Forage Feeding in Intensive Lamb Production

Intake and Performance in Ewes and Lambs

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Abstract

Successful feeding strategies of periparturient ewes and growing lambs are essential in intensive indoor lamb production. This thesis evaluated the effects of chopping grass silage and of mixing silage with concentrate on feed intake, dietary selection, chewing behaviour, faecal particle size and performance in pregnant and lactating ewes and in suckling and finishing lambs. In addition, the effects of silage digestibility on feed intake, dietary selection and performance in pregnant and lactating ewes and in suckling lambs were evaluated. Lastly, the effects of feeding whole crop maize silage, harvested at different maturity stages, as the sole forage or combined with grass silage on feed intake, dietary selection, chewing behaviour, faecal particle size and performance in finishing lambs were evaluated.

Three experiments were conducted at Götala Beef and Lamb Research Centre, SLU, Sweden. The results show that by chopping grass silage prior to feeding pregnant and lactating ewes, eating time and dietary selection were decreased whereas rumination time was increased. Chopping of silage also increased growth rate of finishing lambs. Mixing of silage and concentrate increased feed intake in lactating ewes and growth rate of suckling lambs, indicating a higher milk yield of the ewes. Furthermore, improved digestibility of grass silage, due to earlier harvest, increased silage intake and body weight in pregnant and lactating ewes and reduced loss of body condition in lactating ewes. Early harvested silage also decreased concentrate intake and increased the growth rate of the suckling lambs, indicating a higher milk production of the ewes. To optimize feed efficiency, silage of maize harvested at dent stage of maturity should be fed as the only forage, whereas maize harvested at the dough stage could be fed in a mix with grass silage. Feeding maize silage as the sole forage decreased eating and rumination time per unit of intake. Lambs selected particles between 1 and 8 mm and sorted against particles high in fibre. Furthermore, to maximize lamb growth rate, the protein content and quality seem to be the most important dietary factors.

In summary, to maximize production output in intensive lamb production by optimizing feeding, highly digestible chopped grass silage or maize silage harvested at dent stage of maturity should be fed mixed with concentrate.

Keywords: chopping, eating, faecal particles, grass silage, lamb growth, maize silage, rumination, sheep, silage digestibility, total mixed ration

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Dedication

To Sophie

Every closed eye is not sleeping, and every open eye is not seeing
Bill Cosby

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List of Publications

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

I Helander, C., Nørgaard, P., Arnesson, A. & Nadeau, E. (2014). Effects of chopping grass silage and of mixing silage with concentrate on feed intake and performance in pregnant and lactating ewes and in growing lambs. *Small Ruminant Research* 116(2-3), 78-87.

II Helander, C., Nørgaard, P., Jalali, A.R. & Nadeau, E. (2014). Effects of chopping grass silage and mixing silage with concentrate on feed intake, chewing activity and faecal particle size of ewes in late pregnancy and early lactation. *Livestock Science* 163, 78-87.

III Nadeau, E., Helander, C. & Arnesson, A. Grass maturity at harvest affects silage intake and performance of pregnant and lactating ewes and their suckling lambs. (manuscript).

IV Helander, C., Nørgaard, P., Zaralis, K., Martinsson, K., Murphy, M. & Nadeau, E. Effects of maize crop maturity at harvest and dietary inclusion rate of maize silage on feed intake and performance of lambs fed high-concentrate diets. (submitted to Livestock Science).

V Helander, C., Nørgaard, P., Zaralis, K. & Nadeau, E. Maturity stage of maize at harvest and inclusion of grass silage affect feed intake, dietary selection, chewing behaviour and faecal particle size in lambs. (manuscript).

Abbreviations

ADF	acid detergent fibre
ADL	acid detergent lignin
APS	arithmetic mean particle size
BCR	basic chewing rate
BCS	body condition score
BW	body weight
CP	crude protein
CPI	crude protein intake
DM	dry matter
DMI	dry matter intake
DOMD	digestible organic matter in dry matter
GPS	geometric mean particle size
iNDF	indigestible neutral detergent fibre
IVOMD	in vitro organic matter digestibility
JM	jaw movements
JMO	jaw movement oscillations
LWG	live weight gain
ME	metabolizable energy
MEI	metabolizable energy intake
MJ	mega joule
MP	metabolizable protein
MPI	metabolizable protein intake
NDF	neutral detergent fibre
NDFI	neutral detergent fibre intake
OM	organic matter
peNDF	physically effective neutral detergent fibre
VFA	volatile fatty acids
WSC	water-soluble carbohydrates

1 Introduction

1.1 World Lamb Production

Most of the circa 1.2 billion sheep in the world are found in developing countries in Asia (45%) and Africa (28%), holding 73% of the world sheep population (FAO, 2014). Oceania (11%; mainly New Zealand and Australia), Europe (9%) and America (7%) together hold the remaining 27%. As the increase in sheep population in Asia and Africa was higher than the decrease in the rest of the continents, the average annual increase between 1999 and 2012 was 8.7 million sheep (FAO, 2014).

Most of the lamb production is performed under extensive conditions and/or outdoors, and consequently most of the sheep nutrition research performed focuses on use of cheap local feed stuffs and on grazing systems.

Intensive lamb production is herein determined as high input - high output systems, *i.e.* systems with maximized biological output rather than optimized economical or environmental output. A key question concerns the maximum output level of healthy productive sheep in temperate climate conditions.

In this thesis, the focus lies on maximizing performance by optimizing feeding strategies. All diets in the experiments were created to maximize production given some common parameters, *i.e.* silage and concentrate type and silage:concentrate ratio. Well aware of the fact that production is not *per se* optimized when output is maximized, only after attempting to maximize output the optimum may be revealed.

1.2 Swedish Lamb Production

In the last four decades, the Swedish lamb production has undergone a major structural change. The herds with 1 to 9 sheep have decreased by 58%, herds with 10 to 24 sheep have increased by 68%, herds with 25 to 49 have increased by 95% and herds with more than 49 sheep have increased by 128% from 1970 to 2013. Still, in 2007, there were only 409 herds with 100-399 ewes and 26 herds with 400 ewes or more (Statistics Sweden, 2013). As Kumm (2009) showed, sheep herds need 500 ewes or more to be profitable under Swedish conditions and there is a need for additional large sheep farms to increase overall profitability of Swedish lamb production. Unless costs are decreased and efficiency increased, lamb production in Northern Europe will have difficulties competing with import from *e.g.* New Zealand on a deregulated world meat market (Dýrmundsson, 2006). The recently decreased EU payment for production further actualizes increased efficiency as a key concern for profitable intensive lamb production.

The number of adult sheep in Sweden has been almost doubled over the latest decades, from 145,000 sheep and 9,300 herds in 1970 to 285,000 sheep and 8,800 herds in 2013 (Statistics Sweden, 2013). During the same period, the production potential of Swedish sheep has increased by genetic improvement and imports of continental breeds (such as Texel and Dorset) and a high production potential is a prerequisite for a high output. As the knowledge of improved techniques for forage harvesting and preservation has drastically increased during the latest decades, it is now possible to harvest large quantities of ley herbage at an early maturity stage and store it as silage rather than as hay. Well-preserved grass silage has been shown to improve ewe and lamb performance compared to hay in previous experiments under Nordic conditions (Sormunen-Cristian & Jauhiainen, 2001). By harvesting the plants at an early maturity stage, herbage digestibility will be high, which increases the potential for forage intake and performance by sheep (Nadeau & Arnesson, 2008; Keady *et al.*, 2013).

In Swedish intensive indoor production of lambs, ewes are mated off-season in August, with lambing in January, which enables fresh Swedish lamb meat in time for Easter and before the grazing lambs are traditionally slaughtered. To create a mother sheep able to naturally come in heat off-season, the breeds Dorset and Finewool are often used in Sweden. To maximize carcass gain, the sire breed most commonly used is Texel. In this production system, lambs are commonly slaughtered at 3-4 months of age, at a carcass weight of circa 20 kg. In this kind of intensive system with daily live weight gain (LWG) of circa 400 g, there is an obvious demand for high feed efficiency using high quality feeds for both ewes and lambs. Forage as the only feed source is rarely adequate to meet the nutritional demands for maximum performance of lambs with high production potential (Eknæs *et al.*, 2009; Bernes *et al.*, 2012). Consequently, it is important to evaluate the effects of relevant feeding strategies on feed utilisation and sheep performance in intensive production systems.

1.3 Feeding Sheep

Sheep are classified as 'intermediate feeders preferring grass' or 'selective grazers' (Van Soest, 1982) and differ evolutionarily in feeding behaviour from goats, which are 'intermediate browsers' and cattle, which are 'fresh grass eaters'. As the term 'selective grazer' indicates, sheep are selective in their eating behaviour and small ruminants are in general more selective than large ruminants (Van Soest, 1982). Even though there are obvious similarities between ruminant species, there are fundamental differences. This work mainly refers to previous studies performed on sheep.

As all ruminants, sheep exist in symbiosis with their reticulo-rumen (hereafter: rumen) microbes (mainly bacteria, protozoa and fungi). By the combination of physical degradation of feed particles during rumination and the highly efficient rumen microbes, sheep can access nutrients in the form of volatile fatty acids (VFA; mainly acetic, propionic and butyric acid) derived from fermentation of various plant carbohydrates. In symbiosis with the rumen microbes, ruminants obtain high-value microbial protein produced from non-protein nitrogen and rumen degradable protein sources using adenosine triphosphate created in the fermentation of carbohydrates (Merchen & Bourquin, 1994). Fermentation of carbohydrates in the rumen is the key factor for microbial protein synthesis, and the microbial protein accounts for the majority of the amino acids absorbed in the small intestine (Merchen & Bourquin, 1994). Metabolizable protein (MP) is the part of the crude protein (CP) which is metabolizable in the small intestine of ruminants. MP originates from microbial protein synthesis and from rumen undegradable feed protein. In the Nordic countries MP is also referred to as the AAT-value, which is defined as the amino acids absorbed in the small intestine.

Generally, a certain level of intake of forage is necessary for maintaining health and welfare of domesticated ruminants (cattle, sheep, goats, buffaloes, reindeer and yaks) and of many of their wild relatives. As sheep are easily adapted to different feed rations, the forage proportion of the diets may, however, vary from close to 0 to up to 100% of the diet. Both the intake potential and performance of sheep fed large proportions of forage are determined by the nutritional and hygienic quality of the forage (Keady *et al.*, 2013). The nutritional quality is herein referred to as *in vitro* and *in vivo* organic matter (OM) digestibility and the contents of neutral detergent fibre (NDF), indigestible NDF (iNDF), CP, sugar, crude fat and, for some forages, content of starch. Hygienic quality of forage is referred to as the contents of fermentation products from ensiling, such as various organic acids and alcohols and ammonia-nitrogen content and occurrence of undesired microorganisms in the silage.

1.4 Forages for Intensive Production

Feeding conserved forages during winter is common practice in lamb production in parts of the world where year-around grazing is not possible. In the Nordic countries, sheep in large indoor production systems are mainly fed grass silage and concentrates indoors for approximately half of the year.

The quality, and consequently the feeding value, of dry or ensiled forages is dependent on management (*e.g.* maturity stage at harvest, fertilisation, storage manner), climate and plant species used (Buxton *et al.*, 1995; Collins & Moore, 1995). For grass, as the plant matures, the contents of hemicellulose, cellulose and lignin increase primarily in the stem, as reflected by a higher NDF concentration when chemically analysed (Jung & Allen, 1995). Also, the NDF digestibility decreases with increased grass maturity and both the increased content of NDF and the decreased digestibility of NDF decreases intake in ruminants (Van Soest, 1965; Allen, 1996). Forage digestibility, which to a major part is affected by content and digestibility of NDF, as well as physically effective NDF (peNDF), which includes forage particle size, are important factors for feed intake and performance in sheep (Cannas, 2002; Mertens, 1997). As sheep live in symbiosis with their individual rumen microbes, forages need to enable normal rumen function by providing fibres that physically stimulate the papillae in the rumen epithelium, thereby promoting rumen wall contraction, rumination and microbial fermentation (Allen, 1996). Chewing and especially rumination, of feed stuffs, such as forages, are essential factors for utilisation of nutrients by sheep. During rumination, feed particles are reduced in size and saliva is added. The particle size reduction enables microbes to attach to the surface and continue the physical and chemical break-down of the feed particles. In this process, the microbes need a suitable environment, in which a stable pH-value is required and ensured via the rumen buffering capacity, which is mainly dependent on bicarbonate. In a stable rumen, bicarbonate buffer is mainly provided from the saliva and from the buffer excreted into the rumen during bicarbonate-dependent VFA absorption through the rumen wall (Djikstra *et al.* 2012). Minimizing ruminal pH fluctuations is expected to promote high energy intake, fibre digestion and microbial protein production in ruminants (Allen, 1997; Allen *et al.*, 2006).

As faecal particle size distribution reflects the size distribution of the fibre particles escaping the rumen, rumen function can be evaluated by analysis of particle size distribution in faeces from sheep (Ulyatt *et al.*, 1986; Jalali *et al.*, 2012). The theoretical critical threshold size for feed particles to leave the rumen in sheep is 1 mm (Poppi *et al.*, 1980). In practice, larger particles can escape the rumen and be found in faeces. A large number of small particles (< 0.5 mm) indicates a long rumen retention time with thorough rumination, whereas a high number of very long particles (> 10 mm) in the faeces indicates insufficient rumination and chewing of particles and a too high passage rate of particles leaving the rumen (Jalali *et al.*, 2012).

As the foetuses grow during pregnancy, the rumen of the ewe decreases in volume, which limits space for feed digestion. Less space makes it more difficult for the ewe to utilize sufficient energy from feeding, especially when fed forage of low or medium nutritional quality only (Roche *et al.*, 2008). Animals with insufficient energy supply from feeding use body reserves to release energy. Energy insufficiency in pregnant and lactating ewes affects the production negatively in both ewes and their lambs (Ledin, 1995). To avoid production losses, it is necessary to supplement low and medium quality forages with concentrate during late pregnancy and lactation. The other alternative is to feed high quality forages enabling no or minimal concentrate use depending on the number of foetuses and the condition of the ewe (Robinson *et al.*, 1999; Eknæs *et al.*, 2009). The performance of sheep with high production potential, *i.e.* high milk yield or high growth rate, in feeding systems based on forage is heavily dependent on high forage intake and efficient forage utilization (Keady *et al.*, 2013).

1.4.1 Grass Silage Digestibility

It is well-known that increasing grass silage digestibility increases forage intake and performance of ruminants (Keady *et al.*, 2013). By delaying grass harvest, forage digestibility decreases by the elevated fibre proportion and decreased fibre digestibility resulting in increased rumen-fill. This in turn increases the rumen retention time of the feed and, thereby, limiting feed intake in ruminants (Mertens, 1994; Allen, 1996; Roche *et al.*, 2008). As it is possible to produce grass silages of high nutritional and hygienic quality under temperate climate conditions, there is a potential of including large proportions of forages in ruminant diets without negatively affecting feed intake or performance (Nadeau & Arnesson, 2008; Eknæs *et al.*, 2009).

1.4.2 Chopping Length

In extensive feeding systems, the common practice is to feed un-chopped grass silage ad libitum using feeding crates, which increases the risks for silage waste, sorting of silage and, thereby, decreasing silage intake. By using feed troughs, silage waste may be minimized, but the amount of labour spent distributing feed will most likely increase. Chopping grass silage, and consequently decreasing silage particle length, from long (250-370 mm) to intermediate (70-120 mm) and further to short (5-20 mm) has been shown to increase intake and performance in sheep. Chopping silage increased feed intake of pregnant and lactating ewes (Apolant & Chestnutt, 1985; Elizalde & Henríquez, 2009), improved BCS of pregnant ewes (Elizalde & Henríquez, 2009), increased ewe body weight (BW) after lambing, lamb birth weight and LWG of suckling lambs (Apolant & Chestnutt, 1985) and increased feed intake and daily LWG of finishing lambs (Fitzgerald, 1984; Fitzgerald, 1996a, 1996b, 1996c).

1.4.3 Mixed Feeding

Mixed feeding systems are mainly used in large herds of sheep and cattle, providing a rational system for feeding forages and concentrates indoors. Feeding sheep mixed rations, based on grass silage of high nutritional and hygienic quality is not a common practice world-wide, which is reflected in the lack of published studies focusing on the effects of mixing such silage with concentrate on feed intake and performance of sheep. Chestnutt & Wylie (1995) showed improved BW and BCS during late pregnancy of ewes fed a mixed ration of precision-chopped silage and concentrate compared with those fed the feeds separately.

1.4.4 Maize Silage

In the Nordic countries, the forage part of the diet most often consists of grass-dominated silage, as the favourable climate conditions enable making grass silages of high digestibility. As early maturing hybrids of forage maize have been developed in recent years, it is now possible even in northern regions to obtain yields well above 10 tons dry matter (DM) per hectare of forage with starch contents above 350 g kg^{-1} DM. However, if the growing season gets shortened by a cold spring or an early frost in the autumn, the harvest must occur at an earlier than desired maturity stage, *i.e.* at starch contents often lower than 300 g kg^{-1} DM (Ritchie *et al.*, 1997; NCIS, 1998). Maize silages with low starch contents are not biologically suitable to replace grass silage in the diets of high-producing sheep, as the fibre digestibility of forage maize is low compared to high quality grass silage. When including forage maize in the diets of high-producing sheep, it is necessary to feed an additional protein source with a sufficient content of metabolizable protein to avoid negative impact on performance, as maize silage seldom contain more than 100 g CP kg^{-1} DM (Mussadiq *et al.*, 2012).

Maize silage has been shown to increase feed intake and diet digestibility in wethers when partly replacing early and late harvested grass silages (Vranić *et al.*, 2008). However, Keady & Hanrahan (2013) showed no clear effects on silage intake or LWG of finishing lambs when fed maize silage containing 3 or 28% starch of DM. No published studies on maize silage fed to lambs with high growth capacity (> 400g day^{-1}) fed concentrate-based diets, were found in the literature.

2 Aims

The overall aim of the thesis was to investigate the effects of maturity stage at harvest and feeding strategies of grass and maize silages on intake and performance in ewes and lambs.

The specific objectives of the thesis were to evaluate the effects of

- chopping grass silage on feed intake, dietary selection, BW, BCS, chewing behaviour and faecal particles in pregnant and lactating ewes and on intake, LWG and carcass traits in suckling and finishing lambs
- mixing grass silage with concentrate on feed intake, dietary selection, BW, BCS, chewing behaviour and faecal particles in pregnant and lactating ewes and on intake, LWG and carcass traits in suckling and finishing lambs
- grass silage digestibility on feed intake, dietary selection, BW and BCS in pregnant and lactating ewes and on intake and LWG in suckling lambs
- maturity stage of maize at harvest on feed intake, dietary selection, chewing behaviour, faecal particle size distribution, LWG and carcass traits in finishing lambs
- replacing maize with grass silage on feed intake, dietary selection, chewing behaviour, faecal particle size distribution, LWG and carcass traits in finishing lambs

3 Materials and Methods

The components of the work consisted of two two-year studies and one one-year study. In **Papers I, II** and **III**, periparturient ewes and suckling lambs were studied. In **Papers IV** and **V**, finishing lambs were studied. The sheep were selected from a nearby commercial farm with circa 250 ewes. Number of foetuses was determined by ultrasonically scanning the ewes on farm. The experimental ewes were all carrying two foetuses and were of similar BW, BCS and age. All animals were kept indoors during Swedish winter and early spring. The overall design of the experiments was to feed the sheep with experimental diets, enabling *ad libitum* intake, while altering the forage parts of the diets.

3.1 Animals, Housing and Experimental Design

The ewes used in **Papers I-III** were all multiparous crosses between Swedish Finewool and Dorset. The lambs used in **Papers I-V** were all three-breed crosses, as their Finewool x Dorset mothers had been mated with Texel rams.

The sheep were housed in 6.0 m^2 pens, with one ewe per pen during pregnancy. During lactation, the ewes shared the pens with their lambs. The lambs also had access to an additional 15 m^2 pen shared with two other lamb litters within the same treatment. From weaning to slaughter, the lambs were kept with their respective sibling (**Papers I** and **II**) or with a randomly selected lamb (**Papers IV** and **V**).

The sheep were divided into homogenous groups with respect to BW, BCS and age. The groups, consisting of six (**Paper III**) or seven (**Papers I** and **II**) twin-bearing ewes, or ten lambs (**Papers IV** and **V**) per treatment, were then randomly allocated to three (**Papers I** and **II**) or four (**Papers IV** and **V**) different dietary treatments.

3.2 Experimental Diets, Feeds and Feeding

3.2.1 Papers I and II

The three treatments were: i) un-chopped grass silage and 0.8 kg concentrate, fed separately (US); ii) chopped grass silage and 0.8 kg concentrate, fed separately (CS); and iii) chopped grass silage mixed with concentrate (CM). The silages were fed *ad libitum* in the US and CS treatments, whereas the whole ration was fed *ad libitum* in the CM treatment, allowing refusals of 10-15% of offered feed in all treatments. In the CM treatment the forage:concentrate ratio was kept the same as that in the CS treatment, by recalculating the forage:concentrate ratio consumed of the CS ewes every 3-4 days.

The mean particle length of the un-chopped silage was 170 ± 110 mm (Exp. 1) and 349 ± 169 mm (Exp. 2) and the mean particle length of the chopped silage was 13 ± 2.7 mm (Exp. 1) and 18 ± 2.3 mm (Exp. 2). The grass was ensiled un-chopped in roundbales without additives. The concentrates fed to the ewes contained 12.2 and 12.8 mega joule (MJ) metabolizable energy (ME), 205 and 209 g CP, 217 and 232 g starch and 260 and 267 g NDF kg^{-1} DM in Exp. 1 and Exp. 2, respectively.

Silage was fed twice a day, at circa 10 a.m. and 4 p.m, respectively. The daily concentrate supplementation in the US and CS treatments was kept at 0.8 kg throughout both experiments and was fed just prior to morning feeding of silage. The animals had free access to minerals and water.

3.2.2 Paper III

The three experimental diets were *ad libitum* feeding, allowing 10-15% refusals, of: i) early harvested grass silage (E), ii) medium harvested grass silage (M) and iii) late harvested grass silage (L). In addition, all ewes were fed 0.8 kg concentrate daily throughout the experiment.

The grass was harvested at the leaf stage on the 2 of June (E), at the early heading stage on the 12 of June (M) and at the late heading stage of maturity on the 21 of June (L). All grasses were harvested in the spring growth from the same sward, consisting of timothy (*Phleum pratense* L.), meadow fescue (*Festuca pratensis* L.) and perennial ryegrass (*Lolium perenne* L.). The grass was ensiled as long (300 ± 150 mm) herbage in roundbales without additives. The concentrate contained 13.0 MJ ME, 199 g CP, 244 g starch and 260 g NDF kg^{-1} DM.

Silage was fed twice a day, at circa 10 a.m. and 4 p.m, respectively. The daily concentrate supplementation was kept constant at 0.8 kg and was fed just before morning silage feeding. The ewes had free access to minerals and water.

3.2.3 Papers IV and V

The treatments were: i) early cut maize silage as 50% of the forage DM proportion (E50), ii) early cut maize silage as 100% of the forage DM proportion (E100), iii) late cut maize silage as 50% of the forage DM proportion (L50) and iv) late cut maize silage as 100% of the forage DM proportion (L100). All diets consisted of circa 58% concentrates on a DM basis, with varying ratios of dried distiller's grains plus solubles, rolled barley and cold-pressed rapeseed cake (Exp. 1) and heat-treated rapeseed meal (Exp. 2). The diets were planned to contain the same concentrations of metabolizable energy (ME) and CP and similar concentrations of NDF in DM within year. The early cut maize was harvested for silage at the dough stage of maturity, at a DM content of 25 and 28% in year 1 and year 2, respectively. The late cut maize was harvested at the dent stage of maturity, at a DM content of 34 and 36% in Exp. 1 and Exp. 2, respectively.

Experimental diets were offered *ad libitum* (allowing circa 20% refusals) once daily at 10.00 h throughout the experiment. The lambs had free access to minerals and water.

3.3 Sample Collections, Recordings and Analyses

3.3.1 Feeds and Refusals

The silage (**Papers I-III**) and mixed rations (**Papers I, II, IV** and **V**) were weighed and sampled daily. Concentrates were sampled four times during each experiment. All feed samples were stored at -25°C until analysis for chemical composition.

In **Papers I, III** and **IV**, refusals were sampled from each pen three days per week, whereas in **Papers II** and **V**, the refusals were sampled daily.

Samples of silages, mixed feeds and refusals were pooled per treatment and week before determination of DM intake (DMI). Additional samples of silages, mixed feeds and refusals were pooled into monthly samples for analysis of chemical composition.

The composite samples of silages, mixed feeds and concentrates (and refusals in **Papers I-III**) were analysed for contents of DM, ash, CP, NDF, acid detergent fibre (ADF), acid detergent lignin (ADL) and starch. The DM was determined by drying the samples in a drying cabinet at 60°C for 24 h. The NDF, ADF and ADL were analysed using an ANKOM^{220} fibre analyser (Ankom Technology, Macedon, NY, USA) following the method described by van Soest *et al.* (1991), with heat-stable α-amylase included and sodium sulphite omitted from the NDF analysis. Fibre values are expressed on an ash-free basis. The ash content was determined according to AOAC (2004). The *in vitro* organic matter digestibility (IVOMD) of the grass silages and refusals was analysed according to the VOS method (rumen digestible organic matter; 96 h incubation in 38°C of 0.5 g dried sample with 49 ml buffer and 1 ml rumen fluid) and the ME value was calculated from the VOS value using the formula of Lindgren (1983, 1988):

$$\frac{\text{MJ ME}}{\text{kg OM}} = 0.160 \text{ x VOS} - 1.91$$

Organic matter digestibility in the dry matter (DOMD) was estimated by use of the formulas below (Lindgren, 1983):

$$\text{In vivo OMD} = 0.90 \text{ x VOS} - 2.0$$

$$\text{DOMD} = \text{In vivo OMD x OM}$$

The IVOMD of the maize silages was analysed according to Tilley & Terry (1963) and ME values of the maize silages and of the concentrates were calculated according to Axelsson (1941). Starch content in the maize silage, concentrate and in the refusals from the mixed diet was determined enzymatically according to Åman & Hesselman (1984). Total nitrogen content was analysed using the Kjeldahl nitrogen determination and CP was calculated as total N x 6.25. The concentration of water-soluble carbohydrates (WSC) was estimated according to Ekelund (1966) in **Papers I-III** and according to Lengerken & Zimmermann (1991) in **Papers IV** and **V**.

For analysis of ammonia-nitrogen and fermentation products in grass silages used in **Papers I-III**, composite silage samples were thawed and water was added in 1:1 ratio before storing samples at 4-8°C overnight. The juice was pressed out of the samples using a hydraulic press before analysed for fermentation products. The concentrations of lactate, butyrate, acetate, propionate and ethanol were measured using high pressure liquid chromatography (Andersson & Hedlund, 1983). Ammonium nitrogen was quantified using an auto-analyser system (Broderick and Kang, 1980). The pH was determined with a Metrohm 654 pH meter (Metrohm AG, Herisau, Switzerland). For analysis of ammonia-nitrogen and fermentation products in maize and grass silages used in **Papers IV-V**, samples were analysed at Humboldt University, Berlin. The pH was determined potentiometrically using a calibrated pH electrode. Lactic acid was analysed by high pressure liquid chromatography (Weiss & Kaiser, 1995). Volatile fatty acids were determined by gas chromatography as described by Weiss (2001). Ammonia concentration was determined colorimetrically by Scalar (CFSA) based on the Berthelot reaction.

The silage particle length of the un-chopped silage in **Papers I** and **II** was determined by hand, and of the chopped silages in **Papers I, II, IV** and **V** by horizontally shaking of samples in sieves with pore sizes of 30, 19, 8, 1 mm and a solid bottom bowl, according to Heinrichs & Kononoff (2002).

The dietary selection, or sorting for or against feed particles of certain characteristics, was performed by comparing the offered feeds and refusals in contents of NDF and ADF and in proportions of particles retained on the 30, 19, 8, 1 mm sieves or the bottom bowl (**Papers II** and **V**). In **Paper III**, dietary selection was estimated by comparing the concentrations of NDF, CP and ME in the offered silages and in the corresponding refusals.

3.3.2 Body Weight and Body Condition Score

In all Papers, animals were weighed on two consecutive days at the start and at the end of the experiments and once weekly throughout the experiments.

In **Papers I, II, IV** and **V**, the time of slaughter of lambs was based on a minimum body weight of 45 kg for males and 40 kg for females and the probable fat content in the carcass, which was estimated by manual assessment during weighing of live lambs.

Body condition scoring of the ewes in **Papers I-III** was performed weekly throughout the experiments, according to Jefferies (1961) and Russel *et al.* (1969), using a five-point scale with quarter-grade steps, where 1 is emaciated and 5 is obese.

Figure 1. One of the ewes with her suckling lambs from **Paper I**. *Photo: Annika Arnesson.*

3.3.3 Chewing Behaviour

In **Paper II**, jaw movements (JM) and JM oscillations (JMO) were sampled at 40Hz continuously for 96 h. The individual JM were identified from the JMO. The JM were clustered into crude cycles and the basic chewing rate (BCR) within cycles was estimated as the reciprocal most frequent time interval between JM (Nørgaard & Hilden, 2004). The crude cycles was further clustered into crude chewing periods, which were classified as either rumination, eating or non-chewing activity based on the regularity of JMO, JM and the BCR values, using the principles described by Schleisner *et al.* (1999). The mean daily time spent eating and ruminating was calculated as the accumulated duration of all eating and rumination periods recorded. The effective daily time spent eating and ruminating was estimated by exclusion of the time between cycles.

Chewing behaviour in **Paper V** was recorded by continuous filming during 96 h. During video observations, eating, rumination, standing and lying behaviours were recorded by use of scan sampling once every 10 min, as described by (Weary & Tucker, 2003). To estimate the daily time spent on each of the recorded behaviours, the lambs were assumed to perform the same behaviour during the 10 min between two recording points.

3.3.4 Faeces

In **Papers II** and **V**, faeces were sampled daily during one (**Paper V**) or two (**Paper II**) four-day periods from each pen and immediately put in freezer. Samples were pooled per ewe (**Paper II**) or per pen (**Paper V**) per period prior to analysis.

After pooling, faeces were washed by use of a detergent in a washing machine to clean the fibre particles from protein, fat and starch. After washing and freeze drying, the particle size distribution was determined by horizontal shaking and sieving as described by Nørgaard *et al.* (2004) and Jalali *et al.* (2012). The six fractions included sieves with pore sizes of 2.360 mm, 1.000 mm, 0.500 mm, 0.212 mm, 0.106 mm and a solid bottom bowl. The arithmetic mean particle size (APS), the geometric mean particle size (GPS), the median and the 95 percentile of the largest sizes (95_PS) were estimated according to Nørgaard (2006).

3.4 Statistical Analyses

Statistical analyses were all performed in SAS (version 9.3, SAS Institute Inc., Cary, NC, USA). Intake and performance data were analysed in completely randomised designs, using PROC MIXED. In **Papers I-III**, treatment and periods were fixed effects, while ewe was a random effect nested within treatment. In **Papers IV** and **V**, inclusion rate of maize silage in the diet and maturity stage at harvest were included as fixed effects, whereas pen was treated as a random effect nested within treatment for feed intake and feed conversion ratio data. For performance data, lamb was treated as a random effect nested within treatment.

Contrasts were used for analysis of un-chopped *vs.* chopped diets and separate *vs.* mixed diets in **Paper I** and for evaluating the effects of inclusion rate of maize silage in the diet and maturity stage at harvest on CP intake (CPI) in relation to BW and on BW in relation to daily LWG in **Paper IV**.

In **Paper IV**, stepwise regression analysis was performed in PROC REG, to evaluate the effects of intakes of CP, MP, ME, NDF, crude fat and starch on LWG, using data on pen level.

In **Papers II, III** and **V**, PROC GLM was used to evaluate the difference in the contents of nutrients and particles of varying sizes in feeds and refusals, using treatment means as repeated variable.

4 Main Results

The main findings in **Papers I-V** are presented in this chapter. All differences are significant ($p < 0.05$) unless stated otherwise. Some syntheses of results from the different experiments are also included. Detailed results from the experiments are presented in the individual papers.

4.1 Paper I

The hypothesis that chopping of silage and mixing of silage and concentrate would increase intake and performance was partly confirmed.

Chopping silage led to a 0.03 kg higher daily increase of DMI during the first ten days of lactation in Exp. 1. During day 11 and day 42 of lactation in Exp. 2, feeding chopped silage increased average daily DMI by 0.5 kg compared to feeding un-chopped silage, whereas feeding a med ration of silage and concentrate increased daily DMI by additionally 0.6 kg. In lactation in Exp. 2, mixing silage and concentrate increased average daily DMI (4.4 *vs.* 3.8 kg) and NDF intake (NDFI; 21.2 *vs.* 18.6 g kg^{-1} BW).

Ewes fed the chopped silage gained 6.6 kg more BW during pregnancy than those fed the un-chopped silage in Exp. 2. Furthermore, lactating ewes fed the chopped diets lost 4.6 kg less BW than those fed the un-chopped diet in Exp. 1. Lactating ewes fed the chopped diets lost 0.3 points less BCS than those on the un-chopped diet, when averaged over physiological status, in Exp. 2.

In Exp. 2, the mixed diet increased LWG from birth to weaning of the lambs by 63 g (454 *vs.* 391 g) compared with the separate diets and the chopped diets increased LWG by 71 g from weaning to slaughter, compared with the un-chopped diet (444 *vs.* 373 g).

Chopping silage increased BW at slaughter by 1.8 kg and decreased age at slaughter by 9 days (Exp. 2) and increased carcass fatness by 1 point (Exp. 1).

Mixing silage increased carcass weight by 1.1 kg and dressing percentage by 1.6%-units (Exp. 1) and decreased age at slaughter by 11 days.

4.2 Paper II

The hypothesis that the chopping of silage and mixing of silage and concentrate would increase intake and rumination time and decrease eating time and dietary selection was partly confirmed.

Chopping silage decreased the dietary selection against NDF, but did not increase DMI in pregnant or lactating ewes. Chopping the silage also decreased daily effective eating time by 83 and 84 min during pregnancy in Exp. 1 and Exp. 2, respectively. Across pregnancy and lactation, chopping the silage shortened the average daily eating periods by 7 min in both experiments. From pregnancy to lactation, ewes fed the chopped diets increased their daily eating time in Exp. 1, and ewes increased their eating periods from pregnancy to lactation, when averaged over treatments in both experiments.

Averaged over pregnancy and lactation, chopping silage increased daily rumination time by 91 and 93 min and by 37 and 28 min kg^{-1} DMI in Exp. 1 and Exp. 2, respectively, with corresponding responses in effective rumination time and JM kg^{-1} silage NDFI. The ewes fed the chopped diets spent 7 and 6 s longer time ruminating each bolus than those fed the un-chopped diet, in Exp. 1 and Exp. 2, respectively. From pregnancy to lactation, the daily effective rumination time decreased by 50 min in Exp. 1 but increased by 84 min in Exp. 2, whereas the rumination time kg^{-1} DMI decreased by 61 and 36 min in Exp. 1 and Exp. 2 respectively, averaged over experimental diets.

From pregnancy to lactation, total chewing time kg^{-1} DMI and kg^{-1} silage NDFI decreased by 66 and 137 min in Exp. 1, and by 63 and 276 min in Exp. 2, averaged over treatments. In lactation in Exp. 1, the daily total chewing time was 24% longer in the mixed diet compared with the un-chopped diet. Averaged over pregnancy and lactation, the eating to rumination time ratio was 25 and 34% lower in the chopped diets compared to the un-chopped diets in Exp. 1 and Exp. 2, respectively. Averaged over treatments and in both experiments, ewes spent more time ruminating than eating per day, except in the treatment with un-chopped silage in lactation in Exp. 1.

Mixing silage and concentrate increased the proportion of faecal particles larger than 2.36 mm by 124% and the particles larger than 1.0 mm by 69%, which increased the arithmetic mean particle size by 15% and the 95_PS by 50% compared to separate feeding of silage and concentrate, averaged over pregnancy and lactation in Exp. 1. From pregnancy to lactation, the proportion of faecal particles larger than 1.0 mm was increased by 75% in Exp. 1 and by 44% in Exp. 2, when averaged over treatments.

4.3 Paper III

The hypothesis that increased digestibility of grass silage by earlier harvest would increase intake and performance in ewes and lambs was confirmed. The early harvested (E) silage contained 58 and 85 g higher CP, 63 and 85 g higher WSC, 148 and 193 g lower NDF, 90 and 116 g lower ADF and 20 and 33 g lower ADL concentrations kg^{-1} DM than the medium harvested (M) and late harvested (L) silages, respectively. The E silage also had 74 and 170 g higher IVOMD kg^{-1} OM and 87 and 191 g lower iNDF content kg^{-1} NDF than the M and L silages, respectively.

The E silage increased daily silage DMI of ewes by 0.6 and 1.0 kg in pregnancy (2.5 *vs.* 1.9 and 1.5 kg DM) and by 1.0 and 1.3 in lactation (3.5 *vs.* 2.5 and 2.2 kg DM), which increased daily silage CPI and ME intake (MEI) in both pregnancy and lactating, compared to the M and L silages. The silage NDFI was 430 g higher per day in the M than in the L treatment and 3.1 g higher kg^{-1} BW (20.3 *vs.* 17.2 g) in the M than in the other treatments in lactating ewes. Averaged over late pregnancy and lactation, the E silage increased silage DMI kg^{-1} BW by 7.3 and 9.0 g (30.7 *vs.* 23.4 and 21.7 g) compared to the M and L treatments, respectively.

The ewes lost 0.25 units of BCS during pregnancy, with no differences between treatments. In lactation, the ewes fed the E treatment had, on average, no loss in BCS, whereas the ewes fed the M and L treatments lost 0.7 and 0.8 units of BCS, respectively. In lactation, ewes fed the E treatment gained, on average, 1.2 kg BW while M and L ewes lost 6.5 and 7.7 kg BW, respectively.

Averaged over sexes, the lambs born from ewes fed the E treatment had 37 and 68 g higher daily LWG than lambs born from ewes in the M and L treatments (421 *vs.* 384 and 353 g). The higher LWG increased weaning weight by 2.2 and 4.0 kg of lambs born from ewes fed the E treatment compared to lambs born from ewes fed the M and L treatments. The total individual concentrate intake by the lambs was 5.8, 6.8 and 8.2 kg for lambs born from the ewes fed the E, M and L treatments, respectively. The birth weights of the lambs were not affected by the treatments.

4.4 Paper IV

The hypotheses that increased maize crop maturity at harvest and that feeding maize silage as only forage would increase intake and performance of finishing lambs was partly confirmed. In Exp. 1, the diets containing maize silage as the sole forage increased DMI and estimated intakes of ME, CP, MP and crude fat, compared to diets containing both grass and maize silages, averaged over maturity stages. Averaged over inclusion rates, the diets containing early maize silage increased daily NDFI and NDFI in relation to BW compared to the late maize silage diets. Lambs fed the late harvested maize silage as the only forage had, on average, 33% higher starch intake than those on the other diets.

In Exp. 2, the diets with maize silage as the sole forage increased intakes of MP starch and crude fat and tended to decrease NDFI compared to the diets with grass and maize silages, averaged over maize maturity stages. Averaged over inclusion rates, the late maize diets increased daily MP intake (MPI), daily NDFI and NDFI in relation to BW, compared to the early maize diets. The starch intake of the lambs fed the late harvested maize silage as the only forage was 27% higher than for those fed the grass-maize diets and 13% higher than for lambs fed the early harvested maize silage as the only forage, which in turn had 12% higher starch intake than those on the grass-maize diets. The fatness of the carcasses was 10% higher in the diets with maize as the only forage compared to the diets containing grass and maize silages, averaged over maturity stages in Exp. 2.

Averaged over treatments and years, the daily CPI and MPI influenced to a similar extent LWG in the stepwise regression analysis:

$$\text{LWG (g)} = 0.149 + 0.0011\ x\ \text{CPI (g)}$$

$$\text{LWG (g)} = 0.231 + 0.0014\ x\ \text{MPI (g)}$$

Across treatments in both years, the daily CPI ($R^2 = 0.70$; $p < 0.001$) and MPI ($R^2 = 0.69$; $p < 0.001$) increased linearly with increasing BW.

The estimated dietary MP:ME ratio ranged between 6.5 and 6.7 in Exp. 1 and between 9.0 and 9.6 in Exp. 2 and across treatments and years, the MP:ME ratio was linearly correlated to the daily LWG according to the equation below ($R^2 = 0.86$; $p < 0.001$):

$$\text{LWG (g)} = 198.3 + 26.9\ x\ \text{MP:ME ratio}$$

4.5 Paper V

The hypothesis that increased stage of maturity at harvest and that increased inclusion rate of maize silage in the diet would increase feed intake, dietary selection, rumination time and faecal particle size and that eating time would be unaffected in finishing lambs, was not confirmed. Neither daily DMI nor NDFI was affected by maturity stage or inclusion rate of maize silage, but the daily ADF intake tended to increase by including grass silage in the diets (p = 0.06).

Lambs fed diets with maize silage as the sole forage spent 35 min less on eating daily and 40 min less on eating kg^{-1} DMI, when compared to lambs fed diets containing grass and maize silage. The length of the eating bouts was 3.3 min longer for the lambs fed the maize diets than for those on the grass-maize diets, averaged over maize maturity stages.

The inclusion of grass silage in the diets tended to increase the rumination time kg^{-1} DMI by 33 min. Total daily chewing time kg^{-1} DMI was 72 min longer in grass-maize diets than in maize diets and maize diets increased proportion of the ruminating time standing compared to grass-maize diets. Grass-maize diets decreased the number of standing bouts by 1.3. The lambs fed the late harvested maize silage as the only forage spent on average 9 min more time daily lying down than lambs on the other treatments. Increased maturity stage at harvest of maize silage tended to decrease the daily time spent lying down by 34 min.

Averaged over maize inclusion rates and maturity stages at harvest, the proportion of particles retained on the 30 and 19 mm sieves did not differ between offered feeds and refusals. The proportion of particles retained on the 8 mm sieve was 26% higher and particles on the bottom bowl were 119% higher in the refusals than in the offered feeds. The proportion of particles retained on the 1 mm sieve was 62% higher in the offered feeds than in the refusals, when averaged over maize inclusion rates and maturity stages at harvest. Averaged over inclusion rates of maize silage, the late harvested maize increased the sorting for particles retained on the 1 mm sieve by 121% compared to the early harvested silage.

Averaged over maize inclusion rates and maturity stages at harvest, the NDF and ADF contents were 19 and 26% higher, respectively, in the refusals than in the offered feeds.

Averaged over maturity stages at harvest, the grass-maize diets increased the proportion of faecal particles between 0.106 and 0.212 mm and smaller than 0.106 mm by 18 and 20%, respectively, compared to the maize diets. The maize diets increased the proportions of faecal particles between 0.212 and 0.5 mm by 8% compared with the grass-maize diets.

4.6 Dietary Factors Affecting Production

4.6.1 Pregnancy, Lactation and Suckling Lambs

The daily silage DMI of pregnant and lactating ewes was positively correlated to the silage DOMD and CP concentrations and negatively correlated to the NDF concentration of the silages used in **Papers I** and **III** (Figure 2).

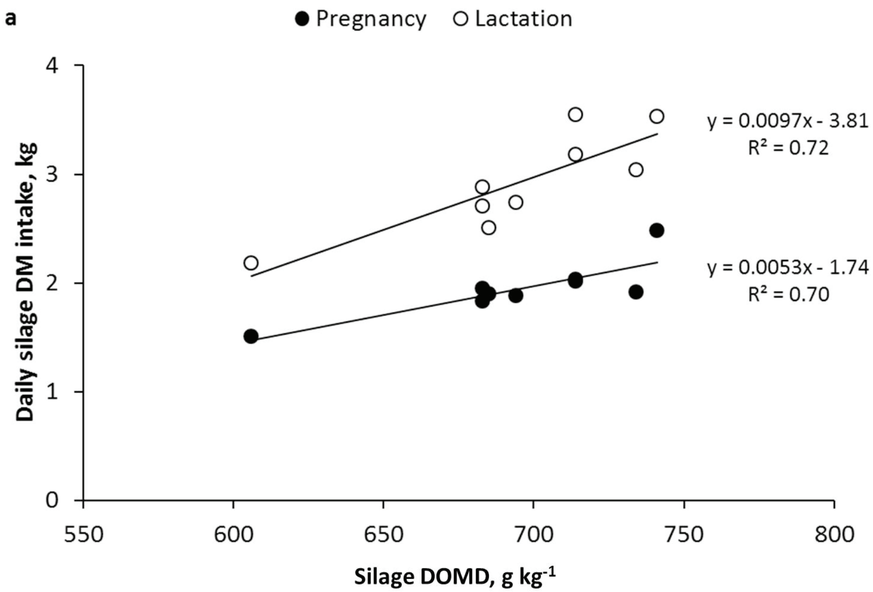


Figure 2a. Relationship between silage digestible organic matter in the dry matter (DOMD) and daily silage dry matter (DM) intake in pregnant and lactating ewes in **Papers I** and **III**.

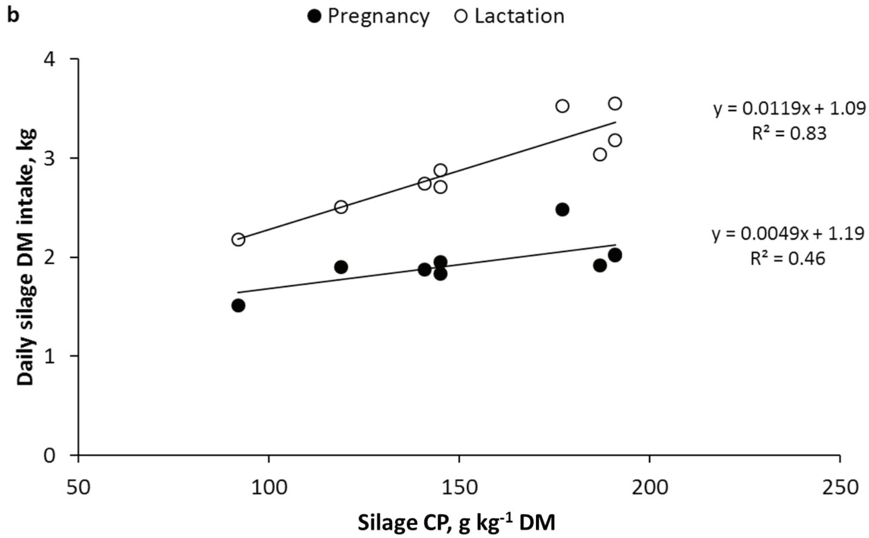


Figure 2b. Relationship between silage crude protein (CP) concentration and daily silage dry matter (DM) intake in pregnant and lactating ewes in **Papers I** and **III**.

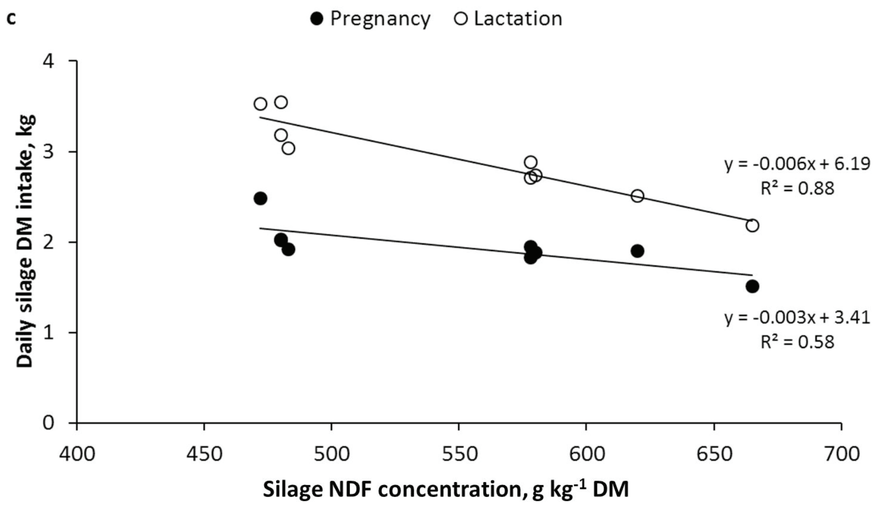


Figure 2c. Relationship between silage neutral detergent fibre (NDF) concentrations and daily silage dry matter (DM) intake in pregnant and lactating ewes in **Papers I** and **III**.

The ewe BW and lamb LWG were affected by the increased DOMD, CP and ME concentrations in silages used in **Paper III** (Table 1). The BWs of the ewes were to a greater extent affected by the increased DOMD, CP and ME concentrations from M to E than from L to M harvest (**Paper III**). There was a greater effect of the increased CP content on LWG of suckling lambs from L to M than from M to E harvest, whereas there was a larger effect of the increased DOMD content on LWG of suckling lambs from M to E than from L to M harvest (**Paper III**). The increased energy density by 1 mega joule (MJ) ME from L to M harvest in silage fed to lactating ewes, increased daily LWG by 21 g of their suckling lambs. The corresponding increase in daily LWG per 1 MJ ME increase from M to E harvest was the double, 42 g (**Paper III**; Table 1).

Table 1. *The response to 10 units of increased digestible organic matter in the dry matter (DOMD) and crude protein (CP) and to 1 unit of increased metabolizable energy (ME) on BW (kg) in lactating ewes and live weight gain (LWG; g day^{-1}) in suckling lambs in* ***Paper III***.

				From L[1] to M[2]		From M to E[3]	
Per kg DM	L	M	E	Ewe BW	Lamb LWG	Ewe BW	Lamb LWG
DOMD, g	605	684	739	0.2	3.9	1.4	6.8
CP, g	92	119	177	0.4	11.5	1.3	6.5
ME, MJ	9.3	10.8	11.7	0.8	20.7	8.6	41.7

[1]Late harvested grass silage, [2]Medium harvested grass silage, [3]Early harvested grass silage

The daily LWG in suckling lambs were correlated to the daily ME intake of the lactating ewes according to the equation below (**Papers I** and **III**; Figure 3; $R^2 = 0.69$; $p < 0.001$):

$$\text{LWG (g)} = 257 + 3.42 \text{ x ME intake (MJ)}$$

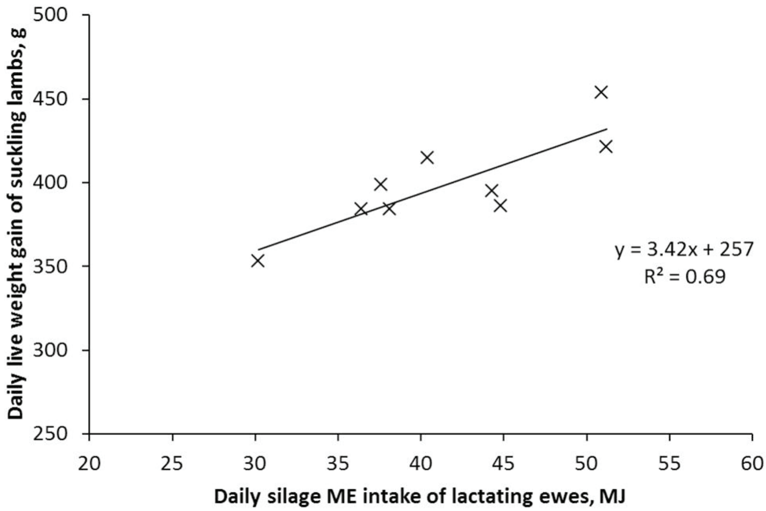


Figure 3. The correlation between daily live weight gain (g) of suckling lambs and daily intake of mega joule (MJ) metabolizable energy (ME) from silage in lactating ewes in **Papers I** and **III**.

4.6.2 Finishing Lambs

The main dietary factors affecting daily LWG of lambs in **Paper IV** were the estimated daily CPI and MPI, caused by dietary contents of CP and MP. A synthesis of the CPI *vs.* BW in **Papers I** and **IV** is shown in Figure 4. The data is divided into two groups: i) the two "medium" performing years (Exps. 1 in **Papers I** and **IV**) and ii) the two "high" performing years (Exps. 2 in **Papers I** and **IV**). According to the equations in Figure 4, the daily CPI of a medium performing lamb (average daily LWG 376 g) of 30 kg and 40 kg is 184 g and 234 g, respectively, whereas the daily CPI of a high performing lamb (average daily LWG 434 g) of 30 kg and 40 kg is 227 g and 294 g, respectively.

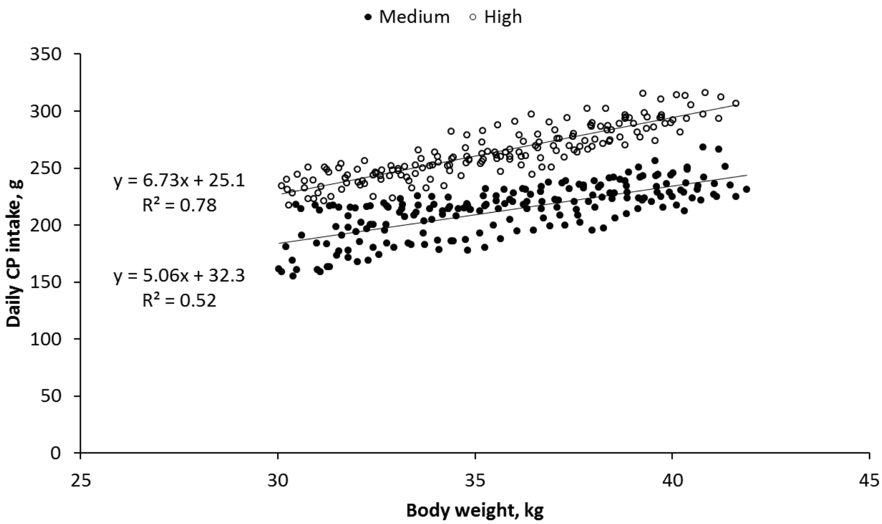


Figure 4. The correlation between daily CP intake and body weight of finishing lambs in **Papers I** and **IV**, divided into years with medium (376 g d^{-1}) and high (434 g d^{-1}) live weight gain.

5 Discussion

5.1 Chopping Silage

The daily DMI was not increased in pregnant or lactating ewes by chopping the grass silage just before feeding (**Papers I** and **II)**. This is in contrast to other studies which showed increased DMI in wethers fed silage chopped just before feeding (Dulphy & Demarquilly, 1973, Dulphy *et al.*, 1975; Deswysen et al, 1978). The increased DMI was thought to be a cause of a decreased rumen retention time of the chopped silage (Deswysen *et al.*, 1978). Additional studies found increased DMI due to chopping silage fed to pregnant and lactating ewes (Apolant & Chestnutt, 1985; Chestnutt, 1989; Elizalde & Henríquez, 2009). As the forages in those previous studies were chopped before ensiling, the ensiling process and the silage digestibility were likely improved compared with the un-chopped silages studied (Huhtanen *et al.*, 2002). An increased grass silage digestibility will increase feed intake in pregnant and lactating ewes (**Paper III**; Keady *et al.*, 2013). In addition Huhtanen *et al.* (2002) showed that improved fermentation characteristics of silage also have a direct effect on DMI by ruminants. Thus, the increased feed intake as a response to chopping in the previous studies (Apolant & Chestnutt, 1985; Chestnutt, 1989; Elizalde & Henríquez, 2009) cannot be separated from the effects of the silage fermentation characteristics. Another difference between those earlier studies and **Paper I** and **II** is that the ewes in our study had higher BCS (3.1-3.7 *vs.* 2.4-2.5 in Apolant & Chestnutt, 1985; Elizalde & Henríquez, 2009). The ewes in the earlier studies might have had a need for compensating previous underfeeding and therefore the feed intake was enhanced when the silage was fed chopped, as chopping increases intake rate, rumination time and efficiency of rumination (Deswysen *et al.*, 1978; Deswysen & Ehrlein, 1981). Ewes fed chopped silage in **Paper II** increased their eating time from pregnancy to lactation, whereas no difference was found for ewes fed un-chopped silage. The ewes fed un-chopped silage spent longer time eating compared with the other treatments in pregnancy, suggesting more time spent on selective behaviour. However, during lactation the ewes fed the chopped diets spent as long time eating as those fed the un-chopped diet (**Paper II**).

Chopping the silage decreased the dietary selection of forage particles with low NDF concentration in **Paper II**, reflected by a larger difference between NDF concentration in the feed and in the refusals when fed the un-chopped compared to the chopped silages. Ewes in the chopped diets, however, also sorted against NDF. The selection of silage particles with low NDF concentration was more prominent in lactation than in pregnancy, when averaged over treatments, suggesting that ewes spent more time and effort on selecting desired particles in lactation than in pregnancy. Sorting for desired and against undesired silage particles is common in ruminants and both sheep and cattle have been shown to sort against NDF in silage (Bernes *et al.*, 2008; Rustas & Nadeau, 2011).

Ewes fed chopped silage spent less time eating and more time ruminating compared to those fed un-chopped silage, both in pregnancy and lactation in both experiments in **Paper II**, which agrees with results by *e.g.* Deswysen *et al.* (1978) and Deswysen & Ehrlein (1981). In addition, the ewes fed either of the chopped diets spent relatively more time and effort on rumination than on eating, compared with the ewes fed the un-chopped diet, reflected both in the daily time and the number of JM on rumination and eating (**Paper II**). The chewing process during rumination is more efficient in degrading the forage particles than during eating, which can be visualised by the higher number of JM kg^{-1} silage NDFI while ruminating (circa 33 300) than while eating (circa 24 500), averaged over treatments, pregnancy and lactation and experiments in **Paper II**. This reflects how crucial rumination is for the reduction of forage particle size, which is essential for the particles to escape the rumen and enter the omasum (Ewing & Wright, 1918). Therefore, increased daily rumination time and increased rumination relative to eating time should increase the potential for silage intake by decreased rumen retention time as a result of reduced particle size. However, the silage DMI was not increased by chopping the silage in **Paper II**. As the particles are reduces in size, their density in relation to size increases, which is an as important physiological aspect in explaining rumen retention time as the particle size reduction. The increased rumination time in the chopped diets might have improved the extent of fermentation of particles in the rumen and nutrient absorption by the ewes (Allen, 1996). This is reflected by the increased BW of ewes due to chopping silage in Exp. 1 in **Paper I**, without a corresponding increase in feed intake.

In Exp. 2 in **Paper II**, chopping of silage tended to decrease effective eating time and the number of chews (JM) kg^{-1} silage NDFI. These effects were not found in Exp. 1 in **Paper II**. As the animals used in the two experiments were selected from the same farm and were similar in genotype, BW, BCS and age, the different responses found are most likely due to the differences of the silages used. The silage used in Exp. 1 had higher DM (583 *vs.* 353 g kg^{-1}) and NDF content (575 *vs.* 466 g kg^{-1} DM) and lower IVOMD (876 *vs.* 924 g kg^{-1} DM) and CP content (139 *vs.* 193 g kg^{-1} DM) than that in Exp. 2. Consequently, the ewes spent less time and effort (JM) on eating when the chopped silage contained less fibre, more water and protein, and had higher digestibility. Similar effects were found by Jalali *et al.* (2012), where a decreased NDF content from 578 to 449 g kg^{-1} DM decreased the effective eating time kg^{-1} DMI by 30% in pregnant ewes fed un-chopped grass silages varying in digestibility. The higher IVOMD and the lower NDF content of the silage were assumed to be the major reasons for the higher intake, the smaller faecal particle size and the decreased eating time per unit of silage NDFI in lactation, in Exp. 2 compared to Exp. 1 (**Paper II**), which is in agreement with Jalali *et al.* (2012). Also, the chewing recording period during lactation was circa two weeks later in lactation in Exp. 2 than in Exp. 1, which might have contributed to the higher intake level in Exp. 2 than in Exp. 1, as rumen re-expansion after lambing might have come further four weeks than two weeks after lambing. However, the intake level was not consistently higher in week 4 than in week 2 of lactation in **Papers I** and **III** (Figure 1 in **Paper I**; Figure 1 in **Paper III**).

Furthermore, highly digestible silage needs less rumination kg^{-1} DMI and kg^{-1} NDFI to be reduced in size and is more easily digested by microbes in the rumen, compared to forages with low digestibility, as shown and discussed by Jalali *et al.* (2012), suggesting the higher silage digestibility being a main factor for the higher DMI in lactation in Exp. 2 compared to Exp. 1 (**Paper I**), as shown in Figure 2a in this thesis.

In Exp. 2 of **Paper I**, the chopping of silage increased the BW gain of the ewes during pregnancy, which is in line with Chestnutt (1989), when pregnant ewes were fed either early harvested, chopped silage or late harvested, un-chopped silage. Obviously, in that study, the effect of chopping length on feed intake cannot be separated from the effect of improved silage fermentation and increased digestibility on silage intake. In Exp. 1 of **Paper I**, lactating ewes fed the chopped silage lost 62% less BW than the ewes fed un-chopped silage, which is in line with Exp. 1 of Apolant & Chestnutt (1985), where lactating ewes lost 41% less BW when fed chopped as compared to un-chopped silage. However, in Exp. 2 of **Paper I**, ewes on all treatments *gained* BW during lactation, most likely due to the relatively high silage digestibility. In Exp. 2

and 3 of Apolant & Chestnutt (1985), the lactating ewes *lost more* BW when fed chopped silage, partly explained by decreased silage digestibility in Exp. 3. Although the BW decreased due to chopping silage in Exp. 2 of Apolant & Chestnutt (1985), the silage DMI, milk yield and LWG of suckling lambs increased due to chopping silage.

In pregnant ewes in **Paper I**, BCS was not affected by chopping silage. In contrast to our results, Elizalde & Henríquez (2009) showed a better maintained BCS of ewes in late pregnancy when fed precision chopped compared to long haylage (56-70% DM). The chopped haylage, however, had higher DM and lower ammonia content than the long haylage. Consequently, it is not possible to determine whether or not the chopping *per se* improved the BCS of pregnant ewes in the study by Elizalde & Henríquez (2009). Apolant & Chestnutt (1985) showed increased silage intake (1.4 *vs.* 1.0 kg DMI) in ewes during the first 28 days of lactation due to precision chopping grass silage of varying qualities. As stated before, such difference was not found in our study (**Paper I**), but the average silage intake during lactation was considerably higher (3.0 kg DMI) than that in Apolant & Chestnutt (1985). Compared to **Paper I** there are large differences in animals *and* feeds used. For example, the animal feed intake level, which cannot be fully explained by differences in ewe BW (circa 70 *vs.* circa 90 kg), although a major difference between the studies. One other possible explanation for the different intake levels in the compared experiments is the lower DM content (19-23% *vs.* 35-56% in **Paper I**) of the silages used by Apolant & Chestnutt (1985), which probably inhibited the ewes from fully utilizing their intake potential.

The increased daily LWG from 386 to 424 g (+38 g) of suckling lambs from ewes fed the chopped diets compared with those fed the un-chopped diet in Exp. 2 of **Paper I** are in accordance to the findings by Apolant & Chestnutt (1985), where chopping silage increased daily LWG from 185 to 243 g (+58 g) as a cause of increased milk yield. The magnitude of the response is larger in the latter and this magnitude difference between studies is difficult to explain. However, as indicated by others (*e.g.* Deswysen *et al.*, 1978; Apolant & Chestnutt, 1985; Nadeau *et al.*, 2012), the silage fermentation quality is improved by chopping the herbage before ensiling, which was the case in the studies by Apolant & Chestnutt (1985).

The response to chopping grass silage on feed intake and LWG of finishing lambs has been thoroughly investigated by others and the increased average daily LWG from 373 to 444 g (+71 g) of lambs from weaning to slaughter fed chopped silage diets in Exp. 2 in **Paper I** is in agreement with results by Fitzgerald (1984) and Fitzgerald (1996a, 1996b, 1996c), where average lamb performance ranged from daily live weight loss of 6 g to LWG of 151 g, when fed silage only and with results by Fitzgerald (1996c), where average lamb daily LWG was 90 to 150 g when supplemented with barley. In contrast to those earlier studies, the feed intake of lambs was not increased by chopping silage in **Paper I**. The increased LWG and lack of increase in feed intake (**Paper I**) was possibly due to higher feed efficiency as a result of more efficient rumination by the lambs fed chopped silage in our experiments, as suggested by Deswysen *et al.* (1978) and Deswysen & Ehrlein (1981), who found that pseudo-rumination was more frequent in lambs fed un-chopped silage than in those fed chopped silage. It is likely that the supplementation of concentrate in **Paper I** enhanced feed efficiency resulting in increased daily LWG without increased intake, in agreement with Fitzgerald (1996c), where inclusion of barley increased feed efficiency by a relatively larger increase in LWG, than in total DMI. One possible explanation for the different responses to chopping silage in Exp. 1 and 2 in **Paper I** is the different silage characteristics in the two experiments. The higher silage digestibility in Exp. 2 than in Exp. 1 is thought to have caused the higher LWG of lambs fed chopped silage due to the same synergy mechanisms between silage digestibility and chopping in *e.g.* Apolant & Chestnutt (1985), as increasing digestibility has been shown to be one of the most important factors for enhancing production in sheep (Keady *et al.* 2013).

5.2 Mixing Silage and Concentrate

In **Paper I**, mixing of grass silages (DOMD of 686 and 722 g kg^{-1} DM) and concentrates did not increase DMI in pregnant ewes. In contrast to our study, Chestnutt & Wylie (1995), showed a 42-49% increase of silage DMI during the last 4 weeks of pregnancy when ewes were fed a total mixed ration compared to silage and concentrate separately, using two grass silages (DOMD of 658 and 705 g kg^{-1} DM). The increased DMI of pregnant ewes fed the mixed ration in the study by Chestnutt & Wylie (1995) also increased the BW gain during late pregnancy and resulted in less weight loss at lambing, which was not seen in the mixed ration in **Paper I**. The most obvious differences between the studies were that Chestnutt & Wylie (1995) fed silages containing less DM (19-24 *vs.* 35-56% in **Paper I**), which were chopped before ensiling, which is well-known to improve fermentation as discussed above (5.1). The low DM content of the silages used by Chestnutt & Wylie (1995) most likely lead to DM losses and probably affected the DMI of the pregnant ewes negatively. This negative effect on silage DMI is reflected in the large difference in average daily silage DMI of pregnant ewes between the previous study (954 g) and our study (1,985 g). No other published studies could be found and the area of mixing ensiled forages and concentrate before feeding pregnant ewes needs further attention.

In lactating ewes in Exp. 2 of **Paper I**, the mixed diet increased daily silage DMI and daily total DMI in relation to BW compared to the diets with concentrate fed separately. As the concentrate intake was more evenly distributed in the mixed diet, the degradation of starch from the concentrate was more evenly distributed over time in the mixed diet compared with separate diets and, therefore, the rumen pH fluctuations were minimized (Mould *et al.*, 1983; Ørskov, 1999), which might have improved the fibre degradation in the mixed diet when compared to the separate diets (**Papers I-II**).

As increased forage NDF content and decreased digestibility of NDF and DM decrease voluntary DMI of ruminants (Van Soest, 1965; Allen, 1996), a high rate of degradation of NDF and DM in the rumen to enable high intake, is especially important in lactation, when the nutritional demands of the ewe are at the highest. Restriction of pH fluctuations in the rumen by simultaneous feeding of starch-rich concentrates and fibre-rich silages promotes forage fibre digestion and a higher outflow rate from the rumen (Mould *et al.*, 1983; Allen, 1996), which would explain the higher intake of the ewes fed the mixed diet as compared to the ewes fed separate diets in lactation in Exp. 2 (**Paper I**). In lactation in Exp. 1, the proportion of large particles in faeces increased by mixing silage with concentrate, which further indicates a higher outflow rate from the rumen with mixed feeding compared to separate feeding (**Paper II**). However, the outflow rate may also have been increased by a higher concentrate intake due to sorting for concentrate in the mixed diet. Dietary selection may partly explain the lack of intake and production response to mixing silage with concentrate in Exp. 1 (**Paper I**), as the ewes and the lambs selected the concentrate in the mixed ration to a larger extent in Exp. 1 than in Exp. 2. The most likely explanation is a too high DM content of the mixed ration in Exp. 1, as a result of the higher DM content of the silage (583 *vs.* 353 g kg^{-1}) in Exp. 1 than in Exp. 2. Thus, the synergy effects on intake and performance of consuming silage and concentrate simultaneously seen in Exp. 2, were unexploited in ewes fed the mixed diet in Exp. 1 (**Paper I**). Furthermore, although not statistically analysed, the ewes in all treatments sorted against NDF to a larger extent in Exp. 1 than in Exp. 2, most likely due to both the higher contents of DM (583 *vs.* 353 g kg^{-1}) and NDF (580 *vs.* 483 g kg^{-1} DM) and the lower IVOMD (870 *vs.* 905 g kg^{-1}) of the silages in Exp. 1 than in Exp. 2 (**Paper II**).

Milk yield response by the ewes was assumed to be reflected by differences in daily LWG of suckling lambs (**Paper I**). Thus, the higher LWG of suckling lambs born from ewes fed the mixed diet in Exp. 2, shows and increased milk yield by the ewes fed the mixed diet in Exp. 2, most likely due to the higher DMI. Increased milk yield could also be an effect of improved nutrient utilisation in the mixed diet, as feeding silage and concentrate in a mixed ration gives a more even supply of energy from carbohydrate fermentation to be used for microbial protein synthesis (Børsting *et al.*, 2003).

In pregnant and lactating ewes, the mixed diet increased daily rumination time, total chewing time and daily JM compared to the diet with un-chopped silage and concentrate fed separately, in both experiments in **Paper II**, suggesting a synergy effect on chewing behaviour of both chopping silage and mixing it with concentrate.

In the Exp. 1 in **Paper I**, the lambs on the mixed diet had heavier carcass weights than the lambs on the separate diets, due to a higher dressing percentage at slaughter. These findings are comparable to those of Czarnik-Matusewicz *et al.* (1999) where lambs fed a mixed ration of hay, ground barley and rapeseed meal had heavier slaughter weights than lambs fed the feedstuffs separately. However, Czarnik-Matusewicz *et al.* (1999) showed decreased intake by feeding a mixed diet, which was not observed in our experiments (**Paper I**). No other published studies could be found and the research area of ensiled forages in mixed ration feeding for growing lambs needs further investigations.

In addition to the positive production response in **Paper I**, Johansson (2007) showed in a farm survey that other benefits from using mixed feeding systems as compared to separate feeding systems are; decreased labour related to feeding, reduced animal stress around feeding and the possibility of using cheap feed stuffs. Furthermore, economical calculations from the experiments in **Paper I**, showed that the mixed feeding system increased gross margin (slaughter income – feed costs) by circa 20 euro per ewe, mostly due to the slightly higher slaughter income and the lower lamb concentrate costs (Nadeau *et al.*, 2011).

5.3 Grass Silage Digestibility

The increased DMI of pregnant and lactating ewes due to higher grass silage digestibility (**Paper III**) is in agreement with earlier findings in pregnant ewes (Chestnutt, 1989) and in finishing lambs (Bernes *et al.*, 2008; Keady & Hanrahan, 2013). Early harvest of grass for silages leads to lower NDF content, higher DM and NDF digestibility and higher CP and ME contents, which will increase silage CPI and MEI due both to the higher DMI and due to the higher CP and ME contents of the silages. This 'double effect' increased CPI by circa

200% and MEI by circa 100%, averaged over pregnancy and lactation, by feeding early compared to late harvested grass silage in **Paper III**.

Prior to the start of the study in **Paper III**, the chewing behaviour and faecal characteristics of the pregnant ewes were studied and are presented in Jalali *et al.* (2012). The ewes fed early harvested silage spent shorter time eating and ruminating kg^{-1} DMI compared with those fed medium or late harvested silages. Furthermore, feeding the early harvested silage increased the proportion of faecal particles larger than 1 mm and smaller than 0.2 mm, when compared to the late harvested silage. The proportion of small particles increased, however, more than the proportion of large particle, which led to smaller mean faecal particle size and width in ewes when feeding early compared to late harvested silage (Jalali *et al.*, 2012).

The higher intake of the early harvested silage compared to the late harvested silage in **Paper III** resulted in 55% lower BW loss and 53% lower BCS loss from pregnancy to lactation, which is in line with Apolant & Chestnutt (1985), where ewes lost 61% less BW after lambing when fed early harvested compared to late harvested grass silage. Ewes fed the late harvested silage (**Paper III**) had BCS lower than recommended levels in both pregnancy and lactation (Arnesson & Eggertsen, 2006), even though their nutritional requirements were fulfilled according to national (Spörndly, 2003) and international (NRC, 2007) estimations. Although the ewes in all treatments (**Paper III**) increased their intake from pregnancy to lactation, the BCS decreased for all ewes and to a greater extent in ewes fed late compared to early harvested silage. This decrease in BCS has been shown to commonly occur in lactating sheep and cattle (Robinson *et al.*, 1999; Roche *et al.*, 2008). However, the ewes fed early harvested silage in **Paper III** kept their BCS within recommended levels and even increased their BCS slightly during week 6 and 7 of lactation, showing that this inevitable loss of BCS may be limited without increasing the supplementation of concentrates. The better maintained BCS of the lactating ewes fed early harvested compared to the medium and late harvested silages suggests that when fed early harvested silage, ewes will not have to mobilize as much of their body reserves, to cover their protein and carbohydrate requirements for milk synthesis, as ewes fed medium or late harvested silage (**Paper III**).

With earlier harvested grass silage fed to lactating ewes, suckling lambs increased their LWG (**Paper III**) in agreement with *e.g.* Apolant & Chestnutt (1985). Increased LWG with earlier harvest of grass silage has also been shown in previous studies with finishing lambs (Bernes *et al.*, 2008; Keady *et al.*, 2013). Increased LWG will decrease number of days to weaning and possibly to slaughter, thereby potentially lowering the labour cost. In addition, the suckling lambs consumed less concentrate when the earlier cut grass was fed to their mothers, indicating a higher milk production and decreased feed costs with earlier harvested grass silage (**Paper III**). One possible explanation to the lower LWG of suckling lambs born from ewes fed medium or late harvested silages (**Paper III**) is under-nutrition of the ewes, as under-nutrition of pregnant ewes has shown to decrease ewe milk production and quality during lactation (Kiani *et al.*, 2011) and LWG of suckling lambs (Tygesen & Harrison, 2005). It is, however, unlikely to have been the most important factor in **Paper III**, as the ewes were ensured a nutrition intake in accordance with or above the minimum recommendations (NRC, 2007), in contrast to the earlier studies (Tygesen & Harrison, 2005; Kiani *et al.*, 2011).

The GPS and APS values were generally higher in Exp. 1, which most likely is due to the lower digestibility of the silage in Exp. 1, in agreement with the findings by Jalali *et al.* (2012), who found increased GPS value in faeces from the pregnant ewes used in **Paper III** due to decreased silage digestibility.

Although straw intake was not recorded, it was considered minor and not to have limited intake or to have caused any effects on the results in this thesis, as the average NDFI levels from the experimental diets in pregnancy (1.3% of BW) and lactation (2.0% of BW) in **Papers I** and **III**, were relatively high.

5.4 Pregnancy *vs.* Lactation

In **Paper III**, the silage intake was somewhat lower in late than in mid-pregnancy, partly because the supplement feeding of concentrate started during end of mid-pregnancy, partly because the foetal growth decreases the space for the rumen and thereby limits the rumen fill capacity, which limits forage intake (Roche *et al.*, 2008).

Some of the silages fed to the ewes during lactation was consumed by the lambs and was considered equal over treatments (**Papers I-III**). Although not analysed statistically, the lambs born from ewes fed the early silage diet compared to the lambs born from ewes fed the medium and late silage diets in **Paper III**, and lambs born from ewes in the mixed diet in Exp. 2 compared to lambs born from ewes in the separate diets in **Paper I** had a somewhat lower lamb concentrate intake. Consequently, the increased DMI of lactating ewes fed early harvested silage in **Paper III** and the mixed diet in Exp. 2 in **Paper I** might reflect a higher intake by the lambs and the increased LWG of suckling lambs might therefore not solely be an effect of increased milk production by the ewes. The increased BCS during lactation week 6 and 7 of the ewes fed the early diet (**Paper III**), suggests decreased milk production, which might indicate that lambs had adopted to a solid diet and needed less milk for growth.

The ewes were fed 0.8 kg concentrate daily during the last four weeks of pregnancy and during the whole lactation in **Papers I-III**. Daily silage DMI increased by 20 and 30% in Exp. 1 and 2 in **Paper I** and by 40% in **Paper III** from late pregnancy to lactation. The increased DMI from pregnancy to lactation (**Papers I-III**) was associated with a decreased rumination time kg^{-1} DM from pregnancy in lactation (**Papers I** and **II**). As the daily intake of concentrate was constant throughout the experiments and the higher DMI in lactation was a result of a higher silage DMI, consequently the forage:concentrate ratio increased from pregnancy to lactation (**Papers I-III**). A higher forage:concentrate ratio increases the NDF concentration in the consumed diet, which should increase chewing kg^{-1} DMI. However, Faichney & Brown (2004), also showed decreased rumination time kg^{-1} DMI with increasing DMI in wethers. The rumination efficiency also increased with increased DMI in the wethers, which is likely to have been the case also in lactation in **Papers I-III** as compared to the pregnancy in the respective experiment. The main factor affecting daily rumination time is daily silage NDFI, which increased substantially from pregnancy to lactation, in both experiments with increased daily rumination time in Exp. 1. Also daily eating time was increased from pregnancy to lactation in both experiments and eating periods and eating cycles were longer in lactation compared with pregnancy, which means that the ewes were more eager to eat in lactation than in pregnancy (**Paper II**).

The daily NDFI in relation to BW of lactating ewes was generally higher (19 to 22 g kg^{-1} BW), than that of pregnant ewes (11 to 15 g kg^{-1} BW; **Papers I-III**). This indicates the high daily intake potential of lactating ewes. Most published studies on intake of ensiled forages of sheep focus on wethers (*e.g.* Deswysen *et al.*, 1978; Apolant & Chestnutt, 1985), pregnant ewes (*e.g.* Chestnutt, 1989; Chestnutt & Wylie, 1995), early lactation (*e.g.* Apolant & Chestnutt, 1985; Bernes & Stengärde, 2012) or finishing lambs (*e.g.* Weston, 1974; Fitzgerald, 1996a, 1996b, 1996c; Bernes *et al.*, 2008; Keady & Hanrahan, 2013), which means there is little information available on the feed intake of indoor fed lactating ewes until weaning of lambs.

The lower daily NDFI of pregnant ewes in Exp. 2 than in Exp. 1 (1.0 *vs.* 1.2 % of BW; **Papers I** and **II**) suggests, given the high intake potential shown in lactation, metabolic rather than physical regulation of intake during pregnancy in Exp. 2, *i.e.* the ewes could easily have eaten more, if they had needed the energy, before reaching the full volume capacity of the rumen. Further supporting this suggestion is the lower correlation between silage NDF concentration and daily silage DMI in pregnant than in lactating ewes in **Papers I** and **III** (Figure 2c). In connection, the increased proportion of large particles in faeces from late pregnancy to early lactation, in all treatments in both experiments in **Paper II**, suggests a higher outflow rate from the rumen in lactation than in pregnancy.

Compared to the nutrient requirements by NRC (2007), the ewes in our studies exceeded their daily estimated energy requirements by 1 to 16 MJ ME in pregnancy and by 6 to 27 MJ ME in lactation (**Papers I** and **III**). In **Paper III**, the medium silage as the sole feed would have covered the average requirements in late pregnancy, but without supplementation with concentrate during lactation, only the early silage would have met the requirements of ewes with two suckling lambs.

5.5 Maize Maturity at Harvest

To obtain maize silage of high nutritional and hygienic quality, the optimum maturity stage at harvest is generally considered to occur when the DM of the maize crop is 30-35% (Nadeau *et al.*, 2010).

Daily DMI and LWG was only to a minor extent affected by the maturity stage of the maize crop at harvest (**Paper IV**), which might be due to that the diets were balanced for CP and ME. In line with our findings, the study of finishing lambs by Keady & Hanrahan (2013) showed no increase in feed intake or LWG of lambs with increasing starch content of the maize silage from 3 to 28% of DM as a response to increased maturity of the maize crop. However, the maize silage DM in that study was lower compared to the DM of maize silages used in **Papers IV-V** (18-22 *vs.* 26-38%) and compared to the optimum DM at harvest (30-35%). In the study by Keady & Hanrahan (2013) the average daily LWG of lambs was lower (155-200 *vs.* 360-468 g), in diets with similar concentrate intake to that of the lambs in our study (**Paper IV**). The differences in silage DM and average lamb LWG between our study and the study by Keady & Hanrahan (2013), make it difficult to conclude the magnitude of the effect of delayed maize harvest on finishing lamb performance, which should be considered when inferring these experimental findings to on-farm practices.

The daily NDFI in relation to BW was higher in lambs fed early compared to late maize diets in Exp. 1 and surprisingly vice versa in Exp. 2 (**Paper IV**). However, the NDFI in **Paper V** ranged from 10.9 to 12.0 g kg^{-1} BW, and was not affected by maize maturity at harvest. The NDFI in relation to BW in **Papers IV-V** was similar to that found in pregnant ewes but lower than that of lactating ewes in **Papers I-III**. The NDFI in relation to BW of the animals in **Papers I-V** is considered sufficient for enabling a functional and healthy rumen, and well above the equivalence of 2% straw on a DM basis proven sufficient in whole-wheat based diets of finishing lambs (Weston, 1974). As the straw intake of the lambs (**Papers IV-V**) was not registered, it cannot be fully ruled out that the lambs completed the experimental diets by eating straw from the bedding. However, as the NDFI was at an expected level (1.1 to 1.2 % of BW) and no signs of clinical or subclinical ruminal disorders were detected at any point of the experiments in **Papers IV-V**, the straw intake was considered of minimal relevance to the results in this thesis.

Averaged over diets (**Paper V**), lambs sorted against NDF in the diets as reflected by the higher NDF content of refusals than of offered mixed rations, which agrees with results by Rustas *et al.* (2010) when barley silage at the dough stage of maturity was fed to dairy steers. Dietary sorting of particles is often reported in small ruminants (Baumont *et al.*, 2000), as shown by Bernes *et al.*, 2008, where finishing lambs sorted against NDF and selected high CP particles of timothy silage. In both maize silage and barley silage, selection for the highly digestible starch in the kernels is favoured on the expense of the less digestible fibres in the stover, especially at advanced maturity stages of the forages. Furthermore, the sorting against NDF and selection for particles 1 to 8 mm size, which was especially pronounced when fed the late harvested maize silage in the mixed ration, shows sorting in favour for grains and fine leaves in the maize silage and for concentrate in the diet (**Paper V**). Another possible explanation for the sorting might be the high DM contents of the experimental rations, especially in those containing the late harvested maize silage, enabling the lambs to easily sort for desired feed particles. Neither chewing time nor faecal particle size distribution was affected by maturity stage at harvest of the maize. It should be noted that the starch level and hygienic quality of silages in the present study were high, as a result of beneficial weather conditions during the two seasons and good preservation practices. If lower quality maize silages, or maize harvested earlier than at the dough stage, at starch concentrations below 20%, had been used, larger differences in intake and other studied parameters might have been obtained (**Papers IV-V**).

5.6 Maize *vs.* Grass

Even though the diets were formulated to contain the same CP and ME contents on a DM basis, the lambs fed diets with maize as the only forage, hereafter called maize diets, had higher estimated intakes of starch, crude fat and MP than lambs fed diets containing both grass and maize silages, hereafter called grass-maize diets, in both years (**Paper IV**). In Exp. 1, intakes of DM, ME and CP were also higher for lambs fed maize diets compared to those fed grass-maize diets (**Paper IV**).

The starch intake was the intake parameter most influenced by the inclusion of grass silage in the diet, with more than 20% higher starch intake in maize diets than in grass-maize diets in both years, averaged over maize maturity stages at harvest. The most likely explanation to this deviation in starch intake of the diets is the consistently higher starch content in the late harvested maize, leading to higher average starch content in maize diets than in grass-maize diets, even though we tried to compensate the starch contents of the grass-maize diets by altering the concentrate mix (**Papers IV-V**).

The higher feed intake of maize diets did not result in increased LWG of the lambs, but did increase the carcass fat content in lambs in Exp. 2 compared to grass-maize diets (**Paper IV**). The lack of a similar response in Exp. 1 might be explained by the somewhat higher starch concentration of the maize diets compared to grass-maize diets in Exp. 2, not seen in Exp. 1. It should be noted that similar and even higher dietary starch content and starch intake by lambs fed concentrate *ad libitum* did not affect carcass fat content in previous studies with similar lamb genotypes (Nadeau *et al.*, 2009). Vranić *et al.* (2008) found that, when feeding wethers diets consisting of 100% forage, feed intake was lower when maize or grass silages were fed as the only forage compared to when both maize and grass silages were included in the diet. No such intake response was seen in our study (**Papers IV-V**), probably as all diets in each year of the present study were balanced nutritionally by changing the proportions of concentrates to ensure similar contents of ME, CP and NDF in DM within year. Such balancing is not possible to the same extent when using experimental diets with 100% forage, as in the study by Vranić *et al.* (2008). Furthermore, as high concentrations of ammonia and butyric acid in silage has been associated with depressed feed intake (Krizsan & Randby, 2007), it is possible that the higher content of butyric acid and ammonia in the grass silage in Exp. 1 than in Exp. 2, negatively affected the feed intake of lambs fed the grass-maize diets in Exp. 1, partly explaining the higher intake of lambs fed maize diets as compared to grass-maize diets in Exp. 1 (**Paper IV**).

When feeding grass and maize silages of similar OM and NDF digestibility to ewes, Crosby *et al.* (2005) found higher DMI and better maintained BCS of pregnant ewes fed maize silage than in those fed grass silage, whereas O'Doherty *et al.* (1997) found no effects on feed intake of pregnant or lactating ewes or daily LWG of suckling lambs. Similarly, Keady & Hanrahan (2013) found no clear effects of feeding maize or grass silage to finishing lambs on feed intake or performance. As stated earlier, it is of importance to note that in the studies here referred to, the growth rates of the lambs were considerably lower than the potential growth rates in intensive lamb production as studied in the present experiment (**Papers I-V**). Nonetheless, both the previous and the present studies show that there is, without doubt, a possibility to use maize silage as the only forage source for growing lambs. Perhaps the use is even more appropriate in ewes during late pregnancy or lactation, in order to replace some of the cereal concentrates used.

Grass-maize diets increased daily eating time and eating, ruminating and total chewing time kg^{-1} DMI compared to maize diets (**Paper V**). This was likely due to the higher forage NDF content of the grass silage than of the maize silage, although all diets in the study had similar NDF contents. Forage NDF has previously been shown to be the main factor affecting chewing time in ruminants (Shaver *et al.*, 1988; Mertens, 1997; Fimbres *et al.*, 2002). Lambs fed maize silage as only forage source tended to spend a longer time in a standing position when ruminating than did lambs fed grass-maize diets. It is however unclear whether this is an expression of discomfort or of any other practical relevance. The longer chewing time kg^{-1} DMI for the grass-maize diets was associated with a larger proportion of faecal particles smaller than 0.212 mm and in a smaller proportion of faecal particles between 0.212 and 0.500 mm and larger than 2.36 mm (**Paper V**). The increased proportion of large and middle sized faecal particles in lambs fed maize diets compared to lambs fed grass-maize diets (**Paper V**) indicates a less effective selective retention of large particles in the rumen, *i.e.* a faster digesta passage rate when using maize as the sole forage to lambs (Poppi *et al.*, 1980). However, the average fraction of large particles in the faeces ranged from 0.03 to 0.32% of faecal particle DM and, consequently, the effect of forage type on digesta passage rate in the lambs in **Paper V** is considered to have been negligible and is unlikely to have affected the performance of the animals.

5.7 Protein, Energy and Performance

The lower MP:ME ratio and the higher crude fat:ME ratio of the diets in Exp. 1 compared to Exp. 2, might have constrained the growth of the lambs in Exp. 1 compared to the lambs in Exp. 2 (**Papers IV-V**). In both years, the BW was linearly correlated to the age of the lambs, indicating a more or less constant LWG from 25 to 45 kg BW of finishing lambs fed well balanced high-concentrate based mixed rations.

The most important parameters for increased LWG in finishing lambs were the CPI and MPI (**Paper IV**), suggesting that animals with high production potential have high protein demands. However, it is unlikely that an average daily CPI during the finishing period above 280 g will increase performance of lambs of similar genotypes as those used in our experiments (**Papers I-V**). The higher LWG of the lambs in Exp. 2 as compared to those in Exp. 1 may be caused by the change in concentrates used, *i.e.* feeding rapeseed meal in Exp. 2 instead of rapeseed cake in Exp. 1, which increased the CP and MP contents and decreased the crude fat content of the diets (**Paper IV**). Lastly, the positive linear relationship between daily LWG of the suckling lambs and the daily MEI of the lactating ewes in **Papers I** and **III** highlights the requirements of energy of lactating ewes for maximized production.

6 Conclusions

Overall, positive production responses were obtained from increasing grass silage digestibility, chopping silage, mixing silage with concentrate and of increasing crude and metabolizable protein contents in the diets of intensively reared sheep.

Chopping highly digestible grass silage decreased dietary selection, daily eating time and eating to rumination ratio while increasing daily rumination time in pregnant and lactating ewes. Chopping silage also increased daily LWG of finishing lambs, without increasing feed intake.

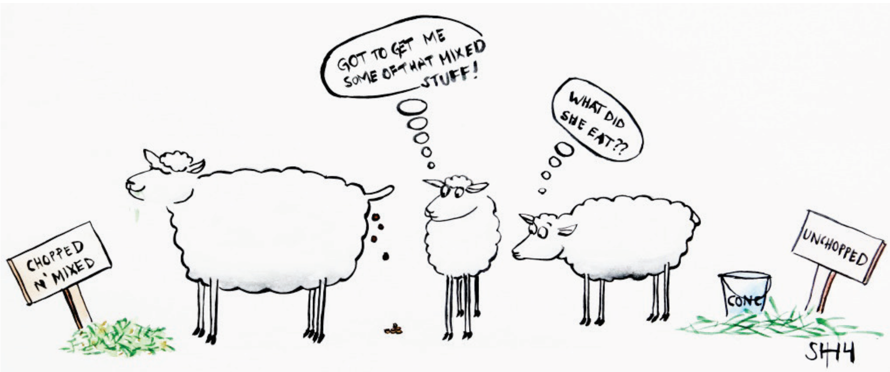
Mixing highly digestible grass silage with concentrates increased feed intake in lactating ewes and daily LWG of suckling lambs. Mixing silage and concentrates also increased proportion of large particles in faeces, indicating higher digesta passage rate.

Increasing grass silage digestibility increased silage DMI as well as BW and BCS of lactating ewes. The improved digestibility also increased LWG of suckling lambs and decreased the lamb concentrate intake.

Feeding maize as the sole forage decreased eating and rumination time in relation to feed intake, but did not have a major effect on intake or performance of finishing lambs. Ewes and lambs selected feed particles low in fibre and high in starch and protein. The daily crude and metabolizable protein intake were the most important parameters for promoting lamb growth rate, but also the dietary ratio of metabolizable protein to metabolizable energy could be used when formulating diets for fast-growing lambs.

7 Implications

The findings presented in this thesis show that the production level in intensive lamb production may be increased by mixing chopped silage of high digestibility with concentrates. As profitability of Swedish sheep farms is generally low, a high production output is essential when using high input systems as in the 'off-season' intensive indoor lamb production. Although one should keep in mind that response in intake and performance in this thesis are obtained under experimental conditions, the responses are relevant for intensive production. Thus, by harvesting the grass sward early, using adequate ensiling manners and mixing the silage with concentrates before feeding it to ewes and lambs, one can improve performance of the lambs, better maintain the condition of the ewes and at the same time decrease feed costs.



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8 Future Perspectives

To increase knowledge in the area of feeding regimes in intensive lamb production, future research should focus on:

- The effects on ewe body condition and milk production of replacing highly digestible grass silage with maize silage harvested at the dent stage of maturity
- The optimum ratios between CP, MP, digestible starch and digestible NDF for ewes and lambs
- The effects on total farm profitability of using mixed feed rations as compared to separate feeding systems and to forage- or grazing-based systems
- The effects on ewe life-time performance when fed early harvested grass silage during late pregnancy and lactation
- The possibility of decreasing the time between parturitions of ewes by using feeding regimes which counteract body condition loss during lactation
- The feeding of ewes around parturition for optimized feed efficiency
- The optimal feeding strategy of periparturient ewes with varying numbers of foetuses/lambs
- Increased knowledge of the feeding value of highly digestible grass silage and the utilization in the high-producing sheep

9 Sammanfattning

Den svenska lammproduktionen har under de senaste decennierna genomgått en omfattande strukturell förändring. Antalet tackor och baggar har ökat från 145 000 får fördelade i 9 300 besättningar år 1970 till 285 000 får fördelade i 8 800 besättningar år 2013. Under samma period har antalet fårbesättningar med 1-9 får minskat med 58 % medan besättningar med 10-24, 25-49 och 50 eller fler ökat med 68, 95 respektive 128 %. Eftersom skördeteknik och lagringsmöjligheter för grovfoder förbättrats avsevärt under de senaste decennierna, kan vi nu skörda stora mängder vallväxter vid tidigt mognadsstadium och lagra det som ensilage istället för som hö. Genom en tidig vallskörd skapas ett ensilage med högt näringsmässigt värde, som kan öka produktionen och minska behovet av kraftfoder.

Får lever i symbios med sina våm-mikrober, som främst består av bakterier, protozoer och svampar. Genom att fåren tuggar sönder foderpartiklar under idisslingen kan mikroberna bryta ner växtdelarna till näring som fåren tillgodogör sig. Den främsta energikällan för får är de flyktiga fettsyrorna (främst ättiksyra, propionsyra och smörsyra) som våm-mikroberna producerar genom att förjäsa växtdelar. Får klassas som ett slags mellanting av en get och en ko och brukar benämnas som ”selektiva gräsätare”. Anledningen till definitionen är att får är selektiva när de äter och behöver grovfoder. Generellt behövs grovfodret för att ge tillräcklig struktur för att papillerna i våmmen ska retas och därigenom framkalla idissling. På så sätt upprätthålls den grundläggande hälsan hos alla våra domesticerade idisslare (nötkreatur, får, getter, bufflar, renar och jakar) och många av deras vilda släktingar. Eftersom får är väldigt anpassningsbara till rådande förhållanden kan foderstaterna bestå av allt mellan 0 och 100 % grovfoder. Oftast brukar det rekommenderas att foderstaten består av ca 50 % grovfoder på torrsubstans-basis, men behovet för en någorlunda fungerande våm har visats vara så låg som motsvarande ca 2 % halm i foderstaten till växande lamm. Fåren har alltså å ena sidan ett behov av strukturen från grovfoder, men intag och produktionsnivå kan även lätt begränsas om grovfodret blir alltför fiberrikt.

Intensiv inomhusuppfödning av lamm är tämligen nytt i Sverige och bygger på att tackorna brunstar och lammar tidigare än i traditionella produktionssystem med vårlamning. Under svenska förhållanden innebär det att tackorna brunstar och blir dräktiga i augusti och lammar i januari efterföljande år. Detta produktionssystem möjliggör för svenska konsumenter att köpa färskt svenskt lamm tidigare på året än på hösten, då svenska lamm traditionellt har slaktats. Inom den svenska intensiva lammproduktionen med januarifödda lamm slaktas lammen vid 3-4 månaders ålder vid en slaktkroppsvikt av ca 20 kg. Lammen växer ca 400 g/dag, vilket innebär att behovet av hög foderkvalitet och högt foderutnyttjande är uppenbart. Eftersom växande lamms tillväxtpotential inte utnyttjas fullt med enbart grovfoder (Bernes *et al.* 2008), bör foderstaterna kompletteras med kraftfoder i intensiv produktion.

Syftet med den här avhandlingen var att undersöka om foderintag, fodersortering, tuggbeteende och produktionsnivå hos högproducerande får kan ökas genom att dels hacka, dels tidigarelägga skördetidpunkt av gräs och majs, dels genom att utfodra fullfoder. Vi har fokuserat på de kategorier av får som har högst näringsbehov, nämligen dräktiga och digivande tackor och snabbt växande lamm.

Studierna utfördes på Götala nöt- och lammköttscentrum utanför Skara, Sveriges lantbruksuniversitet. I den första studien följdes tackor från de sista fyra veckorna av dräktigheten fram till avvänjning av lammen och senare även deras lamm från avvänjning till slakt (**Papers I-II**). I den andra studien följdes tackor från de sista fyra veckorna av dräktigheten fram till avvänjning av lammen (**Paper III**). I den tredje studien följdes lamm från avvänjning till slakt (**Papers IV-V**).

Resultaten visar att genom att hacka gräsensilage före utfodring till dräktiga och digivande tackor minskas ättiden medan idisslingstiden ökar, men hackning ökade inte foderintaget hos tackorna eller tillväxten hos diande lamm. Däremot ökades lammens tillväxt från avvänjning till slakt, när ensilaget hackades. När det hackade ensilaget blandades med kraftfoder ökades de digivande tackornas foderintag samtidigt som de diande lammens tillväxt ökade, vilket tyder på en högre mjölkproduktion hos tackor utfodrade med fullfoder.

Resultaten visar även att ökad smältbarhet genom tidigare ensilageskörd ökade tackornas foderintag, vikt och hull både under dräktighet och digivning. Den ökade smältbarheten minskade också de diande lammens kraftfoderintag, samtidigt som den ökade lammens dagliga tillväxt, vilket visar på en högre mjölkproduktion hos tackorna som fick det tidigt skördade ensilaget.

Det visades även att majsensilage kan användas som enda grovfoder till växande lamm från avvänjning till slakt. För maximal fodereffektivitet bör majsensilage från dentmognad utfodras som enda grovfoder medan majsensilage från mjölmognad kan utfodras i blandning med gräsensilage. Att använda majsensilage eller både majs- och gräsensilage spelade ingen avgörande roll för lammens foderintag eller tillväxt när välbalanserade foderstater användes. Däremot minskade majsensilage som enda grovfoder lammens ättid och idisslingstid i relation till foderintaget. Lammen sorterade bort de foderpartiklar som hade högt fiberinnehåll samt dem som var större än 8 mm och mindre än 1 mm. Slutligen framkom det att intaget av råprotein och omsättbart protein var de viktigaste faktorerna för ökad lammtillväxt hos lamm utfodrade med fri tillgång på fullfoder baserade på kraftfoder.

För att, genom optimal utfodring, maximera foderintag och produktionsnivå i intensiv lammproduktion, ska ensilaget skördas tidigt och utfodras som fullfoder. På så sätt behöver mindre kraftfoder köpas in och fåren utnyttjar fodret bättre då de lägger mer tid på att bryta ner fodret genom idissling än på att sortera bort oönskade foderdelar under tiden de äter. Till växande lamm är proteinnivån i sig och i förhållande till energinivån i foderstaten ett användbart mått på hur optimal foderstaten är.

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