Roughage Feeding of Suckler Cows during Winter

Intake, Utilization and Energy Status in Pregnant Cows

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Cover: Suckler cows in a semi-natural pasture
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Abstract

Feeding late cut forage is a common strategy to provide pregnant suckler cows with feed of suitable nutritional quality during *ad libitum* feeding regimes. Despite this method, commonly grown grasses may result in overfeeding with energy and protein in relation to cow nutrient demands. The aim of this thesis was to evaluate alternative types of high-fibre roughages and their effects on feed intake, utilization, and cow energy status, to improve the effectiveness of feed resource use to spring-calving suckler cows.

In a first study, the effects of forage diet; timothy silage, reed canarygrass silage, and whole-crop oat silage, on intake, digestibility, rumination time, faecal particle size and nitrogen (N) utilization were studied in mid-pregnant cows of Hereford and Charolais breeds. In two further studies, feed intake, N utilization, cow energy status and metabolic profile before and around parturition, and calf performance, were investigated in Hereford cows fed timothy-meadow fescue silage, festulolium silage, reed canarygrass silage or barley straw supplemented with rapeseed meal during pregnancy.

Although cut at similar stage of maturity, all perennial grasses exhibited variations in digestibility and fibre characteristics, which elicited differences in intake and utilization. Traditional timothy and timothy-meadow fescue silage, and festulolium silage, resulted in overfeeding and increased body weight (BW) and body condition (BCS) during pregnancy, whereas the low digestibility of the reed canarygrass and barley straw diets resulted in a catabolic state and losses of BW and BCS prepartum. Intake appeared to be proportional to cow BW and not affected by the breed itself. Nitrogen utilization was improved with increased intake of digestible organic matter.

There is potential to increase effectiveness of the current suckler cow feeding by choosing alternative forages of low digestibility and rich in fibre. This may reduce feed intake and accompanied feed costs, and risk of overfeeding with energy and protein, without negative effects on cow performance.

Keywords: breed, energy status, faecal particle size, festulolium, forage utilization, metabolic profile, nitrogen utilization, reed canarygrass, rumination

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Utfodring av Grovfoder till Dikor under Vintern. Konsumtion, Utnyttjande och Energistatus hos Dräktiga Dikor.

Sammanfattning

En vanlig strategi för att förse dräktiga dikor, som utfodras i fri tillgång, med grovfoder av lämplig näringskvalitet är att skörda fodret sent. Vanligt förekommande grässorter kan trots denna metod leda till att korna utfodras med energi och protein utöver sitt behov. Syftet med denna avhandling var att utvärdera alternativa typer av fiberrika grovfoder och studera effekterna på foderintag, foderutnyttjande och kons energistatus, för att förbättra effektiviteten i foderanvändningen till vårkalvande dikor.

I den första studien undersöktes effekten av grovfodertyp; ensilage av timotej, rörflen eller helsäd av havre, på intag, smältbarhet, idisslingstid, partikelstorlek i träck samt kväveutnyttjande hos lågdräktiga dikor av raserna hereford och charolais. I två ytterligare studier utvärderades effekten av grovfodertyp på intag, kväveutnyttjande, kons energistatus och metaboliska profil före och efter kalvning, samt kalvens födelsevikt och tillväxt, när herefordkor utfodrades med ensilage av timotej/ängssvingel, rörsvingelhybrid, rörflen eller kornhalm kompletterad med rapsmjöl under dräktigheten.

Samtliga perenna gräs skördades vid liknande utvecklingsstadier. Trots det uppvisade de skillnader i smältbarhet och fiberkoncentration, vilket resulterade i olika intag och foderutnyttjande. Utfodring med traditionellt ensilage av timotej och ängssvingel, samt rörsvingelhybrid, ledde till överutfodring och till vikt- och hullökningar under dräktigheten, medan den låga smältbarheten på rörflensensilaget och halmfoderstaten resulterade i ett katabolt tillstånd och i vikt- och hullminskningar under samma period. Foderintaget påverkades inte av rasen på kon utan verkade vara proportionell mot kons kroppsvikt. Kväveutnyttjandet förbättrades vid ett ökat intag av smältbar organisk substans.

Det finns potential att öka resurseffektiviteten i dagens utfodring av dräktiga dikor genom att välja alternativa fiberrika grovfoder med låg smältbarhet. Detta kan reducera kornas intag, foderkostnaderna och risken för överutfodring med energi och protein, utan negativ effekt på kons produktion.

Keywords: breed, energy status, faecal particle size, festulolium, forage utilization, metabolic profile, nitrogen utilization, reed canarygrass, rumination

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Dedication

To Niklas, Svea and Algot

My grandfather used to say that once in your life you need a doctor, a lawyer, a policeman and a preacher, but every day, three times a day, you need a farmer.
Brenda Schoepp – Farmer

Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Jardstedt, M., Hessle, A., Nørgaard, P., Frendberg, L. & Nadeau, E. (2018). Intake and feed utilization in two breeds of pregnant beef cows fed forages with high-fiber concentrations. *Journal of Animal Science,* vol. 96, pp. 3398–3411.

II Jardstedt, M., Hessle, A., Nørgaard, P., Richardt, W. & Nadeau, E. (2017). Feed intake and urinary excretion of nitrogen and purine derivatives in pregnant suckler cows fed alternative roughage-based diets. *Livestock Science*, vol. 202, pp. 82–88.

III Jardstedt, M., Nadeau, E., Nielsen, M. O., Nørgaard, P., & Hessle, A. The effect of feeding roughages of varying digestibility prepartum on energy status and metabolic profiles in beef cows around parturition. (submitted to the journal *Animals*)

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Abbreviations

ADF	acid detergent fibre
ADL	acid detergent lignin
APS	arithmetic mean faecal particle size
BCS	body condition score
BUN	blood urea nitrogen
BW	body weight
CP	crude protein
DM	dry matter
DMI	dry matter intake
DOM	digestible organic matter
GPS	geometric mean faecal particle size
iNDF	indigestible neutral detergent fibre
MP	metabolizable protein
N	Nitrogen
NDF	neutral detergent fibre
NE	net energy
NEFA	non-esterified fatty acids
OM	organic matter
OMD	organic matter digestibility
PBV	protein balance in the rumen
PDM	particle dry matter in faecal dry matter
RDP	rumen degradable protein

Definitions

Forage	includes grasses and whole-crop cereals
Roughage	includes grasses, whole-crop cereals and straws

1 Introduction

Globally, beef cow and calf (suckler-based beef) production is based primarily on different types of grasses, which are fed as grazed and/or conserved forage. In the Nordic countries, year-round grazing is not possible due to the climatic conditions. In Sweden, cows are therefore commonly wintered indoors and fed conserved forage during this period. The length of the indoor period varies depending on geographical location, but is commonly around 5 to 6 months. The cost of harvested grass is usually greater than that of grazing (Kumm, 2009). Thus, winter feed costs constitute a substantial proportion of the total annual costs of feeding the cow (Kumm, 2009; Arnesson & Salevid, 2011).

The majority of the Swedish suckler calves are born in the spring. According to the Swedish feeding recommendations for ruminants (Spörndly, 2003), pregnant suckler cows in normal body condition should be fed according to maintenance requirements until late gestation, *i.e.* the last eight weeks of pregnancy. Thereafter, an addition of energy and protein per cow and day is recommended based on cow body weight (BW) (Spörndly, 2003). Consequently, the nutrient requirements of the spring-calving suckler cows are relatively low during a large part of the indoor period.

Suckler cows are commonly fed forage *ad libitum* during the winter for rational reasons. In addition, about one third of the Swedish suckler cows are found in operations with organic production (Swedish Official Statistics, 2018) where the rules require that animals have free access to roughage. The combination of low nutritional requirements during early to mid-pregnancy and *ad libitum* feeding increases the risk of overfeeding with energy and protein during this period (Arnesson & Salevid, 2011).

Suitable forage quality for pregnant suckler cows is generally achieved by delaying the date of harvest. However, field studies have shown that traditional grasses might have too high nutritive value for this animal category with low nutritional needs also wen cut late (Arnesson & Salevid, 2011). Feeding according to the nutrient requirements of pregnant suckler cows is important to ensure that the cow is in adequate condition to ease calving, enhance transition to lactation, and to facilitate rebreeding. Over-conditioning of suckler cows during pregnancy is expensive and increases the risk of dystocia (Zaborski et al. 2009). On the other hand, negative energy status prepartum and poor body condition at parturition may have negative effects on *e.g.* cow reproductive performance (Houghton et al. 1990) and on calf average daily gain and weaning weight (Stalker et al. 2006). Overfeeding of protein may result in unnecessary losses of nitrogen (N), as protein supplied in excess of rumen microbial and cow requirements are excreted in urine (Tamminga, 1996). Thus, from economic, environmental and cow performance perspective, there is a lot to be gained by house holding with feed resources and feed the correct quality and quantity at the right time.

The aim of this thesis was to evaluate the nutritional quality of different types of high-fibre roughages, and their effects on feed utilization, in an attempt to improve the effectiveness of feed resource use to spring-calving Swedish suckler cows during winter with application also in the other Nordic countries and elsewhere with similar climatic conditions.

1.1 Structure of the Swedish Suckler-Based Beef Production

Like other animal production sectors, the Swedish beef production based on suckler cows are undergoing structural changes. The number of suckler cows has slowly increased by 28% since year 2000 and were about 214 200 in 2018. Simultaneously, the number of herds has decreased by 25% to 10 400 in year 2018. As a result, the average herd size has increased from 12 to 21 cows (Swedish Official Statistics, 2018). The number of dairy cows have decreased during the same period, resulting in less proportion of beef originating from dairy herds. This has, to some extent, been compensated for by the increase in suckler cow heads, which has resulted in that 40% of the Swedish beef now is provided by the suckler cow sector. Since 2007, there has been a down-going trend in degree of self-sufficiency of beef, with the bottom notation in 2013 of 50%. Thereafter, an increased demand for Swedish beef from the consumers has led to higher and more stable producer prices, resulting in a small increase in production (Lannhard Öberg, 2018).

A large part of the suckler cows are found in the forest districts of southern Sweden, with less favourable conditions for *e.g.* grain production. The landscape in these areas is characterised by relatively small fields and pastures interspersed with lakes and forest. It is also in these areas where a large proportion (53%) of the semi-natural grasslands are located (Swedish Official statistics, 2018). Semi-natural grasslands represent a cultural heritage (Emanuelsson, 2009) and constitute the most species-rich type of nature in Sweden (Artdatabanken, 2015). Thus, they are socially and biologically valuable. Grazing cattle is a prerequisite in the preservation of these values (Spörndly & Glimskär, 2018) and the suckler cows has become increasingly important in their management during the last two decades, due to the fewer number of cattle of dairy breed.

The growing importance of suckler-based beef production for both beef supply and conservancy of valuable nature highlights the need of more research on winter feeding systems practiced in this branch of animal production, as most research on cattle feeding until today has been performed on feeding regimes applied in dairy production.

1.2 Roughage Fibre, Protein and Intake

Digestibility and intake are the two major determinants of forage quality. Although intake potential and digestibility of forages are strongly related and largely influenced by the quantity and digestibility of the dietary fibre, it is the animal's response to these forage characteristics that ultimately determines the nutritional quality of forages. Voluntary intake typically accounts for most of the variation in animal productivity among forages, but digestibility is important, because faeces is the greatest loss of ingested nutrients (Mertens, 2007).

Forages have a large volume in relation to dry matter (DM) weight and are therefore bulky and more difficult to digest in comparison to grains and concentrate feeds. Both fibre characteristics and bulkiness of forages affects degree of rumen fill, which is expected to be the main factor limiting DM intake (DMI) in cattle fed high-fibre forages (Mertens, 1994). The filling effect of forage is related to the concentration and digestibility of the neutral detergent fibre (NDF), where digestibility exerts a greater effect (Oba & Allen, 1999). High NDF concentration and low NDF digestibility increases rumen fill and, thus, limits intake. Digestibility of NDF is in turn affected by the concentration of indigestible NDF (iNDF), rate of digestion, and digesta passage rate (Mertens, 2007). Forage DMI has been shown to be more closely related to iNDF concentration than to total NDF, indicating the importance of fibre quality on forage intake (Huhtanen et al. 2007).

Herbage maturity is the factor with greatest influence on the fibre characteristics of forages and includes both aging of tissues and morphological change (Buxton, 1996). The NDF concentration increases and NDF digestibility decreases with increased stage of development (Cherney et al. 1993). Hence, both concentration and digestibility of NDF may vary within grass species due to maturity stage at harvest. Concentration and digestibility of NDF may also differ among forage species cut at the same stage of maturity. This can be related to the proportion of leaves versus stems, the former generally having lower NDF concentration and being more digestible than the latter (Buxton, 1996), and the structure of the fibre, *e.g*. cross-linking of lignin to cell-wall polysaccharides (Moore & Jung, 2001).

Previous studies have demonstrated that *in vivo* digestibility of whole-crop barley and wheat (Rustas et al. 2011), and whole-crop oat (Wallsten et al. 2010), decrease until the milk stage of maturity, after which it remains rather constant. The reduction in organic matter (OM) digestibility until the start of grain-filling is mainly due to decreased digestibility of the stalks, where most of the NDF is found. During grain-filling there is an increase in starch content and digestibility of the ear and the ear's proportion of the plant increases. This counteracts the decreased digestibility of the stalk (Wallsten, 2008) and makes it possible to harvest whole-crop cereals during a wider time-frame than grasses without very large effects on OM digestibility.

The crude protein (CP) concentration of grasses decreases with increasing maturity stage of the plant (Hatfield et al. 2007) and the same general pattern has been reported for whole-crop cereal silages (Nadeau, 2007; Wallsten et al. 2010). In ensiled forage, a large part of the protein is in the form of free amino acids and ammonia, and as rumen degradable protein (RDP) (Givens & Rulquin, 2004). This makes the utilization of dietary protein in ruminants fed only forage a challenging topic, as capturing of free amino acids and ammonia into microbial protein synthesis requires instant energy sources, such as sugars. For the RDP utilization, also digestible fibre is needed as energy source (Merchen & Bourquin, 1994).

Cereal straws generally have high concentrations of NDF (>770 g/kg DM) and iNDF (>300 g/kg NDF), whereas the concentration of CP is low (30 to 50 g/kg DM) (NorFor Feed Table, 2019). The low CP content leads to deficiency of nitrogen in the rumen, which restricts microbial fibre digestion (Hoover, 1986; Mertens, 1994). Therefore, cereal straws must be supplemented with a protein source if offered as the sole feed in order to enhance fibre digestion.

In summary, time of harvest and choice of roughage crop has a great influence on the final quantity and quality of roughage fibre and protein, the need of protein supplement, and, consequently, on animal intake and performance.

1.3 Chewing Activity and Faecal Particle Size

Forage particle size reduction through chewing during eating and rumination, and increases in particle density through fermentation, are two processes necessary for the digesta to be able to pass out of the rumen (Jung & Allen, 1995). It has been proposed that cattle may spend a maximum of 10 h per day ruminating (Welch, 1982). Hence, intake of coarse forages might be limited to some extent by the capacity of the ruminant to decrease particle size mechanically through chewing (Van Soest, 1994). Rumination time is generally proportional to the intake of NDF and, consequently, the rumination time per kg DMI is proportional to the concentration of NDF per kg DM (Nørgaard et al. 2010).

Very little particle size reduction takes place in the lower digestive tract of ruminants (Ahvenjärvi et al. 2001). Therefore, analysis of faecal characteristics, such as the content of particle dry matter in faecal DM (PDM), which is defined as the proportion of faecal DM that is left after washing and freeze-drying, and the faecal particle size distribution, can provide information about diet digestibility and rumen function. The PDM values of faeces from cattle and sheep fed forages generally increase at increasing maturity stage at harvest (Jalali, et al. 2012; Schulze at al. 2015) and Nadeau et al. (2016) showed that the concentration of PDM was negatively related to apparent NDF digestibility in dairy heifers. Increased lignification, *i.e.* increased acid detergent lignin (ADL) to NDF ratio, of grass silages has been shown to linearly increase the mean and median faecal particle size and linearly decrease the proportion of small particles in sheep and cattle (Jalali et al. 2012, 2015). Mean faecal particle size has also been demonstrated to increase due to increasing BW and increasing intake of forage NDF relative to BW in ruminant animals (Jalali et al. 2015).

1.4 Different Types of Roughages

Traditionally, suitable forage quality for pregnant suckler cows with modest nutritive requirements is achieved by delaying the date of harvest. This type of forage results in intake being physically constrained by rumen fill (Allen, 1996) and long rumination time per kg DM intake (Nørgaard et al. 2010), which gives the cow a natural appetite regulation without the need of controlling intake through restrictive feeding. Increased forage maturity at harvest also generates higher yield per cut. Fewer cuts are thereby required, which reduces the production cost per tonne of forage DM. Persistency of the forage crop is also a desirable trait, as it reduces the cost of ley-establishment (Kumm, 2009). In the Nordic countries, timothy (*Phleum pretense* L.) and meadow fescue (*Festuca pratensis* L.) are traditionally used in mixed grass silages, but their inclusion in suckler cow diets has been questioned due to their high digestibility. Hence, other alternative high-fibre roughages have been proposed in order to reduce the risk of overfeeding.

1.4.1 Festulolium

The superior forage quality of the ryegrasses (*Lolium* spp.) has beneficially been complemented with the high persistence and stress tolerance of the fescues (*Festuca* spp.) in interspecific *Lolium* x *Festuca* hybrids called festulolium (Østrem et al., 2014). Festulolium cultivars has become more common alternatives to meadow-fescue in forage mixtures due to their combined traits of high yields (Halling, 2012, Østrem et al. 2014), high regrowth capacity, high persistency (Halling , 2012) and drought tolerance (Hallin, pers. Communication, 2019)[1]. Due to the use of different parent species, festulolium cultivars display distinct variability in their characteristics. Østrem et al. (2014) found that Hykor, a hybrid between Italian ryegrass (*Lolium multiflorum* L.) and tall fescue (*Festulolium arundinacea* L.), had greater NDF and iNDF concentrations, and lower rate of fibre digestion than festulolium entries with meadow-fescue attributes. Nadeau and Hallin (2016) reported similar NDF concentrations in festulolium (cv. Hykor), timothy (cv. Switch) and meadow fescue (cv. Minto) when cut at the same date of the primary growth. However, festulolium displayed significantly lower *in vitro* digestibility of OM than timothy and meadow fescue. In addition, *in sacco* analysis (Åkerlind et al. 2011) showed greater concentration of iNDF in festulolium than in timothy and meadow fescue (135 vs. 79 and 103 g/kg DM) and lower rate of fibre digestion for festulolium than for timothy and meadow fescue (4.64 vs. 7.70 and 6.76 %/hour) (Nadeau & Hallin, 2016). The same study also revealed that the total DM yield in a three-cut system was 12% and 22% greater for festulolium than for timothy and meadow fescue, respectively (Nadeau & Hallin, 2016).

1.4.2 Reed Canarygrass

Cultivation of reed canarygrass (*Phalaris arundinacea* L.) has increased in Sweden during the last two decades because of its potential use as fuel in bioenergy production (Palmborg et al. 2011), but also because of being a possible substitute for straw in areas with limited grain production (Carlsson, 2012). Reed canarygrass is persistent, with leys being productive for 10 to 15 years (Landtröm & Wik, 1997), high yielding, and produces well on both dry and poorly drained soils (Casler & Kallenbach, 2007). In addition, previous studies have shown that reed canarygrass have greater NDF and iNDF concentrations and lower *in vitro* digestibility of DM and NDF than timothy when cut at the same stage of maturity (Collins & Casler, 1990; Cherney et al. 1993).

[1] Ola Hallin, Hushållningssällskapet Sjuhärad, 2019-02-14

1.4.3 Whole-Crop Cereals

Oat (*Avena sativa*) and spring barley (*Hordeum vulgare*) are commonly used as nursing crops when establishing new forage leys. In this context, the cereal is usually harvested as a whole-crop, with oat being the most common whole-crop cereal in Sweden (Swedish Official Statistics, 2018). Whole-crop cereals give relatively high yields per hectare in one cut, which reduces the cost of ley establishment, as a large amount of roughage DM can be harvested already in the establishment year. It has been demonstrated that fresh whole-crop oat has lower digestibility of OM than whole-crop spring barley when averaged over maturity stages (Nadeau, 2007), and that whole-crop oat silage has lower digestibility of NDF than whole-crop spring barley silage when cut at the early dough stage of maturity (Wallsten et al. 2010). In addition, whole-crop oat has been shown to result in approximately 10% greater DM yield than whole-crop spring barley when cut at the early dough stage of maturity (Nadeau, 2007).

1.4.4 Cereal Straw

The quantity of cereal straws used for feeding in practical animal production depends on their nutritive value, availability and costs in comparison with conventional feedstuffs, such as silage and grain. Grass silages with high concentrations of energy and protein can be diluted by the inclusion of cereal straw. However, the small-scale structure of the Swedish suckler-based beef production generally does not allow for investments in mixer- wagons. Another option to increase straw intake could then be to alternate between feeding straw and silage, *e.g.* providing each feed for two to three days at a time, as demonstrated by Dahlström and Arnesson (2016). However, this strategy might not be optimal, as it resulted in loose faeces, probably due to rumen disturbances caused by the frequent feed changes (Dahlström & Arnesson, 2016). The availability of straw might be limited due to weather conditions in the autumn, by the geographical position of the farm, or by the need to reserve the straw for bedding. Despite these factors, feeding only cereal straw supplemented with a protein feed to pregnant suckler cows might be an economic alternative to common mixed grass silages in areas in close vicinity to grain producing regions. Spring barley and winter wheat are the two most commonly grown cereals in Sweden (Swedish Official Statistics, 2018). As barley straw has been shown to be more digestible than straw of winter wheat (Colucci et al. 1992), the former might be a more suitable alternative to include in large proportions of suckler cow diets.

1.4.5 Current Use of Alternative Roughages

There is no widespread use of the alternative roughages mentioned above in suckler-based beef production. Intake and utilization of festulolium and reed canarygrass has been studied in dairy cows (Kammes et al. 2008; Martinsson & Ericson, 2011) and sheep (Narasimhalu et al. 1992), but to our knowledge, there is no information in the literature on studies with suckler cows. Whole-crop oat cut at dough stage of maturity has previously been demonstrated as suitable winter feed for pregnant spring-calving suckler cows (Manninen et al. 2005). However, cows in that study were fed restrictively and data on intake and utilization during *ad libitum* feeding regimens are, therefore, required. Ammoniated straw has previously been evaluated as feed to pregnant suckler cows (Manninen et al. 2000; Wiedmeier et al. 2002). However, ammonia-treated straw is not commonly applied in practice in our region and is not allowed in organic production. Furthermore, trials evaluating non-treated cereal straws fed together with a protein supplement to suckler cows are scarce. Hence, more research on feed intake and utilization in feeding systems relying on these types of alternative roughages to suckler cows are needed.

1.5 Nitrogen Utilization

Ammonia is an air and water pollutant causing acidification and eutrophication of the environment. Ammonia emitted from cattle manure is responsible for a significant proportion of anthropogenic N emissions, contributing 30% of total emissions in EU28 (European Environment Agency, 2016). Around one-third of the 36 million cows in the EU cattle stock are suckler cows (Swedish Board of Agriculture, 2016). However, while much attention has been devoted to investigating dietary effects on urinary N excretion in dairy cattle (*e.g.* Huhtanen et al. 2008; Weiss et al. 2009; Spek et al. 2013), the number of studies on suckler cows is limited (Estermann et al. 2001; Bernier et al. 2014).

Microbial protein is the essential source of metabolizable protein (MP) in cattle fed only roughages (NRC, 2000). A great proportion of the CP in grass silage is rumen degradable protein (Merchen & Bourquin, 1994), which can be used for microbial CP synthesis as long as a source of energy is present. However, efficient use of RDP by the rumen microbes may be challenging when late cut forages are fed, because of the low availability of fermentable carbohydrates. When entering the rumen, RDP is degraded to ammonia by the rumen microorganisms. If energy is limiting, excess ammonia not used in microbial CP synthesis is excreted as urea in urine (Nocek & Russell, 1988), while a smaller proportion is recycled to the rumen by the saliva and across the rumen wall (Reynolds & Kristensen, 2008) (Figure 1). Urea excreted in urine is rapidly hydrolysed to ammonia upon deposition on barn floor or soil. Fresh faeces, on the other hand, contain low amounts of rapidly decomposable N, suggesting that urinary N, at least in the short term, is more susceptible to losses (Bussink & Oenema, 1998). Hence, the efficiency of microbial use of RDP in the rumen affects the environmental impact of production. A minimum amount of RDP must, however, be provided in the diet to avoid N constraints on microbial CP synthesis and OM digestion (Clark et al. 1992).

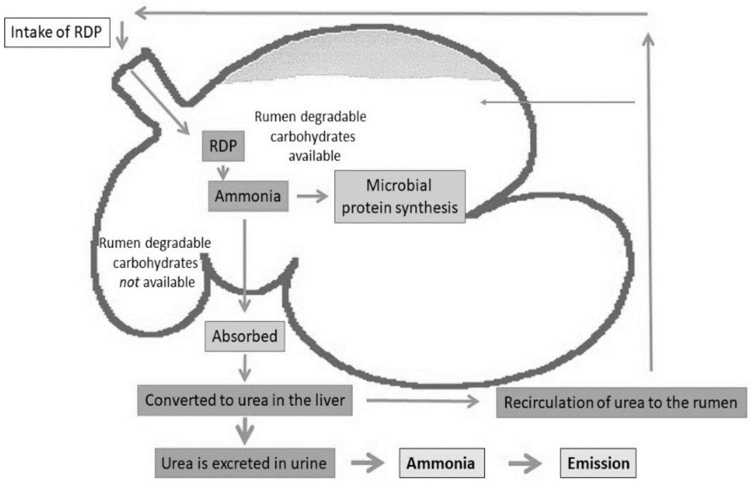

Figure 1. Simplified schematic picture of rumen metabolism of rumen degradable crude protein (RDP). The RDP is degraded to ammonia by the rumen microorganisms. If there is a concomitant supply of energy, *i.e*. rumen fermentable carbohydrates, ammonia is converted into microbial protein. If RDP is supplied in excess of available fermentable substrates, ammonia is absorbed from the rumen and excreted as urea in the urine. A smaller amount of urea is also recirculated to the rumen via saliva and across the rumen wall.

1.6 Breed

The early maturing beef breed Hereford and the late maturing beef breed Charolais are two of the most common beef breeds in Sweden (NAB, 2018). They were historically developed on low and high quality forage diets, respectively. In addition, Swedish breeding goals still dictate that Hereford should be bred for more nutritionally extensive production than Charolais (NAB, 2018). Thus, the question has been raised if intake and feed utilization in these breeds may differ due to their evolutionary backgrounds. Such information is warranted as it could indicate if feeding recommendations should differ between breeds. However, comparisons of feed intake and utilization in these breeds are scarce.

2 Aims

The overall aim of the thesis was to compare different high-fibre roughages to traditionally used grass silages and to study their effects on feed intake, nutrient utilization and energy status in pregnant suckler cows fed *ad libitum*.

The specific hypotheses were that:

- Feeding of different high-fibre, roughage-based diets affects feed intake, rumination time, faecal particle size distribution, apparent diet digestibility and N utilization.

- Breed has an effect on feed intake, rumination time, faecal particle size distribution and apparent diet digestibility.

- Intake of N and digestible organic matter (DOM) affect urinary excretions of N and urea-N, and rumen microbial CP synthesis.

- Feeding of different high-fibre, roughage-based diets affects intake, BW, body condition score (BCS), and metabolic profile prepartum and around parturition, and subsequent calf performance.

3 Materials and Methods

The following paragraphs provide an overview of the materials and methods used in the different studies. For a more detailed description, see Papers I-III.

3.1 Studies Conducted

The papers in this thesis are based upon three different experiments conducted at SLU Götala Beef and Lamb Research Centre in Skara, southwest Sweden (Papers, I, II and III). All animal experimental procedures were approved by the Gothenburg Research Animal Ethics Committee. In the following sections, the results obtained during the studies described in Papers I-III are attributed to Studies I-III, respectively. The overall design of the experiments was to feed the cows with roughage-based diets *ad libitum*, while altering the types of roughages.

Paper I describes an experiment to determine the effects of feeding three different high-fibre forage based diets on feed intake, rumination time, diet apparent digestibility, faecal particle size distribution and N utilization in early to mid-pregnant suckler cows of an early and a late maturing beef breed.

In Paper II, total collection of urine was performed to evaluate the effects of feeding four different high-fibre roughage-based diets on N utilization and rumen microbial protein synthesis in mid-pregnant suckler cows. Furthermore, a multiple linear regression analysis was conducted to study the relationship between intakes of N and DOM, and urinary outputs of N, urea-N and purine-derivatives (PD). The latter being an indirect measure of rumen microbial CP synthesis (Chen and Gomes, 1992).

Paper III describes an experiment where *ad libitum* feeding of four different roughage-based diets to pregnant suckler cows resulted in four intake levels of energy and protein. The diets were fed during the final 16 weeks prepartum and effects on cow energy status, as indicated by changes in BW, BCS, and metabolic profile prepartum and around parturition, were evaluated. The experiment also assessed the subsequent effects on calf performance until weaning and on cow BCS and BW at the end of the grazing season.

3.2 Animals, Experimental Design and Housing

The experiment in Paper I was conducted with 48 multiparous cows of the Hereford breed (n = 24) and Charolais breed (n = 24). At the start of the experiment, cows were pregnant (3.7 ± 0.8 months), non-lactating, with BW (mean ± SD) of 689 ± 76 and 766 ± 75 kg for the Hereford and Charolais breeds, respectively. Cows were group-housed and fed three diets in three 21-d periods. The experiment was arranged as two 3 x 3 Latin squares amalgamated to form a 3 x 6 rectangle for each breed. Within breed, cows were randomly allocated to six pens. Two groups of each breed were randomized to the same diet in each period. The dietary adaption period was 14 days and the data collection period was seven days.

The experiments in Papers II and III used 36 multiparous cows of the Hereford breed. Cows were blocked into three calving groups (Papers II and III), with 12 cows per group, according to expected date of calving: early, medium and late. Within each calving group, cows were randomly assigned to four pens, which were randomly assigned to four diets (Papers II and III).

The total collection of urine (Paper II) was conducted on each calving group when cows were in mid-pregnancy. Each calving group was further divided into two subgroups and the total collection was performed with one subgroup at a time.

In Paper III, initial mean cow BW and BCS (1 = emaciated, 9 = obese; adapted from Herd and Sprott, 1986) at experimental start was 720 ± 88 kg and 5.9 ± 0.9, respectively. Cows were fed the experimental diets for 126 ± 19 d prepartum and results are reported for the final 16 weeks prepartum. Postpartum, cows were immediately comingled with cows from other groups and fed the same diet. Cows remained indoors for at least 21 days postpartum (28 ± 10 d) before being let out on open semi-natural pasture. Week -16 to -1 was defined as the prepartum experimental period, and day 1 to 21 postpartum was defined as the postpartum experimental period. Cows and calves grazed together (152 ± 15 d) until weaning on 3 October and the weaned cows continued grazing until they were housed on 29 October 2014, when the study ended.

In Papers I and III, cows were group-housed in a free-stall barn with scraped alleys and deep litter. In Paper II, cows were kept in individual tie stalls.

3.3 Experimental Diets and Feeding

3.3.1 Paper I

The three experimental forages were: timothy (control, cv. SW Ragnar); reed canarygrass (cv. Palaton); and whole-crop oat (cv. Kerstin). The timothy and reed canarygrass were harvested at the stage of flowering of the primary growth on June 28 and July 4, respectively, and the whole-crop oat at the hard dough stage on August 12. All forages were prewilted and preserved as round bales with the addition of a chemical additive.

The whole-crop oat diet was supplemented with urea (53.7 ± 1.1 g per cow daily), because of its low CP concentration (45 g/kg DM), to avoid constraint of rumen microbial CP synthesis due to lack of N.

Cows were fed *ad libitum* and daily feed intake was recorded on group level. Animals had free access to water and a salt block, and received 100 g of vitaminized minerals per cow and day.

3.3.2 Papers II and III

In Papers II and III, four experimental diets containing different roughages were used: timothy-meadow fescue mixture (control), festulolium (the hybrid Hykor of Italian ryegrass and tall fescue), reed canarygrass (cv. Palaton), and barley straw (cv. Rosalina). The grasses were harvested at the stage of flowering during the primary growth from 7 to 9 July. The postpartum diet consisted of timothy silage harvested in primary growth on June 18. All grasses were prewilted and preserved as round bales with the addition of a chemical additive. The barley straw was baled after threshing.

In the NorFor digestive model, the protein balance in the rumen (PBV, g/kg DM) is used to evaluate the adequacy of rumen protein supply for microbial growth (Volden & Larsen, 2011). The PBV value of a balanced diet should be between 10 and 40 g/kg DM (Volden & Larsen, 2011), but this was negative for the festulolium silage and barley straw (Papers II and III). Hence, these diets were supplemented with urea (6.9 and 11.3 g urea per kg DM, respectively) to avoid N constraints on rumen microbial CP synthesis. The urea was dissolved in water and thoroughly mixed into the festulolium silage and barley straw in a mixer wagon prior to feeding. Cows fed the barley straw plus urea mix were also supplemented daily with rapeseed meal, 0.48 kg DM/day from week -16 to -9, and 0.63 kg DM/day from week -8 to -1 prepartum, to cover their requirement of MP (Spörndly et al. 2003). Hence, the prepartum barley straw diet was composed of barley straw supplemented with urea and rapeseed meal, and the festulolium diet was composed of festulolium silage supplemented with urea.

In Paper II, cows were individually fed roughage *ad libitum* in feed bunks and intake was recorded daily. Cows fed the barley straw diet were supplemented with rapeseed meal once daily.

The roughage diets in Paper III were fed *ad libitum* both pre- and postpartum. The rapeseed meal was fed individually in separate feed stations (Biocontrol, CRFI, Rakkestad, Norway). Postpartum, all cows were fed the same timothy silage. Daily feed intake during the indoor period was recorded individually and continuously using automatic feed mangers (Biocontrol, CRFI, Rakkestad, Norway). Cows had free access to water, vitaminized minerals, and a salt block during the indoor period and at pasture. Calves had free access to hay in a creep feeder during the indoor period.

3.4 Data Collection and Analysis

3.4.1 Feeds, Refusals and Faecal Sampling

The experimental forages and refusals in Paper I were sampled daily in the data collection period and later pooled to one feed sample per diet and period and to one refusal sample per group and period. Daily intake values were corrected for the concentrations of nutrients in refusals.

In Paper II, the roughages were sampled at feeding and pooled to one sample per diet and calving group. Refusals from each individual cow were pooled to one sample per cow. Daily intakes of nutrients were corrected for the nutrient concentrations of the refusals.

In Paper III, roughage samples were collected daily after mixing prior to feeding. Hence, sampling of the festulolium and urea mix, and of the barley straw and urea mix, were performed after urea was mixed into these roughages. Samples were pooled by week for weekly determination of DM content, which was used to calculate DM intake. Daily feed samples were also pooled into three-week composite samples for later analysis of nutrient composition, which were used to calculate cow intake of NE and MP over time. The rapeseed meal was sampled twice (Paper II and III).

Fresh faeces (Paper I) was sampled from each cow once daily on day 17 to 21 of the data collection period and pooled to one sample per group and period. All feed, refusal and faeces samples were stored frozen at -20°C for later analysis (Papers I-III).

3.4.2 BW and BCS

In Paper I, BW was recorded at the start of the experiment and between each experimental period. In Paper II, BW was recorded just prior to initiation of the total urine collection. In Paper III, cows were weighed and BCS (Herd & Sprott, 1986; scale 1 to 9) was assessed by two independent observers at the start of the experiment. Thereafter, BW and BCS were recorded continuously, until calving. Postpartum, BW was recorded on day 1 and 2, and on day 20 and 21, when also BCS was assessed. Furthermore, cow BW and BCS were recorded at weaning and at the end of the grazing period. Changes in BW and BCS over time from week -16 prepartum until day 1 and 21 postpartum were calculated for each cow as the change per week in relation to the BW and BCS recorded just prior to the start of the prepartum experimental period. Changes in BW and BCS during the subsequent grazing period were calculated as the difference between the BW and BCS recorded at 21 days postpartum and the BW and BCS recorded at weaning and at the end of the grazing period. Calves were weighed within 24 h of birth and at weaning.

3.4.3 Rumination and Faecal Particle Size (Paper I)

Rumination time was individually recorded using a Heatime HR rumination monitoring system (SCR Engineers Ltd, Netanya, Israel), as described in Paper I. Mean rumination time per cow and day per group was calculated for each data collection period. Faecal PDM and particle size distribution were determined after washing and freeze drying, see Paper I for details, by horizontal shaking and sieving into six size fractions, as described by Nørgaard et al. (2004) and Jalali et al. (2012). The screen size was 2.360, 1.000, 0.500, 0.212, and 0.160 mm and a solid bottom bowl. The arithmetic mean particle size (APS) and geometric mean particle size (GPS) were estimated according to Waldo et al. (1971).

3.4.4 Chemical Analysis and Calculations

The composite samples of roughages (Papers I-III), refusals (Papers I and II), and faeces (Paper I), were analysed for contents of DM, ash and CP (see Papers I-III for details), and for OM-corrected NDF (aNDFom), OM-corrected acid detergent fibre (ADFom), and ADL with sequential analysis using an ANKOM200 fiber analyzer (Ankom Technology, Fairport, NY, USA) (Paper I) and by the FiberTech method (Papers II and III) according to Van Soest et al. (1991). The NDF analysis included α-amylase, but not sodium sulfite.

The concentration of starch in the whole-crop oat silage (Paper I) was analysed by an enzymatic method where starch is degraded with amylase and analysed as glucose (Larsson & Bengtsson, 1983). The rapeseed meal (Papers II and III) was analysed for the concentrations of aNDFom, ash and CP, see Papers II and III for details.

In Paper I, forage concentrations of iNDF were determined *in situ* on dried and milled samples (1.5 mm screen). The samples were incubated in polyester bags with pore size of 12 μm for 288 h in two rumen-fistulated dairy cows fed a standard maintenance diet (Åkerlind et al. 2011).

The concentration of iNDF in feed, refusals, and faeces were used as an intrinsic marker in Paper I to estimate total-tract apparent digestibility of OM and aNDFom. The marker iNDF was determined by *in vitro* analysis according to Goeser and Combs (2009). See Paper I for details about this analysis procedure and calculations of diet digestibility.

The *in vitro* organic matter digestibility (IVOMD) of the roughages was analysed with different methods as recommended by NorFor (Åkerlind et al. 2011). The grass silages (Papers I-III) were analysed according to the VOS method (ruminal digestible organic matter; Lindgren, 1979, 1983, 1988). For the whole-crop oat diet (Paper I), the IVOMD was determined by the IVOS method (*in vitro* organic matter digestibility) based on Tilley and Terry (1963). In Papers II and III, the IVOMD of the barley straw plus urea mix and the rapeseed meal was analysed separately by the EFOS method (enzyme digestible OM) (Weisbjerg & Hvelplund, 1993).

The methods for analysis of silage hygienic quality, *i.e.* fermentation products, ammonia and pH, are found in Papers I-III.

The NorFor digestive model was used to estimate the concentrations of net energy (NE) and MP of the diets used in Papers I and III (Åkerlind & Volden, 2011), see Paper III for description. The supply relative to the requirement of NE and MP was calculated as daily intake minus daily requirements for maintenance and gestation (Papers I and III), and milk production (Paper III) (Nielsen & Volden, 2011).

3.4.5 Urine Collection and Analysis (Papers I and II)

In Paper I, urine spot samples were collected by vulval stimulation from all cows at 0600 and 1300 h on day 19 or 20 of the data collection period. An aliquot of 40 mL urine was mixed with 160 mL, 10% H_2SO_4, and immediately frozen (-20°C).

The total urine collection in Paper II was performed during 48 consecutive hours for each cow using urine collection harnesses. Urine was collected in 20-

L vessels containing 10% H_2SO_4.The volume of acidified urine was measured every 12 h and a subsample of 200 mL per cow and 12-h period was immediately frozen at -20°C.

Urine samples (Papers I and II) were analysed for concentrations of N, urea-N, PD, *i.e*. allantoin and uric acid, and creatinine, see Papers I and II for details of analysis methods. Urinary creatinine excretion was used as a marker in Paper I to estimate daily urine output from the urine spot samples (Valadares et al. 1999), using the mean urinary creatinine excretion per cow determined in Paper II (Jardstedt et al. 2017). For a detailed description of calculations, see Paper II.

3.4.6 Plasma Metabolites and Hormones

In Paper III, all cows were blood sampled just prior to experimental start (zero samples), in mid-pregnancy (week -13 ± 2.5 prepartum), once per week from week -8 to -3, and twice per week from week -2 to -1 prepartum. Postpartum, blood was sampled within 12 h of parturition (3 h ± 4.1), at 24 h (24 h ± 4.7) and 48 h (48 h ± 2.9) postpartum, and on day 6 and 10 postpartum. All plasma samples were analysed for concentrations of glucose, non-esterified fatty acids (NEFA), and blood urea N (BUN). Insulin was analysed in zero-time samples, in samples collected in week -4 to -1 prepartum, and in all samples collected postpartum. For a detailed description of sampling procedures and methods of analysis see Paper III.

3.4.7 Feed Costs

The total costs of diets based on either timothy-meadow fescue-, festulolium-, reed canarygrass-, or whole-crop oat silage, or barley straw supplemented with urea and rapeseed meal were calculated for a prepartum indoor period of four months (120 d) by multiplying total DMI with the production cost of silage and purchase price of the other feeds. The calculations of total DMI were based on intake data for the Hereford cows (Papers I and III). Urea was excluded from the festulolium and whole-crop oat diets, because it is not commonly used in practice on farms when these types of forages are fed. Mean daily DMI of the Charolais cows were 9% greater than for the Hereford cows when averaged over diets in Paper I. Consequently, diet costs for Charolais would be 9% greater compared to Hereford.

The production costs of the forages were estimated using partial budget calculations (Bidragskalkyler för konventionell produktion, 2018; Agriwise, 2019). The following assumptions were made. All forages were produced in the forest districts in Götaland (Gsk) in southern Sweden, where 44% of the Swedish suckler cows are located (Swedish Official Statistics, 2018). All grasses were harvested twice per season with a total yield of 8 tonnes DM/ha. Festulolium has been shown to be more productive than timothy and meadow fescue when managed similarly (Nadeau & Hallin, 2016). Therefore, the production costs of the festulolium was also calculated assuming a yield of 9 tonnes DM/ha. The whole-crop oat was grown as a nursing crop in grass ley establishment. Thus, the cost of production was distributed on both a harvest of whole-crop oat of 4 tonnes DM/ha and a harvest of grass silage of 1.5 tonnes DM/ha. The most common persistence time for grass leys in Sweden is three years, which was used for the timothy-meadow fescue and festulolium. For reed canarygrass, persistence time was set to 11 years, taking into account that the first harvest will not be taken until the third year after establishment (Landström & Wik, 1997), resulting in nine years of production. All silages were preserved as round bales with the addition of a chemical additive.

The production costs of the silages included the costs of establishment, *i.e.* seed, fertilization, weed control, liming, harvest machines, fuel, interest on working capital, and labour costs. The price for rapeseed meal and urea was set according to current market prices (Andersson, pers. Communication, 2019)[1]. The production of straw in Gsk is very limited. Therefore, the cost of straw was based on two levels of general market prices, including transportation costs, *i.e.* 1.0 and 1.5 SEK/kg (Holmström, pers. Communication, 2019)[2]. Cows fed the barley straw plus urea and rapeseed meal diet were underfed with MP during the prepartum period in Paper III. The total cost of this diet was, therefore, calculated using the amount of rapeseed meal needed to cover the MP requirements of the cows. It was assumed that the prepartum diet had no effect on cow DMI postpartum or cow reproductive performance postpartum, nor on calf weaning weight, based on the results in Paper III.

3.4.8 Statistical Analysis

Data were analysed by ANOVA using the mixed procedure in SAS (SAS ver. 9.3, SAS Institute, Cary, NC, USA, 2012) (Papers I-III). Least squares means (LSmeans) were compared pairwise using Tukey's test at significant F-values. Differences between treatments in the F-test were significant at $P < 0.05$ and a tendency for significance was assumed at $0.05 < P < 0.10$ (Papers I-III). In Paper II, Multiple regression analyses were conducted using Minitab statistical software (ver. 16, Minitab Inc., 2016).

[1] Frida Andersson, Lantmännen Lantbruk, 2019-02-19

[2] Kristina Holmström, Hushållningssällskapet Sjuhärad, 2019-02-18

3.4.9 Paper I

Data were analysed as means at group level by ANOVA. The statistical model used was:

$$y_{hijkl} = \mu + \pi_h + \theta_i + \tau_j + \gamma_k + (\theta\tau)_{ij} + s_{l(i)} + e_{hijkl}$$

where y_{hijkl} is the dependent variable, μ is the overall mean, π_h is the fixed effect of period (h = 1,2,3), θ_i is the fixed effect of breed (i = 1,2), τ_j is the fixed effect of diet (j = 1,2,3), γ_k is the fixed effect of carryover (k = 1,2,3), $s_{l(i)}$ is the random effect of group (l = 1,…,6), $(\theta\tau)_{ij}$ is the interaction between breed and diet, and e_{hijkl} is the residual error. Interactions between breed and period, and between breed and carryover were tested initially, but these effects were not significant ($P > 0.10$) for any of the variables analysed and were thus excluded from the model.

3.4.10 Paper II

Data were analysed by ANOVA in a randomised block design. The statistical model used was:

$$y_{ijk} = \mu + \alpha_i + b_j + s_{k(j)} + e_{ijk}$$

where y_{ijk} is the dependent variable, μ is the overall mean, α_i is the fixed effect of diet (i = 1, 2, 3, 4), b_j is the random effect of calving group (j = 1, 2, 3), $s_{k(j)}$ is the random effect of sub-group nested within calving group (k = 1, 2), and e_{ijk} is the residual error. To further explain the results from ANOVA, multiple regression analyses were conducted to study the relationships between total intake of N, intake of DOM, and urinary excretions of N, urea-N and PD. Random effect of calving group and fixed effect of diet were included in all models and retained even at $P > 0.05$. The models for each response variable were constructed by first testing all single explanatory variable models and then including the other intake variables one by one until all possible combinations had been tested. The regressions were evaluated by visual inspection of residual plots and, based on the R^2-adjusted value (R^2_{adj}), it was decided whether an additional variable improved the explanation of the observed variation.

3.4.11 Paper III

Data were subjected to ANOVA in a randomised block design with data from the pre- and postpartum periods analysed separately. Before statistical analysis, cow DMI pre- and postpartum, and blood samples collected prepartum, were reduced to weekly means for each cow. Feed intake on the day of calving (d 0) was excluded from the intake data. The number of days that each cow was fed the experimental diet before parturition was included as a covariate in all models, but to simplify the formulas below, the covariate is not included. Daily intakes of DM, NE and MP, NE and MP supply in relation to requirements, BW and BCS, and plasma metabolite and hormone concentrations in the zero and mid-pregnancy samples (w. -13) were analysed with the following statistical model:

$$y_{ij} = \mu + \alpha_i + b_j + e_{ij}$$

where y_{ij} is the dependent variable, μ is the overall mean, α_i is the fixed effect of diet (i = 1, 2, 3, 4), b_j is the random effect of calving group (j = 1, 2, 3) and e_{ij} is the residual error.

Changes in BW and BCS prepartum, and changes in blood metabolite and hormone concentrations pre- and postpartum were analysed with the statistical model:

$$y_{ijkl} = \mu + \alpha_i + b_j + \tau_k + c_{l(ij)} + (\alpha\tau)_{ik} + e_{ijkl}$$

where y_{ijkl} is the dependent variable, μ is the overall mean, α_i is the fixed effect of diet (i = 1, 2, 3, 4), b_j is the random effect of calving group (j = 1, 2, 3), τ_k is the fixed effect of time, where k = -16,…,-1 prepartum, and k = 1,…,10 postpartum, $c_{l(ij)}$ is cow nested within calving group and diet, $(\alpha\tau)_{ik}$ is the interaction between diet and time, and e_{ijkl} is the residual error. The covariance structure used for repeated factors was the AR(1) option in SAS for all parameters with evenly spaced data and the CS option for parameters with unevenly spaced data. Simple linear regression analyses were performed for mean plasma NEFA concentration versus BCS change prepartum.

For analysis of calf birth weight, mean growth and weaning weight the statistical model was:

$$y_{ijkl} = \mu + \alpha_i + b_j + \gamma_k + \theta_l + e_{ijkl}$$

where y_{ijkl} is the dependent variable, α_i is the fixed effect of diet (i = 1, 2, 3, 4), b_j is the random effect of calving group (j = 1, 2, 3), γ_k is the fixed effect of sex (k = 1, 2), θ_l is the fixed effect of sire (l = 1, 2, 3), and e_{ijkl} is the residual error.

4 Main Results

The following section describes the main findings of the experiments in this thesis. A more detailed description can be found in Papers I-III. Some synthesis of results from experiment I-III are also included.

4.1 Nutritional Characteristics of Experimental Diets

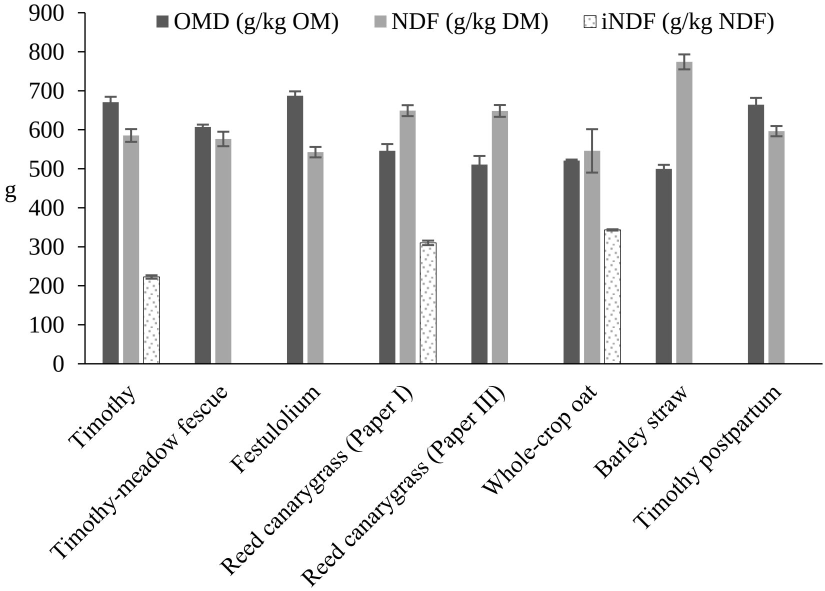

Figure 2. Concentrations of calculated organic matter digestibility *in vivo* (OMD; g/kg OM) (Åkerlind et al. 2011), neutral detergent fibre (NDF; g/kg DM), and indigestible NDF (iNDF; g/kg NDF) determined *in situ* (Åkerlind et al. 2011) of high-fibre roughages fed to pregnant suckler cows (Papers I-III). Values are displayed as means with standard deviations indicated by error bars.

4.2 Intake – Effect of Diet

In Paper I, intake differed among diets when averaged across breeds, where the timothy diet resulted in the greatest daily intake of DM, followed by the whole-crop oat and reed canarygrass diets (Figure 3). In Paper III, DMI of the timothy-meadow fescue and festulolium diets, 12.9 and 13.9 kg/d, respectively, were greater ($P < 0.001$) than the DMI of the reed canarygrass and barley straw diets, 9.2 and 8.2 kg/d, respectively. In Paper I, timothy resulted in the greatest intake of NDF per day and in percentage of BW, followed by reed canarygrass and whole-crop oat (Table 1). Intake of NDF from roughage in percentage of BW was 0.94% (± 0.19) when averaged across breeds and all diets fed prepartum in Papers I and III. In Paper III, intake of NDF in percentage of BW was 1.4% (± 0.19) at three weeks postpartum.

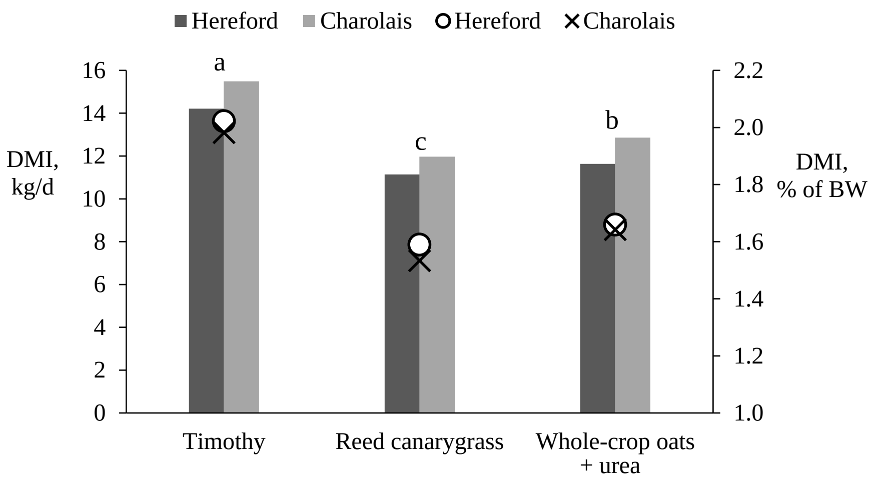

Figure 3. Daily dry matter intake (DMI), displayed by bars, differed between diets when averaged across two breeds of pregnant suckler cows ($P < 0.001$; n = 12). Diets without common letters differ significantly ($P < 0.05$). When DMI was expressed in percentage of body weight (BW), displayed by an open circle for the Hereford breed (O) and a cross (×) for the Charolais breed, there was no difference between breeds ($P = 0.37$; n = 6).

4.3 Digestibility – Effect of Diet (Paper I)

The apparent digestibility of OM and NDF was greatest for timothy and lowest for reed canarygrass and whole-crop oat, which did not differ (Table 1). Cows fed reed canarygrass ruminated longer time per kg DM than cows fed timothy or whole-crop oat (Table 1). Feeding the reed canarygrass and whole-crop oat diets resulted in 13 and 15% longer rumination time per kg NDF intake, respectively, than feeding timothy.

Faecal characteristics, *e.g*. PDM and the particle size distribution of PDM, varied among diets when averaged across breeds. The proportion of PDM in faecal DM were greater when feeding the whole-crop oat and reed canarygrass diets, 753 and 777 g/kg DM, respectively, compared to feeding timothy, 705 g/kg DM ($P < 0.001$). Feeding the of whole-crop oat diet resulted in the largest faecal particle size, *i.e*. highest median, APS, and GPS, and greatest proportion of large particles (≥ 1.00 mm) and smallest proportion of small particles (< 0.50 mm) compared to the other diets (Table 1). The smallest faecal particle size was observed for the reed canarygrass diet, as indicated by the lowest median and GPS values, the smallest proportion of large particles, and the largest proportion of small particles compared to the other diets.

Table 1. *Intake, apparent digestibility coefficients, rumination time, faecal particle size and proportion of large (≥ 1.00 mm) and small (≤ 0.50 mm) faecal particles in pregnant suckler cows fed three forage-based diets ad libitum*

Item[1]	Timothy	Reed canarygrass	Whole-crop oat	SEM	*P*-value
Intake					
NDF, kg/d	8.73^{a}	7.52^{b}	6.77^{c}	0.107	<0.001
NDF, % of BW	1.18^{a}	1.02^{b}	0.92^{c}	0.013	<0.001
Digestibility					
OM	0.65^{a}	0.47^{b}	0.48^{b}	0.019	<0.001
NDF	0.63^{a}	0.49^{b}	0.42^{b}	0.030	<0.001
Rumination					
Min/kg DM intake	40.3^{b}	50.7^{a}	43.4^{b}	1.48	<0.001
Min/kg NDF intake	68.6^{b}	77.5^{a}	79.1^{a}	2.21	<0.001
Faecal particle size (mm)					
Median	0.35^{b}	0.33^{c}	0.39^{a}	0.005	<0.001
Arithmetic mean	0.44^{b}	0.41^{b}	0.50^{a}	0.008	<0.001
Geometric mean	0.24^{b}	0.21^{c}	0.28^{a}	0.005	<0.001
Sieving fractions (mm)					
≥ 1.00	4.00^{b}	2.66^{c}	7.23^{a}	0.371	<0.001
< 0.50	79.7^{b}	84.6^{a}	69.8^{c}	0.86	<0.001

[1] NDF = neutral detergent fibre, BW = body weight, OM = organic matter, DM = dry matter.

4.4 Intake and Digestibility – Effect of Breed

Cows of the Charolais breed were heavier (780 kg) than cows of the Hereford breed (700 kg) ($P < 0.001$). The interaction between breed and diet was significant for DMI (kg/d, $P = 0.048$), where Hereford had lower DMI of timothy and whole-crop oat than Charolais, whereas DMI of reed canarygrass were similar between the breeds. However, the significance of the interaction was negligible in comparison to the main effects and is, therefore, not discussed further. When averaged across diets, daily DMI was 9% greater for Charolais than for Hereford ($P < 0.001$). However, there was no effect of breed when DMI was expressed in percentage of BW (Figure 3). Charolais cows tended ($P = 0.07$) to ruminate longer time per day than Hereford cows (596 vs. 545 min). In addition, when rumination time per kg NDF intake was corrected for BW (min/kg NDF intake per 100 kg BW), Charolais cows ruminated longer per kg NDF intake than Hereford cows ($P = 0.024$). There was no effect of breed on apparent OM or NDF digestibility when averaged across diets ($P > 0.27$). Charolais cows had smaller faecal particle size than Hereford cows when averaged across diets, as indicated by smaller APS and GPS values, and a larger proportion of small particles (< 0.50 mm) ($P < 0.05$).

4.5 N Utilization and Microbial CP Production

Means and standard deviations of daily intakes of DOM and N, and daily urinary excretions of N, urea-N and PD for all experimental diets in Papers I and II are displayed in figures 4a and 4b. Intake of DOM was lower ($P < 0.001$) for cows fed the reed canarygrass and whole-crop oat diets compared to cows fed the timothy diet in Paper I (Figure 4a). In Paper II, cows fed the barley straw and reed canarygrass diets had lower intake of DOM than cows fed the timothy-meadow fescue and festulolium diets ($P < 0.001$) (Figure 4a). Nitrogen intake was similar for cows fed timothy and reed canarygrass in Paper I and for cows fed timothy-meadow fescue, festulolium, and reed canarygrass in Paper II (Figure 4a). The lowest intake of N ($P < 0.001$) was recorded for cows fed whole-crop oat in Paper I and barley straw in Paper II. Within study, the reed canarygrass diet resulted in greater urinary excretions of N and urea-N ($P < 0.001$) compared to all other diets, which did not differ (Papers I and II; Figure 4b).

Urinary output of total N and urea-N were positively related to N intake, with R^2_{adj} of 0.66 and 0.79, respectively (Paper II). Combining total N intake with DOM intake in the regression model improved the explanation of observed variation in urinary N excretion (N excretion = 28.9 + 0.39 x N intake – 4.83 x DOM intake; $R^2_{adj} = 0.67$) and urea-N excretion (urea-N excretion = 10.3 + 0.25

x N intake – 3.40 x DOM intake; $R^2_{adj} = 0.80$), where an increase in DOM intake decreased N and urea-N output.

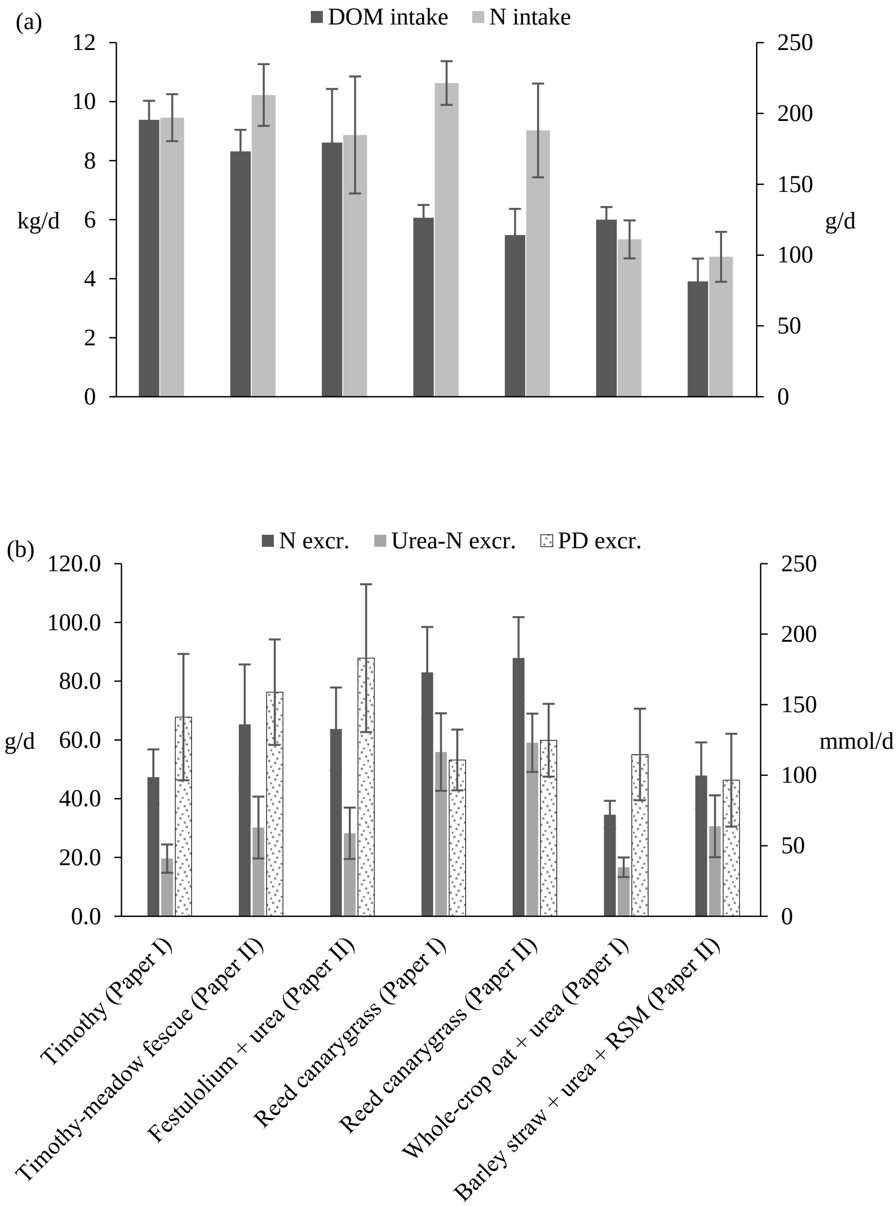

Figure 4. (a) Daily intake of digestible organic matter (DOM; kg/d) and nitrogen (N; g/d), and (b) urinary excretion (excr.) of N and urea-N (g/d) and purine derivatives (PD; mmol/d) in pregnant suckler cows fed different roughage-based diets *ad libitum* (Papers I and II). Values are displayed as means with standard deviations indicated by error bars, RSM = rapeseed meal.

Urinary excretion of PD is an indicator of rumen microbial protein synthesis (Chen & Gomes, 1992). In Paper I, the timothy diet resulted in the greatest excretion of PD (mmol/d), followed by the whole crop oat and reed canarygrass diets (*P* < 0.001; Figure 4b). In Paper II, the timothy-meadow fescue and festulolium diets resulted in greater urinary output of PD than the barley straw diet, which resulted in the lowest excretion (*P* < 0.001). Urinary PD output was more closely associated with intake of DOM (PD excretion = -24 + 26.8 x DOM intake; R^2_{adj} = 0.67) than with intake of N (R^2_{adj} = 0.63), where intake of DOM had a positive effect on PD excretion (Paper II). Addition of N intake to DOM intake did not increase the R^2_{adj} value for observed variation in PD output.

4.6 Intake of NE and MP in Relation to Requirements

In Paper I, there was no effect of breed on NE or MP intakes in relation to requirements when averaged across diets (*P* > 0.38). When averaged across breed, cows fed the timothy diet had greater NE intake in relation to requirements than cows fed the reed canarygrass and whole-crop oat diets, which did not differ (Figure 5). Cows fed the timothy diet in Paper I also had greater intake of MP in relation to requirements, followed by the reed canarygrass and whole-crop oat diets (Figure 5).

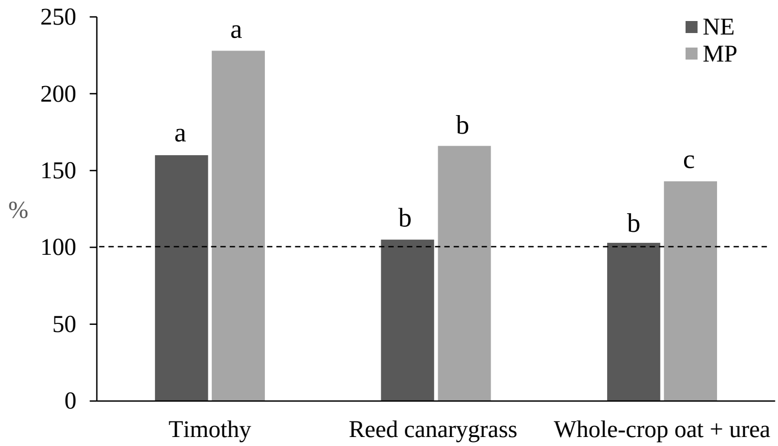

Figure 5. There was an effect of diet (*P* < 0.001; n = 12) on daily intake of net energy (NE) and metabolizable protein (MP) in relation to requirements (%) in pregnant suckler cows fed three forage-based diets *ad libitum* (Paper I). Diets without common letters within NE and MP differ.

In Paper III, intakes of NE and MP in relation to requirements differed significantly between all diets prepartum ($P < 0.001$). Cows fed the timothy-meadow fescue and festulolium diets were fed NE above requirements, 118 and 139%, respectively, whereas cows fed the reed canarygrass and barley straw diets were fed NE below requirements, 79 and 61%, respectively, when averaged over the prepartum period (Figure 6a). The timothy-meadow fescue, festulolium, reed canarygrass and barley straw diets resulted in MP intakes of 166, 188, 106 and 66%, respectively, of requirements when averaged over the prepartum period (Figure 6b). There was no effect of prepartum experimental diet on postpartum intakes of NE or MP.

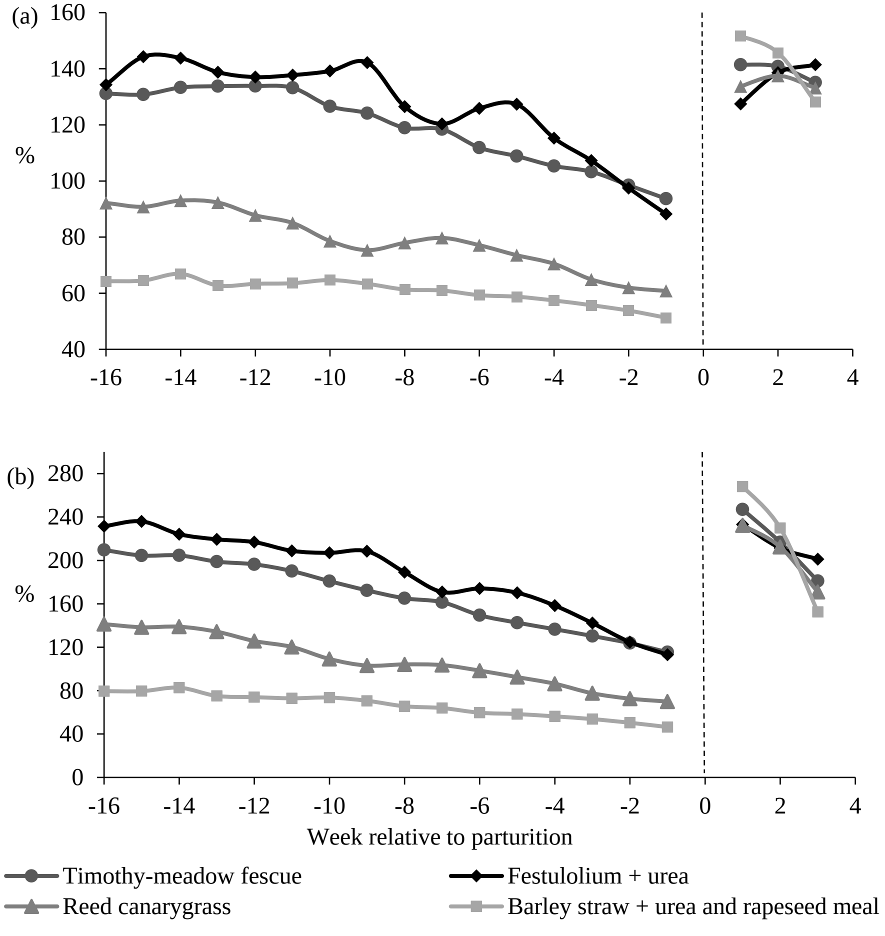

Figure 6. (a) Intake of net energy (NE) and (b) intake of metabolizable protein (MP) in percentage of requirements during the final 16 weeks prepartum and three weeks postpartum in suckler cows offered four roughage-based diets *ad libitum* prepartum (Paper III). The dashed line indicates time of calving.

4.7 BW and BCS (Paper III)

The first BW recording postpartum revealed that cows fed the timothy-meadow fescue and festulolium diets prepartum had increased their BW by 3.3 and 6.6%, respectively, whereas cows fed the reed canarygrass and barley straw diets had lost 3.2 and 3.8%, respectively, of their initial BW during the same period ($P < 0.001$; Figure 7a). However, there was no effect of prepartum diet on cow BW at weaning ($P = 0.30$) or at the end of the grazing period ($P = 0.54$).

Likewise, cows fed the timothy-meadow fescue and festulolium diets gained body condition prepartum, whereas cows fed the reed canarygrass and barley straw diets lost body condition ($P < 0.001$; Figure 7b). From day 21 postpartum to the end of the grazing period, cows fed the timothy-meadow fescue and festulolium diets lost BCS, -0.36 and -0.53 units, respectively, whereas cows fed the reed canarygrass and barley straw diets increased BCS by 0.46 and 0.60 units, respectively ($P < 0.05$). There was no difference in BCS between diets at weaning ($P = 0.10$) or at the end of the grazing period ($P = 0.13$).

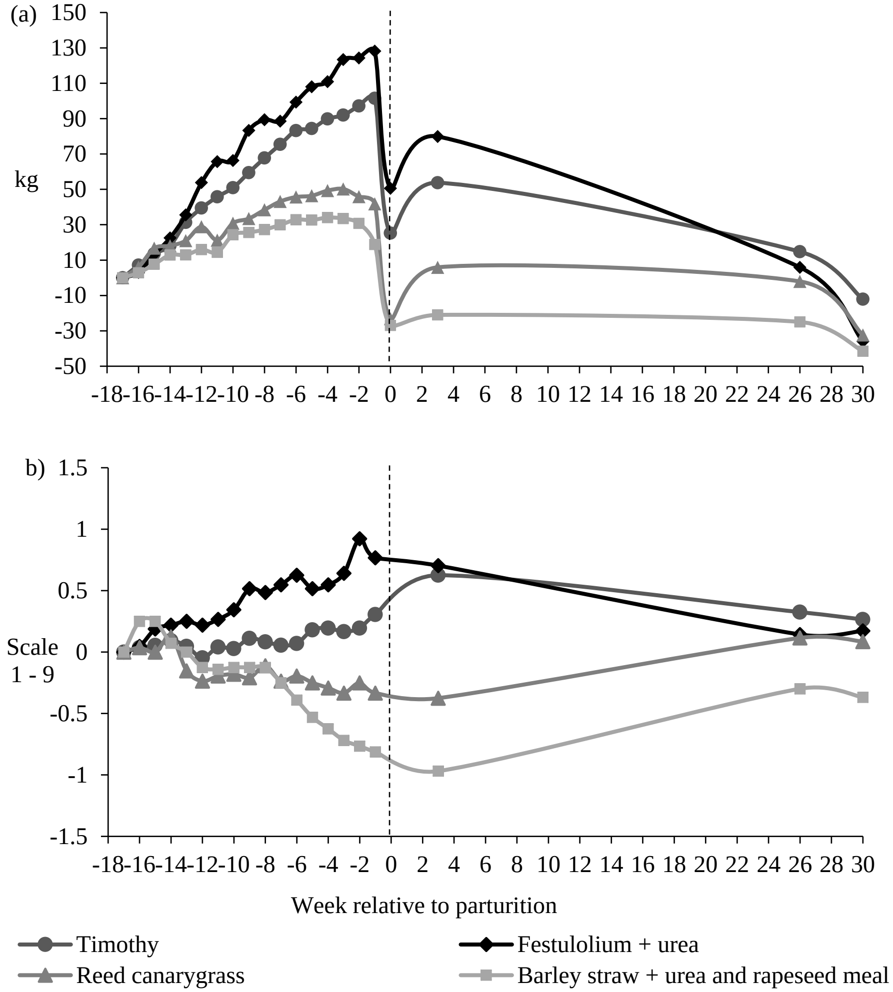

Figure 7. (a) Changes in BW (kg) and (b) changes in BCS (scale 1 to 9) prepartum and postpartum in suckler cows offered four roughage-based diets *ad libitum* during the final 16 weeks prepartum. The dashed line indicates time of calving, week 26 = weaning, and week 30 = end of the grazing season. Data are displayed as LSmeans. For the timothy-meadow fescue, festulolium + urea, reed canarygrass and barley straw + urea and rapeseed meal diets, *n* = 9, 8, 9, and 8, respectively, prepartum, *n* = 8 for all diets in week 3 postpartum, and n = 6, 5, 8, and 5, respectively, in week 26 and 30 postpartum.

4.8 Diet Effect on Calf Performance (Paper III)

There was no effect of prepartum experimental diet on calf birth weight, adjusted 200-d weaning weight, or calf daily growth rate until weaning.

4.9 Plasma Metabolite and Hormones (Paper III)

When averaged over late gestation (week -8 to -1), cows fed the timothy-meadow fescue and festulolium diets had greater plasma concentrations of glucose than cows fed the barley straw diet and greater concentrations of insulin than cows fed the reed canarygrass and barley straw diets ($P < 0.001$, Figure 8a and b).

Plasma concentrations of NEFA, when averaged over late gestation, were greater in cows fed the barley straw diet than in cows fed all other diets, which had similar levels ($P < 0.001$, Figure 9a). Simple linear regression analysis revealed a moderate negative relationship between NEFA concentration and BCS change prepartum ($y = -0.194x + 0.434$, $r = 0.53$, RMSE = 0.27, $P < 0.001$, $n = 34$). There was no effect of prepartum diet on plasma levels of NEFA postpartum ($P = 0.25$).

The BUN concentration in the zero samples differed between diets and was greater for cows fed the reed canarygrass diet than for the other cows, which had comparable levels. This could be attributed to the three cows fed reed canarygrass in the intermediate calving group, which had BUN concentrations of 7.81 to 8.29 mmol/L in their zero samples. If these three cows were not included in the analysis of the zero samples the mean BUN concentration was 3.12 mmol/L and there was no longer an effect of diet. Cows fed the reed canarygrass diet had the highest plasma concentration of BUN in late gestation, followed by cows fed the barley straw diet, with cows fed the timothy-meadow fescue and festulolium diets having similar lower levels ($P < 0.001$, Figure 9b).

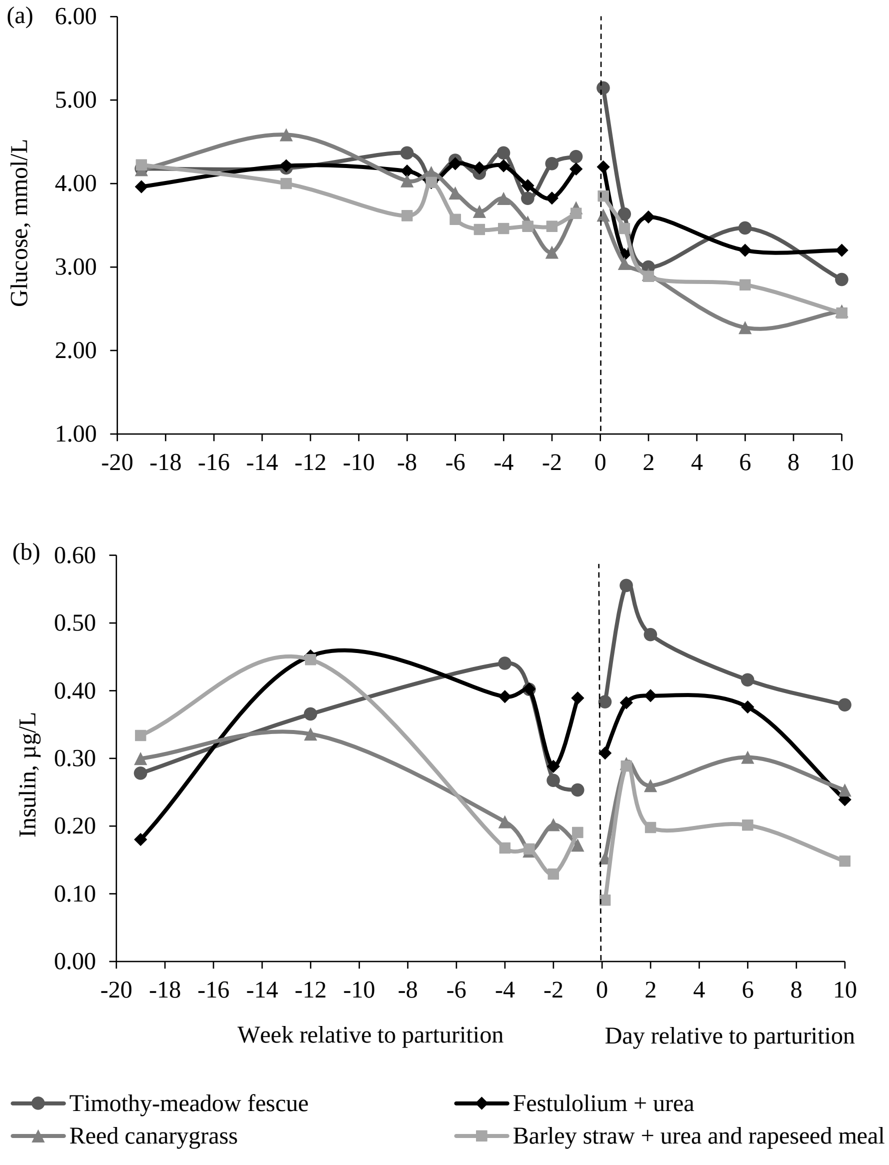

Figure 8. (a) Plasma concentration of glucose and (b) plasma concentration of insulin, in suckler cows fed four roughage-based diets *ad libitum* prepartum (Paper III). All roughages were fed *ad libitum* prepartum and all cows received the same timothy silage *ad libitum* postpartum. Data are displayed as LSmeans. Prepartum week -19 indicates the zero value. The dashed line indicates time of calving (week 0). Blood was sampled within 3 h (± 4.1) of parturition, at 24 h (± 4.7) and 48 h (± 2.9), and on day 6 and 10 postpartum.

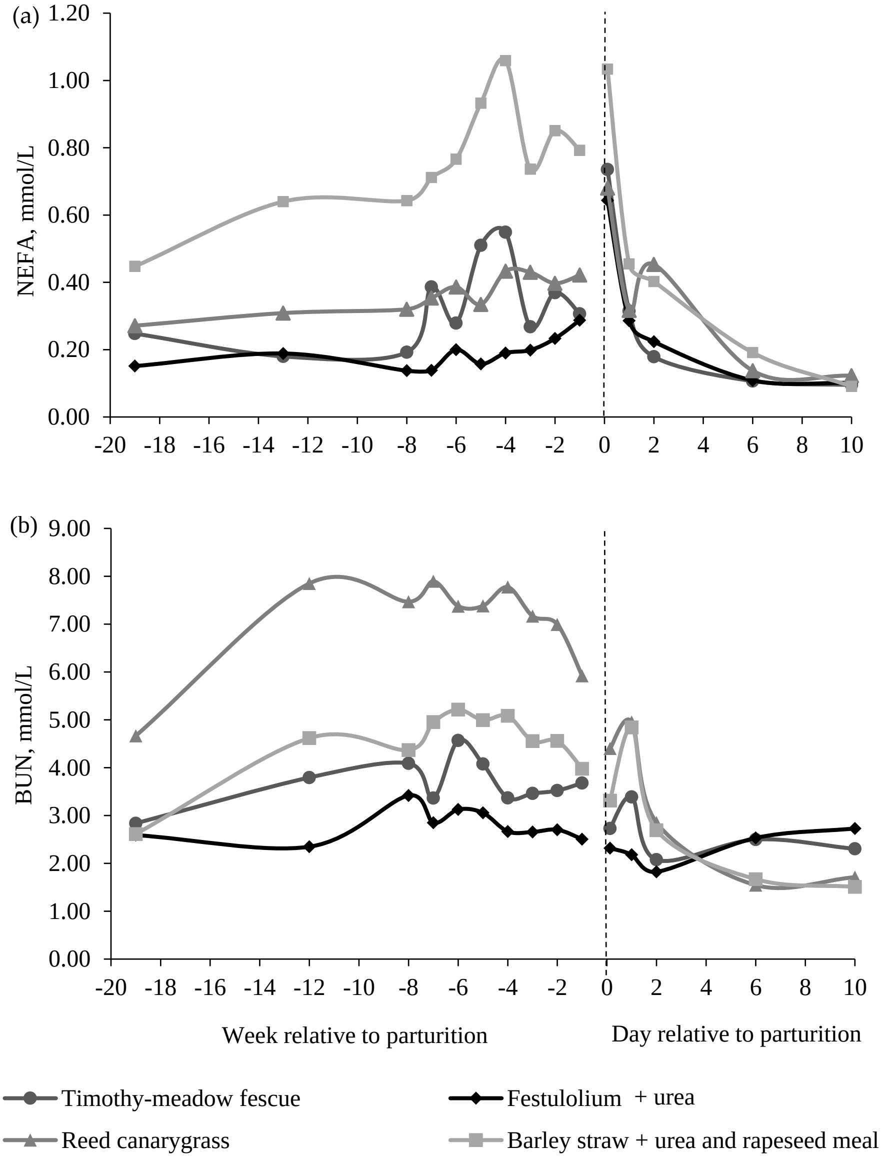

Figure 9. (a) Plasma concentration of non-esterified fatty acids (NEFA) and (b) plasma concentration of blood urea nitrogen (BUN) in suckler cows fed four roughage-based diets *ad libitum* prepartum (Paper III). Data are displayed as LSmeans. All roughages were fed *ad libitum* prepartum and all cows received the same timothy silage *ad libitum* postpartum. Prepartum week -19 indicates the zero value. The dashed line indicates time of calving (week 0). Blood was sampled within 3 h (± 4.1) of parturition, at 24 h (± 4.7) and 48 h (± 2.9), and on day 6 and 10 postpartum. The interaction of diet × time was significant ($P < 0.001$) for the BUN concentration postpartum.

4.10 Diet Costs

Total intake per cow of the timothy-meadow fescue-, festulolium-, reed canarygrass- and whole-crop oat silages, and the barley straw, rapeseed meal and urea during four months prepartum are displayed in Table 2 and, in addition, the cost of each dietary ingredient. The reed canarygrass diet resulted in the lowest total dietary cost prepartum (Figure 10) whereas the barley straw plus urea and rapeseed meal diet resulted in the highest dietary cost when using the higher market price of straw. In general, forage diets resulted in lower costs than whole-crop oat silage and straw diets.

Table 2. *Total intake per cow of different roughages, rapeseed meal and urea during 120 days prepartum, dry matter (DM) yield, costs of production for different silages, and market prices of barley straw, rapeseed meal and urea. Pregnant suckler cows of the Hereford breed were fed diets based on one of the silages, or barley straw plus urea and rapeseed meal prepartum*

Feed item[1]	Total intake (120 days)	Yield (tonnes DM/ha)	Costs of production (SEK)
Timothy-meadow fescue silage	1 548	8	1.07
Festulolium silage	1 668	8	1.07
Festulolium silage	1 668	9	0.95
Reed canarygrass silage	1 100	8	1.05
Whole-crop oat silage[2]	1 396	4 + 1.5	1.54
Barley straw (81% DM), ordinary price	1 207	-	1.00
Barley straw (81% DM), high price	1207	-	1.50
Rapeseed meal	258	-	3.23
Urea	11	-	6.43

[1]Intakes and costs of production for the silages are expressed in kg DM and per kg DM, respectively, and in kg and per kg for the barley straw, rapeseed meal and urea, respectively. The price of straw are based on two levels of regular market prices (Holmström, pers. communication, 2019)[1].

[2]Assuming a harvest of whole-crop oat of 4 tonnes DM/ha plus a harvest of undersown grass of 1.5 tonnes DM/ha.

[1] Kristina Holmström, Hushållningssällskapet Sjuhärad, 2019-02-18

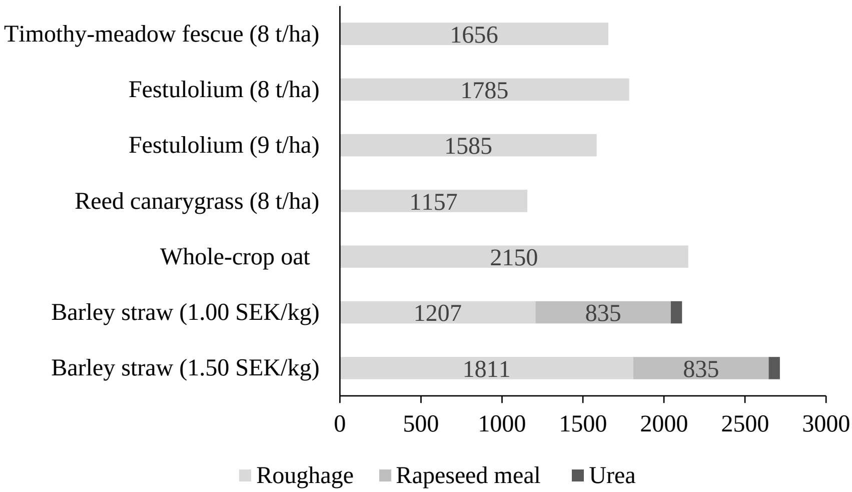

Figure 10. The figure displays the total costs of feeding diets based on timothy-meadow fescue silage, festulolium silage, reed canarygrass silage, whole-crop oat silage or barley straw plus urea and rapeseed meal *ad libitum* to pregnant suckler cows of the Hereford breed during 120 days prepartum.

5 Discussion

5.1 Intake and Feed Utilization – Effect of Diet

Forage quality is highly dependent on crop maturity at harvest (Buxton, 1996), but may also vary among crop species cut at the same stage of maturity (Cherney & Cherney, 1997; Østrem et al. 2014). Although timothy and reed canarygrass in Paper I were cut at similar developmental stage, *i.e*. flowering, reed canarygrass exhibited numerically greater NDF and iNDF concentrations and lower apparent digestibility of OM and NDF, in line with previous findings (Collins & Casler, 1990; Cherney & Cherney, 1997). Similarly, reed canarygrass had numerically greater NDF concentration and lower OMD *in vitro* compared to timothy-meadow fescue and festulolium in Paper III, despite being cut at similar stage of maturity.

The differences in NDF characteristics and OM digestibility among experimental forages were reflected in cow intake. The results in Paper I clearly demonstrated a reduction in DMI when common timothy silage was replaced by reed canarygrass and whole-crop oat silage. Fibre digestibility has a greater influence on rumen fill than fibre concentration (Oba and Allen, 1999). Hence, the reason for the lower intake of the reed canarygrass and whole-crop oat diets compared to the timothy diet was probably their greater proportion of iNDF in NDF, resulting in lower apparent digestibility of OM and NDF (Huhtanen et al. 2007; Mertens, 2007). Despite a similar apparent digestibility of OM and NDF of the reed canarygrass and whole-crop oat diets, cows fed the former had a lower DMI intake, which could be related to the greater concentration of NDF in the reed canarygrass diet, resulting in greater rumen fill (Oba and Allen, 1996). In Paper III, the DMI was lower for the two less digestible diets, *i.e*. the reed canarygrass and barley straw diets, compared to the two more digestible diets, *i.e*. the timothy-meadow fescue and festulolium diets, which is consistent with the well-documented positive relationship between forage digestibility and intake (Huhtanen et al. 2002). Intake of NDF from roughage was nearly 1% of BW when averaged across all diets fed prepartum in Papers I and III. This number could be used as a rough "rule of thumb" on farm level to predict feed consumption during the indoor period, provided cow BW is known and that a proper feed analysis has been conducted.

In Paper I, the observed differences in rumination time and faecal particle size between diets could also be related to the dietary variations in NDF characteristics and OM digestibility. The reed canarygrass diet resulted in longer rumination time per kg DMI than the timothy and whole-crop oat diet, which could be attributed to the greater concentration of NDF in the former (Nørgaard et al. 2010; Schulze et al. 2014). Rumination time per kg NDF intake was approximately 14% longer for the reed canarygrass and whole-crop oat diets than for the timothy diet, which probably was associated with the greater iNDF concentration per kg NDF of those diets (Schulze et al. 2015). When cows were fed the whole-crop oat diet, daily rumination time was within the daily limits of 8-9 h that cattle normally spend ruminating (Welch, 1982). Feeding the timothy and reed canarygrass diets resulted in rumination times that approached the proposed maximum of 10 h/d for cattle (Welch, 1982), implying that DMI of these diets might have been restricted by the extensive time needed for mastication.

Cows fed the reed canarygrass and whole-crop oat diets in Paper I had greater PDM value of faeces compared to cows fed the timothy diet, which reflected the lower apparent digestibility of NDF of the two former, in agreement with the results by Nadeau et al. (2016).

Lignin is the key element in the plant cell wall that limits forage digestibility through cross-linkage with cell wall polysaccharides by ferulic acid bridges. The cross-linking effect on fibre structure might be more important than lignin concentration *per se*, in order for lignin to exert its effect on fibre digestibility (Jung & Allen, 1995). The diets in Paper I resulted in significantly different faecal particle size profiles, which did not follow the general assumption: that increased ratio of ADL to NDF in forage would result in larger faecal particle size (Jalali et al. 2012, 2015). All diets in Paper I had similar ADL to NDF ratios (see Paper I). Hence, the observed variation in faecal particle size might instead have been an effect of differences in fibre structure, *e.g.* lignin cross-linking (Jung & Allen, 1995), which made the forages vary in resistance to degradation by mastication and microbial fermentation. The fibre structures of the experimental forages were not examined in Paper I, but the assumption was partly supported by numerical differences in the iNDF to ADL ratio (see Paper I), which indicates the inhibitory effect of lignin on NDF digestion per unit of lignin (Thorstensson et al. 1992). This ratio was higher (4.8) in the whole-crop oat diet compared to the reed canarygrass (3.7) and timothy diets (3.0), which may explain the larger faecal particle size of the former. However, the faecal particles of cows fed reed canarygrass were more reduced in size than those of cows fed timothy, despite a numerically greater iNDF to ADL ratio, and a lower apparent digestibility of OM and NDF of the former. The explanation for this could be the longer rumination time per kg NDF intake of the reed canarygrass diet. In addition, the reed canarygrass fibre might have been more brittle, as increased maturity of grass silage, *i.e.* increased lignification, have been proposed to increase the fragility of grass feed particles (Rinne et al. 2002).

5.2 Intake and Feed Utilization – Effect of Breed

Daily DMI appeared to be related to the different BW of the two breeds, as the breed difference in daily consumption was no longer present when intake was expressed in relation to BW. This suggests that intake was similarly constrained in both breeds. Likewise, Murphy et al. (2008) reported that observed differences in daily DMI between lactating Charolais and Limousin cows was an effect of differences in BW rather than an effect of breed. Furthermore, Taylor et al. (1986) found that BW explained 80% of the variation in voluntary intake when compared across 25 breeds of growing cattle.

Bae et al. (1983) reported that mean eating and rumination times decreased curvilinearly with increased metabolic body weight of cattle of different breeds, *i.e.* larger animals were more efficient chewers, spending less time chewing per kilogram of ingested cell wall constituents. However, in Paper I the opposite result was found, as Charolais cows ruminated longer time per kg NDF intake when corrected for BW. Foraging behaviour in cattle has been shown to differ between breeds (Hessle et al. 2008) and strains within breeds (McCarthy et al. 2006) due to origin. Hence, the differences in rumination time between Charolais and Hereford might be a consequence of the two populations having evolved in different environments. Hereford originally evolved in a harsher environment than Charolais. In addition, Swedish breeding goals still dictate that the Hereford breed should be bred for a more nutritionally extensive production than the Charolais breed (NAB, 2018). Therefore, it is plausible that certain foraging traits, *e.g.* rumination, have been developed differently for the two breeds in order for them to successfully adapt to prevailing circumstances.

Apparent diet digestibility was similar for the Hereford and Charolais breeds, which may be expected, as no differences in intakes of DM or NDF per kg BW were observed. Mean faecal particle size has been demonstrated to increase at increasing BW in ruminants (Jalali et al. 2015). Hence, the smaller faecal particle size of the Charolais cows was a bit unexpected and suggested that apparent OM digestibility should have been greater in Charolais compared with Hereford, but no such effect was observed. Instead, the smaller faecal particle size was probably a consequence of the longer rumination time observed for Charolais. The study in Paper I showed that pregnant cows of the Hereford and Charolais breeds utilized the experimental forages similarly. Hence, this study did not provide any indications of that the current feeding recommendations should be corrected for type of breed.

5.3 Nitrogen Utilization

In Paper II, increased N intake led to increased urinary N and urea-N output, which is in agreement with other studies on suckler cows fed grass silage (Zou et al. 2016) and low quality forage with protein supplement (Bernier et al. 2014). In addition, N intake explained a larger proportion of the variation in urinary output of urea-N than in the output of urinary N, which implies that the former was more sensitive to N intake than the latter (Bernier et al. 2014).

Urinary excretions of N and urea-N were greatest for cows fed the reed canarygrass diet in both Papers I and II. In Paper I, cows fed reed canarygrass had 11% greater N intake than cows fed the timothy diet, but their urinary excretions of N and urea-N were considerably greater, 71% and 178%, respectively. In Paper II, intake of N on the timothy-meadow fescue, festulolium and reed canarygrass diets were similar, 205, 188 and 207 g/d, respectively, but cows fed the reed canarygrass diet excreted 38 to 46% more N and 95 to 124% more urea-N than cows fed the timothy-meadow fescue and festulolium diets. These results suggested that N intake alone could not be responsible for the greater N and urea-N excretion in cows fed reed canarygrass.

Plasma BUN concentration has been shown to be strongly and positively, correlated with ruminal ammonia concentration (Hammond, 1983). In Paper III, cows fed the reed canarygrass diet had 108 and 148% greater concentrations of BUN prepartum than cows fed the timothy-meadow fescue and festulolium diets, respectively. Altogether, these results imply that cows fed the reed canarygrass diet experienced greater losses of N in the rumen fermentation, which most likely was a consequence of inefficient microbial protein synthesis from RDP due to the lower intake of DOM (Nocek and Russel, 1988). Adding intake of DOM to the regression model with N intake in Paper II increased the proportion of explained variation in N and urea-N excretion, which further suggests that DOM intake needs to be considered in order to reduce undesired excretions of N in urine. This result is in agreement with previous findings in lactating and dry dairy cows (Kebreab et al. 2010; Stergiadis et al. 2015), where intake of metabolizable energy was negatively related to urinary N excretion.

In Paper II, the timothy-meadow fescue and festulolium diets provided more than twice the amount of the recommended daily MP supply, whereas the barley straw diet supplied only 80% (results not shown). Intake of MP in excess of the animal's requirements results in increased formation of urea, which is excreted primarily in urine (Raggio et al. 2004). Hence, a greater urinary excretion of urea-N was expected in cows fed the timothy–meadow fescue and festulolium diets than in cows fed the barley straw diet. However, the urinary urea-N output was similar among these diets (see Paper II). The reason for this result is not clear, but one explanation could be that the MP supplied in excess of requirements on the timothy–meadow fescue and festulolium diets were used for anabolic purposes, rather than being lost through urine.

The timothy diet in Paper I and the timothy-meadow fescue and festulolium diets in Paper II appeared to be better stimulants of rumen microbial CP production, as indicated by the greater urinary excretion of PD for cows fed those diets. This was most likely related to the greater intake and the greater OMD of these diets, which agrees with previous reports of increased urinary excretion of allantoin with greater feeding level and increased intake of digestible OM (Südekum et al. 2006). In addition, intake of DOM was positively related to urinary PD output in Paper II, explaining more than 60% of the variation in PD excretion.

5.4 Dietary Effects on Energy Status and Performance

The timothy diet in Paper I, although cut at late stage of maturity, provided NE and MP in great excess of requirements of mid-pregnant suckler cows, in contrast to the reed canarygrass and whole-crop oat diets, which resulted in a lower degree of overfeeding. According to Martinsson (1991), the NE supply to pregnant suckler cows in good BCS can be reduced to 80% of the requirement during late gestation if the MP requirement is fulfilled. This is also the recommendation currently in use in the Swedish feeding recommendations for ruminants (Spörndly, 2003). Assuming that the cows in Paper I maintained the same mean daily DMI until parturition, as that observed in mid-pregnancy, all experimental diets would provide both Hereford and Charolais cows with NE above 90% and MP above 120% of requirements prepartum (results not shown). However, the lower degree of overfeeding with the reed canarygrass and whole-crop oat diets suggests that they would be preferable to the timothy diet if cows should be given free access to forage prepartum.

The diets in Paper III resulted in four levels of NE and MP supply prepartum, which were reflected in changes in BW, BCS and metabolic status. The timothy-meadow fescue and festulolium diets provided cows with NE and MP above requirements (Volden & Nielsen, 2011), resulting in increased BW and BCS prepartum. In mid-pregnancy, plasma glucose and insulin concentrations were similar among diets in Paper III. However, glucose levels during late gestation were lowest (numerically) in cows fed the barley straw and reed canarygrass diets and, hence, insulin levels were also lowest in these cows. This could be attributed to the lower DM and NE intake observed for cows fed these diets (Douglas et al., 2006) and, hence, lower absorption of glucogenic precursors. With the more digestible timothy-meadow fescue and festulolium diets, cows were able to maintain the plasma glucose levels stable even in late pregnancy, where glucose demand by the growing foetus is greatly increased (Bell & Bauman, 1997).

As expected, the low NE supply by the barley straw diet required that cows mobilized fat reserves to meet the increased demand for energy in late gestation, which was reflected in high plasma concentrations of NEFA in late pregnancy and sustained loss of BCS throughout the prepartum period (Herdt, 2000). Although the group fed reed canarygrass were apparently underfed with energy prepartum, as evidenced by the decrease in BCS, there was no difference in plasma NEFA concentrations between this group and the groups fed the timothy-meadow fescue and festulolium diets.

The prepartum losses of BW and BCS in cows fed the barley straw diet could probably have been limited to some extent if the amount of rapeseed meal had been increased to supply 100% of MP requirements during the prepartum period, instead of the current 66%. Stalker et al. (2006) observed that suckler cows grazing poor quality pasture (5.4% CP, 50% total digestible nutrients) during late gestation managed to maintain BW and BCS when supplemented with 0.2 kg CP per day for three days per week, whereas non-supplemented cows lost BW and BCS.

During the grazing period, cows fed the RC and BR diets prepartum recovered some BCS, whereas cows fed the high-energy diets lost BCS. It was clear that these patterns of BCS change were not a response to environmental constraints, as cows were managed under the same nutritional conditions postpartum (Garnsworthy and Topps, 1987). It appeared that the overfat and thin cows were 'attempting' to return to a target level of body fatness (Friggens, 2003). Similarly, Manninen et al. (2008) found that suckler cows, which lost BCS when fed at maintenance for 148 days prepartum, gained more BCS on subsequent pasture than their *ad libitum*-fed counterparts.

The loss of BCS prepartum experienced by cows fed the barley straw diet could have affected their reproductive performance during the subsequent breeding period, as BCS at calving has been shown to influence pregnancy rate (Lake et al. 2005). These authors reported a lower overall pregnancy rate (64%)

in thinner suckler cows fed to attain a BCS of 4 (scale 1 to 9) at parturition than in fatter cows fed to attain a BCS of 6 (89%). In contrast, Stalker et al. (2006), using the same BCS scale, observed that suckler cows losing BCS during pregnancy to calve at BCS 4.7 displayed similar reproduction results as cows calving at BCS > 5. A BCS of 5 has been suggested as the optimal BCS at parturition to ensure adequate reproductive performance during the next breeding season (Short et al. 1990; Morrison et al. 1999) and a high nutritional plane postpartum has been shown to improve reproductive performance in thin cows (Richards et al. 1986; Houghton et al. 1990). In Paper III, the mean BCS of cows fed the barley straw diet was 4.9 at parturition. Furthermore, cows were provided with high quality forage postpartum that at least met their nutrient requirements. This might explain why all cows in Paper III, except two cows fed the festulolium diet, were found to be pregnant again after the subsequent breeding season (results not shown). However, care is required when drawing inferences about the effect of prepartum plane of nutrition on reproductive performance from this study, as the number of cows was limited.

5.5 Calf Performance

Measures of calf performance are important when new dietary strategies prepartum are considered, as the revenue in cow-calf production is dependent on the cow giving birth to a living calf and weaning a heavy and healthy calf. Plane of nutrition prepartum may significantly alter calf birth weight (Bohnert et al. 2013; Wilson et al. 2016). However, prepartum nutritional level did not elicit differences in calf birth weight in Paper III, confirming some previous findings (Morrison et al. 1999; Stalker et al. 2006). Calf weight gain until weaning and weaning weight were not affected by prepartum level of nutrition, as also found in some previous studies (Morrison et al. 1999; Wilson et al. 2016). Contrary, Stalker et al. (2006) reported lower average daily gain and weaning weight in calves born to cows losing BCS before parturition. The reason for the different results in those studies could be the varying degrees of undernutrition prepartum. In Paper III, the number of calves within each treatment group was limited. Hence, conclusions about the effect of prepartum diet on calf performance should be made with caution.

5.6 Diet Costs

Production costs of roughages are very variable and depend on the local conditions at the individual farm. Hence, the costs of production calculated in this thesis should be used as guidelines. However, the results demonstrate the relative differences in total costs between the diets that might be expected, due to the combination of observed differences in intake and feed costs.

Cows fed the barley straw diet had the lowest total DMI of roughage prepartum. However, the large amount of rapeseed meal required to cover cow MP requirements resulted in a high total cost of this diet, especially under conditions when straw is expensive. Consequently, it would be cheaper to feed a traditional timothy-meadow fescue or festulolium silage instead of barley straw supplemented with urea and rapeseed meal prepartum, even though it would result in unnecessary high intakes of NE and MP. A diet based on only straw may look good from an economic perspective, but is not recommended, as feeding only straw may be of great risk for animal health. Recently, some cases of death in suckler cows have been reported by the Swedish Farm and Animal Health advisory service (Gård & Djurhälsan, 2019), where the autopsy reports indicated rumen constipation to be the probable death reason, probably caused by high straw feeding without enough supplement of rumen degradable protein.

The low cost of the reed canarygrass diet could primarily be related to the lower intake of this roughage compared to the others. Although reed canarygrass may be persistent for 10-15 years (Landström & Wik, 1997), the production cost was influenced only to a minor extent of the reduced need of regular reestablishment. Cows fed reed canarygrass prepartum in Paper III lost BCS prepartum, but recovered during the subsequent grazing period, whereas cows fed the high-energy diets prepartum, *i.e.* timothy-meadow fescue and festulolium, gained BCS prepartum and lost BCS during the grazing period. Dry matter intake at pasture was not measured in Paper III, but based on the observed changes in BCS it could be assumed that cows fed reed canarygrass had greater DMI at pasture than cows fed the high-energy diets. Hence, a feeding strategy where cows are managed to loose BCS during the prepartum indoor period to recover at pasture would require a larger pasture area per cow. If the pastures mainly are constituted by semi-natural pastures, where environmental payment is greater than the costs of fences and related work, the two economic benefits of this strategy would be a larger net income per cow from pasture and a lower feed cost of the indoor period.

6 Conclusions

The high-fibre roughage based diets evaluated in this thesis displayed relatively large variations in fibre characteristics and OM digestibility, with subsequent effects on intake, rumination time, faecal particle size and diet digestibility in pregnant suckler cows fed *ad libitum*.

All perennial grasses were cut at similar stage of maturity, flowering. Still, they exhibited variations in OM digestibility and NDF characteristics that were large enough to elicit differences in cow intake and, hence, NE and MP supply.

Although cut at late stage of development, the diets including traditional timothy and timothy-meadow fescue silage, or festulolium silage, resulted in intakes of NE and MP in excess of requirements and increased BW and BCS during pregnancy. This questions the appropriateness of diets with similar nutritional features being used in *ad libitum* feeding regimes prepartum.

The low digestibility of the reed canarygrass and barley straw diets limited the ability of the cows to compensate for the greater nutrient demand of the growing foetus during pregnancy, which resulted in a catabolic state and losses of BW and BCS prepartum.

Nitrogen utilization was improved with increased intake of digestible OM. The reed canarygrass diets resulted in the highest urinary N and urea-N output, which most likely could be attributed to a poor dietary balance between available rumen degradable protein and digestible OM.

Intake appeared to be proportional to cow BW and not affected by the breed itself. Charolais ruminated longer time per kg NDF intake when corrected for BW and had smaller faecal particle size than Hereford, but despite this disparity no breed difference in apparent OM digestibility was detected.

7 Implications

The findings presented in this thesis showed that there is potential to improve effectiveness of today´s Swedish roughage feeding of pregnant suckler cows during winter. The risk for overfeeding of pregnant suckler cows with energy and protein during pregnancy can be limited if roughages with high fibre concentrations and low digestibility are fed. Traditional grass silages of timothy and meadow fescue need to be cut late, maybe be even later than flowering, to reach the desirable quality if intended for *ad libitum* feeding. Reed canarygrass cut at flowering appeared to be a more suitable forage prepartum than the traditional grass silage, as it resulted in moderate reductions in cow BW and BCS, and a lower feed consumption accompanied by a lower feed cost. However, the low digestibility of OM in combination with the relatively high concentration of CP in the reed canarygrass silage will result in greater urinary losses of N than the other forages. Grazing is often a cheaper alternative to conserved roughage. Thus, a winter feeding regimen where cows in good condition are fed to lose some BCS prepartum during winter and then allowed to recover on pasture, as was observed with two of the diets in this thesis, can be a potential strategy to reduce the annual feed costs of suckler cows. No differences in cow reproductive performance or calf weight at birth or weaning weight were observed in this study. However, the possible influence of feeding energy below requirements prepartum on cow and calf performance should be considered before making this managerial change.

8 Future Perspectives

To further improve the efficiency of feed resource use in suckler cow winter feeding, future research could focus on:

- Investigating if grass silage of traditional timothy and meadow fescue could be suitable to pregnant suckler cows if cut at an even later stage of development than flowering.

- Evaluation of the nutritional quality of reed canarygrass cut at different stages of development, to identify the maturity stages where the digestibility of OM and protein concentration are more compatible in order to reduce the urinary excretion of urinary N and, at the same time, reduce the risk of overfeeding with energy and protein.

- Intake and utilization in pregnant suckler cows fed grass-clover mixtures commonly used in organic production.

- Further development of a suckler cow module in the NorFor digestive model, e.g. by using the results in this thesis.

Popular Science Summary

Today, about 40% of the Swedish beef originates from suckler-based beef production. Furthermore, grazing cattle is a prerequisite in the preservation of semi-natural pastures, which are the most species rich types of nature in the country. Suckler cows have become increasingly important in their management during the last decades due to a decreasing number of dairy cattle.

Beef cow and calf (suckler-based beef) production is based primarily on different types of grasses, which are fed as grazed and conserved forage. In Sweden, suckler cows are commonly wintered indoors and fed conserved forage during this period. As the cost of harvested grass usually is greater than that of grazing, winter feed costs constitute a substantial proportion of the total annual costs of feeding the cow.

A majority of the Swedish suckler calves are born in the spring. Consequently, the nutrient requirements of the spring-calving suckler cow are relatively low during a large part of the indoor period, as the cow does not produce any milk. Suckler cows are commonly fed forage *ad libitum*, *i.e.*, in free access, during the winter for rational reasons. However, the combination of low nutritional requirements during early to mid-pregnancy and *ad libitum* feeding may result in an overfeeding with energy and protein during this period.

To regulate feed intake of pregnant suckler cows during *ad libitum* feeding regimes, a common strategy is to delay the harvest of grass. This results in forages with high concentrations of neutral detergent fibre (NDF) and low digestibility, which limits intake by providing high rumen fill. However, field studies have shown that traditional grass mixtures might have too high nutritive value for this animal category also when cut late. Over-conditioning of suckler cows during pregnancy is expensive and increases the risk of dystocia. On the other hand, negative energy status prepartum and poor body condition at parturition may have negative effects on cow reproductive performance and on calf weight gain and weaning weight. Overfeeding with protein may result in unnecessary losses of nitrogen, as protein supplied in excess of rumen microbial and cow requirements are excreted in urine. Thus, from economic, environmental and cow performance perspective, there is a lot to be gained by house holding with feed resources by feeding the correct quality and quantity at the right time.

The early maturing beef breed Hereford and the late maturing beef breed Charolais are two of the most common beef breeds in Sweden. They were historically developed on low and high quality forage diets, respectively. Today, Swedish breeding goals still dictate that Hereford should be bred for more nutritionally extensive production than Charolais. Hence, the question has been raised if intake and feed utilization in these breeds may. Such information is warranted as it could indicate if feeding recommendations should differ between breeds.

The aim of this thesis was to evaluate the nutritional quality of alternative types of high-fibre roughages, in addition to traditional grasses, when fed *ad libitum* to pregnant suckler cows. Our focus was to study the dietary effects on feed intake, utilization, nitrogen excretion, cow energy status before and around parturition, and calf performance, in an attempt to improve the effectiveness of feed resource use to spring-calving suckler cows.

Three feed trials were conducted at SLU Götala Beef and Lamb Research Centre, located in south-western Sweden. In the first trial, we studied the effects of feeding three late cut forage diets; timothy-, reed canarygrass-, and whole-crop oat silage, on intake, digestibility, rumination time, faecal particle size and nitrogen utilization in mid-pregnant cows of Hereford and Charolais breeds. In two further trials, four roughage diets; timothy-meadow fescue silage, festulolium[1] silage plus urea, reed canarygrass silage, and barley straw supplemented with urea and rapeseed meal, were fed during the last 16 weeks of pregnancy to cows of the Hereford breed. Daily feed intake and cow changes in body condition, body weight and metabolic profile before and around parturition were measured continuously, whereas the dietary effects on nitrogen utilization were evaluated in mid-pregnancy. In the third trial, calf birth weight, growth and weaning weight were also recorded.

The results showed that although all perennial grasses were cut at similar stage of maturity, i.e. flowering, they exhibited differences in digestibility and fibre characteristics that were large enough to elicit differences in cow intake. Cows consumed greater amounts of the diets based on the more digestible timothy-, timothy-meadow fescue-, and festulolium silages, than of the other diets. Cows were able to consume nearly 1% of their body weight as roughage NDF, which could be used as a rough rule of thumb on farm level to predict feed

[1] A hybrid between Italian ryegrass and tall fescue.

consumption, provided the body weight of the cow is known and that a proper feed analysis has been conducted.

It was clear that the late cut traditional timothy-meadow fescue silage, and festulolium silage, became too nutritious for pregnant suckler cows, as they resulted in increased body weight and body condition prior to calving. Contrary, the low digestibility of the reed canarygrass and barley straw diets limited the cows' ability to increase intake to meet the demand of nutrients by the growing foetus during late pregnancy, which resulted in losses of body weight and body condition, and in an apparent energy deficiency in cows fed the barley straw diet. However, cow reproductive performance during the subsequent grazing period and calf performance did not appear to be affected by the nutritional level of the cow before parturition.

Utilization of dietary nitrogen was improved with increased intake of digestible organic matter, resulting in lower excretion of nitrogen in urine. Feeding silage of reed canarygrass resulted in the greatest urinary output of nitrogen, which probably was a result of its poor digestibility in combination with its relatively high concentration of protein.

Cows of the Charolais breed had greater daily dry matter intake than cows of the Hereford breed, but this difference was not significant when intake was related to cow body weight. Hence, intake appeared to be more related to the size of the cow than to the breed *per se*. We observed no differences in diet digestibility between the two breeds, even though differences in rumination time and faecal particle size existed.

The studies in this thesis indicated that there is potential to increase the effectiveness of today's traditional Swedish winter feeding of pregnant suckler cows. Feeding of roughages with high fibre concentrations and low digestibility can result in decreased intake and accompanied feed costs, as well as decreased risks for overfeeding of energy and protein, without negative effects on cow performance. To achieve the desired forage characteristics, the traditional grass silages of timothy and meadow fescue should be cut at a late stage of development, which might be even later than flowering. Late cut reed canarygrass might be a better alternative to traditional grasses, as it resulted in moderate reductions of cow body weight and body condition in late pregnancy and a lower feed consumption accompanied by a lower feed cost.

Populärvetenskaplig Sammanfattning

Nötkött från dikalvsuppfödning i så kallad självrekryterande nötköttsproduktion utgör idag ca 40% av det nötkött som produceras i Sverige. Förutom att bidra till livsmedelsförsörjningen är betande dikor dessutom mycket viktiga i bevarandet av naturbetesmarker. Dessa marker utgör de artrikaste naturtyperna i Sverige och dikornas betydelse för upprätthållandet av deras skötsel har ökat under de senaste decennierna på grund av det minskande antalet mjölkrasdjur.

Foderstater till dikor i dikalvsuppfödning baseras framförallt på olika typer av gräs, antingen i form av bete eller som konserverat foder i form av ensilage eller hö. I Sverige hålls de flesta dikor på stall under vinterhalvåret och utfodras då oftast med ensilage. Kostnaden för skördat foder är vanligtvis högre än kostnaden för att hålla korna på bete sommartid. Därmed utgör foderkostnaden under stallperioden en betydande andel av den totala årliga foderkostnaden för en diko.

En majoritet av de svenska dikalvarna föds under våren. Det innebär att dikornas näringsbehov är relativt lågt under en stor del av stallperioden, eftersom kon inte producerar någon mjölk. Dikor utfodras vanligtvis med grovfoder i fri tillgång under vintern av rationella skäl. Dock medför den fria tillgången på foder, i kombination med det låga näringsbehovet, att korna riskerar att överutfodras med både energi och protein under denna tid.

En vanlig metod för att reglera foderintaget hos dräktiga dikor vid utfodring i fri tillgång är att senarelägga vallskörden. Detta resulterar i ett grovfoder med hög koncentration av fiber (NDF) och låg smältbarhet, vilket ger hög vomfyllnadsgrad och därmed begränsar kons intag. Fältstudier har dock visat att traditionella gräsblandningar, trots en sen skörd, kan ha en för bra näringsmässig kvalitet för dräktiga dikor. Överutfodring av dikor under dräktigheten kan leda till feta kor som löper ökad risk för komplikationer vid kalvning. Underutfodring, som resulterar i negativ energibalans och ett dåligt hull vid kalvning, kan å andra sidan få negativa effekter på kons förmåga att bli dräktig igen efter kalvning, samt på kalvens tillväxt och avvänjningsvikt. Överutfodring med protein kan leda till onödiga förluster av kväve från gödseln, eftersom ett intag av protein som överstiger kons och vommikrobernas behov utsöndras i urinen. Ur ett ekonomiskt och ett miljö- och produktionsperspektiv finns det alltså mycket att vinna på att hushålla med foderresurserna och utfodra rätt kvalitet och kvantitet i rätt tid.

Den lätta köttrasen hereford och den tunga köttrasen charolais är två av de vanligaste köttraserna i Sverige. Historiskt sett har dessa raser utvecklats för att vara anpassade till system baserade på låg- respektive högkvalitativa grovfoder. De svenska avelsmålen säger än i dag att hereford ska avlas för en mer extensiv produktion än charolais. Frågan har därmed väckts om intag och foderutnyttjande skiljer mellan dessa raser. Mer information kring detta är önskat, eftersom det i så fall skulle kunna innebära att utfodringsrekommendationerna bör skilja mellan de olika raserna.

Syftet med denna avhandling var att utvärdera den näringsmässiga kvaliteten på olika typer av fiberrika grovfoder, samt att jämföra dessa med en traditionell gräsvall, genom att utfodra dem i fri tillgång till dräktiga dikor. Vårt fokus har varit att studera grovfodrens effekter på foderintag, foderutnyttjande, kväveutsöndring, kons energistatus före och efter kalvning, samt kalvens födelsevikt och tillväxt, för att på så sätt förbättra effektiviteten i foderanvändningen till vårkalvande dikor.

Tre utfodringsförsök genomfördes på forskningsanläggningen SLU Götala nöt- och lammköttsforskning i Skara. I det första försöket studerades hur tre sent skördade grovfoder; ensilage av timotej, rörflen och helsäd av havre, påverkade foderintag, fodrens smältbarhet, idisslingstid, partikelstorlek i träck och kväveutnyttjande hos dräktiga dikor av raserna hereford och charolais när de utfodrades i fri tillgång. I nästa två utfodringsförsök utfodrades fyra grovfoderstater baserade på ensilage av timotej och ängssvingel, ensilage av rörsvingelhybriden Hykor plus urea, ensilage av rörflen eller kornhalm kompletterad med urea och rapsmjöl till dikor av rasen hereford under de sista 16 veckorna före kalvning. Dagligt foderintag, förändringar i vikt, hull och vissa blodmetaboliter före och efter kalvning registrerades kontinuerligt, medan fodrens effekt på kornas kväveutnyttjande utvärderades i mitten av dräktigheten. I det tredje försöket registrerades också fodrens effekt på kalvens födelsevikt, tillväxt och avvänjningsvikt.

Trots att alla fleråriga gräs i studierna skördades i ett liknande utvecklingsstadium, blomning, uppvisade de skillnader i fiberkoncentration och smältbarhet som var tillräckligt stora för att ge upphov till skillnader i foderintag. Korna konsumerade större mängder av de mer smältbara grovfodren, dvs. av timotej, timotej-ängssvingel-blandningen, och av rörsvingelhybriden, jämfört övriga grovfoder. Kornas dagliga intag av NDF från grovfodret var nära 1% av kroppsvikten, vilket kan användas som en grov tumregel på gårdsnivå när man vill förutsäga foderåtgången. Detta förutsätter dock att kons vikt är känd och att fodret har analyserats.

Resultaten visade tydligt att en foderstat bestående av en sent skördad traditionell blandvall av timotej och ängssvingel, eller av rörsvingelhybrid, blev för näringsrik för dräktiga dikor, vilket avspeglade sig i både vikt- och hullökningar före kalvning. Däremot begränsade den låga smältbarheten på rörflensensilaget och halmfoderstaten kornas möjlighet att öka foderintaget för att möta det högre näringsbehovet av den växande kalven i slutet av dräktigheten, vilket resulterade i vikt- och hullminskningar och i en uppenbar negativ energibalans hos de kor som utfodrades med halmfoderstaten. Nivån av näringstillförsel under dräktigheten hade dock ingen tydlig effekt på kornas dräktighetsresultat eller kalvens tillväxt under den efterföljande betesperioden.

Kornas utnyttjande av kvävet i de olika foderstaterna förbättrades vid ett högre intag av smältbara kolhydrater, vilket resulterade i en lägre utsöndring av kväve i urinen. Utfodring med rörflen ledde till den högsta kväveutsöndringen, vilket troligtvis kunde förklaras av dess låga smältbarhet i kombination med dess relativt höga koncentration av protein.

Korna av rasen charolais hade en högre daglig foderkonsumtion jämfört med korna av rasen hereford, men när foderintaget relaterades till kornas kroppsvikt var det inte längre någon skillnad mellan raserna. Alltså verkade kornas intagskapacitet vara mer beroende av storleken på kon än på rasen i sig. Vi hittade inga skillnader mellan raserna vad gällde fodrens smältbarhet, även om de två raserna skiljde sig lite i idisslingstid och partikelstorlek i träck.

Studierna i denna avhandling visar att det finns potential att öka effektiviteten i dagens traditionella svenska utfodring av dräktiga dikor under stallperioden. Genom att utfodra fiberrika grovfoder med låg smältbarhet kan foderintaget begränsas och därmed också foderkostnaden. Likaså kan risken för överutfodring med energi och protein reduceras utan några efterföljande negativa effekter på kons produktion. För att uppnå de önskade foderegenskaperna måste traditionella gräsvallar baserade på timotej och ängssvingel skördas så sent som i blomning, eventuellt ännu senare. Sent skördad rörflen är ett bättre alternativ, eftersom detta foder resulterade i en måttlig vikt- och hullminskning före kalvning, samt i en låg foderkostnad tack vare det lägre foderintaget.

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