen. Under this feeding regime calves tend to eat more dry matter (Barkema et al., 1998; Suzrez et al., 2007) and achieve greater liveweights (Khan et al., 2011).

Other beneficial effects of optimising forage provision to young calves in this way include the development of foraging and rumination behaviour and stimulation of the development of a fully functioning rumen (Tamate et al., 1962; Vazquez-Anon et al., 1993; Zitnan et al., 1998; Coverdale et al., 2004; Suarez et al., 2006 a,b; Khan et al., 2011; Castells et al., 2012). Therefore, the general objective of this study was to evaluate different forage (moist alfalfa, pasture hay) feeding options to young calves and to assess the short (development of chewing, foraging and rumination behaviour, greater dry matter intake, and liveweight gain) and long term (liveweight, milk yield, protein and fat production) effects of these diets till third lactation of their life.

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Chapter 2

Review of literature

2.1. New Zealand dairy industry

Around 4.92 million dairy cows are being milked within 11927 herds across New Zealand (DairyNZ and LIC, 2016). The New Zealand dairy herd consists of 42.6% crossbreeds (Holstein-Friesian×Jersey), 37% Holstein-Friesian, 11.7% Jersey and 0.7% Ayrshire purebred cattle. The remaining 8.1% belong to other breeds (DairyNZ and LIC,2016). Dairy cows are managed primarily on pasture and supplements are generally provided either to extend lactation or overcome seasonal variation in feed supplies. A dairy cow in New Zealand produces an average of 371kg of milk solids in one lactation and remains in a herd for 4.5 lactations. The national dairy herd in New Zealand annually produces ~18.9 billion L of milk. Approximately 97% of the total milk produced in New Zealand is processed into dairy products (mainly milk powders) and exported to 151 countries (MPI, 2016). Foreign exchange earnings from dairy products are a major contributor to the economy of New Zealand and dairy products have contributed more than $10 billion annually to the national economy during the last five years (MPI, 2016).

2.2. Performance of heifers in New Zealand dairy herds

Generally, a dairy heifer should achieve 60% of her mature liveweight at first breeding and 90% of her mature liveweight at first calving (Table 2.1) (Penno, 1998; Dobos et al., 2004). New Zealand data (Figure 2.1) indicated that majority of heifers on New Zealand dairy farms fail to reach their recommended target liveweights (McNaughton and Lopdell, 2012, 2013). McNaughton and Lopdell (2012) reported that 18% of the New Zealand heifers were 20% behind in target liveweight at 15 months of their age. Around 73% of New Zealand replacement heifers were 5% lighter than their target liveweight at 22 months (Figure 2.1).

Archbold et al. (2012) reported that heifers lighter at 15 months remained lighter at first calving and up to at least their third lactation. Furthermore, heifers that reach their target liveweights calved earlier in the milking season and were more likely to be mated and to be pregnant within 6-weeks than later calving animals and thus were less likely to be culled from a herd (McNaughton and Lopdell, 2013; Roche et al., 2014). Poor growth of heifers can potentially delay their age at first breeding and first calving (Archbold et al., 2012; McNaughton and Lopdell, 2013). Lower liveweight and any delay in entering the lactating herd in calving season can affect the performance of heifers and reduce the productive life of heifers in pastoral herds (Macdonald et al., 2005; Mee, 2008; McNaughton and Lopdell, 2012).

In a recent review, Roche et al. (2014) stated that the heifer growth rate and liveweight at first calving are important because lighter heifers are at a greater risk of reproductive problems, produce less milk in first lactation, and have a shorter lifespan in the herd. McNaughton and Lopdell (2013) reported that the heifers furthest from their target breeding liveweight suffer the most from reproductive failures and reduced milk solid yield. Generally, the onset of puberty is determined by liveweight of a heifer: for example reaching puberty at least two cycles before mating starts leads to improved conception rates (Byerley et al., 1987). Failure to reach liveweight targets may partially explain the poor 'calving pattern of first calvers' commonly seen in New Zealand herds (Macdonald et al., 2005). Data from the New Zealand Grazing Company also indicated that the lightest animals at mating at 15 months of age calved later and had significantly lower 21-day submission rates in their first lactation (Hayes et al., 1999). In New Zealand, the factors likely to contribute to the poor performance and premature culling of heifers within the first two lactations include poor growth rates, reproductive failure and poor milk yield (DairyNZ and LIC, 2016). In New Zealand, 26.4% heifers are lost from the herds by their second lactation (Table 2.2). This loss not only causes greater economic losses on commercial dairy farms but also slows the rate of genetic gain in the New Zealand national herd.

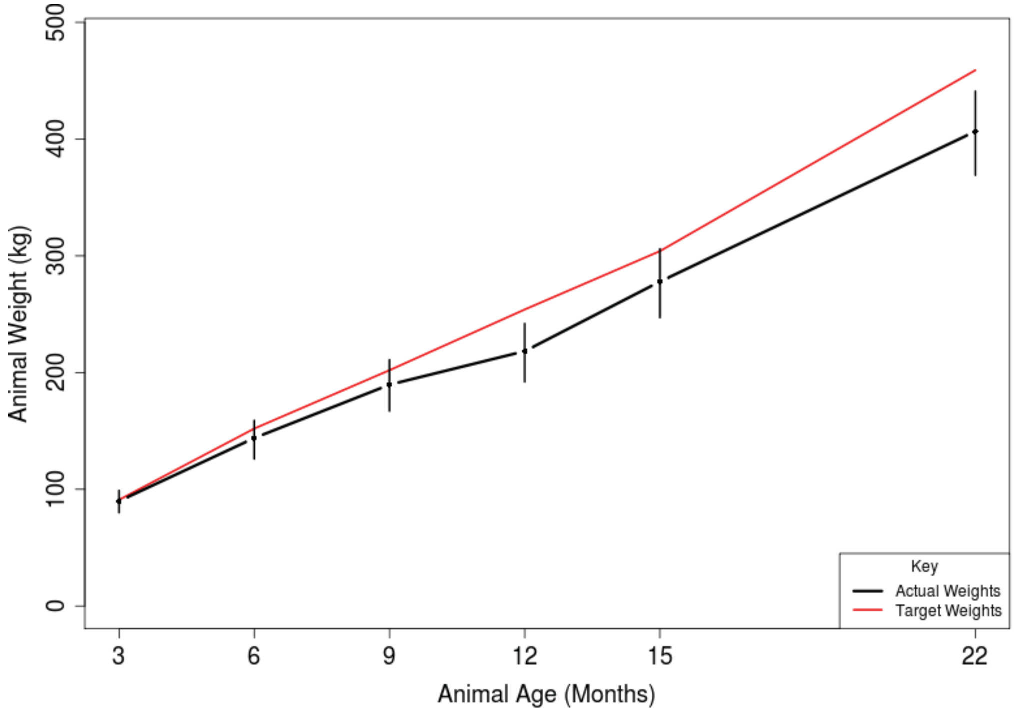

Figure 2.1. Target liveweights by age, compared to actual liveweights of 105,000 heifers in New Zealand born between 2006 and 2010 (adapted from McNaughton and Lopdell, 2013).

Table 2.1. Target liveweights and percentage of mature liveweights (MLW) according to stage of development and age to be achieved by herd replacement dairy calves at different mature liveweights of New Zealand dairy cows.

	Mature liveweights (kg)					
	MLWT%	350	400	450	500	550
Six months of age	30	105	120	135	150	165
Mating (15 months)	60	210	240	270	300	330
Calving (24 moths)	90	315	360	405	450	495

Adapted from Penno (1998).

Table 2.2. National herd loss (%) of cows according to age during the 2003 to 2013 production seasons in New Zealand.

	Age (years)							Annual
Season	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	mean
2003-04	14.8	13.1	14.0	17.0	21.3	25.2	30.6	19.4
2004-05	14.3	12.7	13.3	17.3	20.3	25.4	30.4	19.1
2005-06	15.0	12.5	12.4	15.8	20.3	23.3	29.4	18.4
2006-07	15.2	12.2	11.8	15.3	20.5	25.1	28.8	18.4
2007-08	16.0	12.4	12.8	15.9	20.0	25.1	30.5	19.0
2008-09	13.2	12.3	12.5	16.6	19.8	23.9	29.3	18.2
2009-10	13.0	12.8	13.7	17.8	22.4	27.1	32.7	19.9
2010-11	13.8	12.8	14.0	18.9	23.2	28.8	34.3	20.8
2011-12	12.7	12.3	13.2	18.5	23.2	27.8	34.4	20.3
2012-13	12.4	10.8	12.1	17.3	22.1	28.4	33.9	19.6
Mean	14.0	12.4	13.0	17.0	21.3	26.0	31.4	

Derived from DairyNZ and LIC (2016).

Growth of dairy heifers is influenced by several factors including genetics, nutrition and management (Khan et al., 2011a,b; Bach, 2012). The rearing practices for dairy calves and heifers in New Zealand vary from farm to farm and are poorly defined (Roche et al., 2014). Furthermore, on pastoral dairy farms, genetics make it more difficult to assess the effects of management and nutritional factors. Many New Zealand dairy farmers graze their heifers on a run-off or pay a grazier to grow the heifers, with heifers commonly leaving the dairy farm at weaning, or at about nine months of age and returning at around 22 months of age.

2.3. Long term effects of early nutrition and growth

The level and type of pre-weaning diet are known to affect the growth of dairy heifers (Khan et al., 2011a,b). Early life feeding and rearing practices affect the post-weaning growth rate (Khan et al., 2012) and can have long-term effects on liveweight at first breeding and milk production during first lactation (Soberon et al., 2012). The New Zealand dairy industry recommends weaning calves when they reach 90 kg for Holstein-Friesian, 80 kg for Jersey and 85 kg for Holstein-Friesian×Jersey crossbred calves (DairyNZ and LIC , 2013). However recently, Roche et al. (2014) reported that heifers in New Zealand with very low liveweight gain during the pre-pubertal period do not reach puberty at their planned mating date, resulting in a delay in the date of their first calving as well as a reduced rate of pregnancy, leading to a greater likelihood of culling during first and second lactation (Archbold et al., 2012). Therefore, the level and type of pre-weaning diet is of great importance to determine the future growth rate (Moallem et al., 2010), age at mating and the level of milk production of dairy heifers (Davis Rincker et al.,2011; Khan et al., 2011a,b; Soberon et al., 2012). Soberon et al. (2012) suggested that heifers that had gained more liveweight during the pre-weaning period were likely to have increased milk production during their first lactation i.e., every kilogram of pre-weaning ADG in heifers increased the milk yield by 1550 kg during the first lactation (Soberon and Van Amburgh, 2013). According to Gelsinger et al. (2016) there is a relationship between pre-weaning dry matter intake for improving milk, fat and protein production and there is a positive relationship between first lactation performance and pre-weaning average liveweight gain. This suggests that the provision of adequate nutrient supply during pre-weaning period to maintain average liveweight gain (suggested 0.5 kg/day) can enhance the first lactation of heifers when combined with proper post-weaning practices (Gelsinger et al., 2016). Therefore, early nutrient intake and growth rate of dairy heifers are the main determinant factors of future milk production.

2.4. Calf management in New Zealand

In New Zealand, pregnant cows are typically kept separate from the milking herd and calves are collected from the calving paddock once (after morning milking) or twice (morning and afternoon milking) daily and the calf‘s naval cord is sanitized with iodine solution. Some dairy farmers use DNA testing while others use a collar system to identify the calves and to maintain birth records. It is recommended that calves should receive around four litres of colostrum during the first 12 hours of age (DairyNZ and LIC, 2016). However, in many pastoral dairies the new born calves are transferred to sheds where they are kept in groups and fed colostrum upto 24 hours after birth.

After the colostrum (that often includes transition milk) feeding period (first 2 to 3 days) calves are fed ‘milk products’ that include stored colostrum, and whole milk or milk replacer until weaning. Calves with a birth weight of 40 kg need at least 5.8 L of whole milk per animal per day (average protein = 3.7% and fat = 5%) in order to achieve an average liveweight gain of 0.63 kg (DairyNZ and LIC, 2016). In New Zealand, weaning criteria for a dairy heifer are based on liveweight and generally heifers are required to reach 100 kg liveweight before they are weaned.

Calves in pastoral dairy farms are generally fed a solid feed from the second week of age. The type of solid feed for calves is variable and may include a variety of starter feeds and forage sources. In New Zealand, current milk feeding practices are not yet revised and need comprehensive studies where effects of early life nutrition on long-term growth and performance of heifers are demonstrated. Therefore, there is a need for a comprehensive study to investigate the short and long term effects of early life nutrition of dairy heifers.

2.5. Effect of liquid feeds on development and behaviour of dairy calves

Dairy calves in many USA and European dairies are artificially reared on restricted (10% of liveweight) amounts of whole milk or milk replacer for the first few weeks of their age to save costs (Khan et al., 2011a). However, studies during the last decade have clearly demonstrated that dairy calves given ad-libitum access to whole milk consumed ~20% of their liveweight daily, or ~10 to 12 L/day of milk (Jasper and Weary., 2002; Khan et al., 2007a; Sweeney et al., 2010). Feeding greater amounts of whole milk (Jasper and Weary, 2002; Khan et al., 2007a,b) and milk replacer (Diaz et al., 2001; Bartlett et al., 2006) to calves results in greater growth rate and feed conversion efficiency (FCE) compared to calves fed restricted amounts (~10% of LWT) of whole milk/milk replacer during pre-weaning period. Calves with ad libitum access to whole milk exhibit greater milk feeding frequency, spend more time consuming milk (Appleby et al., 2001), consume milk at a slower rate, have improved milk digestion and have reduced cross sucking behaviour (de Passille, 2001) compared to calves consuming restricted milk supply (Table 2.3) (Rushen and de Passille, 1995; Vieira et al., 2008).

Table 2.3. Effect of restricted milk supply (~10% of liveweight) on starter intake, liveweight gain, stature and behaviour of dairy calves.

Parameters	Effect	References
Pre-weaning		
Starter intake	+	Diaz et al., 2001; Jasper and Weary, 2002;
Liveweight gain	-	Brown et al., 2005; Bartlett et al., 2006; Cowles
Stature gain	-	et al., 2006; Khan et al., 2007a,b.
Post-weaning		
Starter intake	+	Terré et al., 2007; Roth et al., 2009; Raeth-
Liveweight gain	+	Knight et al.,2009; Borderas et al., 2009; Hill et
Stature gain	-	al., 2008; Sweeney et al., 2010.
Behaviour (time/incidence)		
Eating starter	+	Thomas et al., 2001; Phillips, 2004;
Sucking	+	Vieira et al., 2008;
Vocalizing	+	Jasper et al., 2008; Nielsen et al., 2008;
Lying	-	Krachun et al., 2010; Castells et al., 2012.

+ = increased, - = decreased

Non-nutritional (cross sucking) behaviour performed by calves fed a restricted milk supply may be due to milk being fed from buckets (Margerison et al., 2003) ingestion of small quantities of milk (Brake et al., 1982) or inadequate time spent consuming milk (Appleby et al., 2001; Jensen and Holm, 2003). The calves learn cross sucking during the pre-weaning period and continue this behaviour after weaning this can cause a health and welfare issues for other cows in the herd because such animals might steal milk, damage teats, and spread mastitis within the herd (De Passille, 2001; Keil and Langhans, 2001). In pre-weaned calves, cross sucking behaviour is also affected by housing conditions i.e., individual or group rearing (De Passille, 2001; Chua et al., 2002; Jensen and Budde, 2006; Vieira et al., 2010; Rushen et al., 2010), but the feeding management is of more importance than the housing conditions (Veissier et al., 1998). Feeding management that prevent cross sucking include: use of teat feeders (Appleby et al., 2001; Chua et al., 2002; Margerison et al., 2003; Jensen and Budde, 2006), use of automatic milk feeders (Veissier et al., 2002; De Passille and Rushen, 2006), increased milk allowance (Vieira et al., 2008; De Passille et al., 2010), gradual weaning from milk (Roth et al., 2008; De Passille et al., 2010), and access to concentrate and forage after milk feeding (Phillips, 2004; Lidfors and Isberg, 2003; Roth et al., 2008). According to Margerison et al. (2003) calves show cross sucking behaviour immediately after restricted milk feeding that might be due to hunger, which was apparent from the increase in starter intake following weaning (Margerison et al., 2003). One method to prevent cross sucking behaviour is to provide calves with some means (concentrate, fibre) to get oral satisfaction of sucking as previously reported by Margerison et al. (2003) that cross sucking declines as the calves started foraging and ruminating. Foraging behaviour and rumination are influenced by the availability and intake of solid feed (e.g. coarser starters, forages) (Chua et al., 2002; Lindfords and Isberg, 2003; Porter et al., 2007). According to Haley et al. (1998) providing hay immediately after milk feeding reduces cross sucking behaviour in calves. Roth et al. (2008) reported that calves eating more hay showed less cross-sucking behaviour and greater liveweight gains. Therefore, intake of solid feed (concentrate, forage) to supplement milk intake is of prime importance to prevent cross-sucking behaviour in young calves (Chua et al., 2002).

Restricting the amount of milk encourages calves to consume larger quantities of solid feeds, including cereal based starter diets or forages, which encourages rumen development and increases growth resulting from the consumption of solid feeds. Calves fed restricted amounts of milk (~10% of liveweight, or 4 to 5 L/day) develop foraging behaviour sooner and consume more solid feed (Jasper and Weary, 2002; Borderas et al., 2009), than calves fed more milk (>10% LWT) pre-weaning. A negative relationship exists between feeding greater amounts of milk and solid feed intake in young calves (Kertz et al., 1979; Terre et al., 2007; Raeth-Knight et al., 2009). Calves fed restricted milk supply (~10% LWT) consume almost double the amount of solid feed compared with calves fed higher amounts of milk during the week prior to weaning (Jasper and Weary, 2002; Cowles et al., 2006; Raeth-Knight et al., 2009). Researchers (Terre et al., 2007; Weary et al.,

2008) have reported lower solid feed intake when higher amounts of milk were fed, that led to poor rumen development, which was dependent on solid feed intake (Khan et al., 2007a,b).

A variety of milk replacers are available commercially and differ in their nutritional composition and quality (Khan et al., 2007a,b). Milk replacer with a higher protein (27 to 30% CP), and lower fat (15 to 20%) content is beneficial to calves by increasing liveweight gain of lean tissue (Diaz et al., 2001; Cowles et al., 2006; Hill et al., 2010). Lee et al. (2009) provided equal amounts of nutrients using either whole milk or milk replacer upto eight weeks of age to calves and reported greater pre-weaning liveweight gain in calves fed whole milk. Moallem et al. (2010) reported that heifers provided with whole milk during the pre-weaning period reached a target mating liveweight 23 days earlier than calves fed milk replacer. Further, first lactation heifers fed whole milk during pre-weaning showed greater liveweights and higher milk production later in life than calves fed milk replacer (Moallem et al., 2010; Khan et al., 2011a,b; Soberon and Van Amburgh, 2013). The higher body growth rate and physiological development of the mammary gland in young heifer calves being fed whole milk may be due to the availability of additional nutrients and some unknown growth factors gained from whole milk (Lee et al., 2009). Many recent studies reported that the greater pre-weaning growth achieved through provision of more nutrients could reduce the breeding age (Raeth-Knight et al., 2009) and improve first lactation milk yield (Moallem et al., 2010; Soberon et al., 2012) in dairy heifers.

In New Zealand, milk feeding practices for dairy heifers are not standardised (Roche et al., 2014). Efforts are needed to refine the existing standard of milk feeding practices and industry recommendations to improve pre-weaning heifer growth on New Zealand dairy farms. Work from global studies on heifer calves is not directly applicable to New Zealand system because animal genetics, farm management practices and feeding situations (i.e. pasture) differs from those of USA and European systems. Furthermore, the effect of different forms of solid feed on rumen development, behaviour and transition to pasture is not fully understood and requires further work.

2.6. Effect of solid feed on development and behaviour of heifers

2.6.1. Cereal based starter feeds for developing heifer calves

Young ruminants are born with an underdeveloped rumen and initially acquire all nutrients from milk based diets. The initiation of solid feed intake triggers the anatomical, microbial and physiological development of the rumen (Baldwin et al., 2004; Khan et al., 2007a,b) and thus shifts the reliance of young ruminants from milk derived nutrients to rumen fermentation end products (e.g. short chain fatty acids and microbial protein). Rumen development includes rumen epithelial (papillae) development, increased mascularization of the the rumen wall and increased rumen volume, all of which develop independently (Baldwin et al., 2004).

Generally, early rumen development is desired to reduce the associated costs with milk feeding to calves. The amount of solid feed consumed and its nature dictate most aspects of rumen development. Generally, cereal based starter feeds are considered better in triggering the development of rumen papillae than forage based diets (Suarez et al., 2007; Van Ackeren et al., 2010; Montoro et al., 2012) because the former yields more short chain fatty acids. Furthermore, the cereal based starter feeds produce greater amounts of butyrate and propionate in the rumen, both of which stimulate the growth of epithelial cells in the rumen wall (Sander et al., 1959; Tamate et al., 1962; Warner, 1991; Baldwin et al., 2004).

Maize, wheat, rice, barley, oat and sorghum grains are commonly used in calf starter diets (Khan et al., 2008). The grains differ in starch concentrations, rate (Huntington, 1997), and site of starch digestion (Philippeau et al., 1999). Cereals, such as maize and sorghum ferment more slowly while oats, wheat and barley ferment more rapidly (Huntington, 1997) due to their small grain size. Crocker et al. (1998) reported that the highest starch digestibility was found in steam flaked grains, followed by finely ground and dry rolled grains, while the lowest starch digestibility was observed in whole grains. These attributes of raw and processed cereal grains can affect rumen fermentation patterns and thus rumen development (Lesmeister and Heinrichs, 2004; Khan et al., 2007a,b). For example, the length and thickness of rumen papillae was significantly greater in calves fed steam flaked maize based starter diets than calves fed dry rolled and whole maize grains making up 33% of calf starter (Lesmeister and Heinrichs, 2004). Khan et al. (2007a,b) compared the effects of inclusion of corn, wheat, rice and barley in calf starter on fermentation pattern and rumen development of Holstein calves. They concluded that the calves fed on corn had a better rumen fermentation pattern and rumen development compared to those fed wheat, rice and barley.

However, cereal grains ferment rapidly and can result in the rapid production of lactate in the rumen (Anderson et al., 1987; Barkema et al., 1998), which decreases rumen pH (Anderson et al., 1987; Barkema et al., 1998). Oba et al. (2015) reported that calves suffer from ruminal acidosis when fed only cereal based diets. Lower rumen pH or acidosis could potentially reduce the rumen fermentation of solid material, increase the branching of papillae and leads to parakeratosis (Barkema et al., 1998; Suarez et al., 2007). Rumen parakeratosis could reduce the blood flow to the rumen epithelium, and limit the absorption of nutrients, which in turn could cause the sloughing of epithelial cells and papillae degeneration (Hinders and Owen, 1965; Zitnan et al., 1998).The degree of processing or ‘coarseness’ of cereals used in starter feeds can also affect rumen fermentation, digestibility of the nutrients, dry matter intake (Owens et al., 1998) and growth rate of calves. Less processed cereals, or coarsely ground cereals, often referred to as a muesli, have been reported to be effective in avoiding parakeratosis. Coarse feeds have greater feed particle size and along with availability of forage that increases saliva production and improves the buffering of rumen and maintains papillae integrity by the physical removal of the keratin layers to avoid parakeratosis.

2.6.2. Forages for developing heifer calves

The provision of forage promotes foraging behaviour, saliva production, rumination and enhances rumen development including motility, muscularization and volume in pre-weaned calves (Table 2.4) (Tamate et al., 1962; Vazquez-Anon et al., 1993; Zitnan et al., 1998; Coverdale et al., 2004; Suarez et al., 2006b; Castells et al., 2012). Forage in the diet of calves promotes physical development of the rumen because dietary fibre enhances rumen muscle development to a greater extent than cereal based starters (Tamate et al., 1962; Montoro and Bach, 2012). Forage intake could potentially prevent excessive starter intake and subsequent low rumen fluid pH in young calves (Van Ackeren et al., 2010).

The provision of forage allows calves to develop foraging behaviour and rumination at an early age, decreasing the time calves spend performing non-nutritive oral behaviour, including manipulating pen structures, tongue rolling and tongue playing (Kooijman et al., 1991; Mattiello et al., 2002). Furthermore, calves develop long term feed preferences during early in life (Simitzis et al., 2008; Miller-cushon et al., 2013). For example, Phillips (2004) reported that calves that had eaten ryegrass hay during the milk feeding period developed a preference for ryegrass hay and spent more time eating fresh ryegrasspasture post-weaning, compared with calves fed cereal straw. Therefore, the feed offered to calves around weaning significantly influenced on the long term feed preference and feeding motor skills (Arnold and Maller, 1977; Nolte et al., 1990). The other factor in developing motor skills is the repetition of eating the same diet source (Bandura, 1977). Thus, if calves eat more fibre around weaning they develop foraging motor skills in response to their repetitive experience with that particular fibrous diet (Arnold and Maller, 1977; Provenza and Balph, 1987).

Table 2.4. Effect of forage provision on rumen development, intake, liveweight gain and behaviour of dairy calves.

Parameters	Effect	References
Physical rumen growth	+	Franklin et al., 2003; Lesmeister and
Starter intake	+	Heinrichs, 2004; Coverdale et al., 2004;
Weight gain	+	Suárez et al., 2006a; Kehoe et al., 2007;
Stature gain	+	Khan et al., 2011a,b; Castells et al., 2012.
Behaviour (time spent)		
Eating starter	+	Phillips, 2004; Margerison et al., 2005;
Ruminating	+	Vieira et al., 2008; Jasper et al., 2008; van
Lying	-	Ackeren et al., 2009; Khan et al., 2011a,b;
Suckling	-	Castells et al., 2012.

+ Increased - Decreased.

International recommendations for the provision of fibre as forage to developing dairy are not clearly outlined. For example, according to NRC (2001) a calf starter diet should have an adequate digestible fibre along with readily fermentable carbohydrates to support the fermentation necessary for rapid and effective rumen growth (Greenwood et al., 1997; Hill et al., 2008). Morisse et al. (1999) suggested levels of 50g/day of forage to be fed to calves at three weeks of age increasing to 300g/day at 17 weeks of age to support rumen growth. In Europe, calves are recommended to receive a minimum supply of neutral digestible fibre (NDF) between 50 and 250g/d between eight and twenty weeks of age (EU Council, 1997). In New Zealand, there is no study performed to our knowledge to identify the optimum level and source of forage fed to heifers during early age.

Generally, forage is not recommended as a sole diet for calves younger than three weeks of age (Sahoo et al., 2005) because forages are generally less energy dense and developing calves have less ability to ferment forage compared with grains (Nocek and Kesler, 1980; Khan et al., 2011b). Several recent studies however argue that provision of forage to calves is necessary to promote development of the rumen, foraging behaviour and the rumination process (Suarez et al., 2007; Castells et al., 2012; Castells et al., 2013; Terre et al., 2013). Furthermore, provision of forage to young calves promotes pre-weaning growth and post-weaning transition to high forage diets in dairy heifers (Khan et al., 2012). Calves fed 10 to 25% chopped hay, ground hay or straw along with the starter diet showed increased dry matter intake and growth rates (Thomas and Hinks, 1982). Other authors (Franklin et al., 2003; Kehoe et al., 2007; Castells et al., 2012) reported improved digestibility, dry matter intake and feed efficiency when calves were fed forage based diets (16 to 18%NDF) along with cereal based starters. Khan et al. (2011b) reported that calves fed chopped hay along with a starter diet showed greater dry matter intake, and liveweight gain compared with those received only the starter diet. Recently, Moghadam et al. (2015) compared pelleted alfalfa hay with chopped alfalfa hay and reported that the provision of forage had beneficial effects in calves compared to calves fed pelleted alfalfa hay. However, there have not been any studies to compare the effects of moist alfalfa with conventional forage source (pasture hay) in New Zealand.

Offering forage supplements along with starter diets increases time ruminating in calves (Porter et al., 2007) but decreases feed conversion efficiency (Bach et al., 2007); this could be an economic disadvantage in the short term. However, in the long run provision of forage has an advantage over starter diets alone. Calves eating grass hay during pre-weaning spent more time grazing after weaning when they were sent out to pasture post-weaning (Phillips, 2004). According to Castells et al. (2012) calves fed a pelleted starter (18%NDF) with chopped grass hay showed improved total dry matter intake, liveweight gain without affecting nutrient digestibility and feed efficiency. Porter et al. (2007) compared starter diets with high (27%) and low (20%) NDF contents and reported better liveweight gain, dry matter intake and higher rumen pH in calves fed the high NDF diet. Laarman et al. (2012) reported that a high starch diet (cereal based starters) decreased rumen pH and might limit dry matter intake. However, the use of hay increased rumen pH and improves calves' dry matter intake and overall performance and reduced behavioral problems (Phillips, 2004). Many researchers have reported that supplementing developing calves with grass hay (Coverdale et al., 2004; Khan et al., 2011a,b; Castells et al., 2012) promoted concentrate intake, improved feed efficiency and resulted in a better rumen environment, while others (Tamate et al., 1962; Hill et al., 2008) reported that provision of forage can reduce concentrate intake or impaire development of rumen papillae. However, there are more beneficial effects of forage addition to calves' diet than negative effects (Table 2.5) and the negative results of forage feeding might be due to the experimental conditions, forage sources and amount of forage fed.

Table 2.5. Effects of offering forages and concentrate on growth of dairy calves.

Parameter[1]	Concentrate[2]	Forage[3]	References
Rumen weight	+	++	Tamate et al., 1962; Suarez et al., 2006b; Khan et al., 2011b; Castells et al., 2013.
Rumen volume/expansion	+	++	Tamate et al., 1962; Žitnan et al., 1998; Castells et al., 2013.
Papillae differentiation/growth	++	+	Sander et al., 1959; Lesmeister and Heinrichs, 2005; Hill et al., 2009a,b.
Blood BHBA/ketogenesis	+	+	Laarman et al., 2012; Castells et al., 2013.
Rumen motility/passage rate	+	++	Tamate et al., 1962; Žitnan et al., 1998; Castells et al., 2013.
Rumen bacteria	Amylolytic	Cellulytic	Beharka et al., 1998; Castells et al., 2013
Rumen protozoa	-	+	Beharka et al., 1998.
Total organc acids	++	+	Coverdale et al., 2004; Suarez et al., 2006b, 2007; Hill et al., 2009.
Acetate:Propionate	-	+	Stobo et al., 1966; Coverdale et al., 2004, Hill et al., 2009; Terre et al., 2013.
Butyrate	++	+	Stobo et al., 1966; Žitnan et al., 1998; Coverdale et al., 2004; Lesmeister and Heinrichs, 2005; Suarez et al., 2006b; Van Ackeren et al., 2009; Terre et al., 2013.
Lactate	+	-	Suarez et al., 2006b; Terre et al., 2013.

Adapted from Khan et al. (2016).

Table 2.5. Continued: Effects of offering forages and concentrate on growth of dairy calves.

Parameter[1]	Concentrate[2]	Forage[3]	References
Buffering capacity/rumination	-	+	Kay, 1960; Phillips, 2004; van Ackeren et al., 2009; Laarman and Oba, 2011; Castells et al., 2012, 2013; Terre et al., 2013.
Rumen health/parakeratosis	-	+	Hinders and Owen, 1965; Greenwood et al., 1997; Suarez et al., 2006b; Castells et al., 2013.

[1]Parameters were measured (within 3 months of age) in developing calves fed different amounts of milk or milk replacer, weaned at different ages (4 to 8 wk of age) and housed on different bedding materials (no bedding, sawdust, and straw) individually or in groups.
+ = generally a positive effect on a parameter by a feed type;
++ = generally a more positive effect on a parameter by a feed compared with other feed (forage vs. concentrate);
− = generally a negative effect on a parameter by feed type.
[2]Concentrate = grain-based mashed, pelleted, textured, and crumbed feeds.
[3]Forage = fresh, dried, or fermented grasses and legumes, fibrous crop residues (hulls, straw, cobs).

Adapted from Khan et al. (2016).

The beneficial effects of adding forages to the concentrate based diet are summarised in Table 2.5. These studies showed that the addition of forages improved the rumen environment to facilitate the greater dry matter intake that is required for early rumen growth and development (Table 2.5) and foraging behaviour in young calves. However, these studies are inconclusive regarding the exact source, ratio and the time of forage feeding to optimise the overall early growth performance (rumen growth, foraging behaviour, more liveweight gain) in young calves and further research is required.

Legumes (e.g. alfalfa) are high yielding forages and their nutritive value does not decline as fast as that of grasses (De Ruiter et al., 2007). Forage alfalfa is higher in crude protein and digestibility and enables higher intake (10-20%) than perennial ryegrass(Dewhurst et al., 2003). Castells et al. (2012) indicated that while there was a greater dry matter intake in calves fed alfalfa hay, it did not promote the starter intake or liveweight gain compared to calves fed ryegrass hay. Previous research (Wilson and Bartle, 1953) reported that alfalfa silage has not been recommended for feeding to young calves because calves fed alfalfa silage had lower liveweight gain than calves fed alfalfa hay.

Sykes et al. (1955) compared alfalfa silage and alfalfa hay and reported that feeding high levels of alfalfa silage did not promote adequate growth in dairy heifers. However, Porter and Kesler (1957) reported that feeding ad-libitum alfalfa silage to calves as a sole source of roughage for the first 16 weeks of age resulted in similar growth rates to those found in calves fed alfalfa hay and alfalfa hay plus alfalfa silage fed in combination. Thomas et al. (1959, 1961) observed that the liveweight gain of calves fed alfalfa hay was greater than calves fed alfalfa silage as a sole diet or fed along with maize grain. Similarly, Sauer et al. (1980) found that feeding alfalfa silage alone to dairy heifers or when fed along with maize resulted in better liveweights and was considered a suitable diet. The voluntary intake of alfalfa hay is reported to be greater than grass forages (Colburn et al., 1968; Moseley and Jones, 1979). These diets resulted in alfalfa being fed at different maturity stages and being dried or wilted (De Ruiter et al., 2007) and potentially preserved using the application of microbial inoculant and/or formic, lactic, acetic acids (Polan, 1998). The use of higher dry matter (DM) silages showed higher pH and can be preserved using recently developed silage additives in order to increase palatability, intake and calf growth rate. Considering the above results, there is need to investigate the use of alfalfa silage when fed along with cereal based starter diet to improve the performance of calves early in life.

2.7. Summary of the literature review and research concept

Poor growth rate of dairy heifers results in poor reproductive and productive performance of heifers, with 14% of heifers in New Zealand being culled annually. Poor pre-pubertal growth rate delays the age at first calving contributing to their poor survival in dairy herds. Global studies indicate that pre-pubertal growth and lifetime performance of heifers can be improved if heifers are fed according to growth and development requirements during the pre-weaning period. Development of the rumen, rumination and foraging behaviour permits young ruminants to perform and grow after weaning. The level of solid feed intake and its nature (chemical and physical) affects these developments in young ruminants.

Grain based concentrate diets contain large amounts of starch and thus provide necessary triggering agents for the physiological development of the rumen. Concentrate diets ferment to produce greater amounts of propionate compared to forages and propionate is the main triggering agent for the proliferation of rumen epithelium and the development of papillae in the rumen. However, provision of high starch or finer concentrate feeds reduces the rumen pH causing acidosis in developing calves. Lower rumen pH has been shown to reduce the development and absorption capacity of rumen papillae. Provision of forages can help to increase rumen pH.

Forages are thought to provide the bulk and starch required to promote physical development of the rumen and rumination behaviour. However, forages are typically less energy dense and produce more acetate than concentrate diets meaning they are not recommended in the diets of young calves. Because of this, there has been significant interest in exploring the effects of concentrate diets on the development and growth of heifers. But studies on the dietary effects of forages in young calves are scarce. Recent studies from Europe and Canada have demonstrated that dietary forage or fibre promote solid feed intake, rumen development, rumen fermentation and growth of calves. However, further investigation is needed to understand the effects of forage source on the pattern of solid feed intake, behaviour (e.g. foraging, rumination) rumen development and growth performance of calves during the pre-and post-weaning periods.

In the New Zealand pastoral dairy systems, heifers are fed a variety of solid feeds (concentrate and forages) during the pre-weaning period and transitioned to consume pasture. However, scientific data are scarce on how the type of solid feed early in life affects heifer’s feed intake foraging and rumination behaviour and growth performance during pre- and post-weaning. Therefore, the aim of this study was to assess the effect of offering differing forage diets on the early growth and its long term effect on survivability and performance of dairy heifers in their first and subsequent lactations.

This thesis will examine the following objectives:

- Compare the effect of provision of dietary concentrate and forage sources on feed consumption and growth performance of heifers during pre-and post-weaning periods.
- Compare the effects of dietary forage level in total mixed ration on feed consumption and growth performance of heifers during pre-and post-weaning periods.
- Compare the effects of dietary forage source and total mixed rations on the development of behaviour (mainly foraging and rumination) in heifers during pre-and post-weaning periods.
- Examine the long term performance of these heifersfed different forage based diet during pre-and post-weaning periods.

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Chapter 3

Effect of offering a cereal-based starter with and without access to moist alfalfa or pasture hay on the dry matter intake, growth rate and stature development of dairy heifers pre- and post-weaning

Abstract

The objective of this experiment was to assess the effect of offering moist alfalfa or pasture hay based forage source to dairy calves compared to no forage diet on pre- (1 to 49 days of age)and post-weaning (50 to 70 days of age) dry matter intake, liveweight, and stature development. A total of 60 crossbred (Holstein-FriesianxJersey) calves were selected randomly and were allocated to one of three treatments (20 calves/treatment) such that their birth date, liveweight and genetic merit were balanced across the treatment groups. All calves were fed whole milk (4L/head/day) and a cereal based starter diet with access to either; no additional forage (PS), moist alfalfa (PSA), or pasture hay (PSH). Dry matter intake (DMI, kg/day) was measured twice weekly for each animal. Liveweight (kg) and stature (mm) (hip width, hip height, last rib girth) was measured weekly. There was no difference in the intake of starter diet during pre- or post-weaning periods. However, total dry matter intake was greatest in calves fed PSH, intermediate for PSA and lowest in the PS diet during pre-weaning (PS: 367.6[c], PSA: 581.9[b], PSH: 740.9[a]) and post-weaning (PS: 1252.7[c], PSA: 1676.6[b], PSH: 2152.3[a]) periods. Liveweights were greater in calves fed additional forages (PSA, PSH) than calves fed starter only (PS) during pre-weaning (PS: 61.8[b], PSA: 67.0[a], PSH: 67.5[a]), one week post-weaning (PS: 65.1[b], PSA: 71.0[a], PSH: 71.3[a]) and after moving to pasture (PS: 74.3[b], PSA: 81.9[a], PSH: 83.6[a]). There was no difference in the stature of calves among different treatment groups. In summary, offering additional forages (moist alfalfa or pasture hay) increased the total DMI and liveweightsin calves during pre- and post-weaning periods.

Key words: calves, moist alfalfa, pasture hay, growth, DMI

3.1. Introduction

Cereal based starter diets are fed to young calves to produce volatile fatty acids (VFAs) in the rumen, specifically butyric and propionic acid that help to stimulate the growth and development of rumen papillae (Baldwin et al., 2004, Khan et al., 2011). According to NRC (2001) recommendations, calf starter diets should be relatively high in readily fermentable carbohydrates and should contain sufficient digestible fibre to support fermentation as well as rumination, which is required for rumen tissue development (Greenwood et al., 1997; Hill et al., 2008). Starter diets are commonly made up of oat, barley, wheat and maize as the carbohydrate source (Lesmeister and Heinrichs, 2004; Kehoe et al., 2007) in combination with soya bean, canola and cotton seed protein meals. These starter diets contain relatively high concentrations of metabolisable energy (12.5 MJ/kg DM) (Khan et al., 2007), neutral detergent fibre (NDF) (16 to 18%) (Franklin et al., 2003) and crude protein (~19%) (Margerison et al., 2005). The form and texture of cereal based starter diets are important factors affecting rumen development (Greenwood et al., 1997; Baldwin, 2004).

Smaller grain cereals such as wheat and barley ferment rapidly in the rumen, compared to maize or sorghum (Huntington, 1997). Therefore, when finely ground cereals or pelleted starters are fed to calves it results in the rapid production of short chain VFAs and could lead to accumulation of lactic acid, which lowers the rumen pH (Anderson et al., 1987; Barkema et al., 1998), causes degeneration of the papillae and parakeratosis (Hinders and Owen, 1965; Greenwood et al., 1997; Owen et al., 1998). Parakeratosis lowers or inhibiting the absorption of VFAs from the rumen, which in turn leads to lowered dry matter intake, and consequently lowered liveweight gain.

Larger particle size diets improve rumen papillae integrity and growth, and VFA absorption, due to their ability to increase rumination, saliva production, pH buffering and their higher abrasive value (Greenwood et al., 1997; Franklin et al., 2003; Lesmeister and Heinrichs, 2004; Bach et al., 2007; Weglarzy and Bilik, 2008). The addition of forages such as hay or straw has benefits, such as increasing rumen pH as a result of increased saliva production, increased rumination and increased abrasion of the rumen tissue by the fibre. High forage diets also prevent parakeratosis and increase the acetate to propionate ratio (Suarez et al., 2007). Phillips(2004) reported that calves on forage diets spend more time ruminating, have increased rumen volume, more muscularization, and greater motility than controls (Zitnan et al., 1998; Coverdale et al., 2004; Suarez et al., 2007). Calves fed additional forage spend more time eating (Phillips, 2004) thereby avoiding subsequent rumen fermentation disorders (Van Ackerson et al., 2010). European Union regulations stipulate that calves are to receive a minimum of 50 to 250 g of NDF between eight and 20 weeks of age (EU Council, 1997). Offering forages along with cereal based starter diets results in greater dry matter intake, rumen muscle developmentand body growth rate (Khan et al., 2011; Catells et al., 2012; Montoro et al., 2013) compared with calves fed starter pellets only.

Calves of less than three weeks of age might not digest fibre properly (Church, 1980) and therefore, in some studies when pasture hay was fed along with the starter diet a lower liveweight gain (Warner et al., 1956; Stobo et al., 1966; Leibholz, 1975) and poorer feed conversion efficiency were observed (Hill et al., 2008). This may be as a consequence of the fibre (NDF) content and degradation rate of the whole diet. Other studies found that feeding ground and chopped hay or straw increased cereal based starter pellet intake and liveweight gain of calves (Davis and Drackley, 1998, Khan et al., 2011) even in calves of less than two weeks of age (Khan et al., 2011). This result might be due to the effect of feed processing or the fibre degradation rate in calves independent of NDF content.

Increased calf growth rates have been achieved by increasing the crude protein (CP) content of the diet, for example by increasing the amount of milk replacers (Cowles et al., 2006; Bascom et al., 2007) whole milk (Margerison et al., 2013) or cereal starters (Khan et al., 2011) in the diet. A positive effect has been observed of CP content of cereal starters was increased to 19% and milk replacer (MR) increased up to 30%. Some research into the effect of forages on growth has been published (Khan et al., 2011), but little has been reported on the effect of feeding calves lower NDF and higher CP forage, for example, moist alfalfa. The aim of the research presented in this chapter was to offer a starter diet to calves supplemented with either moist alfalfa, with pasture hay or without any additional forage. The effect of these three diets was assessed on dry matter intake, liveweight gain and stature development of dairy calves during pre- post-weaning periods.

3.2. Material and methods

3.2.1. Animals selection, allocation and management

A total of 60 crossbred (Holstein-FriesianxJersey) dairy calves were separated from their dams within 12 hours of birth at Massey University dairy unit 4, weighed (40.1 ± 0.65kg) and allocated randomly at birth to one of the three treatments (20 calves/treatment) according to birth date, breed, liveweight (12 h of age) such that the treatment groups were balanced for these factors. Calves were housed in individual pens (1 x 1.5 m) with an opening that allowed calves to consume starter diets, forages and fresh water *ad-libitum* from the separate plastic buckets suspended above ground level on the front of the pen. Calves were bedded on sand, which had sawdust applied in a layer over the surface, which was replenished daily.

3.2.2. Feeding, feed management and treatment diets

All calves were fed 'first day milking' colostrum and received 2.8 to 4.8 L (~10% of liveweight) of colostrum twice daily for the first two days using individual teat feeders. At three days of age, calves were fed stored colostrum twice daily at a rate equivalent to ~10.5 % of birth weight up to a maximum of 4 L/head/day, which was fed via individual nipple feeders through to abrupt weaning at 49 day of age. All calves were fed a starter diet (PS) (Table 3.1) with additional forages, i.e. moist alfalfa (PSA), pasture hay (PSH) or without any forage (PS) starting from day one until one week after weaning (57 day of age). At 58 days of age, all calves were moved out to pasture, where they remained in three separate adjacent paddocks and continued to be fed the treatment diets at a maximum rate of 1.5 kg/day/calf until 70 days of age.

3.2.3. Measurement of feed intake, liveweight, stature and health

The intake of the calf starter diet and forage were recorded twice weekly from the 1st week until the 8th week of age. Intake was calculated from the difference in weight between feed fed and that remaining in the bucket. Samples of all the feed (~0.5kg DM) fed and remaining were collected once weekly, bulked and were frozen at –20°C for chemical analysis according to AOAC (1990). The liveweight and stature of each calf were measured once weekly until the 10th week of age. Liveweightswere measured using an electronic scale (kg ±0.2kg). Stature was measured by the same person, throughout the trial who measured hip width (mm) using a large calliper and hip height (mm) which was measured using a purpose designed measuring stick and the last rib girth (mm) was measured using a plastic measuring tape. The general health of all calves was monitored twice daily.

3.2.4. Chemical analysis

Treatment diets and hay samples were sent to Massey University Nutrition Laboratory (accredited to ISO 17025) to determine concentrations of DM, ME, CP, NDF, ADF, Ca, P, Mg, K (AOAC, 1990). Total digestible nutrients were calculated by using NRC (2001) equations.The volatile components in the semi-moist ensiled alfalfa feed was determined using the toluene distillation method (AOAC, 1990). The chemical composition of different treatment diets fed to calves is presented in Table 3.1.

Table 3.1. Chemical compositions of starter, moist alfalfa and pasture hay (±SD) fed to dairy calves during pre- and post-weaning.

	Starter diet components		
	Starter	Moist alfalfa	Pasture hay
Dry matter, %	86.2 (0.33)	44.3 (0.20)	87.0
Nutrients, %			
CP	18.9 (0.04)	20.4 (0.14)	10.7
Fat	4.1 (0.04)	2.8 (0.04)	1.7 (0.02)
NDF	20.9 (0.60)	41.7 (0.39)	65.7 (0.45)
ADF	8.2 (0.31)	31.6 (0.47)	35.1 (0.35)
Ash	9.5 (0.06)	10.3 (0.09)	8.2 (0.10)
[1]TDN	86.9	60.0	55.9
ME, MJ/kg DM	13.2	9.1	8.5
Minerals, g/kg DM			
Ca	13.3 (0.47)	12.7 (0.35)	7.0 (0.21)
Mg	3.4 (0.16)	2.3 (0.03)	2.5 (0.04)
K	13.5 (0.25)	27.3 (0.13)	2.5 (0.03)
P	6.2 (0.10)	2.6 (0.26)	3.5 (0.05)

[1]TDN = 96.35 - (%ADF x 1.15).

ME = 0.0362 x TDN (Published By: Montana State University Agricultural Experiment Station Analytical Laboratory McCall Hall Room 10 Bozeman, MT 59717. Updated: June 2012).

3.2.5. Statistical analysis

The data for dependent variables dry matter intake (DMI), liveweight (LW) and hip width (HW), hip height (HH), last rib girth (LRG) were assessed for normality of distribution using the Levene test and found to be normally distributed. The effects of treatment diets on the development variables were evaluated using a repeated measure mixed model (PROC MIXED; version 9.3; SAS Institute, Inc., Cary, NC). Individual calf was included in the model as a random component and treatment diets, age, and the interaction between these factors were included as fixed factors and proportion of

Holstein-Friesian as covariables. Forage intake (moist alfalfa, pasture hay), total DMI, liveweight, liveweight gain and feed conversion efficiency were analysed separately for the pre-weaning and post-weaning periods. The least squares means and standard errors were determined using the LSMEANS statement in the MIXED procedure. Multiple comparisons between means were performed using the LSD test as implemented the LSMEAN option and significant differences between means were declared at P<0.05.

3.3. Results

3.3.1. Feeds and nutrient intake

Table 3.2. Nutrient intake (LSM±SE) of dairy calves fed starter without any forage (PS), moist alfalfa (PSA) or pasture hay (PSH) pre- and post-weaning.

	Weaning		PS	PSA	PSH	P value
DMI	Pre	Starter, g/d	367.6 (22.93)	417.4 (22.93)	424.6 (22.93)	0.1696
		Forage, g/d	-	164.5^{b} (8.47)	316.3^{a} (8.47)	<.0001
		Total, g/d	367.6^{c} (24.52)	581.9^{b} (24.52)	740.9^{a} (24.52)	<.0001
	Post	Starter, g/d	1252.7 (46.40)	1301.2 (46.40)	1365.8 (46.40)	0.2328
		Forage, g/d	-	375.4^{b} (9.61)	786.5^{a} (9.61)	<.0001
		Total, g/d	1252.7^{c} (47.45)	1676.6^{b} (47.45)	2152.3^{a} (47.45)	<.0001
ME	Pre	Starter, MJ/d	48.5 (3.03)	55.0 (3.03)	56.1 (3.03)	0.7937
		Forage, MJ/d	-	14.9^{b} (0.74)	26.9^{a} (0.74)	<.0001
		Total, MJ/d	48.45^{c} (3.14)	69.95^{b} (3.14)	83.0^{a} (3.14)	0.0049
	Post	Starter, MJ/d	165.1 (6.12)	171.5 (6.12)	180.6 (6.12)	0.2994
		Forage, MJ/d	-	34.1^{b} (0.83)	66.8^{a} (0.83)	<.0001
		Total, MJ/d	165.1^{c} (6.19)	205.6^{b} (6.19)	247.4^{a} (6.19)	<.0001
CP	Pre	Starter, g/d	71.3 (4.37)	78.9 (4.37)	80.3 (4.37)	0.3051
		Forage, g/d	-	33.6 (1.28)	33.8 (1.28)	0.8777
		Total, g/d	71.3^{b} (4.67)	112.4^{a} (4.67)	114.1^{a} (4.67)	<.0001
	Post	Starter, g/d	243.0 (8.86)	245.9 (8.86)	258.1 (8.86)	0.4458
		Forage, g/d	-	76.6^{b} (1.32)	84.2^{a} (1.32)	0.0003
		Total, g/d	243.0^{b} (8.94)	322.5^{a} (8.94)	342.3^{a} (8.94)	<.0001

[a-c]Means in the same row followed by differing superscript letters differ significantly at P<0.05.

Table 3.2.Continued: Nutrient intake (LSM±SE) of dairy calves fed starter without any forage (PS), moist alfalfa (PSA) or pasture hay (PSH) pre- and post-weaning.

	Weaning		PS	PSA	PSH	P value
NDF	Pre	Starter, g/d	73.2^{b} (4.72)	87.2^{a} (4.72)	88.8^{a} (4.72)	0.0435
		Forage, g/d	-	68.6^{b} (4.84)	207.8^{a} (4.84)	<.0001
		Total, g/d	73.2^{c} (6.23)	155.8^{b} (6.23)	296.5^{a} (6.23)	<.0001
	Post	Starter, g/d	249.3^{b} (9.51)	271.9^{a,b} (9.51)	285.5^{a} (9.51)	0.0314
		Forage, g/d	-	156.6 ^{b} (5.82)	516.7^{a} (5.82)	<.0001
		Total, g/d	249.3^{c} (10.91)	428.5^{b} (10.91)	802.2^{a} (10.91)	<.0001
ADF	Pre	Starter, g/d	30.1 (1.86)	34.2 (1.86)	33.6 (1.86)	0.7972
		Forage, g/d		51.9 ^{b} (2.86)	111.0 ^{a} (2.86)	<.0001
		Total, g/d	30.1^{c} (3.12)	86.2^{b} (3.12)	144.6^{a} (3.12)	<.0001
	Post	Starter, g/d	102.7 (3.78)	106.7 (3.78)	107.9 (3.78)	0.8227
		Forage, g/d	-	118.6 ^{b} (3.29)	276.1 ^{a} (3.29)	<.0001
		Total, g/d	102.7^{c} (4.76)	225.3^{b} (4.76)	384.0^{a} (4.76)	<.0001

$^{a-c}$Means in the same row followed by differing superscript letters differ significantly at $P<0.05$.

The total DMI, ME and NDF intakes were greatest in calves fed PSH, followed by PSA, and were lowest in calves fed PS with no forage, during the pre- and post-weaning periods (Table 3.2). The mean CP intake was greater in PSH and PSA than calves fed PS during the pre- and post-weaning periods (Table 3.2). There was no difference between pre- and post-weaning in DM and nutrient intake from the starter diet alone between calves fed PS, PSA and PSH. NDF intake was greater in calves fed forages compared with starter diet alone, and intake was higher for PSH compared with PSA. Pre-weaning ME, and CP intake did not differ between calves fed PS, PSA and PSH, whereas DMI and NDF intakes were greater in calves fed forages (PSA, PSH) post-weaning (Table 3.2).

3.3.2. Liveweight and liveweight gain

Liveweight was greater for calves fed PSA and PSH compared to calves fed PS from 49 day onwards (Table 3.3). Daily liveweight gains were greater (<0.001) in PSA and PSH calves during pre-weaning (1 to 49 days) and post-weaning at pasture (58 to 70 days) compared to PS calves (Table 3.3). No difference was observed one week post-weaning between three treatments.

Table 3.3. Liveweight (LSM±SE) and daily liveweight gain (LSM±SE) of dairy calves fed calf starter with no forage (PS), moist alfalfa (PSA) or pasture hay (PSH) pre- and post-weaning.

	PS	PSA	PSH	P value
Liveweight, kg				
Birth	40.7 (0.81)	40.3 (0.81)	40.1 (0.81)	0.8445
49 d	61.8^{b} (2.71)	67.0^{a} (2.71)	67.5^{a} (2.71)	0.0019
57 d[1]	65.1^{b} (2.73)	71.0^{a} (2.73)	71.3^{a} (2.73)	0.0009
70 d[2]	74.3^{b} (1.26)	81.9^{a} (1.26)	83.6^{a} (1.26)	<0.0001
Liveweight gain, kg/d				
1 to 49 d,	0.43^{b} (0.059)	0.54^{a} (0.059)	0.56^{a} (0.059)	<0.0001
50 to 57 d[1]	0.48 (0.041)	0.57 (0.041)	0.55 (0.041)	0.7091
58 to 70 d[2]	0.66^{b} (0.017)	0.79^{a} (0.017)	0.88^{a} (0.017)	0.0365

[1]Weaned and housed.

[2]Weaned and grazing at pasture.

[a-c]Means in the same row followed by differing superscript letters differ significantly at P<0.05.

3.3.3. Stature

There were no differences among treatments (PS, PSA, PSH) for hip width, hip height and last rib girth of calves during pre- and post-weaning periods (Table 3.4).

Table 3.4. Stature (LSM±SE) measurements (hip width, hip height, and last rib girth) of dairy calves fed starter with with no forage (PS), moist alfalfa (PSA) or pasture hay (PSH) pre- and post-weaning.

	PS	PSA	PSH	P value
Hip width, cm				
Birth	17.7 (0.30)	17.9 (0.30)	17.5 (0.30)	0.4408
49 d	21.8 (0.18)	21.9 (0.18)	21.9 (0.18)	0.8945
56 d [1]	22.4 (0.21)	22.3 (0.21)	22.3 (0.21)	0.9555
70 d [2]	23.2 (0.19)	23.6 (0.19)	23.6 (0.19)	0.2627
Hip height, cm				
Birth	78.6 (0.53)	79.1 (0.53)	78.1 (0.53)	0.4175
49 d	89.1 (0.54)	89.7 (0.54)	89.1 (0.54)	0.6648
56 d [1]	90.5 (1.03)	91.6 (1.03)	90.7 (1.03)	0.3287
70 d [2]	93.2 (0.45)	93.0 (0.45)	93.1 (0.45)	0.9493
Last rib girth, cm				
Birth	86.9 (2.71)	87.6 (2.71)	85.4 (2.71)	0.1995
49 d	110.6(3.10)	111.8 (3.10)	113.0 (3.10)	0.4385
56 d[1]	113.6(3.37)	115.8 (3.37)	117.3 (3.37)	0.1627
70 d[2]	117.7(4.19)	122.8 (4.19)	120.4 (4.19)	0.1630

[1]Weaned and housed.

[2]Weaned and grazing at pasture.

[a-c]Means in the same row followed by differing superscript letters differ significantly at P<0.05.

3.3.4. Feed conversion efficiency

During pre-weaning period, the feed conversion efficiency of calves was greatest in calves fed PS, intermediate with PSA and lowest with the PSH diet (Table 3.5). However, post-weaning, the feed conversion efficiency of calves fed PS and PSA was significantly greater than calves fed PSH (Table 3.5).

Table 3.5. Feed conversion efficiency (LSM±SE) of dairy calves fed starter with no forage (PS), moist alfalfa (PSA) or pasture hay (PSH) pre- and post-weaning.

	Treatment diets		
Period	PS	PSA	PSH
1 to 49 d	1.17^{a} (0.068)	0.93^{b} (0.068)	0.76^{c} (0.068)
50 to 57 d	0.38^{a} (0.024)	0.34^{a} (0.024)	0.26^{b} (0.024)

LWG = Liveweight gain.

FCE Feed conversion effeciency calculated as LWG/total DMI (kg) per day.

$^{a\text{-}c}$Means in the same row followed by differing superscript letters differ significantly at $P<0.05$.

3.4. Discussion

3.4.1. Effect of restricted milk supply on solid feed intake

Calves fed milk *ad-libitum* consume more milk than those fed milk plus forages (Wyatt et al., 1977), mainly due to the higher palatability and digestibility of milk (Le Du et al., 1979). The existence of a direct relationship, in which greater supply of milk reduces solid feed intake (Broesder et al., 1990) has led to calves being fed restricted amounts of milk in order to increase solid feed consumption and stimulate early rumen growth and development (Baldwin, 2004; Khan et al., 2007). As a consequence, many dairy calves are fed restricted amounts of milk. In this experiment, the calves were fed milk at ~10.4% liveweight, which is a level of feeding similar to Abdelsamae et al. (2005). Abdelsamae et al. (2005) observed that alfalfa hay intake was greatest when the milk supply was restricted to 2.72 kg/day, whereas a greater milk supply of 10.88 or 13.66 kg/day, lowered the alfalfa hay intake by 36 and 43%, respectively. The greater forage intake in calves fed restricted amount of milk (2.72 kg/day) will likely be partly due to hunger and lower nutrient supply from exclusive consumption of milk (Church et al., 1980). Therefore, calves fed restricted milk supplies tend to meet their nutritional demands by eating more solid feed.

3.4.2. Role of forage provision on dry matter and nutrient intake

Supplementing the starter pelleted diet with forage stimulates the development of the muscular layer of the the rumen, and also acts as a rumen filler (Tamate et al., 1962). Khan et al. (2011) showed that supplementation with forage maintained the integrity of rumen wall and improved rumen health. In this study, offering calves moist alfalfa and pasture hay from early birth and onwards increased DMI and nutrient intake, as well as CP, ME, NDF, and ADF intake in both the pre- and post-weaning periods. Other similar studies showed that feeding forages such as pasture hay and cereal straw resulted in greater DMI (Thomas and Hinks, 1982; Phillips, 2004; Khan et al., 2011). In this study, supplementing the starter diet with forages did not affect starter intake and nutrient intake from the starter diet. Similar results were reported previously by Terre et al. (2013) who found no difference in pelleted starter intake among calves fed different feed treatments (with or without additional forage). However, like previous studies (Castells et al., 2012; Terre et al., 2013) greater total DMI and ME intake was observed in calves fed additional forages (pasture hay, moist alfalfa). Calves fed pasture hay showed the greatest increase followed by moist alfalfa diet, with the lowest being in calves fed starter alone during both pre- and post-weaning periods.

While comparing with NRC (2001) requirements,it was observed that calves fed starter diet only (PS) were getting lower than required amount of ME (Mcal) (required=3.5, actual=2.7) and CP (g) (required=159, actual=166.2) until weaning (49 day) but after weaning lower intake of ME (required=4.4, actual=4) and CP (required=246, actual=243) was observed in calves fed no additional forage. Although calves were eating more starter diet after weaning to meet their nutritional demands but it still it was lower than the recommended amount of ME or CP (calculated from NRC (2001). In calves with additional forages (PSA, PSH) greater intake of ME and CP was observed than PS fed calves (at 49 day, PSA: ME (required=4.3; actual=3.2), CP (required=193; actual=217.1), PSH: ME (required=4.3; actual=3.1), CP (required=194, actual=279.4) and also one week after weaning (at 57 day) PSA: ME (required=4.8; actual=4.9), CP (required=284; actual=322.5), PSH: ME (required=4.9; actual=5.9), CP (required=284; actual=342.3). This greater intake of ME and CP resulted in greater liveweight and liveweight gain in calves fed additional forages (PSA, PSH) than calves fed no additional forage (PS). The total intake of CP was greater for calves fed PS or PSA (19%) compared to calves fed PSH (16%); however greater liveweights were achieved by calves fed PSH during pre- and post-weaning period that might possibly be due to a greater dry matter intake as previously reported (Suarez et al., 2007; Khan et al., 2011). The greater dry matter and nutrient intake was observed in calves fed forages is most likely due to a well developed and functioning rumen (Khan et al., 2011).

Cereal based calf starters typically contain only 16 to 18% NDF (Franklin et al., 2003; Lesmeister and Heinrichs, 2004; Kehoe et al., 2007) and ferment rapidly in the rumen. It is recommended that some fibre from forages be fed along with such starters (Coverdale et al., 2004). This may be achieved by the addition of forage to concentrate rations in the diet, a practise which has been found to increase the DMI in calves (Barkema et al., 1998; Coverdale et al., 2004). In this experiment, the forage to starter/concentrate ratio of the PSA and PSH diets were 39% and 74%, respectively for pre-weaning, and were 29% and 58%, respectively for post-weaning period. In this experiment NDF was 20% of the diet in calves fed PS, during both the pre- and post-weaning periods. The total DMI consisted of 20% NDF for calves fed PS, 27% for calves fed PSA and 40% for calves fed PSH during the pre-weaning period while post-weaning onwards were 20% for calves fed PS, 26% and 37% for calves fed PSA and PSH respectively. Calves fed forages consumed higher levels of NDF, with more NDF being consumed post-weaning compared topre-weaning. The calves in this experiment consumed large amounts of forages and had relatively high NDF intakes even when fed moist alfalfa, which has a lower NDF level than pasture hay. The total dry matter intake was greater in calves fed forage based diets than calves fed no additional forage. These results are in agreement with Terre et al. (2013) who reported a greater dry matter intake in calves fed greater NDF diet from a forage source (27%). This is likely a consequence of greater ruminal pH in the forage fed calves than the calves fed low NDF diet (18%) without any forage. In this study ~40% NDF from a forage source (pasture hay) proved effective in improving dry matter intake and liveweights. ADF concentration in thepasture hay based diet (PSH) were lower (~18% of the total DMI) than the maximum threshold level of 23% ADF (Jahn and Chandler, 1976), and thus did not affect the dry matter intake. NDF in the forages would be more effective due to their larger particle size. In this study, calves fed additional forages had greater DMI compared to starter diet alone. This might have been due to the forage stimulating rumen development, and the consequent stimulation of feed degradation. The additional forage sources such as moist alfalfa and pasture hay play an important role in facilitating the growth of the rumen microflora and fauna, by stimulating more rumination, saliva production, and acting as a buffer to control rumen pH.

Post-weaning, a greater DMI was observed in forage supplemented calves compared with pre-weaning. This greater intake might be due to pressure to meet nutritional demands of growth and due to stimulation of the development and function of the rumen as described above. This could facilitate calves weaning earlier and so adapting to pasture feeding more efficiently. No difference in liveweight was observed between the two groups of forage supplemented calves (PSA or PSH) but the dry matter intake was greater in PSH fed calves than other two groups (PS, PSA). Previously, Castells et al. (2012) used alfalfa hay and grass hay along with a starter diet (NDF 18%) and reported greater dry matter intake and growth rates in calves fed a grass hay based diet compared to other diets with or without additional forages without affecting the feed conversion efficiency. In this study, moist alfalfa and pasture hay proved equally effective in increasing liveweights in young calves during pre- and post-weaning periods but a dry matter intake difference was apparent between two treatments. Greater dry matter intake was observed in pasture hay based diet occurs with previous studies (Khan et al., 2011; Castells et al., 2012).

Suarez et al. (2007) measured the ratio of acetate to propionate (A:P) in rumen fluid, and found it was greater in calves fed forages compared with a cereal based starter. They used the A:P ratio as an indicator of greater rumen forage fermentation. Rumination and saliva production and flow have been found to be important factors in rumen fermentation as they help to maintain a suitable rumen pH (Van Ackersen et al., 2010). These findings suggest that time spent ruminating could be a useful indicator of the adequacy of the forage fibre content of the diet in calves. In this study, it is deduced that the greater forage and functional NDF intakes in calves fed moist alfalfa and in particular pasture hay would have stimulated rumination and produced higher acetate to propionate ratio than those not fed forage. The lower DMI in calves fed starter diet only was likely the result of a lower fibre intake, which lowers rumen pH (Barkema et al., 1998; Greenwood et al., 1997; Huntington et al., 2006). Castells et al. (2012) also reported greater DMI and liveweight gain in calves fed starters with forages such as oat hay, barley straw, and triticale silage, compared with calves not fed forage. No digestibility or acidosis cases were observed throughout the experiment, indicating a better rumen environment (Khan et al., 2011).

3.4.3. Effect of forage provision on liveweight and liveweight gain

In this study, calves that achieved a greater DMI also gained liveweight faster at a younger age similar to previous research (Van Ackerson et al., 2010). As expected, calves fed forages also had greater energy intakes, and greater liveweights than calves fed starter diet only during pre-weaning, as well as one week post-weaning and after sent out to pasture.

A lower liveweight gain and DMI was reported in calves eating a diet of fine particle size (pellets) compared with a coarse particle size starter diet (Stobo et al., 1966; Barkema et al., 1998; Coverdale et al., 2004; Suarez et al., 2007). Similarly, Porter et al. (2007) reported 6% lower average liveweight gain; along with an 11% lower DMI, in calves fed starter diets consisting of small particle size compared to those fed a coarse textured diet. This observation supports the idea that coarse diet and forage based diets are important for maximising liveweight gain, consequent on greater DM and nutrient intake. Previously, it was observed that the use of forages along with starter diet resulted in greater average liveweight gain and DMI in calves compared to calves fed no forage-supplement (Thomas and Hinks, 1982; Davis and Drackley, 1998). In other studies that fed forage to calves within the first two weeks of life, feeding forages such as ryegrasshay (chopped or unchopped) and cereal straw resulted in greater growth rates and DMI (Thomas and Hinks, 1982: Phillips, 2004; Khan et al., 2011) during the pre-weaning period. Similarly, in this experiment, heavier liveweights were observed in calves fed forage post-weaning that was probably due to a more fully functioning rumen, with increased DMI and therefore nutrient supply compared with calves fed starter diet only. Similar outcomes were observed when calves were moved to pasture. No difference was observed in this experiment between the two forage diets of moist alfalfa and pasture hay in terms of liveweight gain. These results are similar to the results obtained by Castells et al. (2012) who reported no difference in weight gain between calves fed alfalfa hay or pasture hay. This study showed that addition of forages along with starter diets increased the DMI, ME, CP and the liveweight gain in calves both pre- and post-weaning.

3.4.4. Effect of forage provision on stature development

In the current experiment, the calves had a greater liveweight gain with forage supplement diets compared with starter alone, even when grazed on pasture. Khan et al. (2012) reported a greater girth and height in calves fed starter with additional forage than calves fed starter only. This result suggests that gut fill is unlikely to be a big influence in mediating the effects of the diets during the post-weaning period. However, a diet effect on rumen development and function was reported in forage-supplemented calves compared with calves fed starter only (Suarez et al., 2007; Khan et al., 2011; Khan et al., 2012). So, rumen function could contribute to the effect of the diets on post-weaning growth rate observed in the current experiment. In this study, no difference was observed in stature development (hip width, hip height, last rib girth) between three treatments, despite the effects of the diets on post-weaning liveweight gains. This higher weight in forage-supplemented calves might therefore be due to stimulation of rumen development a more developed rumen and rumen fill, however a sufficient period had elapsed while calves were grazed at pasture and fed similar diets during which calved fed forages pre-weaning continued to have greater liveweight and liveweight gains.

3.4.5. Effect of forage provision on feed conversion efficiency of dairy calves

Previous studies reported greater feed conversion efficiency in calves fed pelleted starters compared with multi-particle starters (Coverdale et al., 2004; Bach et al., 2007). In this study, during the pre-weaning period the feed conversion efficiency (FCE) was higher in calves fed starter diet only, with calves fed additional moist alfalfa forage having an intermediate FCE, while calves supplemented with pasture hay had the lowest FCE. Dry matter intake and liveweight gain were lower in calves fed starter diet only compared with calves fed the forage-supplemented diets. This suggests that the concentration of nutrients rather than the total nutrient intake is a significant factor influencing the growth outcome. Hill et al. (2008) reported lower FCE in forage supplemented calves compared with calves fed starter diet alone, and that increasing the percentage of forage (hay) used to supplement the starter diet increased the DMI, average liveweight gain, and lowered the feed conversion efficiency. During the post-weaning period, FCE was greater in calves fed starter diet alone than moist alfalfa forage or pasture hay fed calves. A relationship has been reported to exist between intake and liveweight gain (Khan et al., 2011; Castells et al., 2012). Coverdale et al. (2004) reported an increase in rumen pH, DMI and feed conversion efficiency in calves fed hay along with starter compared to starter alone. Castells et al. (2012) also reported improved feed conversion efficiency when pelleted starter feeds containing 18% NDF were fed to calves. However, in this study, lower feed conversion efficiency was observed in forage supplemented fed calves (PSA or PSH) compared with calves fed starter diet alone (PS). The higher liveweight gain observed with the forage supplemented diets might be the result of stimulation of rumen development and greater DMI. Similar to this study, Hill et al. (2008) reported that addition of forage (hay) to the starter diet increased DMI but lowered FCE. This is because of the higher intake of forage fibre (hay). Khan et al. (2012) also reported lower FCE in forage supplemented calves compared with calves fed starter only, but suggested that this might be due to accumulation of particles within the rumen, i.e. a gut fill effect, and suggested a detailed post-mortem study.

3.5. Conclusions

Supplementary feeding of forages, such as moist alfalfa or pasture hay, had no effect on the intake of starter diet. Total DMI and liveweight gain of calves were greater in calves fed moist alfalfa or pasture hay along with a starter diet, presumably as a result of a better rumen environment and function compared with calves fed a starter with no supplementary forage. Feeding moist alfalfa and pasture hay also increased ME and CP intake, and hence liveweight gain. Access to moist alfalfa or pasture hay increased NDF intake and showed lower feed conversion efficiency in young calves during pre- and post-weaning periods. The liveweight gain in calves did not differ between calves fed moist alfalfa and pasture hay, so the increased cost of moist alfalfa would not be justifiable unless there were other production gains that would justify the additional cost.

3.6. Future research

The calves in this experiment that were fed a diet containing either moist alfalfa or pasture hay consumed a large amount of these diets and had a relatively higher NDF intake, even though moist alfalfa had a lower NDF content than pasture hay. It would be useful to feed moist alfalfa and cereals as a total mixed ration to achieve a more controlled diet to calves with higher

CP and NDF so as to manipulate the dry matter intake in calves. It would also be useful to offer lower forage-to-cereal ratio TMR to calves less than 3 weeks of age and compare this with a higher forage-to-cereal TMR. These diets could be compared with a cereal starter ration supplemented with pasture hay, as this is the most frequently used forage supplement of a calf diet in the New Zealand dairy industry. The ratio of forage to cereals could be used to determine the effectiveness of mixed cereal and forage diets in determining the early growth and development of calves. The effect of lower (30%) or higher (70%) proportion of moist alfalfa mixed with starter diet compared with a conventional pasture hay supplemented with starter diet will be investigated in Chapter 4.

3.7. References

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Chapter 4

Effect of varying the proportion of moist alfalfa forage supplementation on the growth of dairy heifers during pre- and post-weaning

Abstract

Lower ratio (LF,30%) or higher ratio (HF,70%) moist alfalfa based total mixed rations (TMR) were prepared and compared with a conventional diet (PSH, starter supplemented with pasture hay) to assess the effect of these diets on the dry matter intake and growth of young calves during pre- and post-weaning periods. A total of 108 crossbred (Holstein-FriesianxJersey) calves (<12 h of age), were randomly allocated to one of the three treatments diets (36 calves/treatment) such that the treatment groups were balanced for date of birth, liveweight, and breed. Calves in each treatment (36) were kept as a group of 3 calves/group in one pen (12 pens/treatment). Mean total dry matter intake (g/day) was lower in calves fed TMR based diets (LF, HF) compared with calves fed PSH during second phase of pre-weaning: 22-49 d (LF: 1100.8^{b}, HF: 1209.3^{b}, PSH: 2323.7^{a}) and post-weaning: 50-57 d (LF: 1740.7^{b}, HF: 1742.4^{b}, PSH: 3714.3^{a}). During pre-weaning, liveweight gain (kg/d) was greater in calves fed PSH compared with calves fed moist alfalfa based TMR: 1 to 21 d: (LF: 0.56^{b}, HF: 0.57^{b}, PSH: 0.66^{a}) 22 to 49 d: (LF: 0.57^{b}, HF: 0.63^{b}, PSH: 0.71^{a}). A similar difference was observed after weaning: 50 to 57 d (LF: 0.55^{b}, HF: 0.56^{b}, PSH: 0.89^{a}) 58 to 70 d (LF: 0.46^{b}, HF: 0.49^{b}, PSH: 0.62^{a}). In conclusion, greater dry matter intake and liveweight gain was observed both during pre- and post-weaning in calves fed pasture hay along with starter compared with calves fed moist alfalfa based TMRs (LF, HF).

Key words: Dairy heifers, alfalfa, ryegrass hay, cereals

4.1. Introduction

Cereal based starter diets stimulate rumen growth and development in young calves by producing volatile fatty acids (butyric and propionic acid) (Sander et al., 1959; Baldwin et al., 2004; Khan et al., 2011). Provision of fibre along with a cereal-based starter diet increases the dry matter intake by improving the rumen environment and also help to avoid parakeratosis and acidosis, which occurs as a consequence of highly fermentable cereals in starter diets (Hinders and Owen, 1965; Thomas and Hinks, 1982; Owen, 1998; Suarez et al., 2007; Khan et al., 2007). According to NRC (2001) recommendations, a calf starter diet should be high in readily fermentable carbohydrates to provide propionate and butyrate, and should contain sufficient digestible fibre to support fermentation and rumination. These processes are required for proper rumen tissue development and full functioning of the rumen (Greenwood et al., 1997; Hill et al., 2008). Castells et al. (2012) reported that calves fed oat hay, barley straw or triticale silage showed greater dry matter intake and liveweights compared with calves fed starter only, supporting the importance of dietary fibre for optimal calf development.

However, some researchers reported negative effects on growth after offering higher forage levels to young calves, due to a shift in rumen fermentation resulting in more acetate than propionate or butyrate being produced, with a consequent delay in rumen papillae growth (Tamate et al., 1962; Zitnan et al., 1998) and voluntary dry matter intake (Hill et al., 2008; Drackley, 2008; Khan et al., 2011). These negative effects might be a consequence of a less developed digestive system at three weeks of age (Church, 1980; Khan et al., 2011). Franklin et al. (2003) suggested that feeding young calves forages with a relatively low neutral detergent fibre content, between 16 to 18% NDF, could avoid these negative effects. Coverdale et al. (2004) found that chopping hay improved the rumen environment and resulted in increased dry matter intake and feed conversion efficiency (FCE). In the previous study (Chapter 3) calves consumed a diet higher in NDF than what has been suggested previously to be optimal (Franklin et al., 2003). The results from Chapter 3 showed that calves consumed 20%, 27% or 40% NDF, when fed the no forage (PS), moist alfalfa (PSA) and pasture hay (PSH) based diets, respectively, during the pre-weaning period. Similarly, the percentage of NDF in the diet was also high for calves after weaning (20%, 26% and 37% for the PS, PSA and PSH diets, respectively). The calves fed the PSA and PSH diets, which contain forage, gained more liveweight than calves fed starter alone (Chapter 3). However, in that experiment calves had *ad libitum* access to forage so they could have consumed more fibre than could be fully digested. It might be possible to improve the growth of calves by specifying an optimal NDF content of the diet to support maximum growth in young calves. Therefore, the aim of this study was to offer total mixed rations to young calves which contained either 30% or 70% of moist alfalfa. These diets were compared with a more traditional diet in which calves were fed a cereal based starter along with pasture hay. The effects of these diets on the dry matter intake and liveweight gain of dairy calves were assessed during the pre- and post-weaning periods.

4.2. Materials and methods

4.2.1. Animals, housing and feeding management

A total of 108 crossbred (Holstein-FriesianxJersey) dairy calves were randomly selected from the Massey University dairy unit 4 and were allocated to one of the three treatments diets (36 calves/treatment) so as to balance the groups for breed, date of birth, and liveweight (<12 h of age). The calves in each group were fed one of the three treatment diets; a low fibre TMR consisting of moist alfalfa and cereals at a ratio of 30:70 by dry weight (LF), a high fibre TMR consisting of moist alfalfa at a ratio of 70:30 (HF), and a starter diet supplemented with pasture hay (PSH). The hay was fed*ad libitum* from a hay net suspended above ground level (Table 4.1).

4.2.2. Feeding and management

Calves in each treatment (36 calves/treatment) were subdivided into 12 pens with three calves in each 1.1 m L x 2 m W pen. The pens were bedded with sand that was replenished with fresh dry sawdust daily. The calves were housed indoors from the day of birth up until weaning at 49day of age. The calves remained indoors for a further week after weaning, until 57days of age and then were turned out to pasture in three different adjacent paddocks until the end of the experiment at 70days of age.

In the pre-weaning period, calves were fed 2.8 to 4.8L (~10% of liveweight) of 'first milking' colostrum for the first two days of life, which was fed twice daily using individual teat feeders. After the first two days of colostrum feeding, calves were fed whole milk twice daily (~10.4% of liveweight up to a maximum of 4 L/h/day) via individual nipple feeders. The milk (20 ml) was analysed weekly for fat and protein concentration. Solid feed diets were fed to calves in 20L troughs that were suspended above ground level inside each pen. The feed remaining in the troughs was removed twice daily and the feed replenished. Fresh clean water was fed using 10L plastic buckets inside each pen, which was replaced twice daily. Pasture hay was suspended in hay nets suspended inside one of the treatment pens.

Table 4.1. Chemical composition (±SD) of total mixed rations fed to dairy calves with low (LF) or high (HF) proportions of moist alfalfa, or starter with pasture hay (PSH) pre- and post-weaning.

	LF	HF	Starter	Pasture hay
Dry matter, %	52.5 (0.17)	45.6 (0.20)	87.5 (0.64)	89.1
Nutrients, %				
CP	14.8 (0.04)	20.2 (0.14)	20.6 (0.34)	12.0
Fat	5.0 (0.04)	3.1 (0.04)	5.2 (0.03)	2.0 (0.02)
NDF	25.9 (0.60)	38.4 (0.39)	27.8 (0.24)	64.4 (0.45)
ADF	16.6 (0.31)	30.8 (0.47)	15.9 (0.98)	34.0 (0.35)
Ash	8.2 (0.06)	10.5 (0.09)	11.7 (0.11)	7.0 (0.10)
TDN	77.3	60.9	78.1	57.2
ME, MJ/kg	11.7 (0.07)	9.3 (0.03)	11.8 (0.01)	8.7 (0.01)
Minerals, g/kg DM				
Ca	13.3 (0.47)	12.7 (0.35)	16.7 (1.16)	7.0 (0.21)
Mg	3.4 (0.16)	2.3 (0.03)	3.0 (0.05)	2.5 (0.04)
K	13.5 (0.25)	27.3 (0.13)	12.9 (0.14)	2.5 (0.03)
P	6.2 (0.10)	2.6 (0.26)	4.3 (0.06)	3.5 (0.05)

[1]TDN = 96.35 - (%ADF x 1.15).

ME = 0.0362 x TDN (Published By: Montana State University Agricultural Experiment Station Analytical Laboratory McCall Hall Room 10 Bozeman, MT 59717. Updated: June 2012).

Calves were fed all solid feed diets *ad libitum* until 57 days of age (1 week following weaning). At this time the calves were moved to pasture and grazed as three separate groups in one of three paddocks in rotation, during which time the treatment diets were fed at a rate of 2 kg/hd/day in two 50 L troughs in each paddock until 70 days of age.

4.2.3. Measurementsof individual animal feed, nutrient intake and growth

The intake by each group of the components of each treatment diet (3 calves /pen) of calves was recorded twice weekly from the 1st week until the 8th week of age. The feed intake was determined from the difference between the weight of the feed that was fed and the weight remaining in the trough (orts). Samples (~0.5 kg DM) of all the treatment diets (LF, HF, TMRs, PSH) were collected once weekly from the troughs after feeding and frozen at (–20 °C) for chemical analysis according to the procedure described by AOAC (1990). Samples were then analysed for DM, ME, CP, NDF, and ADF according to a previously described procedure (AOAC, 1990). Individual calf dry matter intake was calculated by dividing the total intake of each group in one pen by three (the number of calves in each group). Nutrient intake was determined from the nutrient concentration and the dry matter intake. The liveweight and stature of each individual calf was measured once weekly until 70 days of age using an electronic weigh scale (± 0.2 kg). The hip width (mm) was measured by the same person using a large caliper. Hip height (mm) was measured using a purpose-designed measuring stick and the last rib girth (mm) was measured at the last rib using a plastic measuring tape. The health of all calves was monitored twice daily.

4.2.4. Statistical analysis

All statistical analyses were performed using SAS version 9.2 (SAS Institute, Inc., Cary, NC). All animal measures were tested for normality of distribution using the Levene test and found to be normally distributed. Data were analysed separately within periods of age of the animals (1 to 21, 22 to 49 and 50 to 57 d) using the MIXED procedure. Repeated measurements in the same pen were analysed with a mixed linear model that included fixed effect of treatment diet and the random effect of pen.Proportion of Holstein-Friesian were added as covariables in the model. Repeated measures for the same animal were analysed with a mixed linear model that included fixed effect of treatment diet and the random effect of pen and animal nested within pen. The least squares means and standard errors for each treatment diets were obtained, and multiple comparisons were performed using the LSD test as implemented in the MIXED procedure. Significant differences between means were declared at P<0.05.

4.3. Results

4.3.1. Dry matter and nutrient intake

During the first pre-weaning phase (1 to 21 days), no significant difference was observed in mean dry matter intake of calves fed different diets (Table 4.2). In the second pre-weaning phase (22-49 days), mean dry matter was greater in calves fed PSH than calves fed either HF or LF TMR (Table 4.2). Also during post-weaning (50-57 days), calves fed PSH showed greater mean dry matter intake than calves fed different moist alfalfa based TMRs (LF, HF) (Table 4.2).

Greater mean ME (MJ/hd/d) intake was observed in calves fed PSH diet than calves fed different moist alfalfa based TMRs (LF, HF), when measured at either 1 to 21 days of age, 22 to 49 days or at 50 to 57 days of age (Table 4.2).

During the early rearing phase, from 1 to 21 days of age, the CP (g/hd/d) intake was greater in calves fed PSH than calves fed either HF or LH TMR, while there was no difference between calves fed HF TMR and those fed LF TMR (Table 4.2). Between 22 to and 49 days of age, the CP intake was greater in calves fed PSH, intermediate in calves fed HF TMR and least in calves fed LF TMR. Post-weaning, CP intake was greater in calves fed PSH than in calves fed HF or LF TMR.

Table 4.2. Nutrient intake (LSM±SE) of dairy calves fed total mixed rations with low (LF) or high (HF) proportions of moist alfalfa, or starter with pasture hay (PSH) pre- and post-weaning.

	LF	HF	PSH	P value
Total dry matter intake, g/d				
1 to 21 d	112.8 (130.5)	137.0 (142.9)	315.6 (142.8)	0.3801
22 to 49 d	1100.8[b] (74.6)	1209.3[b] (80.3)	2323.7[a] (86.9)	0.0001
50 to 57 d	1740.7[b] (206.4)	1742.4[b] (167.5)	3714.3[a] (364.9)	0.0001
ME intake, MJ/kg DM/d				
1 to 21 d	13.2[b] (3.9)	12.7[b] (3.9)	32.4[a] (3.9)	0.0007
22 to 49 d	128.8[b] (9.0)	112.5[b] (9.0)	238.2[a] (9.0)	0.0001
50 to 57 d	203.6[b] (25.7)	162.1[b] (25.7)	380.7[a] (25.7)	0.0001
Crude protein intake, g/d				
1 to 21 d	16.7[b] (6.31)	27.6[b] (6.31)	51.4[a] (6.31)	0.0096
22 to 49 d	162.9[c] (14.8)	244.2[b] (14.8)	378.8[a] (14.8)	0.0001
50 to 57 d	257.6[b] (41.3)	351.9[b] (41.3)	605.4[a] (41.3)	0.0001
NDF intake, g/d				
1 to 21 d	29.2[b] (34.5)	52.5[b] (35.5)	145.5[a] (24.7)	0.0370
22 to 49 d	285.1[c] (25.6)	464.3[b] (31.3)	1071.3[a] (39.3)	0.0001
50 to 57 d	450.8[c] (53.9)	669.0[b] (65.9)	1712.3[a] (168.5)	0.0001
ADF intake, g/d				
1 to 21 d	18.7 (22.1)	42.1 (26.9)	78.9 (30.1)	0.3651
22 to 49 d	182.7[c] (29.4)	372.4[b] (23.3)	580.9[a] (19.6)	0.0001
50 to 57 d	288.9[c] (32.1)	536.6[b] (50.7)	928.6[a] (89.9)	0.0003

[a-c]Means in the same row followed by differing superscript letters differ significantly at P<0.05.

From 1 to 21 days of age, the mean daily NDF intake was greater in calves fed PSH than calves fed either HF or LF TMR (Table 4.2). However, between 22 and 49 days of age and after weaning (50 to 57 days), the mean daily intake of NDF was greatest in calves fed PSH, intermediate with HF TMR and least in calves fed LF TMR.

At the early pre-weaning period, up to 21 days of age, no significant difference in mean ADF intake was observed among different groups (PSH, HF or LF TMR) (Table 4.2). However, the mean ADF intake was greater in calves fed PSH, compared to calves fed HF or LF TMR during 22 to 49 days and similar trent was observed during post-weaning period (50-57 days) (Table 4.2).

Table 4.3. Liveweight and liveweight gain (LSM±SE) of dairy calves fed low (LF) or high (HF) proportions of moist alfalfa, or starter with pasture hay (PSH) pre- and post-weaning.

	LF TMR	HF TMR	PSH	P value
Liveweight at age, kg				
1 d	38.5 (0.84)	40.2 (0.85)	39.3 (0.83)	0.4417
21 d	50.2 (1.06)	52.1 (1.05)	53.2(1.03)	0.0996
49 d	66.3^{b} (1.51)	$69.8^{a,b}$ (1.51)	73.1^{a} (1.48)	0.0003
57 d[1]	70.3^{b} (1.97)	73.8^{b} (1.98)	79.3^{a} (1.94)	0.0100
70 d[2]	76.6^{b} (1.79)	80.5^{b} (1.79)	88.1^{a} (1.76)	0.0008
Liveweight gain, kg/day				
1 to 21 d	0.56^{b} (0.032)	0.57^{b} (0.032)	0.66^{a} (0.031)	0.0049
22 to 49 d	0.57^{b} (0.022)	0.63^{b} (0.022)	0.71^{a} (0.021)	0.0070
50 to 57 d[1]	0.55^{b} (0.094)	0.56^{b} (0.094)	0.89^{a} (0.093)	0.0004
58 to 70 d[2]	0.46^{b} (0.046)	0.49^{b} (0.046)	0.62^{a} (0.045)	0.0238

$^{a-c}$Means in the same row followed by differing superscript letters differ significantly at P<0.05.

[1]Housed

[2]Grazing pasture

4.3.2. Liveweight and liveweight gain

The liveweights of calves at 49 days of age were greater in calves fed PSH and HF TMR, compared with calves fed LF TMR. Post-weaning, at day 57 and day 70, the mean individual liveweight was greater in calves fed PSH, compared with calves fed HF and LF TMR (Table 4.3). During all the pre- and post-weaning periods, the liveweight gain were greater in calves fed PSH, compared with calves fed LF and HF TMR (Table 4.3).

4.3.3. Stature

At 49 day of age, mean hip width was significantly greater in PSH calves compared with LF TMR-fed calves (Table 4.4). Post-weaning at day 57 and 70, the mean hip width of PSH-fed calves was greater than either the HF TMR or LF TMR-fed calves. At 49 day of age, mean hip height was significantly greater in calves fed PSH or HF TMR compared with LF TMR fed calves. Post-weaning, the mean hip height of calves fed PSH was greater than calves fed the HF or LF TMR at both post-weaning periods (Table 4.4). The mean last rib girth was significantly greater, in calves fed PSH than LF TMR when measured at the day 21 and 49 pre-weaning period (Table 4.4). Post-weaning, the mean last rib girth of PSH fed calves was greater than that of calves fed HF or LF TMR. When the calves were turned out to pasture there was no difference observed between calves fed PSH and HF TMR. However, calves fed PSH and HF TMR had greater last rib girth than calves fed LF TMR at this time period (Table 4.4).

4.3.4. Feed conversion efficiency

Greater feed conversion efficiency (FCE) was observed in calves fed moist alfalfa based TMRs (LF, HF) than PSH fed calves (Table 4.5) during two phases of pre-weaning period (1 to 21 days, 22 to 49 days). However, no significant difference was observed among different treatment groups post-weaning.

Table 4.4. Stature (LSM±SE) of dairy calves fed low (LF) or high (HF) proportions of moist alfalfa, or starter with pasture hay (PSH) pre- and post-weaning.

	LF TMR	HF TMR	PSH	P Value
Hip width, cm				
2 d	17.2 (0.16)	17.5 (0.16)	17.3 (0.16)	0.5406
21 d	18.6 (0.16)	18.8 (0.16)	19.0 (0.16)	0.1099
49 d	20.0^{b} (0.19)	20.4^{a,b} (0.19)	20.7^{a} (0.19)	0.0038
57 d[1]	20.3^{b} (0.23)	20.7^{b} (0.23)	21.3^{a} (0.23)	0.0005
70 d[2]	21.1^{b} (0.20)	21.5^{b} (0.20)	22.2^{a} (0.20)	<.0001
Hip Height, cm				
2 d	634.4 (6.17)	637.6 (6.19)	638.5 (6.09)	0.5394
21 d	671.5 (4.57)	671.1 (4.51)	677.2 (4.44)	0.3636
49 d	727.2^{b} (5.55)	735.1^{a,b} (5.54)	743.9^{a} (5.44)	0.0115
57 d[1]	741.6^{b} (5.87)	742.4^{b} (5.88)	760.2^{a} (5.77)	0.0089
70 d[2]	767.6^{b} (6.32)	769.2^{b} (6.35)	788.2^{a} (6.25)	0.0017
Last rib girth, cm				
2 d	83.7 (1.37)	84.6 (1.38)	85.0 (1.37)	0.2121
21 d	95.5^{b} (1.08)	97.3^{a,b} (1.08)	98.3^{a} (1.07)	0.0073
49 d	106.3^{b} (1.38)	108.5^{a,b} (1.39)	110.8^{a} (1.37)	0.0025
57 d[1]	108.4^{b} (1.59)	111.4^{b} (1.59)	115.5^{a} (1.57)	<.0001
70 d[2]	117.3^{b} (2.07)	120.6^{a} (2.08)	121.0^{a} (2.05)	0.0305

$^{a-c}$Means in the same row followed by differing superscript letters differ significantly at $P<0.05$.

[1]Weaned calves housed.

[2]Calves on pasture.

Table 4.5. Feed conversion efficiency (LSM±SE) of dairy calves fed low (LF) or high (HF) proportions of moist alfalfa, or starter with pasture hay (PSH) pre- and post-weaning.

	Total mixed rations		
Period	LF TMR	HF TMR	PSH
1 to 21d	4.9^{a} (0.081)	4.2^{a} (0.081)	2.09^{b} (0.081)
22 to 49d	0.52^{a} (0.050)	0.53^{a} (0.050)	0.31^{b} (0.050)
50 to 57d	0.32 (0.090)	0.32 (0.090)	0.24 (0.090)

$^{a-b}$Means in the same row followed by differing superscript letters differ significantly at P<0.05.

LWG – Liveweight gain.

FCE: Feed conversion effeciency calculated as LWG/total DMI (kg) per day.

4.4. Discussion

4.4.1. Dry matter intake

Previously it was reported by researchers (Anderson et al., 1987; Hill et al., 2008) that the digestive system of younger calves (<3 weeks of age) is not sufficiently well developed to effectively digest fibre. Also, the diet of young calves affects rumen development (Coverdale et al., 2004) as well as the voluntary feed intake (Drackley, 2008). However, in Experiment 1 (chapter 3) it was observed that pre-weaned calves can eat considerable amounts of fibre from forages. In Experiment 2 (this chapter), the pre-weaning period was divided into 2 phases (1 to 21 d and 22 to 49 days). No difference was observed in terms of dry matter intake during first phase (1 to 21 days). However, from 22 days onwards calves fed PSH showed greater dry matter intake than either HF or LF TMR diets. A similar trent was observe during the post-weaning period (50-57 days). These results demonstrated that calves are fully capable of consuming greater amount of forages. As a result of greater dry matter intake, calves fed PSH diet were consuming more nutrients (ME, CP, NDF) than calves fed moist alfalfa based TMRs (LF, HF). During the early growth protein and energy are the main limiting nutrients for liveweight gain (NRC, 2007). In this experiment, PSH fed calves had more availability of these nutriennts due to greater dry matter intake than other groups (LF, HF TMRs), hence showed greater liveweight gain. This might be due to abailability of pasture hay that stimulate rumination behaviour, early rumen growth and better rumen environment to consume more dry matter than other groups (LF, HF TMRs).

Khan et al. (2011) reported a positive effect on the rumen environment in young calves after supplementing with pasture hay. This finding is consistent with the greater dry matter intake of hay-supplemented calves observed in Experiment 1 and 2. In Experiment 2, the greater dry matter intake in pre-weaned PSH fed calves compared with the alfalfa-supplemented calves was similar to the findings from Experiment 1 (Chapter 3). This could be expected, as calves tend to consume a large amount of hay when given the opportunity. In experiment 2, calves fed HF TMR and LF TMR had lower DMI than a conventional calf diet (PSH). This might be due to a less developed rumen with a lower capacity to support dry matter intake, as moist alfalfa containing TMR has a lesser capacity to improve rumen motility, mascularization and volume development than pasture hay-based forage (Coverdale et al., 2004; Suarez et al., 2007). The other reason for the decreased DMI in the alfalfa-TMR fed calves might be the greater availability of effective fibre in the PSH diet, which promotes dry matter intake and also prevent rumen disorders that occur most commonly when highly fermentable concentrates are fed (Van Ackerson et al., 2010). Similar results were reported by other researchers, that grass hay is a better source of fibre for improving dry matter intake in calves, without affecting nutrient digestibility and feed efficiency (Castells et al., 2012). According to Mertens (1997) hay has more effective fibre to promote chewing activity and rumination, which in turn produces more saliva and helps to maintain an optimum rumen environment to support a greater dry matter intake in young calves.

It was observed that moist alfalfa fibre was not as effective as pasture hay in facilitating liveweight gain. A previous study comparing alfalfa hay with pasture hay did not find beneficial effects of feeding alfalfa hay (Castells et al., 2012). The results of this study showed greater dry matter intake in calves fed pasture hay along with starter (PSH) compared with moist alfalfa supplemented TMRs (LF or HF) during both pre-weaning and post-weaning periods. The DMI increase in calves fed LF TMR post-weaning might be due to restricted milk supply and the high maintenance requirement in LF calves. This in turn could have resulted in the calves consuming more dry matter post-weaning (Drakley, 2008). However, after weaning, the dry matter intake of the PSH group was significantly greater than moist alfalfa based TMR diets (HF, LF). It is possible that this was due to the pasture hay based diet better stimulating rumen development and function. Therefore, pasture hay could be a better forage source fed along with starter diet to increase dry matter intake in young calves.

4.4.2. Liveweight and liveweight gain

Castells et al. (2012) reported ryegrass hay as a better source of forage compared to other forage sources (straw, alfalfa hay), resulting in greater dry matter intake and improved growth rate in calves, with good nutrient digestibility and feed conversion efficiency. In the experiment described in this Chapter, the liveweight of calves fed pasture hay based diet (PSH) was higher than for calves fed the other two treatment diets (LF or HF TMRs), during pre- and post-weaning periods. Longer length and more effective fibre plays an important role in increasing chewing activity, which in turn produces more saliva and acts as a buffer in the rumen. This improves the rumen environment and functioning and increases the dry matter intake in young calves (Khan et al., 2011). Franklin et al. (2003) recommended diets with an NDF content of between 18 to 20% to improve feed digestibility and to promote dry matter intake. Other researchers reported that the addition of 10 to 25% of ground or chopped hay or straw to the diet of young calves increased the dry matter intake and average liveweight gain (Thomas and Hinks, 1982; Davis and Drackley, 1998). The calves in the current study consumed more than 25% of their diet as forage i.e., moist alfalfa and pasture hay. Porter et al. (2007) fed a higher NDF diet to young calves (27%) than was used in the current experiment, and reported positive effects on the rumen pH, starter intake and liveweight compared to calves fed lower, 20%, NDF diet. In this study, the total daily NDF intake, as a percentage of the total intake was 26, 38, and 46% of the diets at different growth phases (1 to 21 days, 22-49 days, 50-57 days). The NDF% of the LF TMR, starter and hay used in the current experiment were quite similar to those used in other experiments. The calves in this experiment ate feed with a relatively high NDF content and had a high NDF intake as a percent of the total diet during pre-weaning and post-weaning periods. Also greater intake of CP and ME was the main contributing factor in greater liveweight gain in PSH fed calves due to greater intake than calves fed either LF or HF based TMR diet. The HF TMR and PSH diets produced higher growth rates and greater stature compared with the LF TMR diet during these periods. Some of this difference could be due to digestive tract 'fill', which indicates the need to assess stature in growing dairy heifers as an independent measure of size and liveweight of calves following weaning when assessing the effect of diet on calf growth. It is important to consider the potential effect of differences in gut contents, because measuring empty liveweight on a weekly basis was not practical during the experiment. Liveweight was also measured post-weaning when all three groups of calves were grazed on pasture and calves had been consuming similar diets. This confirmed that calves fed PSH had higher liveweights than calves fed LF and HF TMRs during the rearing period.

No digestibility problems or disorders were observed during the experiment. This could be due to the presence of sufficient fibre that prevented the excessive intake of concentrated feeds and prevented rumen fermentation disorders (Van Ackerson et al., 2009). In this study greater daily weight gains were observed in PSH fed calves than in HF TMR and LF TMR fed calves pre-weaning (1 to 49 days) and post-weaning periods (50 to 57 days). Previously Khan et al. (2011) fed a starter diet to young dairy calves along with different forage sources and reported increased dry matter intake, more developed rumen and greater daily weight gain in calves fed a hay based fibre diet. In this study, calves fed pasture hay (PSH) proved to be better than moist alfalfa based TMRs in terms of dry matter intake and liveweight gain during pre-weaning and post-weaning periods that could be due to a better rumen environment. Therefore, offering pasture hay could be a good option to optimise rumen environment, increase dry matter intake and subsequently liveweight gain in young calves.

4.4.3. Stature

Khan et al. (2012) reported that calves fed fibre along with the starter diet during pre-weaning showed greater hip height and maintained this greater height after weaning compared with calves fed no additional forage. Similar results were found in this study and it was observed that mean hip width and hip height were significantly greater in PSH and HF TMR-fed calves than LF TMR calves during both the pre- and post-weaning periods. During pre-weaning, the last rib girth was significantly greater in the PSH and HF TMR-fed calves compared with the LF TMR-fed calves. After weaning, the mean last rib girth of PSH-fed calves was greater than for the calves fed HF TMR and LF TMR. After moving to pasture, the last rib girth was greater in PSH and HF TMR-fed calves compared to the LF TMR fed calves. This greater last rib girth might be due to a more developed rumen and the greater rumen fill effect of pasture hay (Khan et al., 2011) compared to moist alfalfa based TMRs (LF or HF).

4.4.4. Feed conversion efficiency

It was observed that in the two pre-weaning periods (1 to 21 d, 22 to 49 d), the feed conversion efficiency was higher in moist alfalfa fed calves (LF TMR or HF TMR) compared to calves fed starter supplemented with hay (PSH). These observations demonstrate that calves eating more dry matter (PSH) grow faster and have greater liveweight gain. In the experiment described in Chapter 3, it was observed that calves eating starter only (PS, no forage) showed better feed conversion efficiency than calves eating starter diet supplemented with forages (PSA, PSH). Other researchers also reported similar results. For example, higher feed conversion efficiency was observed in calves fed pellet starters than in calves fed forage based diets (Coverdale et al., 2004; Bach et al., 2007). A possible reason that has been suggested for the lower feed conversion efficiency in calves fed hay supplement along with starter diet is the greater intake of the calves fed this diet (Bach et al., 2007; Khan et al., 2011). This explanation also appears to be the cause of lower feed conversion efficiency observed in the current experiment which diminished during post-weaning period. Hill et al. (2008) reported a lower feed conversion efficiency when the percentage of hay in calves' diet was increased. According to Porter et al. (2007) a greater intake leading to a greater liveweight gain. The greater dry matter intake observed by these authors one week post-weaning has been suggested to be due to differences in calves consequent on eating exclusively dry feed at this time (Coverdale et al., 2004; Bach et al., 2007). Khan et al. (2012) reported lower feed conversion efficiency in pasture hay supplemented calves than in calves fed no additional forage, but this observation should be treated with caution because it could be the result of variation between treatment groups in their intestinal contents. In the current study, the only factor observed that could explain the lower feed conversion efficiency of the PSH fed calves was the greater dry matter intake. This higher dry matter intake is likely to have also had a positive effect on the rumen growth and development, and so to have helped the calves to start foraging and rumination early in life. This in turn would make it easier for the calves to transition from supplement feeding to a pasture based system. The results reported here are similar to that reported by Khan et al. (2012) who reported improved foraging and nutrient consumption in calves fed pasture hay, compared to calves eating no forage during the pre-weaning and post-weaning periods.

4.5. Conclusion

Greater dry matter intake, nutrient intake, liveweight gains, and stature development was observed in calves fed pasture hay based diet (PSH) compared to calves fed moist alfalfa based TMR diets (LF, HF). Feed conversion efficiency was greater in calves fed moist alfalfa based TMR diets (LF, HF) than calves fed pasture hay (PSH) based diets during pre-weaning period which diminishes post-weaning. Our recommendations would be to feed pasture hay in preference to moist alfalfa (fed either lower (LF) or higher

(HF) ratios) which showed better feed conversion efficiency but lowered the dry matter intake and liveweight gain (detrimental factors of early growth and development).

4.6. Future research

The development of feeding and foraging behaviours in dairy calves is of great importance to the New Zealand dairy industry, which is dominated by a pasture based system. Therefore, a detailed study was needed to assess the effect of different forage based diets on the development of feeding and foraging behaviours in dairy calves, both during pre- and post-weaning periods. This will be explored in Chapter 5.

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Chapter 5

The effect of offering differing forage diets separately or in differing proportions in a total mixed ration on the behaviour of dairy heifers during pre- and post-weaning periods

Abstract

Behaviour development was observed in calves fed different forages (moist alfalfa or pasture hay) during pre- (1 to 49 days) and post-weaning (50 to 57 days, 58 to 70 days) periods. 36 calves (12/treatment) were selected randomly from each experiment (Exp. 1, Exp. 2). In Experiment 1, calves were fed a starter diet with either; no forage (PS); moist alfalfa (PSA); or pasture hay (PSH). In Experiment 2, calves were fed total mixed rations (TMRs) with lower (LF) or higher (HF) proportions of moist alfalfa mixed with starter diet or starter diet with pasture hay. In Experiment 1, calves fed additional forage (PSA, PSH) spent more time eating: (PS: 88.7^{b}, PSA: 129.6^{a}, PSH: 124.7^{a},min/day) and ruminating (PS: 183.0^{b}, PSA: 315.3^{a}, PSH: 321.5^{a}, min/day) and sucked inanimate objects less frequently than calves fed no additional forage (PS) during pre-weaning period. Similarly greater eating (PS:97.8^{b}, PSA: 144.6^{a}, PSH: 142.6^{a}, min/day) and rumination (PS: 271.1^{b}, PSA: 375.4^{a}, PSH: 389.1^{a}, min/day) behaviours were observed one week post-weaning. In Experiment 2, calves fed higher forage (HF) based TMR or pasture hay (PSH) spent more time eating (LF: 75.5^{b}; HF: 97.0^{a}; PSH: 99.7^{a}, (min/day) and allo-grooming than calves fed LF TMR pre-weaning. Post-weaning, calves fed higher forage (HF) based TMR or pasture hay (PSH) spent more time lying down (LF: 754.8^{b}: HF: 811.7^{a}, PSH: 816.1^{a}, min/day) than calves fed lower forage (LF) based TMR. After moving to pasture, no significant differences were observed among calves in different treatments in both Experiment 1 and Experiment 2. In conclusion, calves fed additional forages fed separately (moist alfalfa, pasture hay) or in higher proportion (HF) as a TMR showed more nutritional behaviours (more time eating, allogrooming and less time sucking inaminate objects) than calves fed no forage (PS) or lower proportion of moist alfalfa based forage.

Key words: dairy calves, pasture hay, moist alfalfa, feeding behaviour

5.1. Introduction

Holstein calves fed milk *ad libitum* can consume up to 10 to 12 L/d (approx. 25% of LWT) milk during the pre-weaning period (Sweeney et al., 2010; Duve et al., 2012). Consuming greater amounts of milk increases playing behaviour (Krachun et al., 2010), which indicates a more positive emotional (Spinka, 2006) and welfare status (Yeates and Main, 2008; Held and Spinka, 2011). In New Zealand, dairy heifers have traditionally been fed a restricted milk allowance, typically ~10% of liveweight (LWT) (Appleby et al., 2001; Margerison et al., 2003) which is insufficient to meet the nutritional requirements of dairy calves during the first month of their life (Jasper and Weary, 2002; Sweeney et al., 2010). Calves that are fed restricted amounts of milk undertake more unrewarded visits to milk feeders and show more non-nutritional oral behaviours (Vieira et al., 2008; Jensen et al., 2015) such as oral manipulation of pen structures, cross sucking (Brake et al., 1982; Toates, 1986), vocalization, or tongue rolling (Kooijman et al., 1991; Mattiello et al., 2002).

Provision of forages helps calves to avoid these non-nutritional behaviours and it was observed that calves fed forage based diets spent more time ruminating (Hodgon, 1971; Phillips, 2004; Martin et al., 2006; Castells et al., 2012). And once rumination begins, calves spend less time performing cross sucking, another non-nutritional oral behaviour (Margerison et al., 2003). Therefore, this restriction of milk allowance (Appleby et al., 2001; Borderas et al., 2009) creates a lack of satiety (Savory et al., 1993), which causes calves to eat more solid feed to meet their nutritional demands (Nolte et al., 1990; Miller-Cushion et al., 2012; Miller-Cushon et al., 2013). It was reported previously that calves receiving restricted amounts of milk consume up to 50% more starter feed than calves fed milk *ad libitum* (Appleby et al., 2001; Khan et al., 2011). Therefore, restricting the milk allowance encourages calves to eat solid feed, such as cereal starter and hay (Appleby et al., 2001; Jasper and Weary, 2002). This consumption of solid feed is beneficial, because cereal based starters produce volatile fatty acid (VFAs) which when digested, particularly propionate and butyrate, these VFA stimulate proliferation of papillae in the rumen and increase the rumen surface area (Baldwin et al., 2004; Khan et al., 2007a,b). Forages are beneficial in developing calf foraging behaviour and rumination (Phillips, 2004; Martin et al., 2006; Castells et al., 2012). These behaviours produce more saliva, maintain a higher rumen pH and improve rumen muscularity and volume (Jahn et al., 1970; Thomas and Hinks, 1982; Sambraus et al., 1984, Khan et al., 2011).

Calves develop feed preferences from a relatively early age, and this is affected mainly by diet composition and palatability like calves showing a preference for starters with a sweet taste (Goatcher and Church, 1970; Sambraus et al., 1984; Nombekela and Murphy, 1995). This preference is so strong that calves consume more water when it has an orange odour (Thomas et al., 2007) than plain water, indicating the effect of taste and olfactory senses in food selection and consumption rate. The physical form of starter and the feeding method is also of great importance. Calves prefer to eat more of a multi particle diet than pelleted starters and prefer to eat more from buckets than they do from bins (Bach et al., 2007). Other factors affecting dry matter intake in calves include; the composition of starter (Coverdale et al., 2004), the ability of calves to select differing feed ingredients (Provenza et al., 2003; Montoro and Bach, 2012), and whether the feeds contain the nutrients to meet the nutritional requirements of the calf (Manteca et al., 2008). Also, calves show tolerance to toxins in some feeds (Provenza et al., 1996; Villalba and Provenza, 1996; Scott and Provenza, 1999) as well as the ability to limit dry matter intake (Provenza et al., 1996). Therefore, starter composition, palatability, physical form, and the nutritional demand of the calf is of great importance in the development of feed preference in young calves.

Calf starter diets commonly comprised of cereals such as barley, wheat and maize, along with protein sources such as soya, canola and sunflower, which are highly digestible (Lesmeister and Heinrichs, 2004) and relatively low in fibre (16% to 18% NDF) (Franklin et al., 2003). Feed intake and calf liveweight gain increase when both ground and chopped hay/straw are fed as a source of forage to young calves, along with a cereal starter (Thomas and Hinks, 1982; Davis and Drackley, 1998, Khan et al., 2011). Moreover, dietary experiences within the first 4 to 8 weeks of life determine calf motor skills (Arnold and Maller, 1977; Provenza and Balph, 1987), influencing eating behaviours and future feed preferences in calves (Nolte et al., 1990; Miller-cushon et al., 2012). Phillips (2004) reported that calves fed pasture hay prior to weaning spent more time eating pasture post-weaning when the calves were turned out to pasture. Miller-Cushon etal. (2012) showed that calves fed pasture hay along with a starter diet prior to weaning preferred to eat a similar mixed ration one week post-weaning. Hill et al. (2008) suggested that the amount of hay fed should be limited for young calves, because hay fed as 15% of the diet reduced starter intake, daily weight gain and feed conversion efficiency compared with hay fed at 5% of the total diet.

The first aim of this chapter was to assess the effects of offering pasture hay or moist alfalfa, separately from the cereal starter (Experiment 1) on the pre- and post-weaning behaviour development. The second aim was to assess the effect of feeding lower and higher proportions of moist alfalfa forage based TMRs mixed with starter (Experiment 2) on the pre- and post-weaning behaviour development.

5.2. Material and methods

5.2.1. Animals

The experiments were completed between 1st August 2010 and 10th January 2011 and 1st August 2011 and January 2012, during which time the calves were managed at the Massey University calf unit No 4, Palmerton North, New Zealand, in accordance with the ethical approval of Massey University Animal Ethics Committee. Crossbred (Holstein-FriesianxJersey) calves were collected from the calving paddocks within 12 h of birth and taken to the calf unit where they were fed 2L of fresh first day milking colostrum twice daily (07.00 and 16.00) for the first 3 days. In both Experiment 1 and Experiment 2 the behaviour of 36 calves (12/treatment) were observed individually at three separate time points, which corresponded with the pre-weaning period (1 to 49 days of age), the early post-weaning period (50 to 57 days of age), during which calves were housed indoors, and while calves were grazed on pasture (58 to 70 days of age).

5.2.2. Calf management and milk diet feeding

All calves had their umbilicus treated with a 7% iodine solution, brought to the calf shed and were allocated to their respective treatments. All calves were fed ‘first day’ colostrum, for 3 days (approx. 2.8 to 4.8 L) of colostrum per calf twice daily using plastic bottle feeders with 5L capacity fitted with soft rubber teats. The calves were then fed whole milk (WM) at approx. 10.4% of birth weight (4L) twice daily (0730 and 1600 h) from day 3 until 18 d of age and thereafter once daily (0730 h) until the calves were weaned at 49 d. The milk used was of retail quality (3.51 ± 0.25% protein, 4.42 ± 0.24% fat, 4.2 ± 0.06% lactose and SCC of 157 ± 42.6 × 10^3 per mL), and was fed individually to each calf after warming (approx. 35°C) using 4L plastic calf feeding containers fitted with rubber teats (Stallion Plastics Ltd, Palmerston North, NZ). The milk feeding equipment was rinsed with cold water, washed and disinfected with hot water plus a 5% hypochloride solution following each feeding.

5.2.3. Housing management

The calves were housed in a steel pole barn with a solid concrete floor. In Experiment 1, calves were kept in individual pens (1 x 1.5 m) made of galvanized metal bars, which allowed the calves to have sight, sound and touch of the other calves. In Experiment 2 the calves were kept in the same pens and building, but the individual pens were amalgamated into larger pens (3 x 4.5 m) to allow 3 calves per pen. All pens were bedded on a layer of sand, with sawdust added on top, which was replenished daily. The calves remained housed until 58 days of age, at which time they were turned out in the corresponding treatment groups and grazed on 1 ha paddocks on a rotational basis. At pasture the calves were fed their treatment diet at a maximum rate of 1.5kg/calf/day in two 50L troughs placed in each paddock for a further two weeks.

5.2.4. General health

All calves were observed twice daily for signs of illness (nasal discharge, cough and diarrhoea). While dehorning, calves were given local anaesthetic at 5 ± 0.5 weeks of age using a gas powered hot disbudding iron, and vaccinated (7 in 1 (Ultravac™, Zoetis, USA)) between 4 to 8 weeks of age.

5.2.5. Feeding and treatment diet management

At day 2 of age the calves were weighed and allocated to one of the three diet treatments balanced for their date of birth, breed, and liveweight (<12 h of age).

In Experiment 1, all the calves were fed a calf starter (Table 5.1) with either: no additional forage (PS), moist alfalfa (PSA), or pasture ryegrasshay (PSH). In Experiment 2, calves were fed*ad libitum* access to: a total mixed ration (TMR) of a lower proportion of moist alfalfa to starter (30:70) (LF); a TMR of a higher proportion of moist alfalfa to starter (70:30) (HF); or a starter with pasture hay (PSH) (Table 5.2).

Table 5.1. Chemical compositions of starter, moist alfalfa and pasture hay (±SD) fed to dairy calves pre- and post-weaning.

	Starter diet components		
	Starter	Moist alfalfa	Pasture hay
Dry matter, %	86.2 (0.33)	44.3 (0.20)	87.0
Nutrients, %			
CP	18.9 (0.04)	20.4 (0.14)	10.7
Fat	4.1 (0.04)	2.8 (0.04)	1.7 (0.02)
NDF	20.9 (0.60)	41.7 (0.39)	65.7 (0.45)
ADF	8.2 (0.31)	31.6 (0.47)	35.1 (0.35)
Ash	9.5 (0.06)	10.3 (0.09)	8.2 (0.10)
TDN	86.9	60.0	55.9
ME, MJ/kg DM	13.2	9.1	8.5
Minerals, g/kg DM			
Ca	13.3 (0.47)	12.7 (0.35)	7.0 (0.21)
Mg	3.4 (0.16)	2.3 (0.03)	2.5 (0.04)
K	13.5 (0.25)	27.3 (0.13)	2.5 (0.03)
P	6.2 (0.10)	2.6 (0.26)	3.5 (0.05)

[1]TDN = 96.35 - (%ADF x 1.15).

ME = 0.0362 x TDN (Published By: Montana State University Agricultural Experiment Station Analytical Laboratory McCall Hall Room 10 Bozeman, MT 59717. Updated: June 2012).

Table 5.2. Chemical composition (±SD) of total mixed rations fed to dairy calves with low (LF) or high (HF) proportions of moist alfalfa, or starter with pasture hay (PSH) pre- and post-weaning.

	LF	HF	Starter	Pasture Hay
Dry matter, %	52.5 (0.17)	45.6 (0.20)	87.5 (0.64)	89.1 (0.51)
Nutrients, %				
CP	14.8 (0.04)	20.2 (0.14)	20.6 (0.34)	12.0 (0.17)
Fat	5.0 (0.04)	3.1 (0.04)	5.2 (0.03)	2.0 (0.02)
NDF	25.9 (0.60)	38.4 (0.39)	27.8 (0.24)	64.4 (0.45)
ADF	16.6 (0.31)	30.8 (0.47)	15.9 (0.98)	34.0 (0.35)
ASH	8.2 (0.06)	10.5 (0.09)	11.7 (0.11)	7.0 (0.10)
TDN[1]	77.3	60.9	78.1	57.25
ME, MJ/kg DM	11.7	9.3	11.8	8.7
Minerals, g/kg DM				
Ca	13.3 (0.47)	12.7 (0.35)	16.7 (1.16)	7.0 (0.21)
Mg	3.4 (0.16)	2.3 (0.03)	3.0 (0.05)	2.5 (0.04)
K	13.5 (0.25)	27.3 (0.13)	12.9 (0.14)	2.5 (0.03)
P	6.2 (0.10)	2.6 (0.26)	4.3 (0.06)	3.5 (0.05)

[1]TDN = 96.35 - (%ADF x 1.15).

ME = 0.0362 x TDN (Published By: Montana State University Agricultural Experiment Station Analytical Laboratory McCall Hall Room 10 Bozeman, MT 59717. Updated: June 2012).

The calves had access to the treatment feeds that were placed outside each pen. The feed was accessed through the front gate, which was fitted with three openings that provided each calf access to feed and water from separate plastic buckets suspended above ground level. In Experiment 1 the calves had access to three buckets through the front of each individual pen and in Experiment 2 the calves had access to three gates and nine buckets from which they had access to the treatment feeds.

5.2.6. Observation of behaviour

The behaviours of the calves listed in Table 5.3 were monitored using scan sampling (Colgan, 1978; Martin and Bateson, 2007) over three consecutive continuous 24 hour periods, with recording of animal activity every 5 minutes during daylight hours (05.00 to 19.00) and every 15 minutes during darkness (19.00 to 05.00). The behaviours observed were: time spent drinking water, eating, rumination, standing, lying, and sleeping. The frequency and length of behaviours that were practiced discontinuously for relatively shorter periods, such as grooming/allo-grooming, sucking, vocalization and drinking and sucking behaviour (Table 5.4), were observed by direct measurement of each occurrence. This was done by recording behaviour continuously over a period of 30 min directly prior to, and immediately following, milk feeding (once a day milk feeding) and noting each incidence of the behaviour of interest. The start and end time of each event and the calf/calves involved were recorded in seconds using a stop watch.

Table 5.3. Description of behaviour of dairy calves observed.

Behavior	Definition
Standing	Calf is standing and doing no other activity
Lying	Body resting on the floor
Sleeping	Calf lying on floor, inactive with eyes closed
Eating	Head in feed bucket/trough and food in mouth
Rumination	Regurgitating and chewing previously swallowed food

Table 5.4. Description of behaviour of dairy calves recorded as individual incidences over a period 30 mins directly before and following milk feeding.

Behavior	Definition
Drinking	Consumption of water from bucket
Sucking pen	Calf sucking/ licking pen structure with its mouth
Sucking other calf	Calf sucking / licks other calf
Vocalization	Any vocal noise made such as mooing
Grooming/ Allo-grooming	Calf licks its body with lips or tongue, or both

5.2.6. Statistical analysis

In Experiment 1 and Experiment 2, the individual animal behaviour data were summarized into the mean time (min) spent performing each of the behaviours. The data were not normally distributed and were square root transformed. The transformed data were analysed using a mixed effect model for repeated measures in SAS 9.3 (SAS Institute, Inc., Cary, NC). Period of observation and treatment diet were included in the model as fixed effects, and calf-within-treatment was included as a random effect and proportion of Holstein-Friesian as covariables. Least squares means, standard errors and frequency of differing behaviours were calculated and back transformed. The significance of differences among the groups for cross suckling and non-nutritive behaviours was determined using a least difference test as implemented in MIXED procedure, and the threshold for the existence of a significant difference was chosen to be $P<0.05$.

5.3. Results

5.3.1. Experiment 1

In Experiment 1, calves fed starter with no supplemental forage (PS) had a higher number of incidences of sucking inanimate objects (Figure 5.1) than calves fed PSA or PSH. Calves with no additional forage (PS) showed more non-nutritional sucking bouts (Figure. 5.2) and showed greater average sucking bout length (PS: 355.83, PSA: 87.82, PSH: 48.82 sec) followed by moist alfalfa forage based diet and then pasture hay based forage (PSH). It was observed that calves fed starter along with a forage supplement (PSA or PSH) spent significantly more time eating and ruminating than calves fed calf starter only (PS) during the pre-weaning period (Table 5.5).

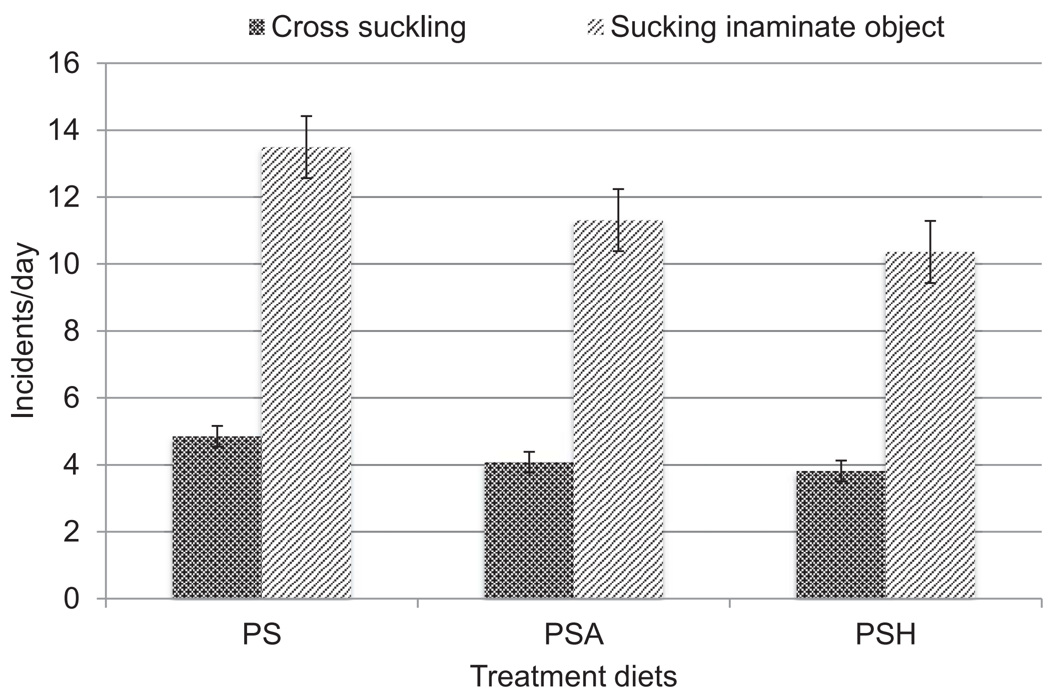

Figure 5.1. Number of sucking incidences/day observed during the pre-weaning period in housed dairy calves fed starter with no additional forage (PS), moist alfalfa (PSA) and pasture hay (PSH) in Experiment 1.

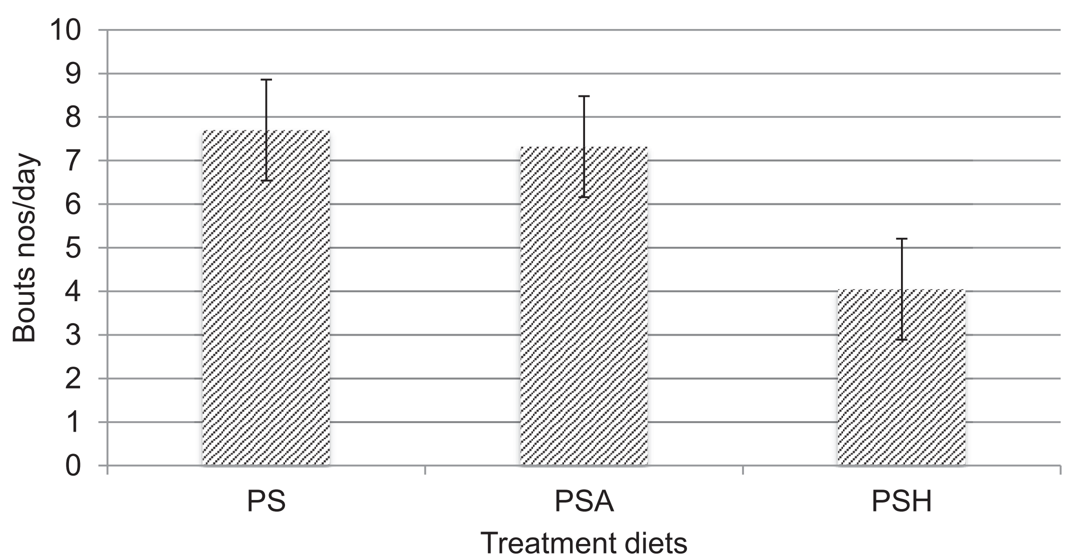

Figure 5.2. Number of sucking bouts/day observed during the pre-weaning period in housed dairy calves fed starter with no additional forage (PS), moist alfalfa (PSA) and pasture hay (PSH) in Experiment 2.

The differences in non-nutritional behaviours among treatment did not persist after weaning, as no significant difference was observed in the number of incidents of vocalizing, allo-grooming or drinking water. However, after weaning, calves fed additional forage supplements (PSA and PSH) spent significantly more time eating and ruminating than calves eating starter diet only (PS). There were no significant difference in time spent standing, lying, and sleeping among calves fed PSA, PSH, or PS (Table 5.5, 5.6).

Table 5.5. Behaviour (time spent) observed during the pre-weaning period in dairy calves fed starter alone (PS), starter with moist alfalfa (PSA), and starter with pasture hay (PSH) in Experiment 1.

	PS	PSA	PSH	P value
Time spent/24 h				
Standing, min.	177.3 (0.87)	136.9 (0.78)	155.6 (0.80)	0.6307
Lying, min.	670.0 (0.48)	707.9 (0.43)	745.5 (0.44)	0.6106
Sleeping, min.	296.9 (1.13)	289.0 (1.00)	201.8 (1.03)	0.1148
Eating, min.	88.7^{b} (0.26)	129.6^{a} (0.20)	184.7^{a} (0.22)	0.0023
Ruminating, min.	183.0^{b} (1.14)	315.3^{a} (1.03)	411.5^{a} (1.06)	0.0009

$^{a-b}$Means in the same row followed by differing superscript letters differ significantly at $P<0.05$.

Table 5.6. Behaviour (time spent) observed during the post-weaning period in housed dairy calves fed starter with no additional forage (PS), starter with moist alfalfa (PSA) and pasture hay (PSH) in Experiment 1.

	PS	PSA	PSH	P value
Time spent/24 h				
Standing, min.	128.7(0.87)	154.7(0.78)	110.1 (0.80)	0.2318
Lying, min.	799.5 (0.48)	752.1 (0.43)	853.4 (0.44)	0.1968
Sleeping, min.	214.9 (1.13)	173.7 (1.00)	154.1 (1.03)	0.6592
Eating, min.	97.8^{b} (0.26)	144.6^{a} (0.20)	142.6^{a} (0.22)	0.0490
Ruminating, min.	271.1^{b}(1.14)	375.4^{a} (1.03)	389.1^{a} (1.06)	0.0456

$^{a-b}$Means in the same row followed by differing superscript letters differ significantly at P<0.05.

After turning the calves out to pasture, there were no significant differences observed in the number of incidents of vocalizing, allo-grooming, and drinking water or the time spent standing, lying, sleeping, eating or rumination among calves fed different treatment diets i.e., PS, PSA, PSH (Table 5.7).

Table 5.7. Behaviour (time spent) observed during the post-weaning period in dairy calves at pasture fed starter with no additional forage (PS), starter with moist alfalfa (PSA) and pasture hay (PSH) in Experiment 1.

	PS	PSA	PSH	P value
Time spent/24 h				
Standing, min.	152.2 (0.87)	200.9 (0.78)	125.6 (0.80)	0.0722
Lying, min.	570.4 (0.48)	451.8 (0.43)	552.5 (0.44)	0.1071
Sleeping, min.	99.4 (1.13)	154.4 (1.00)	102.6 (1.03)	01929
Eating, min.	472.9 (0.26)	455.3 (0.20)	515.7 (0.22)	0.2537
Ruminating, min.	167.5 (1.14)	155.4 (1.03)	143.2 (1.06)	0.7764

$^{a-b}$Means in the same row followed by differing superscript letters differ significantly at P<0.05.

5.3.2. Experiment 2

In Experiment 2, during the pre-weaning period, calves fed the HF and PSH showed higher incidences of allo-grooming and spent more time eating compared to calves fed LF TMR (Table 5.8). The amount of time spent standing, lying, sleeping and ruminating were not different between treatments. There was no significant difference between treatments in terms of cross sucking or sucking inanimate objects (Figure 5.3) but the total bout length (sec) was greater in the LF fed calves (331.3 Sec) than the HF (194.59 Sec) or PSH fed calves (94.01 Sec). There was no significant effect of diet on the number of incidents of vocalizing or drinking water during the pre-weaning period (Table 5.8) or the time spent standing, sleeping and lying among the three treatment groups (LF, HF, PSH) and calves stopped sucking after 20 minutes of milk feeding.

Table 5.8. Behaviour (time spent) observed during the pre-weaning period in dairy calves fed moist alfalfa total mixed rations low moist alfalfa (LF) and high in moist alfalfa (HF) content and starter with pasture hay (PSH) in Experiment 2.

	LF	HF	PSH	P value
Time spent/24 h				
Standing, min.	173.9 (0.38)	162.7 (0.38)	177.6 (0.38)	0.7755
Lying, min.	785.5 (0.39)	812.4 (0.39)	815.2 (0.39)	0.2651
Sleeping, min.	224.5 (0.04)	185.8 (0.04)	184.0 (0.04)	0.1754
Eating, min.	67.4^{b} (0.33)	91.0^{a} (0.33)	99.9^{a} (0.33)	0.0153
Ruminating, min.	328.4 (0.19)	324.4 (0.19)	351.8 (0.19)	0.2644

$^{a-b}$Means in the same row followed by differing superscript letters differ significantly at P<0.05.

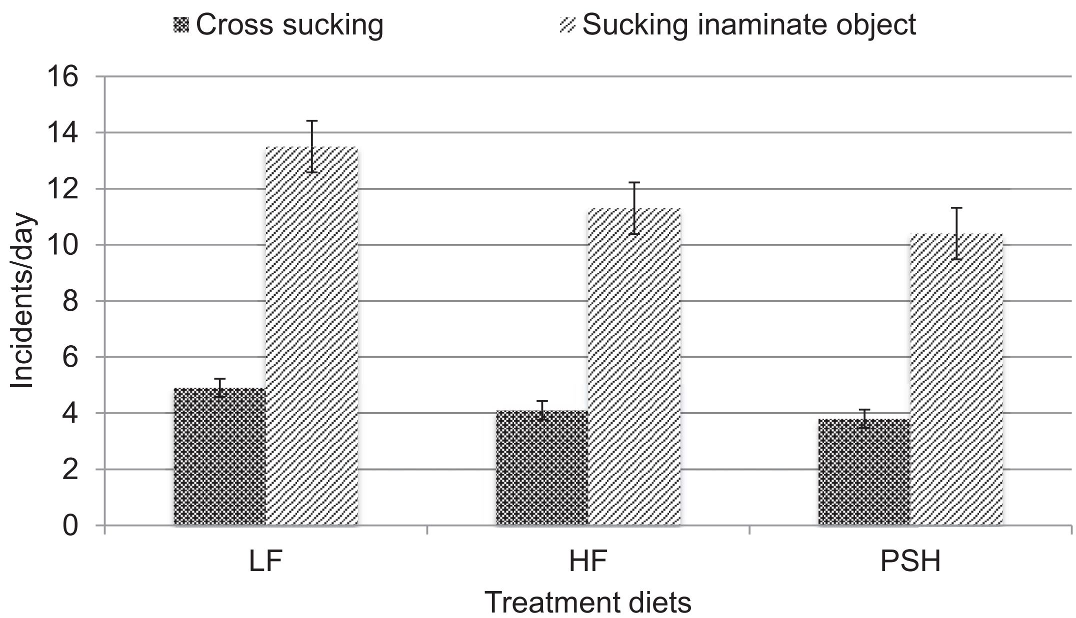

Figure 5.3. Number of incidences (Cross sucking, sucking nominate object/day) observed during the pre-weaning period in calves fed moist alfalfa total mixed rations low moist alfalfa (LF) and high in moist alfalfa (HF) content and starter with pasture hay (PSH) in Experiment 2.

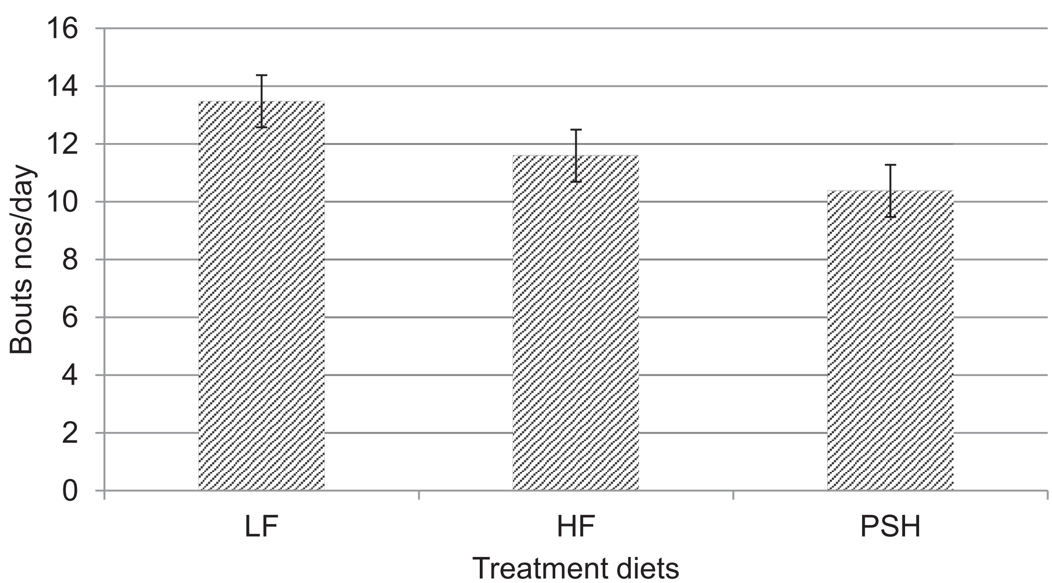

Figure 5.4. Number of bouts/day (Cross sucking, sucking nominate object/day) observed during the pre-weaning period in calves fed moist alfalfa total mixed rations low moist alfalfa (LF) and high in moist alfalfa (HF) content and starter with pasture hay (PSH) in Experiment 1.

During the post-weaning period, calves fed HF TMR or PSH spent more time lying than calves fed LF TMR. However, no significant difference was observed among the different treatment groups (LF or HF TMR, or PSH) in the number of incidents of vocalizing, drinking water, allo-grooming or time spent standing, sleeping, eating or ruminating (Table 5.9).

Table 5.9. Behaviours (time spent) observed during the post-weaning period in housed dairy calves fed moist alfalfa total mixed rations low in forage (LF) and high in forage (HF) content and starter with pasture hay (PSH) in Experiment 2.

	LF	HF	PSH	P value
Time spent/24 h				
Standing, min.	145.7 (0.38)	145.3 (0.38)	155.1 (0.38)	0.4191
Lying, min.	$816.1^{a,b}$ (0.39)	754.8^{b} (0.39)	811.7^{a} (0.39)	0.0324
Sleeping, min.	123.7 (0.04)	156.1 (0.04)	127.3 (0.04)	0.8190
Eating, min.	141.5 (0.33)	149.5 (0.33)	144.9 (0.33)	0.0759
Ruminating, min.	376.9 (0.19)	377.6 (0.19)	373.6 (0.19)	0.1630

$^{a-b}$Means in the same row followed by differing superscript letters differ significantly at P<0.05.

After turning out the calves to pasture, no difference was observed between treatments in terms of the number of incidences of vocalizing, allo-grooming, drinking water or the time spent standing, lying, sleeping, eating pasture, and ruminating among the calves (Table 5.10).

Table 5.10. Behaviours (time spent) observed after turning out to pasture in dairy calves fed moist alfalfa total mixed rations low moist alfalfa (LF), high moist alfalfa (HF) content, or starter with pasture hay (PSH).

	LF	HF	PSH	P value
Time spent/24 h				
Standing, min.	248.7 (0.38)	227.2 (0.38)	240.9 (0.38)	0.6102
Lying, min.	598.5 (0.39)	604.9 (0.39)	612.4 (0.39)	0.5520
Sleeping, min.	80.7 (0.04)	83.5 (0.04)	73.9 (0.04)	0.7036
Eating, min.	444.9 (0.33)	455.7 (0.33)	446.6 (0.33)	0.9887
Ruminating, min.	349.1 (0.19)	353.4 (0.19)	362.4 (0.19)	0.6427

$^{a\text{-}b}$Means in the same row followed by differing superscript letters differ significantly at P<0.05.

5.4. Discussion

5.4.1. Experiment 1

In Experiment 1, pre-weaned calves fed starter with no additional forage (PS) had a greater propensity for sucking inanimate objects, as evidenced by a higher number of bouts of this behaviour and a greater average length of bout (sec) than calves fed starter with additional forage (PSA, PSH). This indicated that these calves were hungry and frustrated, which is consistent with previous findings in which calves were fed restricted milk supplies (Jensen and Holm, 2003; Vieira et al., 2008; Herskin et al., 2010). Another possible reason for the increased sucking inanimate objects behaviour, when fed PS was a lack of forage in the diet and lack of stimulation of foraging behaviour (Margerison et al., 2003). These authors also suggested that calves fed a restricted milk supply (~10% of BW) have a strong motivation to suck, particularly following milk feeding, and this motivation declines as calves start foraging and ruminating. In experiment 1, calves fed additional forage (PSA and PSH) had a lower incidence of sucking inanimate objects because they spent more time exploring and apprehending their feeds, and consuming the forage in their diet. These behaviours would facilitate the learning of foraging behaviour and developing the motor skills necessary for effective feeding on pasture.

During the pre-weaning period, it was observed that calves fed starter diet without additional forage (PS) spent less time eating and ruminating than calves fed supplementary forage (PSA, PSH). This is probably due to the lower fibre content in the PS diet compared to PSA or PSH diet. The starter only diet can reduce rumen pH (Beharka et al., 1998), limit dry matter intake (Montoro et al., 2013) and delay the development of rumination behaviour (Van Ackeren 2009, 2010). On the other hand, calves fed a forage based diet along with the starter diet greater fibre intake, which encourages rumination, stimulates saliva secretion, and maintains a higher rumen pH, all of which contribute to increased total dry matter intake (Khan et al., 2011). Other studies (Kooijman et al., 1991; Mattiello et al., 2002; Castells et al., 2012) showed that calves fed a starter diet (18% NDF) with different forage sources reported that supplementing with chopped grass hay improved the dry matter intake, liveweight gain and feed conversion efficiency. The calves fed additional forage (PSA, PSH) spent more time chewing and ruminating, and therefore spent less time sucking inanimate objects compared to calves fed no forage (PS). Addition of forage addition to the diet of calves stimulates rumination (Martin et al., 2006; Castells et al., 2012) and helps to decrease these abnormal sucking behaviours (Phillips, 2004; Castells et al., 2012). However, no difference was observed between calves eating moist alfalfa based forage (PSA) and those eating pasture hay (PSH) in terms of time spent eating, rumination, standing, lying or in the number of incidents of cross sucking, sucking inanimate objects, allo-grooming or drinking water.

Calves fed additional forage (PSA, PSH) continued to spend more time eating and ruminating during the post-weaning period than calves fed starter diet only. According to Miller-Cushion et al. (2012) after abrupt weaning, calves tend to spend more time eating and foraging to meet their nutritional demand due to the absence of milk (Drackley, 2008). The reduced time spent eating and ruminating observed in calves fed no forage might be due to lack of experience with any fibre source during the pre-weaning period. The effect of the presence of forage in the diet on post-weaning behaviour may be due to better rumen development or a more suitable rumen environment (Khan et al., 2011) in calves fed forage during the pre-weaning period. This would help the calves to eat more and ruminate more than calves fed no forage pre-weaning. Many researchers (Arnold and Maller, 1977; Nolte et al., 1990) reported that calves develop feed preferences and motor skills during the milk feeding period and prefer to eat similar feeds following weaning (Miller-Cushon et al., 2013). Therefore, calves fed fibre pre-weaning developed a preference for forage based diets and better motor skills, and spent more time eating and ruminating following weaning than calves fed starter diet only (Terre et al., 2013). No difference was observed in feeding related behaviour after weaning between calves fed different forage based diets (PSA, PSH).

After the calves were moved to pasture, they showed no significant differences in the time eating, ruminating, standing, lying, sleeping, vocalizing, or the number of water drinking events. This indicates that the availability of grazing and environmental enrichment resulted in a similar maintenance and oral behaviour among each of the treatment groups. This is at variance with the results of Phillips (2004) who compared cereal straw and ryegrasshay and found pasture hay was superior in enhancing the rate of adaption of calves to grazing and ryegrassconsumption. Instead, these results were similar to that reported by Castells et al. (2012) who compared alfalfa hay and pasture hays, and demonstrated the similarity of moist alfalfa and ryegrasshay as forages for rearing calves in terms of intake and time spent foraging. In the experiment described in this thesis, when the starter diet was fed with pasture hay, moist alfalfa and no forage, there was no difference among the groups. Calves fed pasture hay before as well as post-weaning spent similar amounts of time grazing ryegrasswhen introduced to pasture compared with calves that had been fed moist alfalfa or no forage pre-weaning.

5.4.2. Experiment 2

In Experiment 2, calves fed high moist alfalfa or a starter diet with pasture hay spent more time allo-grooming than calves fed low moist alfalfa based diet during pre-weaning period. Veissier et al. (1994) reported that allo-grooming is a behaviour that calves perform when they feel satisfied.

This observation indicates that calves fed HF or PSH were feeling more satisfied than calves fed LF diet. It was also observed that calves fed HF or PSH spent more time eating than calves fed LF diet. In previous studies, heifers eating a more fibrous diet derive more satisfaction from oral manipulation of long particles and spent more time chewing and ruminating (Miller-Cushion et al., 2013). In the current study, calves spent more time eating HF or PSH diet than LF diet but no differences in rumination time were observed. This greater time spent eating may be due to the need to eat more of the fibrous diets in order to meet nutritional needs (Manteca et al., 2008) and to increase rumination and rumen pH (DeVries et al., 2008).

Keunen et al. (2002) reported that when dairy cattle had the option to choose between alfalfa pellets or long alfalfa, they showed a preference for the latter. They also chewed more and had an increased saliva production, which would better buffer the pH of the rumen. These additional effects might be due to greater fibre availability, more effective fibre, or it might be the result of an individual animal's forage requirement (Suarez et al., 2007; Khan et al., 2011; Miller-Cushon et al., 2013). In this study, the beneficial effects of higher forage based diets (HF, PSH) were apparent during the pre-weaning period, as calves showed a greater incidence of allo-grooming and were more satisfied than calves fed LF diet, and they also showed greater liveweight gain, as discussed in previous chapter. However, no significant difference was observed among three treatment diets in terms of cross sucking or sucking inanimate objects. These results are in agreement with the results of Experiment 1, which shows that offering forages re-directs oral activity towards foraging and rumination.

There was an increase in solid feed intake (Chapter 3) after weaning in calves fed starter diet and whole milk (without any forage). This could be due to an insufficiency of nutrients from milk, and requiring calves to eat more to meet their nutritional demands (Drackley, 1998). Therefore, it is not surprising that no significant difference was observed post-weaning in eating or rumination time among the three treatments because all the calves were fed forage based diets and they had already developed their motor skills to eat and ruminate. These results are in agreement with the results of Phillips (2004) that after weaning, calves tend to spend more time eating a similar diet source. However, in the current study, calves fedHF or PSH spent significantly more time lying down than calves fed LF. It was previously reported (Veissier et al., 1994) that calves spent more time lying down when they are satisfied, and calves tend to ruminate more when they are lying down (Terre et al., 2013). In this study, however, no significant difference was observed in calves fed different diets in terms of rumination post-weaning. The presence of forage in the diet also helps calves to reduce non-nutritional sucking behaviours, as reported previously by many researchers (Rebdo and Nordblad, 1997; Jensen and Holm, 2003; Vieira et al., 2008; Herskin et al., 2010). However, there were significant differences observed in terms of dry matter intake, liveweight gain and stature development, and these might be due to differences among the groups in the availability of necessary nutrients from the diet (Chapter 3).

All calves adapted easily to the pasture system. This might be due to availability of forage to all calves pre-weaning and development of early foraging behaviour. Other studies reported a greater rumen development, increased concentrated starter intake, more time spent foraging and ruminating, and less incidences of non-nutritional oral behaviour when calves were fed diets with a higher forage content pre-weaning (Coverdale et al., 2004; Phillips, 2004; Khan et al., 2011; Castells et al., 2012). After moving calves to pasture, no differences were observed in the number of incidences and the time spent performing feeding-related behaviours among different treatments. This might be due to the availability of similar forage source (pasture) or due to the socialization factor. It has been reported that when calves see other calves in the same paddock or in adjacent paddocks eating grass, they become motivated to spend more time eating (Phillips, 2004).

5.5. Summary

In both Experiment 1 and 2, it was observed that addition of forages to calves' starter diets helped calves to reduce non-nutritive oral sucking behaviours including less sucking inanimate objects, a reduced number of bouts and less time spent performing non-nutritional behaviours.Calves fed higher forage diets spent more time allo-grooming than calves fed a lower amount of forage in their diet. This shows that forage produced a greater level of satisfaction in calves than diets containing no forage or lesser amount of forage in their diet. Calves eating additional forages (PSA, PSH) spent more time eating and ruminating in Experiment 1 than calves fed no forage (PS). In Experiment 2, calves fed HF or PSH spent more time eating than LF fed calves but no rumination difference was observed. This might be due to availability of forage to all calves. Therefore, the availability of forage in diets prevents suckling behaviour and encourage rumination behaviour in calves. Many researchers reported a reduction in rumination activity with the absence of forage in calves' diet. The pasture hay based diet (PSH) was not very much different in terms of behaviour development compared with the moist alfalfa based diets (PSA, LF or HF TMRs)in Experiment 1 and Experiment 2. However, it is more economical for the farmer and it produced better results than moist alfalfa based diets in terms of dry matter intake liveweight gain (Chapter 3, 4). Others also reported that the provision of ground or chopped hay to calves results in a greater dry matter intake, less sucking behaviours and better calf welfare.

5.6. Conclusions

Inexperiment 1, calves fed additional forages (moist alfalfa, pasture hay) along with a starter diet spent more time performing nutritive behaviours (eating, rumination), and less time performing non-nutritive oral behaviours (Number of incidents of cross sucking and sucking inanimate objects), compared with calves fed starter with no forage. However, no difference was observed among calves fed additional forage in the form of moist alfalfa or pasture hay.

In experiment 2, calves fed higher moist alfalfa based diet or pasture hay based diet spent more time eating and allo-grooming, indicating that these diets satisfy calves better than diets containing a lower proportion of moist alfalfa. Good quality hay is a better complement to starter diets for calves in order to develop nutritional behaviours and to gain liveweight compared with diets containing moist alfalfa. Traditionally, pasture hay has been the dominant practice on dairy farms in New Zealand, due to its ready availability, storage advantage, and cost effectiveness. It would be counterproductive to replace hay with moist alfalfa for this purpose, as it is higher in cost and has quality issues if stored over a period of time. Therefore, this research confirms that the current dominant practise in dairy farms is optimal to facilitate the early growth and behaviour development of calves in New Zealand.

5.7. Future Research

It would be interesting to explore the long term effects (liveweights, production performance) of these treatment diets (Experiment 1, 2) fed to young calves during pre- and post-weaning periods (Chapter 6).

5.8. References

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Chapter 6

Long term performance of dairy heifers fed different forage based diets during pre- and post-weaning periods

Abstract

The objective of this chapter was to evaluate the effects of offering different forage based diets to dairy heifers during early age (1 to 70 days) on their liveweights and production performance (milk, protein, fat yields) during first and subsequent lactations. Animals from Experiment 1 (60 calves, 20/treatment), and Experiment 2 (108 calves, 36/treatment), were monitored till third lactation. After two weeks moving to pasture, calves from both Experiments (1, 2) were returned to Massey University farms and were assigned randomly to different treatments within the herd. All animals were weighed monthly and individual animal production data (milk, protein and fat yields) was recorded till third lactation. No significant differences were observed in terms of liveweights, liveweight gains, milk, protein or fat yields for 3 lactations in animals from Experiment 1 fed different diets (PS, PSA, PSH) during early age. However, significant differences were observed in calves from Experiment 2 fed different diets (LF, HF, PSH) during early age. Greater liveweight gains were observed in HF and PSH fed animals than LF fed animals till first lactation. During first lactation, greater milk yield was observed in HF fed animals than either PSH or LF animals. During second lactation, no differences were observed in terms of liveweights, liveweight gains, milk, protein or fat yields. Interestingly, in third lactation, greater fat production was observed in LF than either of other two diets (HF, PSH). However, the results of long term performance should be considered with caution due to low number of animals (low power of analysis) available in this study.

Key words: calves, cows, liveweights, liveweight gains, milk yield, lactations

6.1. Introduction

Annual heifer replacement costs are approximately 20-25% of a farm expenses (Heinrichs, 1993; Atkins and Bowler, 2001). This large economic investment in dairy heifers demands that a good management system is in place to monitor and evaluate the growth progress of these replacement heifers (Tozer and Heinrichs, 2001). According to New Zealand standards, a dairy heifer should achieve 60% of her mature liveweight at first breeding and 90% of her mature liveweight at first calving (Penno, 1998). The objectives of having liveweight targets and to reduce the age of onset of puberty are to enable early breeding and consequently early first calving (22-24 months) to minimise expenses and to improve profitability. However, the majority of heifers on New Zealand dairy farms fail to acheive these target liveweights (McNaughton and Lopdell, 2012; McNaughton and Lopdell, 2013). McNaughton and Lopdell (2012) found that 18% of the New Zealand heifers were 20% behind in target liveweight at 15 months of their age and around 73% of New Zealand replacement heifers were 5% lighter than their target liveweight at 22 months.

To achieve the goal of reduced age at first calving and to keep the costs lower (Tozer and Heinrichs, 2001), it is important not to impair the liveweight at calving to optimise milk yield at first lactation (Bach and Ahedo, 2008). Most farmers try to inseminate heifers as early as possible without considering musculoskeletal development of the heifers, which in turn negatively affects the first lactation (Nor et al., 2013). Ideally, the decision to inseminate heifers should be based on heifer liveweight and skeletal measurements (Le Cozler et al., 2008) but mostly it is decided by age alone (Nor et al., 2013). Unsurprisingly, greater liveweight gain during first six months of life enabled a younger age at first calving (Brickell et al., 2009) and greater milk yield at first lactation (Moallem et al., 2010; Bach, 2012; Soberon et al., 2012). However, several researchers have reported that accelerated diets fed before puberty do not always help to achieve these targets or improve first milk lactation yield (Gardner et al., 1977; Peri et al., 1993; Hoffman et al., 1996; Sejrsen and Purup, 1997; Radcliff et al., 2000).

Ample milk feeding in early weeks of life enhances dairy heifers' liveweight gain (Appleby et al., 2001; Jasper and Weary, 2002) and might increase first lactation milk yield (Terre et al., 2009; Soberon et al., 2012). Some researchers have found a positive effect of offering *adlibtum* milk diets on first lactation yield compared to restricted-fed calves, with 450-1300 kg greater milk yield during their first lactation (Foldager and Krohn, 1994; Bar-Peled et al., 1997; Shamay et al., 2005; Terré et al., 2009; Moallem et al., 2010). However, others have found no significant difference in first lactation milk yield between calves fed either restricted or *ad libitum* milk during the pre-weaning period (Morrison et al., 2009; Raeth-Knight et al., 2009).

The long-term effects of calf feeding on lactation and reproductive performance are associated with the type and quality of nutrients fed pre-weaning (Moallem et al., 2010). Feeding*ad libitum* milk pre-weaning becomes a challenge at weaning due to lower solid feed intake (Jasper and Weary, 2002) as the digestive system is not developed fully to enable digestion of solid feed (Terre et al., 2007). Even gradual weaning programmes result in lower dry matter intake in *adlibtum* milk fed calves compared to restricted milk fed calves.

Traditionally, calf management programmes are focused on restricting the amount of milk to encourage solid feed intake, thereby accelerating the process of weaning and reducing the cost of feeding and management (Kertz et al., 1979; Otterby and Linn, 1981; Anderson et al., 1987, Khan et al., 2007a,b). Greater solid feed intake (concentrate and hay) during pre-weaning enhances rumen development (Castells et al., 2012) and assist calves to transit smoothly from liquid to solid feed. To reduce feed costs and to encourage starter feed consumption, restricted milk supply and early weaning programmes are used as a strategy. A greater voluntary feed intake is required to achieve this goal but provision of forages restricts voluntary feed intake, probably due to an accumulation of undigested fibre in the rumen (Drackley, 2008). Many researchers have discouraged the addition of forages to the diet of milk fed heifers (Tamate et al., 1962; Stobo et al., 1966; Kertz et al., 1979; Hill et al., 2008) because they are thought to inhibit rumen papillae development and dry matter intake. However, some dietary fibre is necessary for young calves to maintain abrasion in their rumen and to maintain an optimal rumen growth environment (Greenwood et al., 1997), especially if the starter diet lacks sufficient particle size. Therefore, several researchers (Thomas and Hinks, 1982; Khan et al., 2011b; Castells et al., 2012) recommend offering forage along with the starter diet to increase the overall dry matter intake and early growth rate. Montoro et al. (2013) mixed concentrate diet with coarsely chopped grass hay rather than a finally chopped alternative and demonstrated that not only the forage type but the forage particle size might play a very important role in rumen development of young calves.

Experiment 1 demonstrated that offering additional forages (moist alfalfa, pasture hay) along with starter diet increased dry matter intake in calves and had a positive effect on rumen environment, compared to a no forage diet. In Experiment 2, it was observed that offering pasture hay or a diet with a greater ratio of moist alfalfa (70%) showed greater solid feed intake and liveweight gain than calves fed a lower ratio of moist alfalfa (30%). However, the effect of these pre-weaning diets on later life lactations have not been explored before in New Zealand. Therefore, the objective of this study was to determine the effects of different forages fed during early life (Experiments 1 and 2) on the long term performance of heifers during their first and subsequent lactations.

6.2. Material and methods

6.2.1. Animals

Calves in Experiment 1 (60 calves) and Experiment 2 (108 calves in groups (3 calves/group) were observed at three separate time points, which corresponded with the pre-weaning (1 to 49 days of age), the early post-weaning period (50 to 57 days of age), during which calves were housed indoors, and while calves were grazed on ryegrass pasture (58 to 70 days of age).

6.2.2. Treatment diets

In Experiment 1, all the calves were fed*ad libitum* either: a calf starter (Table 6.1) with either: no additional forage (PS), moist alfalfa (PSA), or ryegrasspasture hay (PSH) from birth till day 70 of life. In Experiment 2, calves were fed*ad libitum* access to: a total mixed ration (TMR) of a lower proportion of moist alfalfa to starter (30:70) (LF); a TMR of a higher proportion of moist alfalfa to starter (70:30) (HF); a starter diet along with pasture hay (PSH) (Table 5.2) from day one till day 70 of life. During this period calves were measured weekly for liveweights and stature until day 70 of life.

6.2.3. Long term performance measurement

After moving to pasture, liveweights of individual calves were measured monthly until three months prior to first calving. After calving, liveweights were measured monthly until three months before following calving for three lactations. Individual cow milk yield (am and pm) was recorded using an automatic milk recording system (Westfalia Separator). Milk composition (fat, protein) and milk volume were measured for individual cows on 3 to 4 occasions during each lactation by routine herd testing carried out by Livestock Improvement Corporation personnel. For each lactation, the accumulated yields were extracted from an average of 4 herd testing results for individual cows. Data was recorded for three lactations according to their respective treatment diets for both Experiment 1 and Experiment 2.

6.2.4. Statistical analysis

Nonlinear random regression (PROC NLMIXED, SAS, 9.3) was used to fit lifetime live weight records of individual cows in each treatment by using the Gompertz equation (Fitzhugh, 1976):

$$W_t = Ae^{-be^{-ct}}$$

Where,

W_t is liveweight at age t (months),

e is the base of the natural logarithms,

A is the asymptotic value for liveweight generally interpreted as average mature weight,

b is constant of integration or the time scale parameter that adjusts for situations in which initial weight at birth is not zero, and

k is the rate at which a logarithmic function of liveweight changes linearly per unit of time, and is generally interpreted as a maturation index. Large k values indicate early maturing animals, and vice versa (López de Torre et al., 1992).

The goodness of fit achieved with the model was evaluated using the correlation coefficient (r), the coefficient of determination (r^2), the mean square prediction error (MSPE), mean prediction error (MPE) and relative prediction error (RPE) (O'Neill et al. 2013).

The MSPE is calculated as follows:

$$\mathrm{MSPE} = (\mathrm{A_m} - \mathrm{P_m})^2 + \mathrm{S_P^2}(1 - \mathrm{b})^2 + \mathrm{S_A^2}(1 - \mathrm{r}^2)$$

where

$\mathrm{A_m}$ and $\mathrm{P_m}$ are the mean actual and predicted LWTs, respectively;

$\mathrm{S_A^2}$ and $\mathrm{S_P^2}$ are the variances of the actual and predicted LWT, respectively;

b is the slope of the regression of actual (A) on predicted (P) and

r^2 is the coefficient of determination of A and P.

The three components of the MSPE are;

mean bias$(\mathrm{A_m} - \mathrm{P_m})^2$,

line bias $\mathrm{S_P^2}(1 - \mathrm{b})^2$ and

random variation $\mathrm{S_A^2}(1 - \mathrm{r}^2)$.

The proportion of MSPE that comes from random variation should be high if the model is predicting with good accuracy. If the proportion of random variation is low then there is a large proportion of the MSPE from the mean or line bias (O'Neill et al., 2013). The MPE and RPE are calculated as follows:

$$\mathrm{MPE} = \sqrt{\mathrm{MSPE}}$$

$$\mathrm{RPE}\ (\%) = \left(\frac{\mathrm{MPE}}{\mathrm{A_m}}\right) \times 100$$

The smaller the RPE, the more accurate the predictions are.
Statistical analysis of growth curve parameters was performed for each cohort using the MIXED procedure with a linear model that included the fixed effect of treatment diet and proportion of Holstein-Friesian as covariable. Multiple mean comparisons among the treatments were performed with the LSD test as implemented in the MIXED procedure. Significant differences between means were declared at P<0.05.

Effects of calf treatment diets on long term performance were evaluated for each cohort and lactation number. Least squares means of lactation yields of milk, fat, protein, and average liveweight during the lactation for each treatment diet were obtained using the MIXED procedure with a linear model that included the fixed effect of treatment diet, cow treatment group and deviation from median herd calving date and proportion of Holstein-Friesian as covariables. The least squares means and standard errors for each treatment diet were obtained and multiple mean comparisons were performed with the LSD test as implemented in the MIXED procedure. Significant differences between means were declared at P<0.05.

6.3. Results

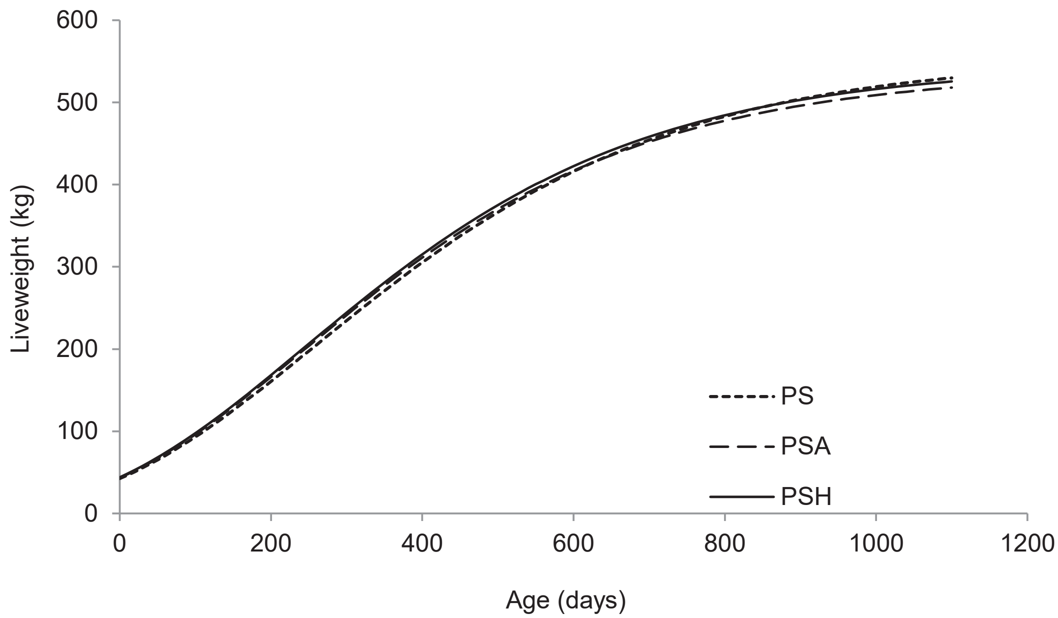

Figure 6.1. Growth curves of calves fed starter with no forage (PS), moist alfalfa (PSA) or pasture hay (PSH) during pre- and post-weaning modelled with the Gompertz equation.

6.3.1. Goodness of fit

Goodness of fit was tested between the predicted and observed liveweights for calves used in Experiment 1 and Experiment 2 by using Gompertz function. A good fit was observed between predicted and actual liveweights that was apparent by the RPE value (smaller the RPE value, more accurate is the prediction, <10 shows more accurate results). The RPE values for Experiment 1 (r^2 = 0.99, RPE = 3.27) and Experimetn 2 (r^2 = 0.99, RPE = 6.66) were smaller than 10 that shows high accuracy in predicted liveweights using the Gompertz function.

In the first Experiment (2010 born), there were no significant differences observed in calves fed different diets (PS, PSA, or PSH) in terms of overall liveweight gain (Figure 6.1), liveweight, milk yield, protein or fat production during the three lactation period (Table 6.1).

Table 6.1. Growth and lactation variables presented as least square means of dairy cows during first and subsequent lactations fed starter with no forage (PS), moist alfalfa (PSA) or pasture hay (PSH) during pre- and post-weaning.

	PS			PSA			PSH			
	N	Mean	SE	N	Mean	SE	N	Mean	SE	Pvalue
Liveweight curve										
A	20	555	7.4	20	538	7.3	20	546	7.3	0.267
b	20	2.57	0.02	20	2.52	0.02	20	2.52	0.02	0.175
k ($x10^4$)	20	36.47	0.84	20	38.18	0.84	20	38.08	0.84	0.2853
Lactation 1										
Milk yield	16	4567	148	14	4533	159	13	4479	165	0.9239
Protein	16	167	5.1	14	166	5.5	13	164	5.7	0.8948
Fat	16	206	10.2	14	206	10.9	13	193	11.3	0.6585
Lwt	15	446	7.9	14	419	8.2	12	436	8.5	0.0785
Lactation 2										
Milk yield	13	5379	279	11	5604	279	11	5385	278	0.7785
Protein	13	194	10.3	11	200	10.3	11	196	10.3	0.8829
Fat	13	245	13.6	11	245	13.5	11	237	13.5	0.8925
Lwt	10	514	14.8	11	516	12.5	12	517	11.4	0.2583
Lactation 3										
Milk yield	10	4843	249	8	5511	285	9	5401	247	0.1897
Protein	10	181	7.5	8	201	8.6	9	200	7.4	0.1608
Fat	10	221	11.2	8	246	12.9	9	232	11.1	0.3800
Lwt	7	518	24.0	8	521	25.0	10	521	18.2	0.6904

A = asymptotic mature liveweight; b = constant of integration; k = growth rate parameter.

Lwt: liveweight

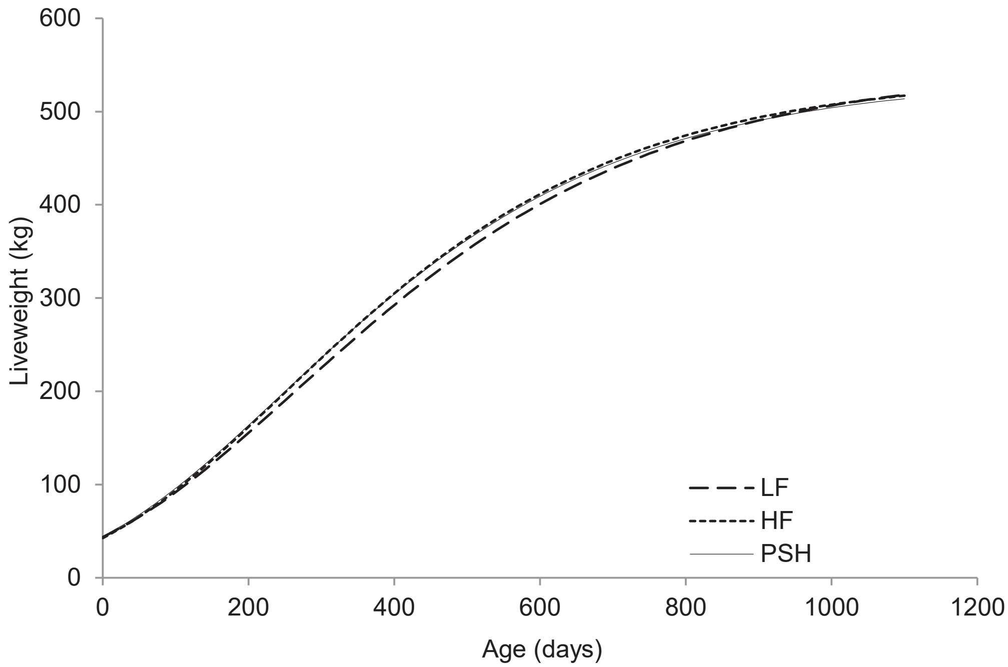

Figure 6.2. Growth curves of calves fed low (LF), or high (HF) moist alfalfa based TMR or starter with pasture hay (PSH) during pre- and post-weaning modelled with the Gompertz equation.

From the second Experiment (2011 born) calves, it was observed that calves fed HF or PSH diet grow faster than LF calves (overall growth shown in fig 6.2). During the first lactation calves fed HF diet showed greater millk yield than LF or PSH calves. No other differences in protein, fat, or liveweight were observed during first lactation among three treatments (Table 6.2). In second lactation, no significant differences were observed in terms of millk yield, protein, fat or liveweights among three treatments (Table 6.2). In third lactation, cows fed LF diet initially, showed greater fat production than HF or PSH calves (Table 6.2). Other than this no significant differences in milk yield, protein or liveweight were observed among three treatments (Table 6.2).

Table 6.2. Growth and lactation variables presented as least square means of dairy cows during first and subsequent lactations fed low (LF), high (HF) moist alfalfa based TMRs or starter with pasture hay (PSH) during pre- and post-weaning.

	LF			HF			PSH			
	N	Mean	SE	N	Mean	SE	N	Mean	SE	Pvalue
Liveweight curve										
A	34	547	7.29	35	539	7.10	36	536	7.01	0.5289
b	34	2.53	0.01	35	2.54	0.01	36	2.49	0.01	0.0908
k ($x10^4$)	34	34.91[b]	0.68	35	37.37[a]	0.66	36	37.01[a]	0.66	0.0257
Lactation 1										
Milk yield	30	4021[b]	97	28	4356[a]	103	27	3855[b]	100	0.0048
Protein	30	148	3.5	28	154	3.7	27	144	3.6	0.1855
Fat	30	175	5.8	28	174	6.2	27	169	6.0	0.7515
Lwt	25	431	7.8	28	455	7.6	20	439	8.4	0.0989
Lactation 2										
Milk yield	28	5116	138	25	5009	140	25	4895	140	0.5385
Protein	28	186	4.9	25	183	4.9	25	181	4.9	0.8456
Fat	28	224	6.4	25	216	6.5	25	222	6.4	0.6719
Lwt	22	481	8.7	25	486	7.9	18	478	9.3	0.8132
Lactation 3										
Milk yield	22	5022	96	20	4849	92	20	4879	98	0.0622
Protein	22	192	3.5	20	192	3.5	20	181	3.6	0.0665
Fat	22	233[a]	5.6	20	209[b]	5.4	20	216[b]	5.7	0.0109
Lwt	14	528	9.3	18	514	7.5	9	520	11.3	0.1484

A = asymptotic mature liveweight; b = constant of integration; k = growth rate parameter.

Lwt: liveweight

6.4. Discussion

No significant differences in liveweight gains were observed till first lactation in animals (Experiment 1) initially fed diet without (PS) or with additional forage (PSA, or PSH). Also no significant differences were observed for liveweight, milk yield, protein or fat production, in the first, second or third lactations.

Castells et al. (2015) reported that although calves fed additional forage during early life showed greater dry matter intake, and liveweight gain pre-weaning than calves fed no forages but no differences in liveweights or milk yield were observed after weaning. The absense of differences may be due to having access to similar forage sources post-weaning. Recently, Kiezebrink et al. (2015), fed whole milk at higher quantities or at a conventional milk feeding programme (10% of BW; similar to this study) and found no differences in milk production during the first lactation. Several other researchers also reported no significant liveweight or milk yield differences among calves after weaning fed different diets pre-weaning (Terre et al., 2009; Davis Rincker et al., 2011).

From Experiment 2 (2011 born), calves fed HF or PSH grew faster (greater liveweight gain) than calves fed LF. This difference might be due to a better adaptability to a grass based system and better utilisation of nutrients after weaning. Phillips (2004) reported that calves fedpasture hay pre-weaning showed greater feed intake and rumination behavior after weaning compared to calves that had no access to pasture hay before weaning. These results suggest that HF and PSH diets had a positive effect on calves and showed greater liveweight gains than calves fed LF.

During first lactation, calves fed HF diet during early age showed greater milk yield than LF or PSH fed calves. Previous studies also reported a positive correlation between liveweight gain pre-weaning and increased future mlik production (Bach and Ahedo, 2008; Bach, 2012). Drackley et al. (2007) reported a 12.6% increase in milk yield with an intensified feeding programme pre-weaning. Soberon et al. (2012) reported 22% increase in milk production due to increased pre-weaning growth. In this study, greater milk yield in HF calves might be due to the availability of more protein compared to other two diets (LF, PSH), which may have played a role in mammary gland development as previously reported by Van Amburgh et al. (2014), they proposed that feeding protein and energy levels above maintenance during early life had effects on tissue differentiation. Therefore, there is a possibility that calves receiving a high forage diet (especially HF with high protein) might have improved mammary growth and development. Brown et al. (2005)

reported that rapid growth rate till first 3 months of age influenced mammary development of heifers more than growth during post-weaning periods. However, mammary gland growth was not studied and the number of animals to analyse data were low so it is difficult to draw firm conclusions from this study. A more detailed study with more animals is required to confirm the preliminary findings of this study.

The other possible reason of these results during the first and third lactations might have been due to different feeding and management practices adopted on that farm. After the initial study (Experiment 1, Experiment 2), animals were not reared in their treatment groups anymore and were mixed randomly with other animals on farm in different groups (herds) at different feeding plans to meet farm's production targets. Therefore, the significant differences observed initially (pre-weaning and post-weaning periods) might have vanished and therefore, no significant differences were observed in liveweights, milk yield, protein or fat production during the second lactation. Previously, Heinrichs and Heinrichs (2011) reported that increasing the dry matter intake at weaning and reducing the number of sick days could increase the first lactation milk production in heifers. They also reported that starter diet consumption at weaning had a positive correlation with first lactation milk production. This is because substantial starter consumption pre-weaning is necessary for calves to consume larger quantities of starter at weaning to maintain their growth rate in the first few months of life (Cowles et al., 2006; Heinrichs and Heinrichs, 2011; Bach, 2012). According to Gelsinger et al. (2016), the provision of adequate nutrients (both liquid and solid diets) and maintaining the liveweight gain above 0.5 kg/day can enhance first lactation performance subject to proper feeding and management post-weaning. Therefore, it is possible that calves fed HF diet pre-weaning had nutrients to peform better during their first lactation compared to other two groups (LF, PSH) but it is difficult to be certain about this due to the low power of these experiments. In the third lactation, calves fed LF diet pre-weaning showed greater fat production than HF or PSH fed calves. Other than this, no significant differences in milk yield, protein or liveweight were observed among three treatments. Again this significant difference should be considered with caution due to the low number of animals per treatment remaining in the third lactation.

A power analysis was performed to calculate the number of animals needed to detect significant differences observed in the current study using the standard deviation estimated in the current experiments assuming power of test 0.80 and $\alpha = 0.05$ (Type I error = 5%). The required sample size was 98 animals per treatment which was much higher than the animal numbers in the current studies (Experiment 1 = 20/treatment, Experiment 2 = 36/treatment). A further power analysis was performed to determine the power of test ($1-\beta$) that can obtained with number of animal used in this experiment with a mean and standard deviation of cows in lactation three. The power of this analysis was only 0.25 indicating that is not enough statistical power to declare the long term effect of diets fed pre-weaning.

Other possible factors might have been feeding and management practices during different lactations. During different lactations there was a random shuffling and re-grouping of animals and there was a possibility that the animals initially in different treatment diets (HF during first lactation, LF during third lactation) were treated better resulting in higher production than other groups.

6.5. Conclusions

Experiment 1:

- No differences in liveweight, milk, protein, or fat yields were observed during the 1^{st}, 2^{nd} or 3^{rd} lactations among calves fed diet without (starter only) or with different additional forages (moist alfalafa, pasture hay).

Experiment 2:

- Feeding high moist alfalfa forage diet, resulted in greater milk yield during the first lactation compared to calves fed either conventional forage (pasture hay) or lower moist alfalfa forage diet.

- Greater liveweights were observed in high moist alfalfa forage diet and in calves fed conventional forage (pasture hay) than low forage diet from weaning onwards.
- Greater fat yield was obsereved in low moist alfalfa forage diet than high moist alfalfa forage or conventional forage (pasture hay) during the third lactation.

Over both experiments, the number of animals per treatment reaching lactation were low. This resulted in low statistical power suggesting that results showed be treated with caution.

6.6. Future research

Future research should examine the effect of offering different hay based TMRs on the dry matter intake, liveweight gain, rumen physiology, and mammary growth development during early age (pre-weaning) with sufficient number of calves (more statistical power) and to keep animals in their respective groups throughout the post-weaning period until their first lactation to determine the long term effects of pre-weaning feeding on the first and subsequent lactation to draw some clear conclusions.

6.7. References

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Chapter 7

General discussion

7.1. The role of forage provision on dry matter and nutrient intake

The physical form of a starter diet is an important factor in determining the dry matter intake and liveweight gain in young calves. Calves eating diets comprised of fine particles such as pellets have a lower DMI, resulting in lower liveweight gains, than those consuming a starter diet comprising a coarse particle size or those fed forages (Stobo et al., 1966; Leibholz, 1975; Barkema et al., 1998; Coverdale et al., 2004; Suarez et al., 2007).

In Experiment 1, calves were fed a starter diet with either moist alfalfa (PSA), pasture hay (PSH) or with no forage diet (PS). In Experiment 2, calves were fed two different TMRs based diets, with low (LF) or high (HF) moist alfalfa, or a conventional starter with pasture hay (PSH). In Experiment 1 (Chapter 3), it was observed that offering additional forages (moist alfalfa, pasture hay) from the first week of life onwards increased the DMI and nutrient intake (CP, ME, NDF, ADF) in calves both before and after weaning, compared with calves fed no additional forage. These findings are similar to other studies (Thomas and Hinks, 1982: Phillips, 2004; Khan et al., 2011) that forage addition (chopped and fed long/straw) to calves' diet in the first few weeks of life increased the DMI and liveweight gain.

In Experiment 2 (Chapter 4), it was observed that calves fed moist alfalfa based TMRs (LF, HF) showed a lower dry matter intake than calves fed a pasture hay based forage source (PSH) during pre-weaning and post-weaning periods. A similar pattern of ME, CP and NDF intake was observed among the treatment groups, which was as expected since these parameters are dependent on dry matter intake. Hence, the greater the dry matter intake, the greater the ME, CP and NDF intake. Previous reports have shown that when different forages (10 to 25% of ground hay, chopped hay and cereal straw) were fed along with cereal based starters, dry matter intake increased in young calves (Thomas and Hinks, 1982; Davis and Drackley, 1998).

In Experiment 1 (Chapter 3), the level/ratio of forage to starter in the diets fed along with starter diet was such that calves fed additional forage consumed a greater amount of forage (PSA 39% pre-weaning, 29% post-weaning) (PSH 74% pre-weaning, 58% post-weaning). The amount of forage used in the diets in this study was higher than the upper limit of 25 % suggested previously (Franklin et al., 2003). However, higher levels of forage eaten did not reduce the DMI. Overall, in Experiment 1, the total dry matter intake and energy intake was greatest in calves fed pasture hay, was at an intermediate level in calves fed moist alfalfa, and was lowest in calves fed starter without any forage. The reason for the low dry matter intake in calves fed no forage in Experiment 1 might have been due to lower rumen pH (Barkema et al., 1998), which limits the dry matter intake in young calves (Huntington et al., 1997; Greenwood et al., 1997). According to Laarman et al. (2012) hay intake in young calves is positively correlated with rumen pH, and it helps calves to achieve an optimal rumen pH to efficiently utilise solid feed.

Therefore, a greater total dry matter and nutrient intake (CP, ME, NDF, ADF) was observed in calves offered pasture hay that might be due to better rumen growth and environment to consume solid feed efficiently.

7.2. NDF intake

In Experiment 1 (Chapter 3), the total diet consisted of 20% NDF in PS fed calves, 27% for calves fed PSA and 40% for calves fed PSH. In Experiment 2 (Chapter 4), the total diet consisted of 26% NDF in LF TMR, 38% in HF TMR, and 46% for calves fed PSH. While comparing to PSH diet, moist alfalfa based TMRs (LF, HF) had lower NDF contents and should have shown a better digestibility and dry matter intake than pasture hay based diet (PSH) assuming NDF as a digestibility issue. However this was not the case in this study and a greater dry matter and nutrients (ME, CP, NDF) intake was observed in PSH fed calves than moist alfalfa based TMRs (LF, HF) during pre-weaning and post-weaning periods.

A greater dry matter intake was observed post-weaning in LF and HF fed calves. This might have been due to the absence of milk and nutrients from milk required for maintenance and growth that forced calves to eat more solid diet to meet their nutritional requirements (Drackley, 2008). However, it was significantly lower than PSH fed calves. A similar trend of increased dry matter intake during post-weaning period was observed in Experiment 1 where calves were fed starter diet only (no additional forage, PS). However, this dry matter intake was lower than the dry matter intake of calves fed additional forages (PSA and PSH) in Experiment 1 or higher forage diet (HF) or pasture hay based diet (PSH) in Experiment 2.

Overall, a pasture hay based diet (PSH) was superior in terms of total dry matter and nutrient intake (especially NDF intake) compared to either no forage (PS) in Experiment 1 or different moist alfalfa based TMR diets (HF, LF in Experiment 2.

7.3. Liveweight gain

Several researchers have reported that provision of forages along with the starter diet increased DMI and average liveweight gain in young calves compared to calves fed no forage (Thomas and Hinks, 1982; Davis and Drackley, 2008). Similar results were observed in Experiment 1 and calves fed additional forages (PSA, PSH) showed greater DMI and liveweight gains than calves fed no forage (PS). In Experiment 2, pasture hay fed calves (PSH) had greater liveweight gain than calves fed LF or HF diet. No liveweight difference was observed during pre-weaning in calves fed either HF or PSH, but after weaning from milk, PSH calves had greater liveweight than any of HF or LF fed calves. However, daily liveweight gain was greater in PSH fed calves compared to HF or LF fed calves during pre-weaning and post-weaning periods. Previously, Castells et al. (2012) compared the effect of diets containing different forage sources and found no difference between pasture hay or alfalfa hay. In this study, in place of alfalfa hay, moist alfalfa was fed to calves because it had higher CP content and higher digestibility than hay, but despite this apparent advantage, moist alfalfa was no better than pasture hay in facilitating liveweight gain.

In Experiment 1 (Chapter 3), greater DMI was observed in forage-supplemented calves (PSA, PSH) than calves fed no forage (PS). This greater dry matter intake might be due to forage based diets contributing to improved rumen environment and function. A more effective development of rumen function has the benefit of allowing calves to be weaned earlier while still attaining their target liveweight and would lead to more efficient adaptation to grazing on pasture. No difference in starter intake was observed between calves fed the two forage sources, moist alfalfa or pasture hay, but the total dry matter intake and liveweights were greater in pasture fed calves (PSH) than moist alfalfa forage (PSA) in Experiment 1. Similarly, greater dry matter intake and liveweights were observed in calves fed pasture based diet (PSH) in Experiment 2 than calves fed different moist alfalfa based TMR diets (LF, HF). These results are in agreement with a previous study that calves fed forages had a greater energy intake and liveweight gains compared with calves fed starter diet without forage supplementation, but this depends on an adequate availability of the feed and sufficient energy intake (Margerison et al., 2005). In Experiment 1 (Chapter 3), a greater gain in liveweight was observed in calves fed additional forage (PSA, PSH) compared with calves fed only the starter diet (PS), both before and after weaning. This effect was most likely due to a better rumen environment in the forage fed calves (Khan et al., 2011), that leads to an increased DMI and increased delivery of nutrients to the calf, thus facilitating the greater liveweight gain.

In Experiment 2 (Chapter 4), a greater dry matter intake was observed in calves fed PSH compared with calves fed LF or HF. This might be due to the presence of longer forage length, or effectiveness of fibre in pasture hay based diet to facilitate rumen functioning (Coverdale et al., 2004; Suarez et al., 2007). The nature of the forage plays an important role in increasing chewing activity, which in turn produces more saliva that acts as a buffer in the rumen, improves the rumen environment and digestive functioning of the rumen and thereby increases dry matter intake in young calves (Khan et al., 2011). In addition to a lower dry matter intake, liveweights of calves fed LF were also lower than calves fed PSH or HF during pre-weaning period. However, after weaning, PSH fed calves showed greater liveweights and liveweight gain than calves fed moist alfalfa based TMRs (HF or LF). These results are similar to a previous study by Khan et al. (2011) who fed a starter diet to calves supplemented with forage obtained from different sources. They reported increased dry matter intake, a more developed rumen environment and a greater liveweight gains in calves consuming pasture hay along with a starter diet compared with a diet containing other types of forage. These heavier liveweightss in calves might be due to digestive tract 'fill' (Khan et al., 2011). To ensure that it was not a gut fill effect, all calves were grazed on pasture for a period of two weeks in order to remove the potential effect of differences in gut contents; the differences in calves' liveweights remained.

Feeding pasture hay diet (PSH) showed greater dry matter intake, and liveweight, compared to any of the moist alfalfa based diets (PSA, LF, HF) in Experiment 1 and Experiment 2.

7.4. Effect of forage provision on stature development

In Experiment 1 (Chapter 3), there was no difference observed in stature (hip width, hip height, last rib girth) among three treatments (PS, PSA or PSH) despite the greater pre- and post-weaning liveweights observed in the forage fed calves. Thus, the greater liveweights in the forage supplemented calves (PSA, PSH) appear to be due to a more developed rumen consequent on this diet.

In Experiment 2 (Chapter 4), the mean hip width and hip height were significantly greater in PSH and HF fed calves than LF fed calves, during pre- and post-weaning peirods. During pre-weaning, last rib girth was significantly greater in PSH and HF fed calves than LF fed calves. After weaning, last rib girth in PSH fed calves was greater than HF or LF fed calves. After moving to pasture, the last rib girth was greater in PSH and HF fed calves than LFfed calves. This shows that calves eating higher forage diets (HF, PSH) were both bigger in stature and heavier than LF fed calves.

7.5. Effect of forage provision on feed conversion efficiency

Previous studies reported greater feed conversion efficiency (FCE) in calves fed pelleted starter diets compared with calves fed multi particle starters (Coverdale et al., 2004; Bach et al., 2007). In Experiment 1, greater feed conversion efficiency was observed in calves fed starter diet only (PS), was intermediate in calves fed starter supplemented with moist alfalfa fibre (PSA), and was least in calves fed pasture hay based diet (PSH). Although the FCE was greater in calves fed starter diet only (PS) compared with the other two groups (PSA, PSH), the liveweight gain was lower. Castells et al. (2012) also reported improved feed conversion efficiency when calves were fed pelleted starter feeds containing 18% NDF. Hill et al. (2008) explained that increasing the percentage of hay along with starter diet increases the DMI, increased the average liveweight gain, but showed lower feed conversion efficiency. Khan et al. (2012) also reported a lower feed conversion efficiency in forage supplemented calves compared with calves fed starter only, but suggested that it might be due to an accumulation of particles in the gut, which would produce a greater gut fill effect in calves fed the supplemented forage. Similar results were observed in Experiment 1, where the feed conversion efficiency was higher in calves fed starter only (PS) compared with calves fed the forage based diets (PSA, PSH).

In Experiment 2 (Chapter 4), lower FCE was observed in PSH fed calves than LF or HF fed calves during pre-weaning periods (1 to 21 days, 22 to 49 days). This was due to greater DMI in PSH fed calves than LF or HF fed calves. These results are similar to Experiment 1 and other previous studies (Coverdale, et al., 2004; Bach et al., 2007) that greater dry matter intake lowers the FCE. Hill et al. (2008) reported lower FCE with increasing percentage of hay in calves' starter diet. Khan et al. (2012) also reported a lower FCE in pasture hay fed calves compared with calves fed no additional forage. However, these differences diminished during post-weaning period and there was no significant difference among calves fed either PSH or moist alfalfa based TMRs (HF, LF).

The only factor affecting FCE of the pasture hay fed calves was the greater dry matter intake. However, greater dry matter intake is essential for calves to stimulate early rumen growth, liveweight gain, stature and behaviour development to efficiently adapt to the pasture based system of New Zealand.

7.6. Effect of diet on calf behaviour

Calves fed additional forages (PSA, PSH), spent more time eating and ruminating, and engaged less in non-nutritive oral sucking behaviours than calves fed no additional forage (PS, Experiment 1), or lower forage diet (LF, Experiment 2). Similar results were reported by other researchers, that calves fed forages (ground or chopped hay) showed greater dry matter intake, less sucking behaviours and better calf welfare (Haley et al., 1998; Davis and Drackley, 1998; Coverdale et al., 2004; Phillips, 2004; Miller-Cushion et al., 2013). Castell et al. (2012) fed chopped alfalfa hay, ryegrass hay, chopped barley straw, maize or triticale silage to neonatal calves and reported less non-nutritional sucking behaviour and more rumination in calves fed alfalfa hay or pasture hay. In this study (Chapter 5), calves eating pasture hay based diet spent more time learning foraging and rumination behaviours and showed less sucking. In this study, addition of forage to the calf's diet increased rumination activity. Reduced rumination activity was reported previously when forage was absent from the calves' diet (Hodgson, 1971; Phillips, 2004; Martin et al., 2006).

Therefore, when additional forage (especially pasture hay) is fed to young calves, they start learning foraging and ruminating skills at a younger age, feel more satisfied, grow better and show less frustration and sucking behaviour compared to calves fed no forage at all or a lower amount of moist alfalfa forage.

7.7. Later life performance

Later life performance of calves was assessed during their first, second and third lactations. Fromexperiment 1, no differences were observed in animals' liveweights, milk yield, protein or fat production during first three lactations. These results are similar to a recent study by Castells et al. (2015), where calves were fed either forage or non forage diets. Calves that were fed a forage based diet showed greater concentrate intake, total dry matter intake and liveweight gain pre-weaning. However, these differences disappeared post-weaning and no differences were observed in terms of liveweight gains or milk yield during their first lactation. Several other researchers reported that significant growth differences observed in calves pre-weaning disappeared post-weaning (Terre et al., 2009; Davis Rincker et al., 2011). Recently, Kiezebrink et al. (2015) fed calves whole milk at a conventional milk feeding programme (10% of LWT, like this study) and found no differences in milk production during the first lactation.

Some researchers have also reported positive correlations between liveweight gain pre-weaning and future milk production (Bach, 2012; Soberon et al., 2012). Soberon et al. (2012) reported a 22% increased milk production due to increased pre-weaning growth. In Experiment 2, calves were fed different moist alfalfa based TMRs (HF, LF) with different ratios compared to a conventional forage source (pasture hay). HF and PSH fed calves grew faster (liveweight gains) than LF calves and during the first lactation HF fed heifers showed greater milk yield than LF or PSH calves. According to Brown et al. (2005), rapid growth rate in the first 3 months of a calf's life influences heifer mammary gland development more than during the post-weaning period. This might be a contributing factor to the greater milk yield in HF fed heifers. Also moist alfalfa based TMR diets (HF, LF) were higher in protein and there was more protein available to calves at a young age. There is a possibility that this higher protein diet (HF) during the pre-weaning period might have played some role in heifer mammary gland growth and development that resulted in greater milk yield during first lactation.

In the second lactation, no significant differences were observed in terms of milk, protein, and fat yield or liveweight among three treatments (HF, LF, PSH). In the third lactation, calves fed LF diet showed greater fat production than HF or PSH calves. No other significant differences in milk yield, protein or liveweight were observed among the three treatments. This single significant difference in third lactation might be more likely to be a chance effect than a real effect. The low number of animals left in each treatment group by the time animals were in their third lactation resulted in very low statistical power, which suggests caution is needed in interpeting this result.

Based on the number of animals available to measure and the pattern of results, it was difficult to draw firm conclusions about the later life performance of calves fed different pre-weaning diets. Differential feeding and management practices might have been a contributing factor to cow performance during first and subsequent lactations. Therefore, this study should be repeated with sufficient animal numbers per treatment and with cows managed under similar treatment/conditions.

7.8. Conclusions

In Experiment 1, offering calves additional forages (moist alfalfa or pasture hay), had no effect on starter diet intake, increased total DMI, increased liveweights, caused more eating and rumination behaviour and less suckling behaviour than calves fed no additional forage. Feed conversion efficiency was lower in calves fed additional forage (moist alfalfa, pasture hay) than calves fed no forage. After moving to pasture, no behavioural or stature difference were observed among calves fed the different diets.

When comparing the long term performance for the first three lactations, no significant differences among three treatments were observed in terms of liveweights, milk yield, protein or fat production.

In Experiment 2, offering calves pasture hay along with a starter diet resulted in greater total dry matter intake, liveweights, and greater stature compared to calves fed moist alfalfa based TMR diets (LF, HF). Calves fed pasture hay along with a starter diet spent more time eating and lying down, displayed a higher number of allo-grooming incidents, and spent less time sucking or sucking inanimate objects than calves fed the low moist alfalfa based TMR (LF). Feed conversion efficiency was lower in calves fed pasture hay diet (PSH) than high moist alfalfa based diet (HF), or low moist alfalfa forage diet (LF) during pre-weaning period. However, this diminished during post-weaning period. After moving to pasture, no behavioural difference was observed among calves fed the different diets in Experiment 2.

Greater liveweight and milk yield was observed in first lactation cows which were fed high moist alfalfa diet (HF) as calves than cows which were fed low moist alfalfa (LF) or pasture hay and starter (PSH) diets as calves. No protein or fat production differences were observed during the first lactation among the three treatment diets. In the second lactation, no significant differences were observed among the three treatments diets in any production traits. In the third lactation, the only significant difference was greater fat production in cows fed low moist alfalfa (LF) compared to cows fed HF or PSH as calves.

7.9. Further research

This study found that it is beneficial to feed a pasture hay based diet to calves to aid their rumen development and consequently their future productive potential. However, some questions remain unanswered and further studies such as those mentioned below, might provide more information for farmers to ensure their replacement heifers are fed to enhance future milk production.

An investigation to verify the effect of forage content of the diet of calves on their rumen development and to better understand the physiological / histological effects which might better inform the type and quantity of forage fed

- Different pasture hay based TMRdiets fed to calves to observe any short term effects such as dry matter intake, rumen development, liveweight gain and oral behaviour development.
- The long term effects of feeding calves different pasture hay based TMR diets such as meeting target liveweights at puberty, mating, calving, survivability and health.
- The long term effects of feeding the above diets on milk yield during first and second lactation, using a larger number of animals than the current study and ensuring animals are under similar feeding and management practices.

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