Effects of particle length and maturity stage of whole crop barley silage on feed intake, chewing activity and eating behaviour by growing dairy steers

Effekt av partikelstorlek och mognadsstadium hos helsädesensilage av korn på konsumtion, tuggningsaktivitet och ätbeteende hos växande mjölkrasstutar

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Examensarbete, 20 poäng, Agronomprogrammet

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FÖRORD

Detta är ett examensarbete omfattande 20 poäng inom agronomprogrammets husdjursinriktning. Arbetet gjort inom ett projekt som är en del av ett riksomfattande forskningsprogram om helsäd, som täcker hela kedjan från odling till utfodring och produktion. Syftet är att öka kunskapen om helsäd som fodermedel samt att genom olika metoder skatta olika smältbarhetsparametrar. Projektet har finansierats av Stiftelsen lantbruksforskning och AgroVäst.

I detta arbete diskuteras det kring effekten av helsädesensilage av korn skördat vid axgång och degmognad som lagrats i rundbalar och utfodrats antingen långstråigt eller exakthackat på konsumtion, tuggaktivitet och ätbeteende hos växande mjölkrasstutar. Min del av arbetet har bestått i att samla in och analysera konsumtionsdata samt delar av tuggningsaktivitets data. Arbetet innefattade också visuella observationer av ätbeteende samt studier av sorteringsbeteende med hjälp av sållning av foder och foder rester.

Jag vill rikta ett stort tack till alla som hjälp mig genom hela arbetet. Främst vill jag tacka mina handledare Elisabet Nadeau och Bengt-Ove Rustas för stöd och vägledning genom hela projektet. Jag vill även tacka Peder Nørgaard vid Institut for Basal Husdyr- og Veterinærvidenskab, Den Kgl. Veterinær- og Landbohøjskole i Danmark för praktisk vägledning vid insamling av och för analys av tuggningsaktivitets data och Börje Ericson med personal på Kungsängens forskningscentrum i Uppsala för instruktion och hjälp vid foder och restanalyser. Tack till min examinator Sölve Johnsson och opponent Jesper Eggertsen för kompletterande kommentarer på arbetet. Ett varmt tack också till Jonas Dahl och David Johansson på Götala försöksgård i Skara för all hjälp i arbetet med stutarna.

Skara, maj 2006
Ann Sahlin

SUMMARY

Whole crop cereal silage has proven to be a good and flexible feed alternative to growing cattle and can be fed alone or together with other forage sources. Whole crop silages constitute a less homogenous material compared to grass silage, with awns rich in starch and stalks with a high fiber concentration. A regular intake of fibrous materials, such as whole crop silage, is of importance to stimulate chewing and to ensure proper digestion and a healthy rumen environment of cattle and other ruminant animals.

Stage of maturity at harvest and particle size of forage affects feed intake, chewing activity and production of animals. A later maturity of the crop is followed by a decrease in fiber digestibility and consequently a decreased feed intake. In barley silage, the feed intake is often unaffected by stage of maturity or even increased at higher maturity silages. This is probably due to a decreasing NDF content as the grain content increases. Chopping before feeding can increase feed intake because of a faster passage rate and a decreased need for chewing. The neutral detergent fiber (NDF) content of the feed is highly correlated with chewing time. Together with particle size of the roughage, the NDF content is a major determinant of chewing activity.

The aim of this study was to investigate the effects of maturity stage and particle size of barley silage stored in round bales on feed intake, chewing activity and eating behaviour by growing dairy steers. Eight dairy steers, weighing around 350 kg at the beginning of the trial, were divided into a duplicated latin square with four periods and four steers in each square. Four diets, which were made up of silage at two different maturity stages and particle sizes of whole crop barley silage, were fed to two randomly selected steers per diet and period. At the end of the trial, all steers had been fed with four diets. Each period lasted for 21 days and the two squares were dislocated in time. During the collection period, data concerning feed intake, chewing activity and eating behaviour were collected. Chewing activity was measured using elastic halters with magnetic sensors fitted under the lower jaw of each steer. Feeding behaviour was mainly described as eating rate and sorting of feed. Sorting was determined by comparing the particle size distribution expressed as the percentage of particles from orts retained on three sieves with different pore sizes to the particle size distribution of the feed.

The dry matter intake (DMI) of long silage harvested at heading was higher than for long silage harvested at dough stage and chopped silage harvested at heading. However, chopping the silage harvested at dough stage resulted in a higher DMI compared to long silage harvested at dough stage. The NDF intake of silage was higher at heading compared to dough stage, whereas no significant differences were found between chopped and long silage.

Time spent ruminating was longer than time spent eating for all diets except for chopped silage at harvested at dough stage, where time spent eating was longer than time spent ruminating. Particle size and stage of maturity affected eating time only, whereas rumination time was constant among diets. The longest time spent eating was for chopped silage harvested at dough stage. Chopping increased the time spent eating for both stages of maturity. Time of harvest only affected time spent eating per kg of NDF intake with a longer eating time for silage harvested at dough stage compared to silage harvested at heading.

The number of jaw movements increased when feeding chopped diets. Feeding silage harvested at dough stage also increased the number of jaw movements per kg of NDF intake. Chopping before feeding increased the eating rate for both harvest times. The number of chewing cycles per chewing period was higher for long silage harvested at heading compared to chopped silage harvested at heading and long silage harvested at dough stage. When feeding silage at dough stage, chopping the silage increased the number of chewing cycles per period compared to long silage. Chopping before feeding increased sorting behaviour compared to feeding long silage and resulted in sorting in favor of shorter particles.

Interactions between effects of stage of maturity and particle size on intake and chewing activity by the steers might have been affected by differences in fermentation between silage at the two different maturity stages. Eating time and the number of jaw movements increased for silage harvested at dough stage, which was probably because of a decreased fibre digestibility. This indicates that rumen fill affects intake resulting in a decreased fibre intake of silage harvested at dough compared to silage harvested at heading. Also, rumen fill probably had an effect on DMI of the long silage.

Chopping whole crop barley silage is more advantageous when harvested at dough stage. However, time of harvest should be adapted to the most suitable combination of harvest time and particle length at feeding in relation to existing production conditions.

CONTENTS

KEYWORDS

Fiber	Nutritionally defined as the slowly digestible or indigestible fraction of feeds that occupies space in the gastrointestinal tract of animals (Mertens, 1997).
NDF	Neutral Detergent Fibre. Consists mainly of lignin, cellulose, hemicellulose and cell wall protein. A measure of the plant cell wall material (McDonald *et al.*, 2002).
peNDF	Physically effective Neutral Detergent Fiber. Related to the physical characteristics of fibre (primarily particle size) that influences chewing activity and the biphasic nature of ruminal contents (Mertens, 1997).
INDF	Indigestible NDF (Mertens, 2003).
Particle size	Refers to different lengths of particles or straws in a diet or roughage.
Total chewing time	The sum of eating and ruminating time (Mertens, 1997).
Chewing efficiency	The number of chews required per unit of feed consumed (Welch and Hooper, 1988).
Chewing rate	The number of chews per unit of time.
Chewing cycle	The time spent chewing between swallowing of feed during eating or between two regurgitated boluses during rumination.
Chewing period	A set of chewing cycles without pauses between the separate cycles.
Eating rate	The amount of feed or dry matter (DM) consumed per unit of time (Mertens, 1994; Nørgaard, 2003a).
DMI	Dry Matter Intake. The intake of the dry weight portion of feed by an animal.
VDMI	Voluntary Dry Matter Intake.
Intake potential	Intake when energy demands of the animal and not the filling effect of the diet limit DMI (Mertens, 1994).
Ruminal fill	Volume of ruminal contents when measured immediately after the cessation of a meal when the animal is provided a diet that does not meet its energy demand and intake is limited by bulkiness of the diet (Mertens, 1994).
Selection	Specifically defined to indicate preferential consumption among feed subcomponents (Mertens, 1994).

INTRODUCTION

Whole crop cereal silage is traditionally not a widely used feed in Sweden but has received increasing attention and has proven to be a good feed alternative to growing cattle (Rustas *et al*., 2003). Whole crop grains for ensiling can increase the flexibility of roughage production on the farm by allowing for adjustments in the amount of harvested whole crop silage in relation to the production of grass and grass/legume silage. Whole crop cereal silages can be offered to beef cattle alone or together with other forage sources and can supplement the forage supply during years of forage shortage. It would also make it possible to rear beef cattle on pure grain farms by adjusting the number of animals from year to year depending on how much of the grain yield can be used for silage production. This is an interesting aspect when considering future structural changes in Swedish meat production. Also, whole crop cereals contain a low to intermediate amount of protein, which can decrease the nitrogen losses in livestock production (Nadeau, 2004; Nadeau, 2006).

Ruminant production from forages is mainly affected by the level of forage dry matter intake (DMI; Minson, 1990) and maximizing feed intake is critical to increase production (Welch and Hooper, 1988). Decreasing the particle size before feeding generally increases the voluntary intake (VI). The particle size of feed has shown to affect the intake of hay and grass silage in growing cattle (Deswysen and Vanbelle, 1978; Jaster and Murphy, 1983) in situations where intake is limited by fill. Chewing time and effectiveness is especially important to consider when dealing with growing animals, because chewing effectiveness is lower in small animals than in large animals (Bae *et al*., 1983). Chopping decreases the time spent chewing (Nørgaard, 2003b) and is therefore of importance when it comes to regulation of feed intake. A decreased chewing time per kg of feed allows for higher intakes and possibly higher levels of production (McDonald *et al*., 2002).

The harvest time of whole crop cereals for silage should also be considered. One incentive for a later harvest time is that yields of DM and digestible organic matter are increased but at the same time, ensiling properties are decreased as there are changes in the chemical composition with advancing maturity of the crop (Nadeau, 2006). Also, there is an increase in grain losses during harvest with advancing maturity of the plant (Sundberg and Olsson, 1998). Fiber digestibility decreases whereas starch concentration increases with advancing maturity of whole crop cereals resulting in only minor changes in organic matter digestibility (Bååth Jacobsson, 2005; Nadeau, 2006).

Most studies of whole crop cereal silage for growing cattle have focused on chopped feed stored in different kinds of silos. This is not always of relevance for Swedish conditions where whole crop silage usually is stored more or less in its long form in round bales. This type of storage is a flexible alternative to precision chopped silage stored in silos.

OBJECTIVE

The aim of the project was to study effects of maturity stage and particle size of barley silage stored in round bales on feed intake, chewing activity and eating behaviour in growing dairy steers. The results from the trial will give farmers a base to make strategic decisions about time of harvest and choice of mechanical treatment at harvest or before feeding.

HYPOTHESES

- Intakes of more mature whole crop barley silage will be higher than for less mature silage.
- Chopping before feeding decreases the need for chewing resulting in increased dry matter intakes and eating rates.
- A later stage of maturity at harvest of whole crop barley silage increase chewing activity probably because of an increased lignin concentration, a decreased fibre digestibility and stiffer stems.
- Animals sort out sharp parts such as bristles and stiff stems, when barley silage is fed in its long form. Chopping before feeding decreases this sorting behaviour.
- Chopping of whole crop barley silage affects intake of silage harvested at dough stage more than of silage harvested at heading.

LITERATURE REVIEW

RUMINANT PHYSIOLOGY AND RUMEN ENVIRONMENT

The ruminant stomach can be divided into a three compartment, nonsecretory forestomach and a secretory stomach compartment called the abomasum. The nonsecretory forestomach consists of the reticulum, the rumen and the omasum (Figure 1). The forestomach acts as a fermentation tank for the microbial fermentation of ingesta, whereas the abomasum is the site of the hydrolysis of protein by pepsin and is similar to the stomach of a nonruminant animal (Leek, 2004). The reticulum allows for regurgitation of feed for further mechanical breakdown, rumination, which is characteristic for ruminants (McDonald *et al.*, 2002).

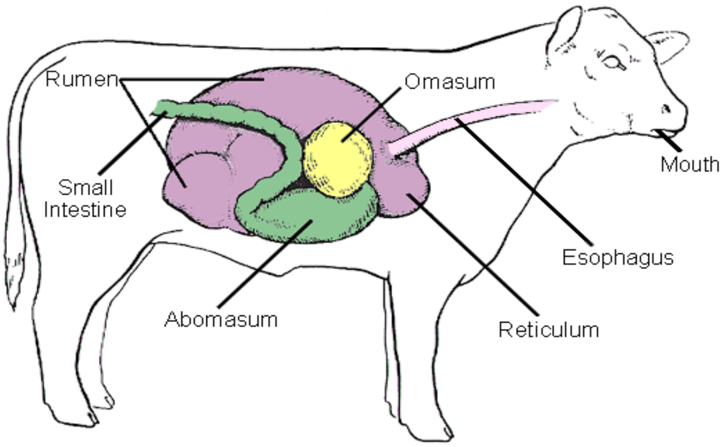


Figure 1. The anatomy of the ruminant digestive tract (University of Kentucky, 2006).

Ruminant digestion has both advantages and disadvantages. The benefits include efficient utilization of highly fibrous diets and the ability to break down cellulose and use it as a major source of nutrients. Some of the costs are the extensive periods of time required for chewing feed (4 to 10 h per day; Kilgour and Dalton, 1984; Leek, 2004) and chewing the cud (up to 9 h per day), the need of a regular supply of adequate food and addition of large amounts of alkaline saliva (Leek, 2004).

A major part of ruminant diets contains β-linked polysaccharides, such as cellulose, which cannot be broken down by mammalian digestive enzymes (McDonald *et al.*, 2002). To be able to break down these and other feed components the animal needs enzymes that are only found in plants and microbes. Therefore, ruminants have developed a symbiotic relationship with a large number of different microbes, which reside in the reticulo rumen and are a part of a continuous fermentation system with anaerobic bacteria, protozoa and fungi. The rumen environment must remain stable so that the microbes are not threatened. The maintenance of the rumen pH around 5.5 to 6.5 plays a major role in ensuring proper fermentation and uptake of feed constituents. Saliva contains buffering substances that minimize fluctuations in ruminal pH. Cattle can produce 60 to 160 litres of saliva per day, which dilute the feed during eating and rumination. Salivation is not a response to reductions in intraruminal pH but is rather a reflex response to increased chewing and rumination, which is a result of a more fibrous diet (Leek, 2004). The amount of saliva produced each day is also increased with higher DM contents of ingested feed (Bergsten *et al.*, 1997). The regular intake of fibrous materials is of particular importance to ensure proper digestion and, to some extent, ruminants exhibit an appetite for fibre. An excess of fibre can inhibit feed intake whereas a deficiency may cause digestive upset (Forbes and Provenza, 2000). The particle length of forage is also critical to maintain ruminal function (Beauchemin *et al.*, 1997).

Rumen contents often exist in two phases: a lower liquid phase with suspended, fine feed particles, and an upper layer which is drier and made up of coarser, solid materials. Feed particles of various shapes and sizes enter the rumen and are suspended in the liquid phase. Large, irregular particles and those of low specific gravity tend to move to the top of the rumen where they are retained (McDonald *et al*., 2002). This allows for regurgitation of coarser materials and further mastication to reduce the particle size.

FACTORS AFFECTING INTAKE

All factors that alter the relationship between the size of the rumen and the size of the animal will affect feed intake (McDonald *et al*., 2002). Feed intake is affected by characteristics of the animal, feed and feeding situation (Mertens, 1994).

Animal characteristics

An animal's intake potential depends on its sex, physiological state (maintenance, growth, pregnancy and lactation), size, body shape and health (Mertens, 1994). Intake is controlled through a combination of signals from the visceral receptors, adipose tissue, social factors and environmental stimuli that are integrated by the central nervous system to a total signal of discomfort. The animal then adjusts its intake to relieve the discomfort (Forbes and Provenza, 2000). The capacity of the rumen (rumen fill) is the main factor in controlling feed intake even though gut capacity can be adjusted to high-energy demands when a bulky, low quality diet is fed (Mertens, 1994). Rumen fill is affected by factors such as particle size of feed as well as chewing efficiency and frequency (Allen, 1996), as well as animal factors such as metabolic body weight, pregnancy and body condition (McDonald *et al*., 2002). The animal responds to an increase in feed intake by increasing the quantity held in the rumen and/or the passage rate until the limit has been reached. To raise these limits and to increase productivity, slowly digested forages can be replaced by more rapidly digested forages and concentrates or by decreasing forage size to smaller, faster-moving particles. Bulky feeds, such as hay and silages will fill the rumen to a greater extent than e.g. concentrates even after chewing (McDonald *et al*., 2002).

Rumen retention time

The limit of turnover and retention can be classified as the most important factor limiting intake and utilization of forage diets (Van Soest, 1994). The daily intake will be reduced if feed and its indigestible residues are retained in the digestive tract, which is the case after ingestion of long, highly fibrous feed particles (Deswysen and Vanbelle, 1978; Allen, 1996). To maintain intake levels, particles must be reduced to a size small enough to pass from the rumen, which is mainly achieved by mastication (primarily rumination) but also by chemical and microbial degradation. For almost all ruminant species, the average maximum dimension of particles leaving the rumen is <1 mm but in cattle the critical size is considered to be around 3-4 mm. The rumen itself does not act as a sieve but rather as a filter bed formed by a mass of feed particles, where larger particles trap smaller ones (Welch and Hooper, 1988; McDonald *et al*., 2002). Particle size and fermentation-based buoyancy, which can constrain escape from the rumen, can partially be overcome by larger animals because of their larger intake capability that generally makes them more efficient ruminators. The physiological reasons for the increased rumination efficiency are not readily apparent (Deswysen and Ellis, 1990).

Reduction of barley silage particle size has been shown to decrease ruminal retention time and increase the rate of digestion and passage of particulate matter in steers (Soita *et al.*, 2002). Similar results have been observed with corn-silage based diets (Teimouri Yansari *et al.*, 2004). The specific gravity of feeds is increased through rumination by the release of gases trapped in plant tissues. Light particles float and are thus unlikely to pass from the rumen (Welch and Hooper, 1988) whereas heavier particles, with higher specific gravities, can pass through the fibrous mat and have a shorter retention time (Teimouri Yansari *et al.*, 2004).

Feed characteristics

Voluntary intake of forage is affected by forage species, cultivar, stage of maturity, soil fertility, climatic conditions, particle size and conservation process (Minson, 1990). Intake is mainly dependant on the structural volume and therefore the cell wall content of the feed. Increased intakes of cell walls increase rumen fill (Bosch *et al.*, 1992b). Voluntary intake may decrease with increasing maturity because of the rise in fibre concentration and increased resistance of the forage to physical breakdown through chewing (Minson, 1990). Digestibility depends on the cell wall and its availability to digestion, which is determined by lignification among other factors. The relation between lignin and intake is similar to the relation of plant age to intake because of their close association with digestibility (Van Soest, 1994).

Processing the forage by grinding or chopping decreases the need of breakdown through chewing (Minson, 1990). A higher intake of highly digestible, low fibre silages than of high fibre silages can be expected because of a faster degradation in the rumen. However, rumination and chewing may be more important in determining intake than breakdown in the rumen (Dawson and Steen, 2000). Processing of feed decreases the particle size and results in a collapse of the cell wall structure, which increases the density and hydration rate of the feed. The greater density will allow faster rates of passage and less rumen volume and therefore increased voluntary dry matter intake (VDMI; Van Soest, 1994; Teimouri Yansari *et al.*, 2004). In general, decreasing the particle size of roughage results in an increase in feed intake of growing cattle (Sniffen *et al.*, 1986; Shain *et al.*, 1999; Einarson, 2004; Teimouri Yansari *et al.*, 2004) but there also are reports made where no effects on intake were observed (Soita *et al.*, 2000; Yang *et al.*, 2001; Clark and Armentano, 2002; Beauchemin and Yang, 2005). The DM intakes as related to the particle size of different feeds are listed in table 1.

The particle size and factors influencing the quality of the feed affects intake, but no single chemical component of silage can be used as a predictor of its intake (Dawson and Steen, 2000). Neutral detergent fibre (NDF) is considered to be the best single chemical predictor of VDMI because it generally ferments and leaves the reticulorumen more slowly than other dietary elements and it has a greater filling effect over time (Allen, 1996; Forbes and Provenza, 2000). The NDF does not explain physical characteristics of fibre such as particle size and density, which can influence animal health, ruminal fermentation, utilization and metabolism independently of the amount or composition of chemically measured NDF (Mertens, 1997). A reduction in forage NDF will allow for a higher VDMI in ruminants consuming an all forage diet although it will reduce the intake of NDF (Jung and Allen, 1995; Bal *et al.*, 2000; Okine *et al.*, 2004)). Feeding more mature forages usually results in a decreased DMI because of the compositional changes that occur in the cell wall in conjunction with increasing maturity.

Fermentation characteristics of the silage are major factors influencing intake. Higher moisture contents of early harvested and ensiled whole crops result in more extensive fermentation of the material during ensiling compared to drier plant material at later maturities (Bergen *et al*., 1991; Nadeau, 2006) and it has been shown that intake of grass/clover silage markedly can be reduced by extensive in-silo fermentation and/or proteolysis (Huhtanen, 2003).

CHARACTERIZATION OF ROUGHAGES

The vast diversity of roughages available for animal production creates a need for an understanding and characterization of the different factors influencing the composition of the feed, the feed intake and animal production. To maximize production and to ensure animal health, it is important to characterize the roughage correctly. Factors such as maturity, fibre characteristics, particle size and feed hygiene all influence the decisions made concerning the feed and feeding practices.

Fiber characteristics and particle size

Physically effective fibre (peNDF) accounts for the fibre fraction of a feed that promotes chewing. The concept is based on the hypotheses that the fibre in long feed particles (>1 cm) promotes chewing and saliva production. The peNDF is related to both fibre concentration and particle size of the feed. Formation of the ruminal mat, fermentation, passage of fibre and stimulation of rumination are all related to peNDF. The peNDF value of a feed is determined by multiplying the NDF content by its physical effectiveness factor (pef; Mertens, 1997). The pef ranges from 0 to 1 and is calculated as the sum of the proportion of particles retained on both 19 and 8 mm sieves (Beauchemin and Yang, 2005). The peNDF could also be estimated from chemical and physical measurements in the laboratory by determining the proportion of particles retained on a 1.18 mm sieve multiplied by its NDF content (Mertens, 1997). The different particle sizes of a feed and their distribution can be determined using e.g. a Penn State Particle Separator, which is a fast and simple method developed for on farm use. Particles are retained on 19, 8 and 1.3 mm sieves (Heinrich and Kononoff, 2002) and the pef value thereby can be obtained (Beauchemin and Yang, 2005). Processing before feeding can reduce the effectiveness of roughage fibre. Reduction of particle size by finely chopping alters the effectiveness of the fibre and thereby the maintenance of sufficient chewing activity and saliva production to ensure proper rumen function (Soita *et al*., 2000). Increasing the particle length increases the peNDF content. A linear increase in the number of chews and total chewing time has been observed when increasing the particle length and, consequently, also the peNDF content (Beauchemin and Yang, 2005). The digestibility and passage rate of feeds is affected by the content of indigestible fibre, INDF. This is the feed component that is the most variable in digestibility and it affects the total DM and OM digestibility of feeds by ruminants. The INDF is an important factor to consider due to its space occupying characteristics (Mertens, 2003).

Researchers have in the past used the theoretical length of cut (TLC) of a forage to describe the general particle size of the feed consumed but this does not represent the actual particle size composition of the forage (American Society of Agricultural Engineers, 1993). From harvesting to feeding, the material may go through many pieces of equipment that further reduce the particle size. It could therefore be of interest to establish the particle size distribution of a feed or forage. This can be done by e.g. sieving.

WHOLE CROP CEREALS

Maturity

Cereals, such as barley, are sometimes grown as forage crops and its nutritive value is mainly dependant on its growth stage at harvest. Increased maturity in whole crop cereals is followed by an increase in yield, NDF and ADF contents but these concentrations level off after heading. Unlike grass silage, the fibre content does not increase continuously with increasing maturity. Most of the fibre is found in the plant stem of whole crops cereals. Up to the heading stage of maturity, fibre concentrations increase because of the increased proportion of stem to leaf/awn. Leaves and stems become more fibrous as the crop matures and the fibre digestibility is decreased, but this is often offset by the increased starch content as the head fills (Nadeau, 2004; Bååth Jacobsson, 2005). During kernel filling, the concentration of fibre decreases and is thereafter rather consistent (Khorasani *et al*., 1997). This results in a recovery in crop DM and organic matter digestibility (OMD; Sutton *et al*., 2002). However, the OMD remains unchanged between early milk and early dough stage of maturity (Nadeau, 2006). Harvesting the crop early may lead to an increased fibre digestibility, mainly because of a lower lignin content. However, if the crop is harvested too early, the yield is low and the physical structure is less favourable (Nadeau, 2001). The DM yield may double when delaying the harvest time of whole crop cereal silage from early growth stages to dough stage. This is mainly because of the increase in grain content (Bergen *et al*., 1991). When considering yields and feeding values, whole crops should be harvested around three to five weeks after heading when fed to beef cattle. The metabolisable energy content can at this point be compared to standard hays (Pettersson, 1989).

Ensiling

Ensiling whole crop cereals has several advantages when compared to ensiling more conventional roughages. The crop is harvested once each season, which keeps production costs down. The DM content is generally higher, especially during less favourable weather conditions. When considering maximum OM yield and good silage quality, triticale, wheat and barley silage should be harvested around the early dough stage of maturity (when compared to harvest at the early milk stage) and ensiled with acid or inoculant to decrease the risks of clostridial growth (Nadeau, 2006). Whole crops harvested at maximum yields, around dough stage, often contain considerable amounts of starch, 20 to 30%, which should be considered to avoid overfeeding of starch (Sundberg and Olsson, 1998). Changes in yield and chemical composition in relation to increasing maturity of whole crop cereals are illustrated in figure 2.

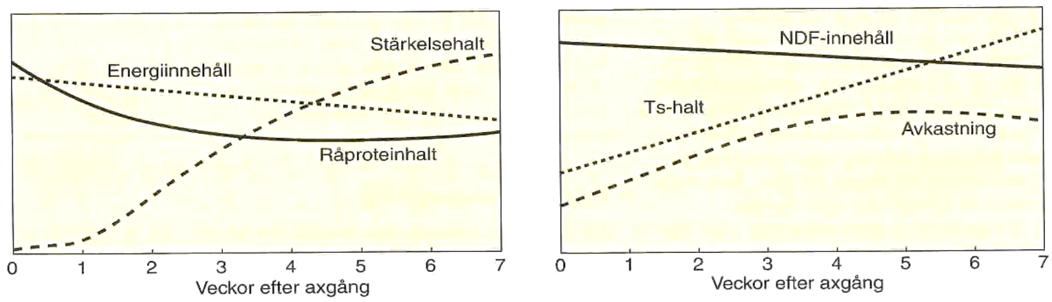


Figure 2. General changes in chemical composition and yield of whole crop cereals (Sundberg and Olsson, 1998). Energiinnehåll: energy content, stärkelsehalt: starch content, råproteinhalt: crude protein, NDF-innehåll: NDF content, Ts-halt: DM content, avkastning: yield, veckor efter axgång: weeks after heading.

There are some problems involved in growing and ensiling whole crop cereals. Ensiling whole crop cereals differs from the ensiling of grass silage. Whole crops constitute a less homogenous material with awns rich in starch and stalks with a high fibre concentration (Ohlsson, 1996). The need of nitrate fertilisers and herbicides may be higher compared to grass and legume silages. Also, whole crops might be hard to pack due to its rough structure at later maturities (Ohlsson, 1995), but generally they are easily ensiled even with DM contents of between 50 and 60% (Pettersson, 1989). Packing becomes harder with increasing maturities because of the increasing DM content and rough structure. When ensiling in round bales, the risks for puncturing holes in the plastic wrapping is increased and bales should therefore be protected with more layers of plastic compared to conventional roughages (Sundberg and Olsson, 1998). Because of its structure there is an increased risk of gas leakage and the aerobic stability is usually lower than for grass silage (Ohlsson, 1995).

Ensiling of whole crop cereals is usually a slow process and there are often high levels of clostridial spores despite otherwise acceptable ensiling properties (Lingvall, 1995). Compared to conventional roughages, whole crop cereals contain nitrate in levels too low to inhibit clostridial growth until there is enough protection from lactic acid formation. Aerobic stabilities decrease when air leaks into the system or if the ensiling and packaging process is prolonged. There is a growth of fungi, which causes increased temperatures. To avoid environmental gas exchanges during storage, whole crop cereals should be ensiled with 240 to 260 kg of DM per m^3 (Lingvall, 1995). Losses of DM can be decreased and fermentation can be improved by using additives during ensiling (Nadeau, 2004; Nadeau 2006).

FEEDING VALUE OF BARLEY SILAGE TO GROWING CATTLE

Barley is a hardy crop, which can resist great variations in weather conditions and can be grown all across Sweden (Weidow, 1998). Based on considerations of grain yield, storage losses as well as hygienic and nutritive quality, barley for ensiling should be harvested when the DM content is 30 to 35% (Pettersson *et al*., 1996). Early harvested and well-fertilized whole crop barley can contain up to 10.5 MJ and 110 g of crude protein (CP) per kg of DM. Yields in the northern parts of Sweden are usually only two to three tons of DM per ha (Pettersson, 1989).

Barley is a feed rich in fibre which adds structure to the ration. The feed conversion efficiency of barley silage is lower than that of high quality grass silage but they have the same effects on meat quality. Whole crop silages are, however, associated with whiter carcass fat when compared to grass silages. The grain content of the silage significantly influences growth characteristics of cattle (O'Kiely, 2002) and harvesting at the mealy compared to the milky stage of maturity increases the carcass weight gain in finishing steers and heifers both with and without added concentrates (O'Kiely and Moloney, 1995). This is because starch is fermented to propionate in the rumen. Propionate is a precursor to glucose that is needed for muscle formation (McDonald *et al*., 2002).

CHEWING ACTIVITY

Cattle belong to a group of ruminants that are classified as coarse grazers. This group has a few occasions each day when they eat most intensively and they ruminate infrequently for longer periods (Leek, 2004). Cattle are crepuscular which means that they are most active at sunrise and sunset, but this is most pronounced in grazing animals (Albright, 1993). A rhythm for total chewing activity has been reported in cattle fed long hay whereas animals fed chopped hay distribute their chewing evenly throughout the day (Jaster and Murphy, 1983).

Cattle are usually consistent in biting, jaw movements, eating and rumination times (Albright, 1993; Albright and Arave, 1997). Chewing activity occurs during 8 to 20 periods evenly distributed throughout the day and they last from five minutes up to two hours each time (Nørgaard, 2003a). Chewing activity and efficiency (number of chews required per unit of feed consumed) reflects the physical (particle size) and chemical properties of feeds (NDF, DM) but it is also a function of the physical state of the animal (age, size, VDMI, stage of production). More chewing is required with increasing NDF content and especially rumination time is highly correlated with NDF intake (Welch and Hooper, 1988; Oba and Allen, 2000). Particle size and NDF content of the forage in a diet are more reliable indicators of chewing activity than the NDF content of the forage alone (Yang *et al*. 2001). The level of intake also affects chewing time as animals that eat high levels of feed spend less time eating and ruminating per unit of feed (Welch and Hooper, 1988; Kovacs *et al*., 1997). A major determinant of rumination efficiency is body weight. Larger animals are usually more efficient than smaller ones both within and among species. Rumination efficiency is increased until a maximum value is reached after two years of age (Welch and Hooper, 1988). In animals ranging from 261 to 861 kg, an increased chewing efficiency has been observed in larger animals (Bae *et al*., 1983).

Eating bouts and feed consumption are highly influenced by social facilitation in group-housed cattle. Group-fed cows tend to eat more than separately fed animals (Albright and Arave, 1997). Cattle may be stimulated to start eating by copying the first individual to resume eating after a break. Therefore, the intake and production levels might be controlled by whether the first animal to start eating has a low or high DMI (Kilgour and Dalton, 1984).

Physiological significance of chewing

Chewing activity during eating and ruminating is a major factor affecting the performance of an animal. To investigate the correlations among chewing activity, diet, rumen function, feed utilization and different production parameters, it is necessary to record the chewing activity. Up to 50,000 chews per day act to reduce particle size of ingested feed, which is necessary for passage of material through the rumen and the shearing and crushing that takes place during chewing exposes feed particles to microbial breakdown (Beauchemin, 1991). Chewing is of direct importance in decreasing the size of solids to improve the entry of ruminoreticular microbes (Leek, 2004) and to alleviate gut fill by promoting passage of undigested feed particles from the rumen, ensuring high levels of feed intake (Beauchemin, 1991). Its indirect importance is to increase saliva secretion and rumen buffering capacity, which enhance fibre digestion and rumen motility (Beauchemin, 1991). Foodstuffs that require little mastication and rumination fail to provoke salivation and gastric contractions and may, therefore, have unfavourable digestive consequences (Leek, 2004). Conversely, fibrous diets may induce an increase in liquid passage rate through the rumen and this may "wash out" sufficient amounts of bacteria to result in related digestive problems and decreased digestibility of the feed (McDonald *et al*., 2002). The added saliva increases the specific gravity of the feed, which affects the passage from the rumen (Welch and Hooper, 1988).

Mechanics and behaviour of chewing and eating

Chewing involves the premolar and molar teeth on the upper and the much narrower lower jaw. The teeth of the lower jaw are higher on the outer side and the opposite occurring on the upper jaw. The chewing motion involves the upward and inward motion of the lower teeth against the upper teeth, thus creating shearing and grinding actions. Chewing motions during eating are easily recognized in laboratory recordings (Figure 3) by fast, irregular chews of various amplitudes (Leek, 2004). Chewing varies with time and is separated by unpredictable pauses during a meal. Chewing is a grinding rather than a cutting process because of the lateral jaw movements. Long particles are cut into pieces just small enough to be formed into boluses, which can be swallowed (Welch and Hooper, 1988). Initial feed particle size and DM content influences the magnitude of particle size reduction during initial mastication but the type of forage is also of importance. There is very little particle size reduction during chewing of forages with small particle sizes at feeding (Bailey *et al*., 1990). Between 10 to 50% of ingested DM is broken down into particles of <1 mm during eating depending on the type of feed (Welch and Hooper, 1988).

Mechanics and behaviour of rumination

Rumination involves the regurgitation of ingesta followed by mastication, bolus formation and reswallowing. This cyclic process is closely integrated with reticuloruminal motility. Rumination contributes to further particle size reduction, increases in specific gravity of forages, breakdown of rough plant tissue coatings and increases in forage surface area available to microbial breakdown (Welch and Hooper, 1988). During rumination, chewing the cud is characterized by a repetitive series of boli chewed uniformly, separated by short pauses (Beauchemin, 1991) and boluses are usually kept on one side with occasional changes of sides. The bringing up of the cud stimulates increased salivation and the typical slow, regular chewing movements (50 to 55 chews/min; Figure 4), which is about 5 to 20% slower than the chewing frequency during eating, for about 40 seconds before the food is re-swallowed (Nørgaard, 2003a; Leek, 2004). The jaw movements cease for about five seconds until the cycle is repeated. Swallowing always occurs at least two seconds before the next reticular contraction and regurgitation. A three- to fivefold increase of salivation and its associated benefits is achieved through rumination (Leek, 2004). Rumination bouts range from one minute to two hours and occur 10 to 20 times per day (Nørgaard, 1989). During this time between 30 and 60 boluses are regurgitated (Nørgaard, 2003a).

Ruminants ruminate up to 9 hours per day (Bae *et al*., 1983). After this time, animals will not increase time spent ruminating but rather decreases their intake of feed (Bosch *et al*., 1992a; Van Soest, 1994). Type, quantity and physical form of roughage affects the need of rumination and, therefore, the number of rumination periods, the duration of each period and the number of ruminated boli (Nørgaard, 1989). The number of rumination bouts is generally increased with increasing intakes of high fibre roughages in a long physical form (Nørgaard, 2003a). Increased feed intake also results in a decreased rumination time per unit of DM or fibre intake. This might be due to increased efficiency in reducing particle size or that other means of reducing particle size, such as eating and microbial degradation, becomes more important (Van Soest, 1994). Rumination efficiency can be measured by units of NDF consumed per unit of rumination time and is influenced by several factors where level of intake is of importance (Welch and Hooper, 1988).

Feeding highly fermentable diets is inhibitory to rumination because it can cause low rumen pH, high osmotic pressure and high VFA concentrations (Beauchemin, 1991; Leek, 2004). Rumination will only occur after suitable conditioning stimuli. The rumination centres need to receive adequate peripheral excitatory stimuli from receptors in the ruminoreticilum (Leek, 2004). Rumination can be stimulated by tactile means or by the pressure of coarse material. These inducing factors are related to both particle size and cell-wall content of the diet (Van Soest, 1994). Rumination time decreases when the animals are fed low-roughage diets or when the roughage is finely ground as a finely ground diet might not provide enough stimuli to evoke rumination. Normal rumination patterns require forage particles greater than 5 mm to be retained in the rumen. Unsuccessful rumination attempts, pseudorumination, may occur if the feed particles exceed 300 mm, which can be the case with long-cut silages and it may also cause a delayed and less efficient rumination activity (Deswysen and Vanbelle, 1978; Leek, 2004).

Rumination takes up 20 to 40% more time than eating (Nørgaard, 2003a). Finely chopping, grinding and pelleting feeds reduce rumination time. The extent of reduction is variable and is influenced by the specific particle size reduction (Duckworth and Shirlaw, 1958; Jaster and Murphy, 1983). Increased intakes reduce time spent ruminating per gram of feed, which explains the increase in average faecal particle size at higher intakes (Van Soest, 1994).

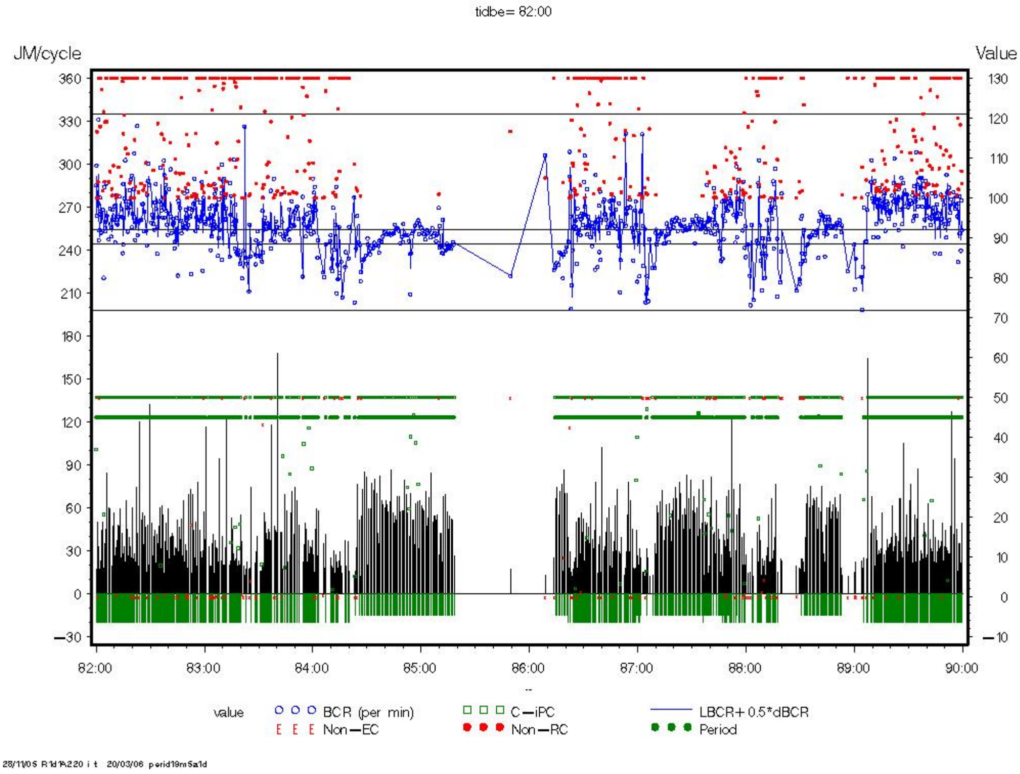


Figure 3. Plot of chewing activity during eating. BCR – Basic chewing rate. The upper part of the figure shows the BCR and the bottom part shows the number and amplitudes of jaw movements during chewing, where each line represents one jaw movement (Nørgaard, personal communication).

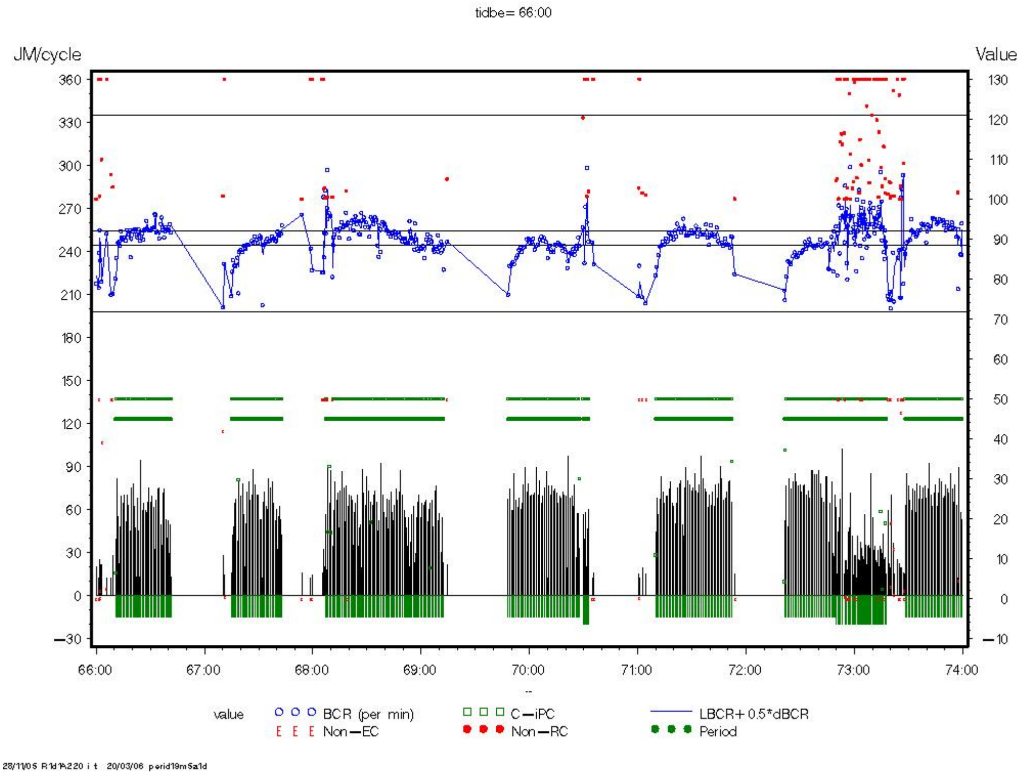


Figure 4. Plot of chewing activity during rumination. BCR – Basic chewing rate. The upper part of the figure shows the BCR and the bottom part shows the number and amplitudes of jaw movements during chewing, where each line represents one jaw movement. A cluster of jaw movements constitutes one chewing cycle (Nørgaard, personal communication).

Eating rate and time spent chewing

Time spent eating and ruminating is a function of both animal and dietary factors (Beauchemin, 1991). Cattle chew relatively more during rumination than during eating (Bergsten *et al.*, 1997) and more time is normally spent chewing during rumination (Van Soest, 1994). Chewing is typically 10 to 20% faster during eating than during rumination but the number of chews is normally 10 to 30% higher during rumination per day (Nørgaard, 2003a). The NDF concentration and particle size of feed are the major dietary factors affecting chewing time (Beauchemin, 1991). An exponential relationship between theoretical length of cut and chewing activity can be expected. Chewing activity of forages with theoretical lengths of cut of 40, 20, 5 and 1 mm has been estimated to 80, 70, 50 and 25%, respectively, of that for long forage based values from late lactation or non-lactating cows (Mertens, 1986). Longer particle sizes of feed stimulate the time spent eating, the time spent ruminating, the number of ruminating periods, the length of the ruminating periods and the frequency of double contraction cycles in the reticulorumen (Nørgaard, 1989). In general, reducing the particle size before feeding leads to a decreased total number of chews per day (Yang *et al.*, 2001; Clark and Armentano, 2002; Krause *et al.*, 2002; Beauchemin and Yang, 2005) and, therefore, a reduced total time spent chewing (Jaster and Murphy, 1983; Deswysen *et al.*, 1984; Krause *et al.*, 2002; Leonardi *et al.*, 2005). Chewing activity may be affected by increased dietary peNDF through prolonging chewing time and increasing chewing rate and number of chews (Beauchemin and Yang, 2005). It has been reported that chopping silage increased the number of bites while eating. This is probably due to the increased number of jaw movements to get the feed into the mouth compared to long silage and the decrease in the amount of feed consumed per bite. Long silage is generally more easily collected, resulting in a decreased number of bites during eating. An increased number of chews during rumination can also be achieved by chopping before feeding (Duckworth and Shirlaw, 1958). The reduction in total chewing time when decreasing the particle size is generally due to the decreased rumination time (Colenbrander *et al.*, 1991).

Time spent eating is affected by the nature of the feed, the time required to select feed particles and reduce them to a swallowable bolus (Van Soest, 1994). When fed *ad libitum*, 30 to 45% of the daily chewing time is spent on feed intake. The daily chewing time is generally increased with increased intakes and particle length. Time spent eating can be reduced and the eating rate can be increased by chopping the forage before feeding. The eating rate is affected by the animal, the feed, the feeding regime and the surrounding environment (Nadeau and Allen, 1998; Nørgaard, 2003a). Cattle tend to ingest feed rapidly and ruminate it later. More intense chewing occurs initially but diminishes as the bolus is masticated (Van Soest, 1994). The decrease in eating rate during a meal is due to a gradual satiation of appetite or decreased saliva production (Duckworth and Shirlaw, 1958). Feed is chewed less when eating is rapid and this results in larger particles being swallowed (Gill *et al.*, 1966). Eating, ruminating and total chewing times per day in relation to different feeds and particle sizes are summarized in table 1.

Table 1. Observations of DMI, eating and ruminating times and total chewing times per day.

Feedstuff	Animal	Property	Physical form				Reference
			Long	Coarse	Medium	Fine	
10% alfalfa hay 90% concentrate	Steers	PS (cm)	12.7	2.45	-	-	Shain et al., 1999
		DMI (kg/d)	10.33	9.92	-	-	
		Eating (min/d)	105	120	-	-	
		Ruminating (min/d)	184	196	-	-	
		Total chewing (min/d)	289	316	-	-	
5.2% wheat straw 94.8% concentrate	Steers	PS (cm)	12.7	2.45	-	-	
		DMI (kg/d)	9.83	10.57	-	-	
		Eating (min/d)	118	139	-	-	
		Ruminating (min/d)	240	229	-	-	
		Total chewing (min/d)	358	368	-	-	
Grass silage, *ad lib*	Heifers	PS (cm)	8.3	-	1.2	-	Deswysen and Vanbelle, 1978
		Eating (min/d)	405	-	367	-	
		Ruminating (min/d)	535	-	576	-	
		Total chewing (min/d)	940	-	943	-	
42% corn silage 58% concentrate	Lactating cows	PS (cm)	-	1.91	1.1	-	Beauchemin and Yang, 2005
		DMI (kg/d)	-	21.1	21	-	
		Eating (min/d)	-	289.7	296.7	-	
		Ruminating (min/d)	-	493.6	471.8	-	
		Total chewing (min/d)	-	783.3	768.5	-	
20% corn silage 20% alfalfa hay 60% concentrate	Lactating cows	GMPL (cm)	-	0.783	0.404	0.114	Teimouri Yansari *et al*., 2002
		DMI (kg/d)	-	24.81	22.64	21.26	
		Eating (min/d)	-	209.4	232.8	257.8	
		Ruminating (min/d)	-	236.1	286.1	338.9	
		Total chewing (min/d)	-	445.5	518.9	596.7	
57.4% corn silage 42.6% concentrate	Lactating cows	GMPL (cm)	0.88	0.83	0.78	0.74	Kononoff *et al*., 2003
		DMI (kg/d)	25.7	26.8	26.8	28	
		Eating (min/d)	212.5	185.1	214.2	201.5	
		Ruminating (min/d)	454.4	420.2	413.7	446.5	
25.1% oat silage 25.1% corn silage 49.8% concentrate	Lactating cows	GMPL (cm)	0.668	0.539	0.519	0.435	Leonardi *et al*., 2005
		DMI (kg/d)	20.4	21.1	21.7	22.1	
		Eating (min/d)	229	242	262	267	
		Ruminating (min/d)	529	539	542	549	
		Total chewing (min/d)	758	779	807	817	
28.5% barley silage 16.1% alfalfa silage 10.4% alfalfa hay	Lactating cows	PS (cm)	-	-	0.759	0.608	Yang *et al*., 2001
		DMI (kg/d)	-	-	20.3	19.9	
		Eating (min/d)	-	-	271.8	242.4	
		Ruminating (min/d)	-	-	448.2	440.4	
		Total chewing (min/d)	-	-	720	684	
55% barley silage 45% concentrate	Lactating cows	PS (cm)	-	1.875	-	0.468	Soita *et al*., 2002
		DMI (kg/d)	-	21.6	-	22.8	
		Eating (min/d)	-	298	-	264	
		Ruminating (min/d)	-	555	-	508	
		Total chewing (min/d)	-	853	-	772	
55% alfalfa silage 45% concentrate	Lactating cows	PS (cm)	-	0.95	0.95/0.48	0.48	Grant *et al*., 1990
		NDF intake (kg/d)	-	6.3	6.5	5.9	
		Eating (min/d)	-	245	250	222.9	
		Ruminating (min/d)	-	550	513.3	368.8	
		Total chewing (min/d)	-	795	763.3	591.7	

Sorting of feed

The morphology of the feed affects the selection and intake of feed. When silage is offered to cattle, there is often a “nosing” and “tossing” behaviour. By nosing the silage, the feed particles that smell and taste the best can be found and ingested (Phillips, 1993). When feed is given in excess, the animal has the opportunity to select what particles to ingest and leave the less desirable parts, usually the stemmy portions, unconsumed. This may increase the feed intake. Selection is limited by the form of the feed and by the animal’s ability to manipulate the feed. Sorting is made more difficult by chopping, grinding or pelleting the feed (Van Soest, 1994). Animals usually show similar eating behaviour when forage is fed either long or coarsely chopped (Jaster and Murphy, 1983). If intake of feed is to be measured, it should be available *ad libitum* as animals eat forages selectively and intake may be higher if greater refusal is allowed, therefore allowing for greater selection (Mertens, 1994; Leonardi and Armentano, 2003).

MEASURING CHEWING ACTIVITIES AND PARTICLE SIZE DISTRIBUTIONS

Computerized chew meter

Computerized monitoring of jaw movements allows for processing of events each hour and time devoted to activities of ruminating, eating and resting can be distinguished. Assessments of total number of eating and ruminating chews, number of boli, chews per bolus and eating and rumination rates can be presented in tabular or graphic form. Information about segments of each meal can be obtained. Problems with this technology might include custom fitting of halters, positioning the sensing device on each animal and maintenance of the latex tube (Burns *et al*., 1994). When comparing observational and electronic chewing measurement it was concluded that the chewing time tends to be overestimated using observational techniques. Absolute values of chewing activities should not be compared among experiments when methods of estimation differ (Kononoff *et al*., 2002).

Dry and wet sieving

Particle size of feed and faeces can be measured in two ways: by dry or wet sieving. They are both based on the principle of screens arranged by decreasing pore openings from top to bottom. Dry sieving involves drying samples and tends to sort particles according to cross-sectional diameter. Electrostatic charge on particles may pose a problem with the dry method. In wet sieving, wet suspensions are slurried trough calibrated screens and particles are sorted according to length. Both characteristics are important in classifying fibre but since the rumen is a wet system, wet sieving is preferred (Van Soest, 1994). A technique developed for on-farm use to determine the particle size of feeds is the Penn State Forage Particle Separator. The particle size distribution can be obtained by sieving the feed in its as fed form (Lammers *et al*., 1996).

Results from dry and wet sieving does not always correspond to each other. One reason could be that larger amounts of samples are generally used for wet sieving, resulting in more particles being sieved than in dry sieving creating a slightly different picture of the particle size distribution of the sample (Nordqvist, 2006). Wet sieving is a more uncertain method compared to dry sieving (Nørgaard, 2003b) but the results are more representative due to the lager amount of sample used. Wet sieving gives a better description of large particles, whereas dry sieving is better to determine the distribution of smaller particles (Vaage *et al*., 1984).

MATERIALS AND METHODS

ANIMALS AND HOUSING

Eight dairy steers, plus one reserve of Swedish red and white dairy breed, weighing around 350 kg at the beginning of the experiment, were used. The animals were taken in from pasture, de-wormed, put on whole-crop barley silage and allowed to get used to the new surroundings about four weeks before the start of the trial. The animals were tied up in separate stalls in a tempered stable at Götala Research Station in Skara, Sweden during the fall and winter of 2005/2006. The floor of each stall was covered with rubber mats in the front and rubber slats in the back. The animals had individual mangers and water bowls.

DIETS

Whole crop barley (*cv*. Kinnan), harvested during the summer of 2005 at heading (June 28th) and at dough stage (July 18th), was cut with a mower conditioner, pressed into round bales and wrapped with eight layers of plastic. At the time of harvest, four litre per ton of green mass of Kofasil Ultra (ADDCON Agrat Gmbh, Germany) was added to the crop. At heading, the crop was wilted for 22 hours before pressing. At dough stage, the crop was baled directly after cutting. The four feeds made up of two harvest times and two particle lengths were fed to the eight animals allowing two animals per feed. The silage was fed either in its long form or after chopping in a precision chopper with a theoretical length of cut (TLC) of 2 cm. Each animal was also given about 0.6 kg of soybean meal and 100 g of minerals per day.

Concentrations of DM, NDF and ash of the different diets are shown in tables 2 and 3. The DM content was 15.5% higher at dough stage compared to heading stage (Table 3).

Table 2. Concentrations of DM (%), NDF and ash (% of DM) of the whole crop barley silages.

	Heading long		**Heading chopped**		**Dough long**		**Dough chopped**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
DM	37.00	4.82	35.67	3.24	41.61	3.73	41.73	3.11
NDF	49.89	1.88	50.69	2.15	48.40	2.22	49.57	1.40
Ash	6.05	0.64	6.15	0.46	5.52	0.45	6.17	0.47

Table 3. Concentrations of DM (%), NDF and ash (% of DM) of the different maturity stages and chop lengths of the whole crop barley silages.

	Heading stage		**Dough stage**		**Long**		**Chopped**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
DM	36.34	4.02	41.67	3.32	39.30	4.79	38.70	4.41
NDF	50.29	1.99	48.98	1.89	49.14	2.13	50.49	1.84
Ash	6.10	0.54	5.84	0.55	5.78	0.60	6.16	0.45

EXPERIMENTAL DESIGN

The eight steers were divided into two squares and randomly assigned to a 2 x 2 factorial arrangement of treatments in a duplicated 4 x 4 balanced latin square design. Each period lasted for 21 days. Each 21-day period consisted of a seven-day adaptation period followed by a ten-day collection period, when intake was registered and faeces were collected, and ended with a four-day period of restrictive feeding. Steers were fed at 115% of *ad libitum* intake during the adaptation and collection periods. Chewing activity was measured on steers in square 1 during the first five days, and on steers in square 2 during the following five days of the ten-day collection period. During the last four days of the period, the animals were fed 85% of *ad libitum* and eating rate was measured on day 21. The animals were weighed before feeding on day six and seven of each period (Table 4).

Table 4. Trial design and time schedule. A - *ad libitum* feeding, R - restricted feeding.

	Day	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
	Block																					
Feeding									A	A	A	A	A	A	A	A	A	A	R	R	R	R
Body weight	1, 2						X	X														
Consumption	1, 2								X	X	X	X	X	X	X	X	X	X				
Faeces	1									X	X	X	X	X	X	X	X	X	X			
	2											X	X	X	X	X	X	X	X			
Chewing activity	1								X	X	X	X	X									
	2													X	X	X	X	X				
Eating rate	1, 2																					X
Video recording	1, 2																					X
Orts																						
Weight	1, 2							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Sieve	1									X	X	X										
	2														X	X	X					
Chop										X	X	X	X	X	X	X	X	X	X			
Sample										X	X	X	X	X	X	X	X	X	X			
Floor orts																						
Weight										X	X	X	X	X	X	X	X	X	X			
Chop														X				X				
Sample														X				X				
Silage sample									X	X	X	X	X	X	X	X	X	X				
Soy/mineral sample									X							X						

FEED AND ORTS

Silage was weighed and divided into a morning and an afternoon ration. Concentrate was fed twice and minerals once daily in a separate manger. During collection periods, samples from each treatment were taken once daily for silage and once weekly for soybean meal and were then frozen at -20ºC. Silage samples from each treatment were pooled to one sample per each five-day period during the collection period. Orts were chopped daily and representative samples were frozen. Ort samples from each animal and period were pooled during the same period as for feed samples and were then frozen.

Particle size distribution of the feed and orts was determined using a Penn State Forage Particle Separator (Heinrichs and Kononoff, 2002) with the lower, 1.3 mm sieve removed. The upper and middle sieve had a pore size of 19 mm and 8 mm respectively. Approximately 200 g of feed and orts were sieved according to the method of Heinrichs and Kononoff (2002). The shaking frequency was increased from 1.1 Hz to about 2 Hz due to the moisture content and large particle size of the samples. Feed samples were taken from three separate bales from each harvest time and sieved in its long and chopped form. Orts from the different diets were sieved on three consecutive days per period (Table 2).

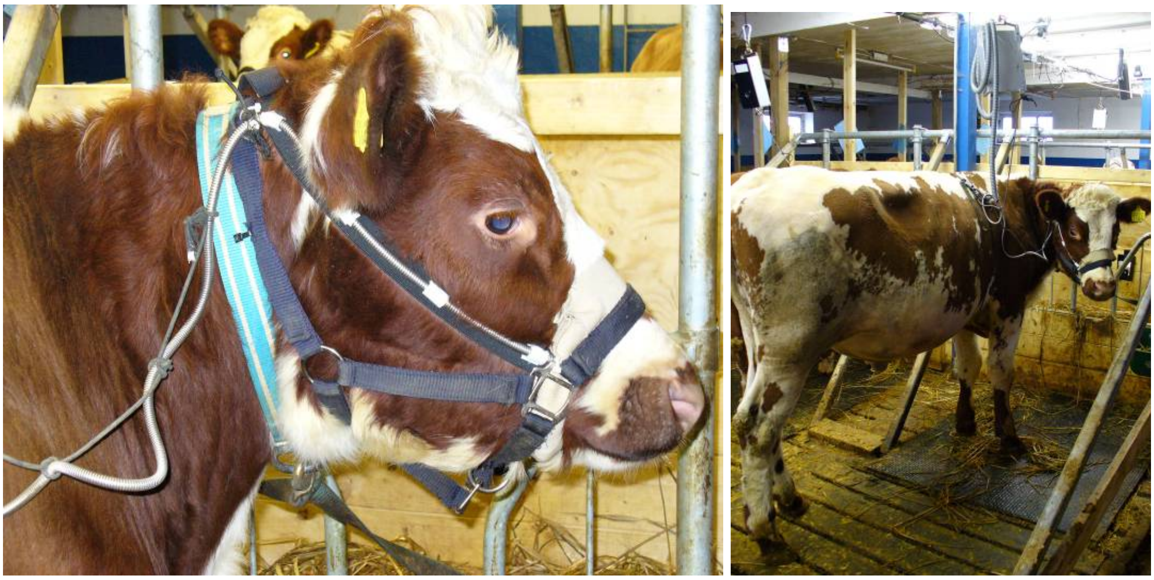
The average length of the unchopped silage was determined by taking 2 kg of samples from three separate bales of each stage of maturity. From each sample, 50 straws were measured and categorized into 5 cm intervals between 30 and 90 cm (Figures 5 and 6). Number of straws in each interval was noted and the mean number of straws within each interval was calculated. From these values, the average straw length was determined.

Figures 5 and 6. Straws from heading and dough stage sorted after size. Each black mark represents 5 cm.

CHEWING ACTIVITY

Chewing activity was recorded during four consecutive days per square and period using elastic halters fitted with magnetic sensors in soft rubber tubes that were placed under the lower jaw according to the method of Nørgaard (personal communication; Nyqvist, 2005; Figure 7). Cords were attached to elastic bands fitted around the bellies and attached to the chewing loggers that were hung from the ceiling in an elastic string (Figure 8). Jaw movements were recorded at a frequency of 12 Hz during the first period and at 20 Hz during the remaining three periods. Four pieces of registration equipment were available, explaining the separation in time of measurements for the two squares. Steers were video taped during collection of chewing data to be used as a reference in case of any uncertainties in processing the data.

Chewing activity data from period 1 was analysed in this thesis. Data for four days was retrieved from four steers, for three days from two steers, for two days from one steer and for one day from one steer. Total chewing time, eating time and rumination time and the number of jaw movements, chewing periods, chewing cycles per period and basic chewing rate was obtained from the registration data. Data was analysed by Nørgaard at The Royal Veterinary and Agricultural University in Denmark according to the method of Nørgaard and Hilden (2004). A second-degree polynomial regression of five continuous digitised signal (DVT) values was used to identify local maximum and minimum as well as the individual jaw movements. The amplitude values of the identified jaw movements were calculated as the difference between maximum and minimum DVT values. The time interval between two subsequent jaw movements is was calculated from the corresponding maximum values. The rate of a jaw movement was estimated by using on sinus and co sinus relationships assuming the oscillation of a jaw movement proceeds like a harmonic oscillation. Jaw movements were clustered into eating and ruminating cycles using the principals described by Schleisner *et al*. (1999). The most frequent time interval (MFTI) between maximum DVT values within cycles was calculated from a gamma distribution and the basic chewing rate within cycles was estimated as 1/MFTI (Nørgaard and Hilden, 2004; Nørgaard, personal communication).



Figures 7 and 8. Halter measuring chewing activity fitted on a steer.

EATING RATE

Eating rate was measured on the fourth day of the restrictive feeding period. Steers were given 85% of VDMI divided into four rations of which two were fed in the morning and two were fed in the afternoon. Time spent eating during a period of 20 minutes with 30-minute intervals was recorded. The procedure was performed twice in the morning and then repeated in the afternoon on the day of recording. Feed consumed was registered by weight and the amount of feed eaten per minute (g fresh weight/min) was calculated. Pauses of over 10 seconds were recorded and subtracted from the total eating time.

FAECES

During the collection periods, spot samples were taken twice daily and frozen. The samples from each animal and period were pooled. Analyses of these samples were not of relevance for this study.

ANALYSES

Feed and Orts

Feed and ort samples were analysed for NDF and ash at Kungsängen Research Center, Uppsala, Sweden. An ND solution was used with sulphite and amylase added to all the samples before placing in 85ºC for 18 hours (Van Soest and Robertson, 1980; Weizhong and Udén, 1998; Mertens, 2002). Following the analysis, samples were dried at 103ºC for 16 hours and then weighed and dried at 550 °C for another three hours to determine the ash content. The DM content was determined by drying the samples at 60°C for 18 hours at SLU, Skara, Sweden.

STATISTICAL ANALYSES

Concentrations of DM, NDF and ash of the four diets are described as means and standard deviations of four replicates sampled during each of four periods in the 4 x 4 Latin square design used for the experiment.

Data regarding intake, eating rate and particle size of orts from the four diets of whole-crop barley silage (heading long, heading chopped, dough long and dough copped) were analysed via analysis of variance for a duplicated 4 x 4 Latin square design by using the GLM procedure of SAS (1999). Square, steer (square), period and diet were used as main effects. The interactions square x period and square x diet were not significant and were, therefore, excluded from the model when $P > 0.10$. Contrasts were used to determine significant differences between maturity stages (heading *vs*. dough stage) and particle sizes (long *vs*. chopped) of the diets. When a significant F-value was detected at $P < 0.05$ or at $0.05 < P < 0.10$, least significant difference (LSD) at $P < 0.05$ or $P < 0.10$, respectively, was used to determine significant variation among the four dietary treatment means.

Chewing activity data from the first period were analysed via analysis of variance for a completely randomized design with the effect of diet being tested against the error term steer (diet) by using the GLM procedure of SAS (1999). Contrasts were used to determine significant differences between maturity stages (heading *vs*. dough stage) and particle sizes (long *vs*. chopped) of the diets. When a significant F-value was detected at $P < 0.05$ or at $0.05 < P < 0.10$, least significant difference (LSD) at $P < 0.05$ or $P < 0.10$, respectively, was used to determine significant variation among the four dietary treatment means.

RESULTS

FEED INTAKE

The DM intake in kg per day of long silage at heading was 8.9 and 7.1% higher than the DM intake of long silage at dough stage and chopped silage at heading, respectively (Table 5). However, chopped silage resulted in a 7.1% higher DMI than long silage at dough stage. Similar differences among diets were found for OM intake (Table 5). Intake of NDF was 9.5 to 10% higher at heading compared to silage at dough stage, when averaged over particle sizes (Table 6).

Table 5. Intakes of DM, OM and NDF (kg/d; % of live weight) of the four diets averaged over four periods.

	Diet				
Intake	**HL**	**HC**	**DL**	**DC**	***P***
DM intake (kg/d)	7.97^{a}	$7.44^{b,c}$	7.32^{b}	$7.84^{a,c}$	0.0724
OM intake (kg/d)	7.51^{a}	6.98^{b}	6.93^{b}	$7.31^{a,b}$	0.0893
NDF intake (kg/d)	4.12^{a}	3.94^{a}	3.59^{b}	3.77^{b}	0.0016
DM intake (% of LW)	2.15	2.01	2.00	2.11	NS
OM intake (% of LW)	2.04	1.89	1.89	1.97	NS
NDF intake (% of LW)	1.12^{a}	$1.07^{a,c}$	0.98^{b}	$1.02^{b,c}$	0.0026

Significant differences among diets are indicated by different superscripts. When $P < 0.05$, least significant difference at $P < 0.05$ was used and when $0.05 < P < 0.10$, least significant difference at $P < 0.10$ was used. HL - heading stage of maturity in its long form, HC – heading stage chopped, DL - dough stage in its long form, DC – dough stage chopped.

Table 6. Intakes of DM, OM and NDF (kg/d; % of LW) of the diets averaged over two particle lengths and maturity stages.

	Maturity/Particle size					
Item	**Heading stage**	**Dough stage**	**Maturity *P***	**Long**	**Chopped**	**Particle size *P***
DM intake (kg/d)	7.70	7.58	NS	7.64	7.21	NS
OM intake (kg/d)	7.24	7.12	NS	7.22	7.14	NS
NDF intake (kg/d)	4.03	3.68	0.0004	3.85	3.85	NS
DM intake (% of LW)	2.08	2.06	NS	2.08	2.06	NS
OM intake (% of LW)	1.96	1.93	NS	1.97	1.93	NS
NDF intake (% of LW)	1.10	1.00	0.0006	1.05	1.04	NS

CHEWING ACTIVITY

Eating constituted 45% of the total chewing time and 55% of the chewing time was spent ruminating over all diets (Figure 9). Significant differences among diets were found for eating time only. Steers fed chopped silage at dough stage spent on average 61% more time eating than steers fed the other silages that did not differ in eating time. Feeding chopped instead of long silage increased eating time by 49% (Figure 9).

Time spent eating was shorter than time spent ruminating for long silage at heading and dough stage and for chopped silage at heading (5.1 *vs.* 8.3, 4.8 *vs.* 8.7 and 6.1 *vs.* 7.5 h, respectively). Eating and ruminating times for chopped silage at dough stage were 8.7 and 5.8 h, respectively (Figure 9).

Figure 9. Total time spent chewing different diets during eating and ruminating in minutes per day. One day equals 24 hours. Different letters on bars indicate a significant difference (*P* < 0.1) among diets. Eating and ruminating times are separated within each bar. Asterisks on bars show a significant difference between maturity stages and particle sizes. * *P* < 0.05. HL - heading stage of maturity in its long form, HC – heading stage chopped, DL - dough stage in its long form, DC – dough stage chopped, H – heading, D – dough, L – long, C - chopped.

When chewing time was expressed in minutes per kg of DM intake, steers fed chopped silage at dough stage spent, on average, 86% more time eating than steers fed long silage at both maturity stages (Figure 10). Eating time per kg of NDF intake was, on average, 83% longer for steers fed chopped silage at dough stage than for steers fed the other silages, that resulted in similar eating times (Figure 11).

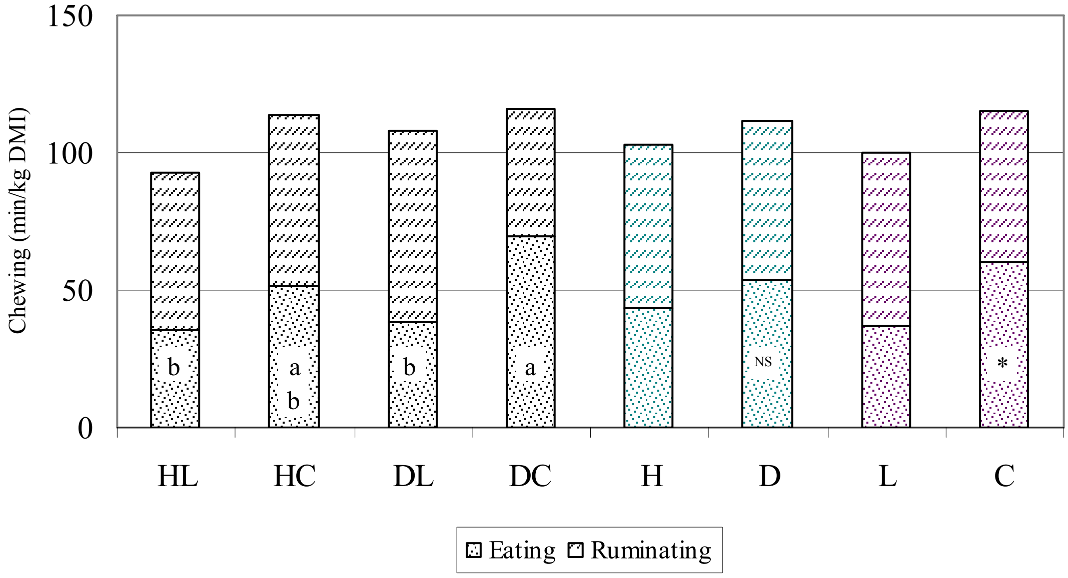


Figure 10. Total chewing time per kg DM intake (min/kg DMI). Different letters on bars indicate a significant difference (*P* < 0.1) among diets. Eating and ruminating times are separated within each bar. Asterisks on bars show a significant difference between maturity stages and particle sizes. * *P* < 0.05. HL - heading stage of maturity in its long form, HC – heading stage chopped, DL - dough stage in its long form, DC – dough stage chopped, H – heading, D – dough, L – long, C - chopped.

Feeding chopped silage instead of long silage increased eating time by 63% (Figures 10 and 11). Steers fed silage harvested at dough stage spent 47% more time eating per kg of NDF intake than steers fed silage at heading stage (Figure 11).

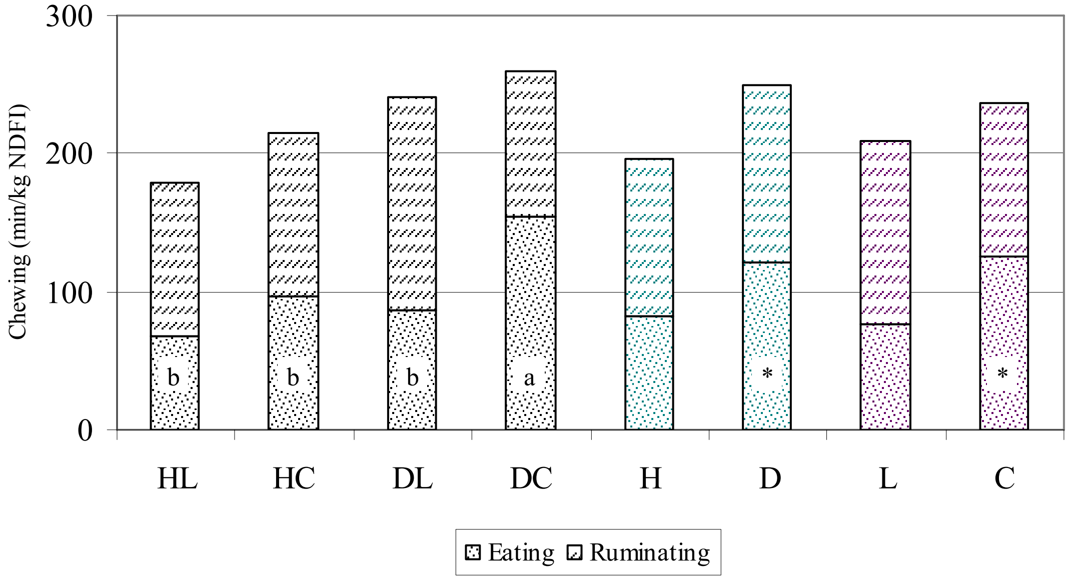


Figure 11. Total chewing time per kg NDF intake (min/kg NDFI). Different letters on bars indicate a significant difference ($P < 0.05$) among diets. Eating and ruminating times are separated within each bar. Asterisks on bars show a significant difference between maturity stages and particle sizes. * $P < 0.05$. HL - heading stage of maturity in its long form, HC – heading stage chopped, DL - dough stage in its long form, DC – dough stage chopped, H – heading, D – dough, L – long, C - chopped.

Significant differences among diets were found only for the number of jaw movements during eating with a differentiation between particle lengths but not maturity stages (Figure 12). Feeding chopped instead of long silage increased the number of jaw movements per day during eating by 49%.

Similarly, the number of jaw movements during eating per kg of DM intake was 64% higher for steers fed chopped instead of long silage (Figure 13). When the number of jaw movements was expressed per kg of NDF intake, steers fed chopped silage of dough stage had, on average, 77% more jaw movements during eating than steers fed the other silages that resulted in similar number of jaw movements (Figure 14). Steers fed chopped silage had 64% more jaw movements per kg of NDF intake during eating than steers fed long silage, when averaged over maturity stages. In addition, steers fed silage at dough stage had 37% more jaw movements during eating per kg of NDF intake than steers fed silage at heading stage, when averaged over particle sizes (Figure 14).

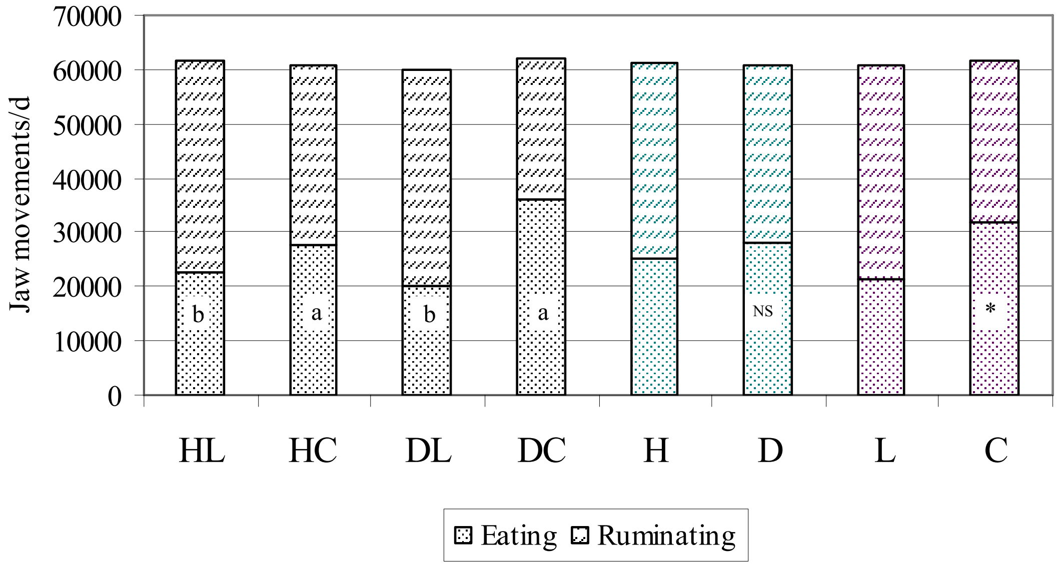


Figure 12. Number of jaw movements per day for the different diets. Different letters on bars indicate a significant difference ($P < 0.05$) among diets. Eating and ruminating times are separated within each bar. Asterisks on bars show a significant difference between maturity stages and particle sizes. * $P < 0.05$. HL - heading stage of maturity in its long form, HC – heading stage chopped, DL - dough stage in its long form, DC – dough stage chopped, H – heading, D – dough, L – long, C - chopped.

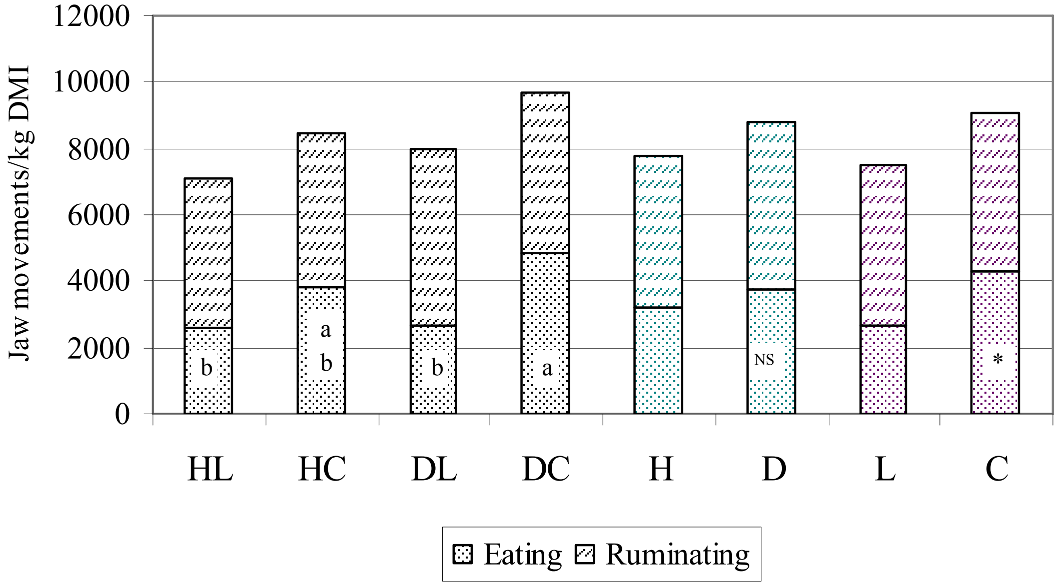


Figure 13. Number of jaw movements per kg of DMI for the different diets. Different letters on bars indicate a significant difference ($P < 0.05$) among diets. Eating and ruminating times are separated within each bar. Asterisks on bars show a significant difference between maturity stages and particle sizes. * $P < 0.05$. HL - heading stage of maturity in its long form, HC – heading stage chopped, DL - dough stage in its long form, DC – dough stage chopped, H – heading, D – dough, L – long, C - chopped.

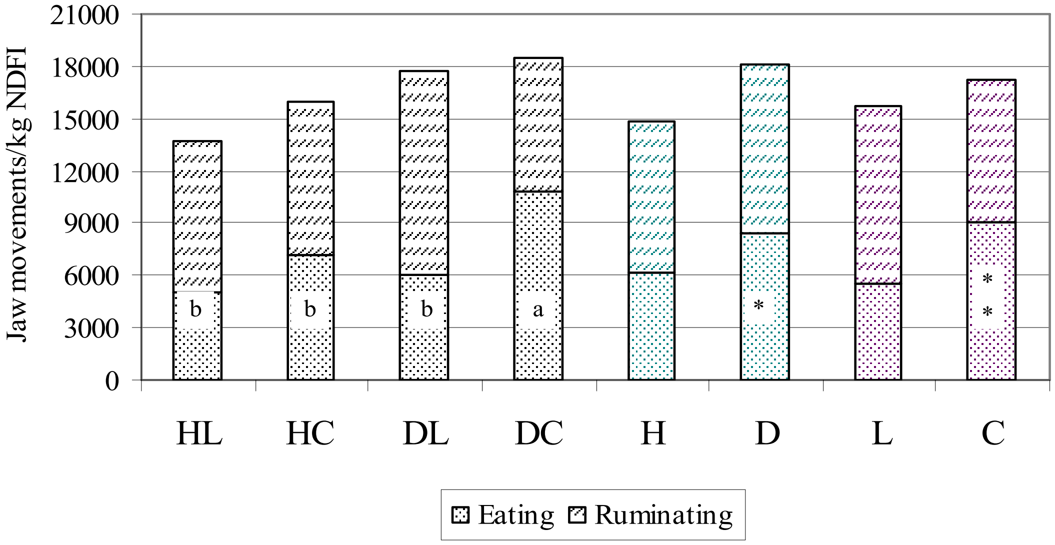


Figure 14. Number of jaw movements per kg of NDF intake for the different diets. Different letters on bars indicate a significant difference ($P < 0.05$) among diets. Eating and ruminating times are separated within each bar. Asterisks on bars show a significant difference between maturity stages and particle sizes. * $P < 0.05$, ** $P < 0.01$. HL - heading stage of maturity in its long form, HC – heading stage chopped, DL - dough stage in its long form, DC – dough stage chopped, H – heading, D – dough, L – long, C - chopped.

Chopping of silage before feeding increased eating rate by 43%, when averaged over particle sizes (Tables 7 and 8). The number of chewing cycles per period was 22 and 40% more for long silage at heading stage than for chopped silage at heading and long silage at dough stage, respectively (Table 7). However, chopping the silage before feeding increased the number of chewing cycles per period by 31% compared to feeding long silage at dough stage.

Table 7. Effective chewing time, number of chewing periods per day, number of chewing cycles per period, chewing rate (jaw movements/min) and eating rate (g fresh weight/min) of the four diets.

	Diet				
Item	**HL**	**HC**	**DL**	**DC**	***P***
Effective chewing time (h)	18.25	17.54	16.35	18.29	NS
Chewing periods/d	39.37	40.62	43.75	40.00	NS
Chewing cycles/period	27.53^{a}	$21.10^{b,c}$	19.61^{b}	$25.76^{a,c}$	0.0225
Chewing rate (JM/min)	87.55	87.86	87.34	88.41	NS
Eating rate (g/min)	87.76^{b}	126.48^{a}	90.46^{b}	128.25^{a}	0.0003

Significant differences among diets are indicated by different superscripts at $P < 0.05$. HL - heading stage of maturity in its long form, HC – heading stage chopped, DL - dough stage in its long form, DC – dough stage chopped.

Table 8. Effective chewing time, number of chewing periods per day, number of chewing cycles per period, chewing rate (jaw movements/min) and eating rate (g fresh weight/min) of the diets averaged over two particle lengths and maturity stages.

	Maturity/Particle size					
Item	**Heading stage**	**Dough stage**	**Maturity *P***	**Long**	**Chopped**	**Particle size *P***
Effective chewing (h)	17.89	17.32	NS	17.30	17.91	NS
Chewing periods/d	39.99	41.87	NS	41.56	40.31	NS
Chewing cycles/period	25.06	22.68	NS	23.57	24.18	NS
Chewing rate (JM/min)	87.70	87.87	NS	87.44	88.13	NS
Eating rate (g/min)	107.12	109.35	NS	89.11	127.36	<0.0001

PARTICLE SIZE

Feed

Long silage at both stages of maturity consisted mostly of particles that were retained on the upper sieve with 98 and 96% of silage at heading and dough stage, respectively, on the upper sieve (Figures 15 and 17). The distribution of particles from chopped silage was more even with 36, 36 and 28% retained on the upper and lower sieve and bottom pan, respectively, for silage at heading stage and with 38, 35 and 27% retained on the upper and lower sieve and bottom pan, respectively, for silage at dough stage (Figures 16 and 18). The mean length of long silage was 70.6 and 66.1 cm for silage at heading and dough stage, respectively. Too few samples were taken to perform statistical analysis of feed particle size.

Orts

The amount of feed orts retained on the upper sieve was 69% higher for long compared to chopped silage (Tables 9 and 10). On the lower sieve, the amount of orts from chopped silage was 359% higher than orts from long silage. The amount of orts retained on the bottom pan was 142% higher for chopped compared to long silage (Tables 9 and 10).

Early harvest increased the amount of feed orts retained on the lower sieve by 31%. Delayed harvest increased the amount of feed orts retained on the bottom pan by 44% (Table 10).

Table 9. Percentage of orts retained on different sieves of the four diets averaged over four periods.

	Diet				
Retained %	**HL**	**HC**	**DL**	**DC**	***P***
Upper sieve	88.72^{a}	47.15^{b}	82.67^{a}	54.39^{b}	<0.0001
Lower sieve	5.77^{c}	33.83^{a}	6.74^{c}	23.53^{b}	<0.0001
Bottom pan	5.41^{c}	19.66^{a}	12.50^{b}	23.61^{a}	<0.0001

Significant differences among diets are indicated by different superscripts at $P < 0.05$. HL - heading stage of maturity in its long form, HC – heading stage chopped, DL - dough stage in its long form, DC – dough stage chopped.

Table 10. Percentage of orts retained on different sieves of the diets averaged over particle sizes and maturity stages.

	Maturity/Particle size					
Retained %	**Heading stage**	**Dough stage**	**Maturity *P***	**Long**	**Chopped**	**Particle size *P***
Upper sieve	67.93	68.53	NS	85.69	50.77	<0.0001
Lower sieve	19.80	15.13	0.0107	6.25	28.68	<0.0001
Bottom pan	12.53	18.05	0.0064	8.95	21.63	<0.0001

Figure 15. Long silage at heading stage of maturity after sieving. Upper and lower sieve and bottom pan are shown from left to right.

Figure 16. Chopped silage at heading stage of maturity after sieving. Upper and lower sieve and bottom pan are shown from left to right.

Figure 17. Long silage at dough stage of maturity after sieving. Upper and lower sieve and bottom pan are shown from left to right.

Figure 18. Chopped silage at dough stage of maturity after sieving. Upper and lower sieve and bottom pan are shown from left to right.

DISCUSSION

Differences in silage fermentation among maturity stages have been observed in previous studies of various whole crop silages (Nadeau, 2004; Nadeau, 2006). The lower sugar content and higher DM content at a later maturity stage limits and changes fermentation during ensiling compared to silage harvested at an earlier stage of maturity. However, the DM content of the silages did not differ to a great extent between maturity stages in this trial. Extensive fermentation has shown to reduce intake (Huhtanen, 2003). For this study, whole crop barley silage was harvested at the heading and dough stage to attain silages with different fibre characteristics. Silages at two different maturity stages such as in this study constitute two totally different feeds. This makes it hard to make proper conclusions about the combined effect of particle size and stage of maturity. At heading, whole crop barley silage is relatively similar to grass silage of later maturity, whereas at dough stage it is more comparable to for example maize silage. Therefore, particle size of the silage was expected to have the main effect on feed intake and chewing activity among diets in this trial. Interactions between stage of maturity and particle size on intake and chewing activity by the steers were probably affected by differences in fibre characteristics of the crop at heading and at dough stage.

Chopping of whole crop barley silage is more motivated for silage harvested at the dough stage compared to the heading stage due to the higher intake of chopped silage harvested at dough stage. Furthermore, chopping the silage facilitates in the handling of the feed, which together with the increased intake provides an incentive for reducing the particle size of whole crop barley silage before feeding when harvested at the dough stage.

FEED INTAKE

Feed intake was expected to be highest for chopped silage at dough stage. Results show that the intake of long silage at heading was the highest although not significantly different to silage at dough stage (Table 5). Reasons for these results could be a softer and more easily ingested structure of the long silage at heading. At the late maturity stage, chopping increased the intake. This might have been due to chopping improving the structure of silage at dough stage by decreasing the size of sharp and rough particles, making it more easily ingested. However, steers fed the silage harvested late were observed feeding the steer beside them if that diet was made up of silage harvested at heading. Also, steers fed early harvested silage were seen “stealing” feed from the neighbouring manger if it contained silage at dough stage. This was noticed only for long silage as steers could not reach into the other manger well enough to reach chopped silage. There is a possibility that silage at heading was favoured for its easily ingested structure, whereas silage at dough stage was preferred for other unspecified reasons.

The hypothesis was that chopping whole crop barley silage before feeding would increase the feed intake. However, results from this study where the particle size did not affect the intake across maturities are somewhat contradictory. A reduced particle size usually reduces rumen retention time and increases passage rate of particular matter, which in turn results in a higher feed intake (Soita *et al*., 2002; Teimouri Yansari *et al*., 2004). A decrease in particle size has resulted in an increase in intake and daily weight gain in steers fed whole crop barley silage (Rustas, unpublished data). The increase in intake of chopped forage is usually explained by a combination of the increased particulate passage rate and improved microbial degradation (Soita *et al*., 2002). As a result of a faster rate of passage with smaller particles, an increased mean fecal particle size can be expected (Jaster and Murphy, 1983). The chopped silages in this study were of a relatively large size compared to other studies (Table 1), which could explain the varying results. Furthermore, Dawson and Steen (2000) concluded that rumination and chewing may be more important determinants of intake than breakdown in the rumen. Relatively constant DM and NDF values with increasing maturity might explain the low significance of differences in intake among diets in this trial.

Another explanation to the small differences in intakes across the different diets could be the intake and growth capacity of the animals. Effects of particle size and stage of maturity could be greater in smaller animals that have a higher growth capacity and may be more limited by rumen fill compared to older and larger animals. These animals are dependant on a maximum feed intake to ensure a fast growth rate and are more likely to be limited by varying physical and chemical characteristics of the diet than an animal experiencing a slower growth rate. It could be hypothesized that animals in this study, in which there was no effect of maturity stage on DMI, had a comparatively low daily weight gain and lower capacity to grow and are therefore less limited by rumen fill, resulting in similar weight gains.

Dry matter intake

Usually, the DMI from forages is decreased with increasing maturity, which disagrees with results from this study. Despite the 41.67% DM content of the feed at dough stage compared to 36.34% at heading, the DMI of silages at the two maturities was similar (Tables 3 and 6). In contrast, Sutton *et al*. (2002) found that the DMI intake increased with advancing maturity of whole crop wheat. However, the particle size of these diets was considerable smaller compared to diets in the present study and the NDF content decreased with a later stage of maturity. When comparing the different maturity stages in this study within the same particle length, the intake of DM from long silage at heading was 8.9% higher compared to silage at dough stage in its long form (Table 5). However, intake of chopped silages did not differ between maturity stages. These results may partly be explained by a greater difference in DM content between the chopped diets than the long diets (Table 2) although this could not have been the major influencing factor. Rather, the structure of the feed at dough stage could be the principal determining aspect. Chopped silage at dough stage had the highest DM content (Table 2), which might have allowed for the high DM intake from this diet. Also, the rough structure of the unchopped silage at dough stage might have led to more difficulties in ingesting the feed, consequently leading to a lower DMI.

The DMI across diets was unaffected by particle length (Table 6), which is in agreement with previous observations (Table 1; Yang *et al*., 2001; Clark and Armentano, 2002; Krause *et al*., 2002; Beauchemin *et al*., 2005). Other studies report increased DMI with decreasing particle size (Table 1; Kononoff *et al*., 2003; Einarson *et al*., 2004; Teimouri Yansari *et al*., 2004; Leonardi *et al*., 2005). This is in contrast to results by Nadeau and Allen (1998) that showed a decreased intake with decreasing particle size. The highest DMI among all diets was reached for long silage at heading (Table 5), which coincides with results by Nadeau and Allen (1998) who showed the highest DMI with early harvested, long lucerne silage. The dietary NDF concentration of diets had a major effect on DMI, whereas in this study it seemed to affect the DMI to a lesser extent. The DMI usually decreases with increasing NDF contents of forages (Jung and Allen, 1995;

Khorasani *et al*. 1997), but that does not explain the results obtained in this study as the NDF content of the different diets was similar between maturity stages. It should be noted that the type of forage used in the different studies varied in species, maturity, storage and particle size, and results should be compared with that in mind.

Intake of NDF

Intake of NDF across diets did not differ between particle sizes (Tables 5 and 6), which is in accordance with results by Beauchemin *et al*. (2005) and Beauchemin and Yang (2005). This is in contrast to the study by Leonardi *et al*. (2005) where the NDF intake linearly decreased with increasing particle size and by Bal *et al*. (2000) where increased NDF intakes were observed with increased particle size. In this study, the NDF content of the feed was similar between the two maturity stages. Intake of NDF was increased by 10% with an earlier harvest date (Table 6). Although, a decreased NDF content of the feed usually results in a decreased NDF intake (Bal *et al*., 2000; Okine *et al*., 2004). However, in this study, the increased NDF intake at an earlier maturity stage of the silage most likely was related to a higher NDF digestibility of the silage at an early maturity stage (Bååth Jacobsson, 2005).

Time of harvest

Stage of maturity at harvest seems to be a major determinant of NDF intake. The intake of NDF across particle sizes was higher for silage at the heading stage (Table 6). Lack of difference in DM intake between the two maturities contradicted the hypothesis that barley silage harvested at the dough stage of maturity would have the highest intake due to a lower NDF content and higher grain content, which was thought to result in a higher preference for these silages. However, the NDF content across diets did not differ. In this study, the higher grain content of the crop at dough stage probably was counteracted by a potential discomfort in the mouth of the animal while eating sharp bristles and straws from the crop at dough stage.

Barley silage at boot stage fed to growing dairy heifers has shown to be more digestible compared to silage at the soft dough stage (Acosta *et al*. 1991). Despite the earlier harvest time compared to this study, it could be assumed that more immature barley silage could be a better feed also for growing dairy steers. This should be taken into consideration when choosing time of harvest, but also that the composition of the silage and therefore animal performance can vary significantly during the early growth stages of the crop (Figure 3). Advantages with an early harvest include less grain loss, better establishment of interseeded grass leys, better ensiling properties, and a higher nutritional value. Some of the disadvantages are lower yields, which leads to a more expensive feed and weather dependant drying of the crop (Sundberg and Olsson, 1998). A harvest time of whole crop cereals one week after heading has been suggested for the northern parts of Sweden, whereas the harvest time in Denmark and Canada is normally four to five weeks after heading (Petterson, 1996; Sundberg and Ohlsson, 1998). Sutton *et al*. (2002) concluded that feed intake increases with increasing maturity of whole crop wheat and the increase in crop yield per ha with advancing maturity is likely to be the most important factor influencing the decision to delay harvest. Also, delayed harvest increases yield of digestible organic matter (Nadeau, 2006). No practical implications for feeding were noted and should not affect the decision of time of harvest. Also, Rustas (unpublished data) showed that whole crop barley silage harvested at dough stage is an economically sound choice because of the low cost per ha and per kg of live weight gain compared to an earlier harvest.

Factors that could explain the relatively constant NDF content of the feed with increasing maturity (Table 3) includes harvesting technique, storage, processing before feeding and handling at feeding. Normally, the NDF content decreases as the crop matures due to an increasing grain to straw ratio (Figure 3; Nadeau, 2004; Bååth Jacobsson, 2005; Nadeau 2006). Storage and processing techniques used in this trial resulted in a grain loss similar to the observed 6 to 8% in previous trials (Rustas, personal communication), which explains the higher than expected NDF content of silage at dough stage.

Based on these facts and the results from this study, time of harvest should be adapted to the most suitable combination of harvest time and particle length at feeding. Chopping of whole crop barley silage is more important to increase intake when harvested at the dough stage compared to the heading stage. Considering there were no significant differences in DMI between the two opposites long silage at heading and chopped silage at dough stage, the time of harvest could not be determined by varying DMI among diets. The intake of NDF, however, differed significantly between maturity stages and could therefore be a better determinant for the time of harvest according to this study.

CHEWING ACTIVITY

No significant differences in total chewing activity between particle lengths were found in this study (Figure 9). This contradicts the hypothesis that chopping would decrease chewing activity. In contrast to results from this study, increased total chewing times with increasing particle lengths have been reported in numerous cases (Krause *et al*., 2002; Kononoff *et al*., 2003; Teimouri Yansari *et al*., 2004; Leonardi *et al*., 2005). Mertens (1997) found a 70% chewing activity of that of long forage with a TLC of 2 cm. However, particle size of the feed significantly affected eating time per day, per kg of DMI and per kg of NDF intake in this study (Figures 9 to 11).

Eating time per day (5.1 to 8.7 h) coincides with the normal four to ten h reported in the literature (Kilgour and Dalton, 1984; Leek, 2004). Increases in time spent eating with increasing particle lengths have been observed (Yang *et al*., 2001; Krause *et al*., 2002; Teimouri Yansari *et al*., 2004; Leonardi *et al*., 2005), which again is contradictory to results obtained in this study where eating time was increased by 63% after chopping. This is in accordance to results by Shain *et al*. (1999) who also observed an increased eating time after chopping of long silage fed to steers. However, steers in that study were fed either alfalfa hay or wheat straw together with a high level of concentrate. Nadeau and Allen (1998) concluded that cows chew more with a higher content of forage in the diet, which means that a high concentrate diet could have a shorter eating time compared to a high forage diet. In addition, no effect on time spent eating after chopping has been reported (Grant *et al*., 1990; Bal *et al*., 2000). Nørgaard (personal communication) suggested a lower eating time after chopping when the particle length was similar to that of chewed feed before swallowing. Chopping, therefore, decreases the need of chewing but results in similar ruminating times. It would also allow for higher DM intakes.

The time spent ruminating (6.9 to 8.3 h/d) was in accordance to the 3 to 9.6 h/d reported in other studies (Table 1; Deswysen and Vanbelle, 1978; Shain *et al*., 1999). Rumination time was increased, although not significantly, when feeding long silage, which is in agreement with several other observations (Clark and Armentano, 2002; Soita *et al*., 2000; Krause *et al*., 2002; Teimouri Yansari *et al*., 2004). However, this increase was not significant. Yang *et al*. (2001) observed no change in rumination time. Time spent ruminating for all diets was 22% higher than eating time, which lies within the normal range of 20 to 40% (Nørgaard, 2003a). Decreasing the particle length of forage has shown to affect the daily chewing pattern by decreasing the number and duration of rumination periods (Krause *et al*., 2002), although no effect of particle size also has been reported (Grant *et al*., 1990). No significant differences between particle sizes or maturity stages of the number of chewing periods were observed in this study (Table 8). The number of rumination periods is usually increased with increasing TLC (Nørgaard, 2003a). This did not seem to be the case with steers in this study where the number of eating and ruminating periods was mainly affected by the individual. In this study, number of chewing cycles was 30% more for long than for chopped silage at heading stage but 24% less for long than for chopped silage at dough stage.

Results from Kovacs *et al*. (1997) indicate that the time spent chewing, eating and ruminating increases with increasing intakes. This is in accordance with results from this study where eating time increased with a tendency to increasing intakes of chopped silage harvested at dough stage (Table 5; Figure 9).

Nørgaard (1989) suggested a substitutional relationship between the time spent eating and the time spent ruminating. Variations in eating time (min/kg DM) of the same feedstuff due to different levels of feeding or animal seem to have little influence on the total time spent chewing because of this substitution between the time spent eating and ruminating (Nørgaard, 1981). A tendency of this can be seen in this study, where total chewing times did not differ significantly even though it did in the case of eating time of chopped silage at dough stage compared to other silages (Figure 9).

Number of chewing periods per day, around 40, was a lot higher than the ones reported at 8 to 20 per day (Nørgaard, 2003a). Reasons for this could be differences in animal factors, such as age and size of the animals in the different trials but also differences in diets. Steers used in this trial were relatively young and had a lower body weight than the lactating cows often used in chewing activity experiments, which might have caused the increase in the number of chewing periods. Furthermore, the diet usually contains a higher proportion of concentrates whereas in this case animals were fed a diet consisting almost entirely of whole crop barley silage. This gives a more fibrous and structured diet, which should require more chewing for effective particle size reduction. There is a possibility that this increased need of chewing leads to an increased number of chewing periods throughout the day even if the total chewing times were in accordance to the literature. This could be explained by the particular factors affecting chewing activity in this experiment favoring a higher number of short chewing periods compared to other studies with fewer but longer chewing periods. A study by Jaster and Murphy (1983) showed that cattle fed long alfalfa hay had a rhythm for total chewing activity, whereas those fed chopped hays distributed their chewing evenly throughout the day. No conclusions about this could be drawn from the present observations.

Total chewing times per kg of NDF was between 178 and 259 min (Figure 11), which corresponded fairly well with the theoretical upper limit for chewing of 200 to 300 min per kg of NDF intake (Mertens, 1997). Concentrations of NDF and peNDF in feed and the level of their intake seem to affect chewing activity, although the effects vary across experiments. Yang *et al*. (2001) showed that peNDF was a poor predictor if chewing activity whereas Beauchemin and Yang (2005) concluded that dietary particle size, expressed as peNDF was a reliable indicator of chewing activity. Some studies have reported no effects of NDF intake on chewing activity (Krause *et al*., 2002; Okine *et al*., 2004) whereas others show an increased chewing activity with increasing NDF or peNDF intakes or feed contents (Oba and Allen, 2000; Yang *et al*., 2001; Krause *et al*., 2002; Beauchemin *et al*., 2005). It was suggested that differences in chewing time per kg of NDF might be due to differences in intake (Mertens, 1997), which is contradictory to the result of this trial where the highest intakes had the lowest eating time per kg of NDF intake (Tables 5 and 6; Figure 11).

Eating time per kg of NDF intake was higher for chopped silage at dough stage compared to other silages in this study. Stage of maturity only affected eating time per kg of NDF intake with a longer time spent eating silage harvested at dough stage, which coincides with the hypothesis that a later maturity increases chewing activity. The same NDF concentration but lower NDF digestibility of silage at later maturity may have resulted in this increase in eating time. Eating time might be determined by the concentration of dietary NDF, which is indicated by the results of Oba and Allen (2000) where the DMI was lower for high NDF diets but animals fed high NDF diets spent more time eating. Similarly, ruminating time per day, per bout and per kilogram of DMI is greater for animals fed high NDF diets. Chewing rate during rumination is faster for high NDF diets (Oba and Allen, 2000). Due to the fairly constant NDF values of the different diets, none of these effects could be observed in this study. In addition, chewing times for long silage at heading and dough stage (178.4 and 241 min/kg NDF, respectively) were higher than for long grass silage, where a mean chewing time of 150 min/kg NDF has been observed (Mertens, 1997). This could be a result of the harder and rougher structure of whole crop silage compared to grass silage. Even though NDF contents of whole crop silage could be comparable to that of late harvested grass silage, the digestibility of the fiber has a major influence on chewing activity. Whole crops contain fiber with a lower fiber digestibility and higher hardness factor compared to grass silage (Bååth Jacobsson, 2005; Nørgaard, 2005), thereby leading to an increased chewing time.

Dietary peNDF may affect chewing activity either through prolonging chewing time or increasing chewing rate (Beauchemin *et al*., 2005). Dairy cattle may maintain a relatively constant rumination time per unit of NDF intake at NDF concentrations greater than 30% (Okine *et al*., 1994). It has been suggested that changes in chewing behaviour are caused by fiber particle size rather than the level of NDF intake (Grant *et al*., 1990; Soita *et al*., 2000). Forage particle size together with the NDF content of the diets are more likely to be reliable indicators of chewing than the NDF content of the forage alone (Beauchemin, 1991; Yang *et al*., 2001). This was not the case in this study, where the NDF content of diets was similar. However, this study showed that fiber digestibility and particle size affected eating time (Figures 9 to 11) and number of jaw movements (Figures 12 to 14).

Number of daily chews during eating was higher for the chopped diets (Figures 12 to 14). The number of jaw movements (JM) per day is usually higher for diets with longer particle lengths (Yang *et al*., 2001; Clark and Armentano, 2002; Krause *et al*., 2002; Beauchemin and Yang, 2005). This may be explained by the increased number of jaw movements needed to get chopped material into the mouth (Duckworth and Shirlaw, 1958) even though the literature is inconclusive. Another explanation is that steers spent more time sorting out kernels when fed the chopped diets, thereby resulting in an increased number of jaw movements. There are more loose kernels in the chopped diets compared to the long due to the more extensive processing before feeding. Also, the finer particles in the chopped diets might be harder to keep in the mouth while chewing, meaning that animals might keep less feed in their mouth while chewing chopped silage compared to long silage. This could also explain the increase in eating time with chopped diets. Ingesting the same amount of feed of the two particle sizes would require more jaw movements for the chopped diets to get the feed into the mouth and therefore also an increase in total time spent eating, even though the feed intake of the silage with different particle sizes did not differ significantly. In addition, chopping the silage increased the eating rate. However, eating time and feed intake was measured during the *ad libitum* feeding period, whereas the eating rate was measured during restrictive feeding. A faster eating rate was expected to result in increased intakes. These contradictory results might indicate a difference in eating behaviour between *ad libitum* and restrictive feeding. Furthermore, there was an interaction with maturity on the effect of particle size on intake (Table 5).

Eating and chewing rate

The difference in eating rate (g fresh weight/min) between diets was highly significant (Table 7). When expressed as g DM per minute, eating rates were in accordance or slightly higher to the normal rate of 20 to 50 g DM per minute (Nørgaard, 1981; Beauchemin, 1991). Chopped silage was eaten more rapidly than long silage both within and across maturities. This is in accordance with Deswysen *et al*. (1984) where the eating rate (min/g DM) in heifers was significantly increased by chopping (1.9 cm) grass silage. However, reduction of barley silage particle size had no effect on eating rate (min/kg roughage or NDF) in the study of Soita *et al*. (2002) or rumination rate (chews/sec) of forage in the study of Grant *et al*. (1990).

Although no significant differences were found in basic chewing rate among diets, eating rate for chopped silage was significantly higher than for long silage (Table 8). The eating rate (g/min) was faster for chopped compared to long silage although eating time was the longest for chopped silage, when averaged across maturities (Table 8; Figure 9). One explanation for the increased eating time of chopped silage could be the increased number of jaw movements needed to get the feed into the mouth, but that would not explain why the intake rate is higher for these diets. Furthermore, DMI did not differ significantly between particle sizes. A reason for these contradicting results could be that the eating rate was measured during the restricted feeding period, whereas consumption and chewing activity was measured during the *ad libitum* feeding period. This indicates that the particle size might have a higher influence on eating behaviour when there is a plenty supply of feed compared to restricted amounts. Another possibility could be that intake of long silage was limited by fill during the *ad libitum* feeding period, explaining the shorter time spent eating despite a slower eating rate. The longer total time spent eating chopped silage might have contributed to the rather similar DMI among diets.

In his study, the number of jaw movements per minute was increased by 8.2% during eating for all diets (Figure 12), which is close to the normally reported 10 to 20% increase in chewing rate during eating (Nørgaard, 2003a). The number of chews per day is normally 10-30% higher during rumination (Nørgaard, 2003a), which is in accordance to the 13.5% increase obtained in this study. The number of jaw movements per day for chopped silage at dough stage was highest for eating, which contradicts previous reports and results from the other diets in this study. Normally, the number of jaw movements per minute is higher during eating whereas the number of chews per day is higher during rumination (Nørgaard, 2003a). The chewing rate of the steers in this study was expected to be slower based on studies on dairy cows (Nørgaard, personal communication). This, however, could be due to the smaller body size and younger age of the animals used in this trial. Furthermore, the number of JM/min during rumination (18 to 27/min) was not in accordance to the 50 to 55 chews/min reported by Beauchemin (1991). This could be due to differences in measuring methods, animal and dietary factors and/or differences in interpreting the chewing data. Differences among diets in this study existed, which can be explained by the varying DM contents, chop lengths and structure of the diets.

A number of studies with the aim to determine the effect of particle size, sometimes expressed as peNDF, on feed intake and chewing activity have been conducted although results are inconclusive. The variability in chewing time in cattle between different studies may be due to differences in body size, intake levels, diet composition and stage of production (Beauchemin, 1991). It has, for instance, been suggested by Bae *et al*. (1983) that body size may account for 22% of differences in chewing time in cattle. Data, compared to results in this study, have come from observations on lactating and non-lactating cows, heifers and steers of varying body weights, *ad libitum* and restricted feeding, separate and total mixed rations and chewing activity was measured using different measuring techniques. Absolute values of chewing activities between experiments should not be compared when the method of estimation is different (Kononoff *et al*., 2002). Comparisons were also made across experiments using different feeds, feeding systems, facilities and animals of which the last three factors represent a major source of variation. It should also be noted that the chewing activity data in this report is a result of measurements from the first period of four only. Furthermore, results may be misleading due to behaviours such as biting and licking of the interior and interactions with the neighbouring steer. The values only indicate tendencies of the effect of diet on chewing activity and effect of period is therefore missing. Variations among individuals may affect the result more than the different diets. The values are not completely reliable and should therefore not be seen as final. Data from all of the periods and steers is needed to make final conclusions about the results of this part of the trial.

EATING BEHAVIOUR

Sorting of feed

Results show signs of steers sorting the feed while eating (Tables 9 and 10; Figures 15 to 18). At both maturities, sorting was in favor of long particles when feeding long silage. However, steers sorted in favor of shorter particles when fed chopped silage. In contrast, sorting of feed in favour of long feed particles has been observed with a more pronounced effect the finer the diet (Beauchemin *et al*., 2005). Feeding long alfalfa hay increased the selective intake of finer particles in the study by Leonardi and Armentano (2003) and by Leonardi *et al*. (2005). Results from this study show a tendency of more sorting of the chopped silages. This could be because the chopped silages were easier to distribute in the manger allowing for selection of particles, whereas the long silages were harder to distribute and the intake of particles was more random. However, the steers were observed moving long silage to the side of the manger to reach loose kernels. Rustas (unpublished data) observed sorting against sharp bristles in whole crop barley silage at dough stage. However, this tendency was not as pronounced in this study although it was observed throughout the trial.

In contrast to a previous study by Rustas (unpublished data) on dairy steers fed whole crop barley silage, the daily amount of orts in the manger, averaged over particle sizes, was higher for chopped silage. However, this increase was neglectable. These previous results showed a significant increase in orts from long silage diets compared to chopped. Steers had a higher intake of chopped barley silage compared to long, which explains the higher amount of orts from long silage (Rustas, personal communication). Factors which might have affected the results in this study include problems in reaching the whole feed bunk, making it harder for the steers to reach and ingest finer particles, differences in the daily amount of orts, which might have led to a higher amount of finer feed particles being ingested when a smaller amount of orts was left over and differences in the silage quality between bales.

When the concentration of NDF in long particles increases, as is the case with lower quality forages, sorting of feed particles in favor of smaller particles will result in greater sorting against forage NDF and total NDF. This will result in a decrease of forage NDF consumed related to forage NDF offered with lower quality compared to higher quality forages. This means that sorting may not be greater with high fiber forages, but the impact of sorting might be (Leonardi and Armentano, 2003). Kononoff *et al*. (2003) reported a decreased NDF concentration of feed remaining in the feed bunk with decreasing particle size, which means selection in favor of long particles increases the NDF intake. This was not the case in this study were the intake of NDF was unaffected by particle size of the silage.

CONCLUSIONS

- Particle size of the feed had major effects on dry matter intake, eating time, jaw movements during eating, chewing cycles and eating rate. However, effect of particle size on DMI and number of chewing cycles per period was influenced by stage of maturity. Interactions between stage of maturity and particle size on intake and chewing activity by the steers might have been affected by differences in fibre characteristics.

- Eating time and number of jaw movements during eating was higher for silage harvested at dough stage compared to heading, which could reflect a decreased fibre digestibility and harder structure of the feed harvested at dough stage. This also indicates that rumen fill affects intake resulting in a decreased fibre intake at dough compared to heading stage. Furthermore, rumen fill probably had an effect on DMI of the long silage.

- Chopping before feeding increased sorting behaviour compared to feeding long silage and resulted in sorting in favor of shorter particles. However, feeding long silage resulted in increased intake of longer particles.

- It is more motivated to chop whole crop barley silage harvested at dough stage compared to silage harvested at heading. However, time of harvest should be adapted to the most suitable combination of harvest time and particle length at feeding in relation to existing production conditions.

SAMMANFATTNING

Helsädesensilage har visat sig vara ett bra och flexibelt grovfoderalternativ till växande nötkreatur och kan utfodras ensamt eller tillsammans med andra grovfoderkällor. Helsädesensilage utgör ett mindre homogent material än vallensilage, då det innehåller stärkelserika ax och stjälkar med hög fiberandel. Ett regelbundet intag av fiberrikt material, såsom helsädesensilage, behövs för att stimulera tuggning och för att bidra till effektiv fodernedbrytning och hälsosam vommiljö hos nötkreatur och andra idisslare.

Mognadsstadiet vid skörd och partikellängden hos grovfoder påverkar foderintag, tuggningsaktivitet och produktion. Senare skörd leder till en nedsatt fibernedbrytbarhet och följaktligen ett lägre foderintag. Foderintaget av helsädesensilage av korn påverkas inte alltid av mognadsstadiet utan kan till och med öka vid senare mognad. Detta beror troligtvis på ett minskat NDF innehåll då andelen kärnor ökar. Hackning av fodret innan utfodring kan öka intaget på grund av en ökad passagehastighet och ett mindre tuggningsbehov. Fodrets innehåll av neutral detergent fiber (NDF) är starkt korrelerat med tuggningstid. Tillsammans med partikelstorleken utgör innehållet av NDF den mest avgörande faktorn för tuggningsaktivitet.

Syftet med den här studien var att undersöka effekterna av mognadsstadium och partikelstorlek hos helsädesensilage av korn lagrat i rundbalar på foderintag, tuggningsaktivitet och ätbeteende hos växande mjölkrasstutar. Åtta stutar, som vägde runt 350 kg i början av försöket, delades in en upprepad romersk kvadrat med fyra perioder och fyra djur i varje kvadrat. Fyra behandlingar, som utgjordes av två olika utvecklingsstadier och partikelstorlekar hos helsädesensilage av korn, utfodrades till två slumpmässigt utvalda stutar per behandling och period. Vid slutet av försöket hade alla stutar utfodrats med alla fyra foder. Varje period varade i 21 dagar. Under den tio dagar långa uppsamlingsperioden registrerades foderintag, tuggningsaktivitet och ätbeteende. Tuggningsaktiviteten mättes med hjälp av elastiska grimmor utrustade med magnetiska sensorer som fästes under käken på varje stut. Ätbeteendet registrerades som äthastighet vid restriktiv utfodring och sortering av foder. Fodersorteringen bestämdes genom att jämföra den procentuella fördelningen av partiklar på tre såll med olika storlek i fodret med fördelningen av partiklarna i resterna.

Intaget av torrsubstans (ts) från långstråigt ensilage skördat vid axgång var större än för långstråigt ensilage skördat vid degmognad och hackat ensilage vid axgång. Däremot resulterade hackning av ensilage skördat vid degmognad i ett större ts-intag jämfört med långstråigt. Intaget av NDF var större vid ensilage skördat vid axgång jämfört med degmognad medan inga skillnader kunde påvisas mellan hackat och långstråigt ensilage.

Idisslingstiden var längre än ättiden för alla behandlingar utom för hackat ensilage skördat vid degmognad, där ättiden var längre än idisslingstiden. Partikellängd och mognadsstadium påverkade endast ättiden medan idisslingstiden var konstant. Mest tid åtgick för att äta hackat ensilage skördat vid degmognad. Hackning ökade ättiden för båda mognadsstadierna. Skördetidpunkten påverkade endast ättiden per kg NDF-intag med en längre ättid för ensilage skördat vid degmognad än för ensilage skördat vid axgång. Antalet käkrörelser var högre vid utfodring av hackat ensilage än av långstråigt ensilage. Uttryckt som antal käkrörelser per kg av NDF-intag, var antalet högre även vid degmognad. Hackning innan utfodring ökade äthastigheten av ensilage vid båda mognadsstadierna.

Antalet tuggningscykler per tuggningsperiod var större för långstråigt ensilage skördat vid axgång än för hackat ensilage skördat vid axgång och långt ensilage skördat vid degmognad. För ensilage skördat vid degmognad var däremot antalet tuggningscykler per period större vid utfodring av hackat ensilage än vid utfodring av långstråigt ensilage. Hackning av ensilaget ökade sorteringsbeteendet jämfört med utfodring av långstråigt ensilage och resulterade i sortering till förmån för korta partiklar.

Samspel mellan effekt av mognadsstadium och partikelstorlek på foderintag och tuggningsaktivitet hos stutarna kan ha påverkats av skillnader i fermentationen av ensilage skördat vid axgång jämfört med ensilage skördat vid degmognad. Ättiden och antalet käkrörelser ökade för ensilage skördat vid degmognad troligtvis beroende på en minskad fibersmältbarhet. Detta tyder på att vomfyllnaden påverkar foderintaget, vilket resulterar i ett minskat fiberintag vid utfodring av ensilage skördat vid degmognad jämfört med ensilage skördat vid axgång. Dessutom påverkar troligen vomfyllnaden även ts-intaget av det långstråiga ensilaget.

Det är mest motiverat att hacka helsädesensilage skördat vid degmognad. Skördetidpunkten bör emellertid anpassas till den bästa kombinationen av skördetidpunkt och partikelstorlek med hänsyn till rådande produktionsförhållanden.

REFERENCES

Acosta, Y. M., Stallings, C. C., Polan, C. E. & Miller, C. N. 1991. *Evaluation of barley silage harvested at boot and soft dough stages*. J. Dairy Sci. 74:167-176.

Albright, J. L. 1993. *Feeding behavior of dairy cattle*. J. Dairy Sci. 76:485-498.

Albright, J. L. & Arave, C. W. 1997. *The behaviour of cattle*. CAB International. Oxon, UK.

Allen, M. S. 1996. *Physical constrains on voluntary intake of forages by ruminants*. J. Anim. Sci. 74:3063-3075.

American Society of Agricultural Engineers. 1993. *S472*: *Terminology for forage harvesters and harvesting*. 40th ed. Am. Soc. Agric. Eng. St. Joseph, MI.

Bae, D. H., Welch, J. G. & Smith, A. M. 1981. *Efficiency of mastication in relation to hay intake by cattle*. J. Anim. Sci. 52:1371-1375.

Bae, D. H., Welch, J. G. & Gilman, B. E. 1983. *Mastication and rumination in relation to body size*. J. Dairy Sci. 66:2137-2141.

Bailey, A. T., Erdman, L. W. & Sharma, B. K. 1990. *Particle size reduction during initial mastication of forages by dairy cattle*. J. Anim. Sci. 68:2084-2094.

Bal, M. A., Shaver, R. D., Jirovec, A. G., Shinners, K. J. & Coors, J. G. 2000. *Crop processing and cop length of corn silage: effects on intake, digestion and milk production by dairy cows*. J. Dairy Sci. 83:1264-1273.

Beauchemin, K. A. 1991. *Ingestion and mastication of feed by dairy cattle*. Vet. Clin. North Am. Food Anim. Pract. 7:439-463.

Beauchemin, K. A., Rode, L. M. & Eliason, M. V. 1997. *Chewing activities and milk production of dairy cows fed alfalfa hay, silage, or dried cubes of hay or silage*. J. Dairy Sci. 80:324-333.

Beauchemin, K. A. & Yang, W. Z. 2005. *Effects of physically effective fibre on intake, chewing activity, and ruminal acidosis for dairy cows fed diets based on corn silage*. J. Dairy Sci. 88:2117-2129.

Bergen, W. G., Byrem, T. M. & Grant, A. L. 1991. *Ensiling characteristics of whole-crop small grains harvested at milk and dough stages*. J. Anim. Sci. 69:1766-1774.

Bergsten, C., Bratt, G., Everitt, B., Gustafsson, A. H., Gustafsson, H., Hallén-Sandgren, C., Olsson, A. C., Olsson, S-O., Plym Forsell, K. & Widebeck, L. 1997. *Mjölkkor*. LTs Förlag, Stockholm.

Bosch, M. W., Lammers-Wienhoven, S. C. W., Bangma, G. A., Boer, H. & Adrichem, P. W. M. 1992a. *Influences of stage of maturity of grass silage on digestion processes in dairy cows. 2. Rumen contents, passage rates, distribution of rumen and faecal particles and mastication activity*. Livest. Prod. Sci. 32:265-281.

Bosch, M. W., Tamminga, S., Post, G., Leffering, C. P & Muylaert, J. M. 1992b. *Influence of stage of maturity of grass silages on digestion processes in dairy cows. 1. Composition, nylon bag degradation rates, fermentation characteristics, digestibility and intake*. Livest. Prod. Sci. 32:254-264.

Burns, J. C., Pond, K. R. & Fisher, D. S. *Measurement of forage intake*. In: Fahey, G. C. Jr., Collins, M, Mertens, D. R. & Moser, L. E. (ed.). 1997. Forage Quality, Evaluation, and Utilization. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, WI.

Bååth Jacobsson, S. 2005. *Vomnedbrytningsprofil av fiber i helsäd – effekt av gröda, skördetidpunkt och metodik*. Studentarbete 29. Sveriges Lantbruksuniversitet, Institutionen för husdjurens miljö och hälsa, Avdelningen för produktionssystem. Skara.

Clark, P. W. & Armentano, L. E. 2002. *Influence of particle size on the effectiveness of the fibre in alfalfa silage*. J. Dairy Sci. 85:3000-3007.

Colenbrander, V. F., Holler, C. H. & Grant, R. J. 1991. *Effect of fibre content and particle size of alfalfa silage on performance and chewing behavior*. J. Dairy Sci. 74:2681-2690.

Dawson, L. E. R., & Steen, R. W. J. 2000. *Relationship between dry matter, fibre and nitrogen degradation characteristics of silage and silage intake of steers*. Anim. Sci. 70:537- 546.

Deswysen, A. G. & Ellis, W. C. 1990. *Fragmentation and ruminal escape of particles as related to variations in voluntary intake, chewing behavior and extent of digestion of potentially digestible NDF in heifers*. J. Anim. Sci. 68:3871-3879.

Deswysen, A. & Vanbelle, M. 1978. *How chopping improves grass silage intake by sheep and heifers*. Pp. 6.19-6.26. Constraints to grass growth and grassland output. Proceedings of the 7th General Meeting of the European Grassland Federation. Gent-Belgium, June 5-9.

Deswysen, A., Bruyer, D. C. & Vanbelle, M. 1984. *Circadian rumination and voluntary silage intake in sheep and cattle*. Can. J. Anim. Sci. 64:341-342.

Duckworth, J. E. & Shirlaw, D. W. 1958. *A study of factors affecting feed intake and the eating behaviour of cattle*. Animal Behaviour. VI, 3-4. pp. 147-154.

Einarson, M. S., Plaizier, J. C. & Wittenberg, K. M. 2004. *Effects of barley silage chop length on productivity and rumen conditions of lactating dairy cows fed a total mixed ration*. J. Dairy Sci. 87:2987-2996.

Forbes, J. M. & Provenza, F. D. 2000. *Integration of learning and metabolic signals into a theory of dietary choice and food intake*. In: Ruminant physiology: Digestion, metabolism, growth and reproduction. Cronjé, P. B. (ed.). CAB International, Wallingford.

Gill, J., Campling, R. C. & Westgarth, D. R. 1966. *A study of chewing during eating in the cow*. Br. J. Nutr. 20:13-23.

Grant, R. J., Colenbrander, V. F. & Albright, J. L. 1990. *Effects of particle size of forage and rumen cannulation upon chewing activity and laterality in dairy cows*. J. Dairy Sci. 73:3158-3164.

Heinrichs, J. and Kononoff, P. 2002. *Evaluating particle size of forages and TMRs using the new Penn State Forage Particle Separator*. Cooperative extension. Penn State College of Agricultural Sciences, Department of Dairy and Animal Science, the Pennsylvania State University, PA.

Huhtanen, P. 2003. *Factors influencing on voluntary intake of silage-based diets, and the response of silage quality in milk production*. Garmo, T. H. (ed.). Proceedings of the International symposium "Early harvested forage in milk and meat production". 23-24 Oct., Kringler, Nannestad, Norway. Agricultural Univ. of Norway, Dept. of Animal and Agricultural Sci., Ås, Norway.

Jaster, E. H. & Murphy, M. R. 1983. *Effects of varying particle size of forage on digestion and chewing behavior of dairy heifers*. J. Dairy Sci. 66:802-810.

Jung, H. G. & Allen, M. S. 1995. *Characteristics of plant cell walls affecting intake and digestibility of forages by ruminants*. J. Anim. Sci. 73:2774-2790.

Kilgour, R. & Dalton, C. 1984. *Livestock behavior. A practical guide*. Granada Publishing Limited, St Albans.

Khorasani, G. R., Jedel, P. E., Helm, J. H. & Kennely, J. J. 1997. *Influence of stage of maturity on yield components and chemical composition of cereal grain silages*. Ca. J. Anim. Sci. 77:259-267.

Kononoff, P. J., Heinrichs, A. J. & Lehman, H. A. 2003. *The effect of corn silage particle size on eating behavior, chewing activities, and rumen fermentation in lactating airy cows*. J. Dairy Sci. 86:3343-3353.

Kononoff, P. J., Lehman, H. A. & Heinrichs, A. J. 2002. *Technical note-A comparison of methods used to measure eating and ruminating activity in confined dairy cattle*. J. Dairy Sci. 85:1801-1803.

Kovacs, P. L., Sudekum, K. H. & Stangassinger, M. 1997. *Effects of intake level of a mixed diet on chewing activity and on particle size of ruminated boli, ruminal digesta fractions and faeces in steers*. Reprod. Nutr. Dev. 37:517-528.

Krause, K. M., Combs, D. K. and Beauchemin, K. A. 2002. *Effects of forage particle size and grain fermentability in midlactation cows. II. Ruminal pH and chewing activity*. J. Dairy Sci. 85:1947-1957.

Lammers, B. P., Buckmaster, D. R. & Heinrichs, A. J. 1996. *A simple method for the analysis of particle size of forage and total mixed rations*. J. Dairy Sci. 79:922-928.

Leek, B. F. 2004. *Digestion in the ruminant stomach*. In: Reece, W. O. (ed.). 2004. Dukes' physiology of domestic animals. 12th ed. Cornell University Press, New York.

Leonardi, C. and Armentano, L. 2003. *Effect of quantity, quality, and length of alfalfa hay on selective consumption by dairy cows*. J. Dairy Sci. 86:557-564.

Leonardi, C. Shinners, K. J. & Armentano, L. E. 2005. *Effect of different geometric mean particle length and particle size distribution of oat silage on feeding behavior and productive performance of dairy cattle*. 88:698-710.

Lingvall, P. 1995. *Ensilering av helsäd*. In: Utfodringskonferens 1995. Svensk husdjursskötsel. Djurböndernas kunskapsförening och SLU Info/Husdjur, Institutionen för husdjurens utfodring och vård.

McDonald, P., Edwards, R. A., Greenhalgh, J. D. F. & Morgan, C. A. 2002. *Animal nutrition*. 6th ed. Pearson Educational Limited, Essex.

Mertens, D. R. 1986. *Effect of physical characteristics, forage particle size and density on forage utilization*. P. 91 in Proc. Nutr. Symp., St. Louis, MO. An. Feed Ind. Assoc., Arlington, VA.

Mertens, D. R. 1994. *Regulation of forage intake*. In: Fahey, G. C. Jr., Collins, M, Mertens, D. R. & Moser, L. E. (ed.) Forage Quality, Evaluation, and Utilization. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, WI.

Mertens, D. R. 1997. *Creating a system for meeting the fibre requirements of dairy cows*. J. Dairy Sci. 80:1463-1481.

Mertens, D. R. 2002. *Gravimetric determination of amylase-treated neutral detergent fibre in feeds with refluxing in beakers or crucibles: collaborative study*. J. AOAC Int. 85:1217-1240.

Mertens, D. R. 2003. *Challenges in measuring insoluble dietary fibre*. J. Anim. Sci. 81:3233-3249.

Minson, J. D. 1990. *Forage in ruminant nutrition*. Academic Press Inc., San Diego, California.

Nadeau, E. & Allen, M. S. 1998. *Physical effectiveness of NDF in alfalfa silages differing in particle size and maturity*. J. Anim. Sci. 76, Suppl. 1/J. Dairy Sci. 81, Suppl 1.
Nadeau, E. 2001. *Satsa på fiber kvalitet!* Svensk mjölks djurhälso- och utfodringskonferens.
Nadeau, E. 2004. *Effekt av spannmålsgröda, skördetidpunkt och tillsatsmedel på foderkvaliten hos helsäd*. Sveriges Lantbruksuniversitet, Institutionen för husdjurens miljö och hälsa, Avdelningen för produktionssystem. Skara. Rapport 6.
Nadeau, E. 2006. *Effects of plant species, stage of maturity and additive on the feeding value of whole crop cereal silage*. J. Sci Food Agric. (Accepted).
Nordqvist, M. 2006. Studentarbete 59. *Träckvärdering som metod för att uppskatta våmfunktion och foderutnyttjande hos mjölkkor*. Sveriges Lantbruksuniversitet, Institutionen för husdjurens miljö och hälsa, Avdelningen för produktionssystem, Skara.
Nyqvist, J. 2005. *Instruktion för mätutrustning av tuggaktivitet*. Projektarbete hörande till den Kvalificerade Yrkesutbildningen Agrotekniker. Biologiska Yrkeshögskolan. Agroväst, Skara.
Nørgaard, P. 1989. *The influence of physical form of ration on chewing activity and rumen motility in lactating cows*. Acta Agric. Scand. 39:187-202.
Nørgaard, P. 2003a. *Optagelse af foder og drøvtygning*. Chap. 6 in: Hvelpelund, T. & Nørgaard, P. 2003. Kvægets enæring og fysiologi. Bind 1 Næringsstoomsætning og fodervurdering. DJF Rapport, Husdyrbrug nr. 53.
Nørgaard, P. 2003b. *Tyggetid som mål for foderets fysiske struktur*. Chap. 17 in: Hvelpelund, T. & Nørgaard, P. 2003. Kvægets enæring og fysiologi. Bind 1 Næringsstoomsætning og fodervurdering. DJF Rapport, Husdyrbrug nr. 53.
Nørgaard, P. 2005. *Nordic structure evaluation system for cattle*. NorFor Plan Seminarium, SLU, Uppsala, 5 april.
Nørgaard, P. & Hilden, K. 2004. *A new method for recording mastication during eating and ruminating in sheep*. J. Anim. and Feed Sci. 13, Suppl. 1:171-174.
Oba, M. & Allen, M. S. 2000. *Effects of brown midrib 3 mutation in corn silage on productivity of dairy cows fed two concentrations of dietary neutral detergent fibre: 2. Chewing activities*. J. Dairy Sci. 83:1342-1349.
O'Kiely, P. O. & Moloney, A. P. 1995. *Performance of cattle offered whole-crop barley or wheat silage*. Irish J. Agri. Food Res. 34:13-24.
O'Kiely, P. O. 2002. *Whole crop cereal silages for beef cattle*. Forage guide: Liam de Paor/Farmers monthly. April.
Ohlsson, C. 1995. *Helsädsensilering i Danmark – försöksresultat från det senaste decenniet*. In: Utfodringskonferens 1995. Svensk husdjursskötsel. Djurböndernas kunskapsförening och SLU Info/Husdjur, Institutionen för husdjurens utfodring och vård. Skara.
Ohlsson, C. 1996. *Effects of silage additives, harvest date, and particle reduction on quality of whole-crop-barley – 1996*. Report to Biotal Limited. Research Center Foulum, Denmark. 11 pp.
Pettersson, T. 1989. *Ensilering av helsäd*. Landsbygd i Västerbotten. 4:19.
Pettersson, T. 1995. *Helsäd i norra Sverige – av korn och havre med ärtor*. FAKTA – Jordbruk. Nr. 9. 4 pp. Sveriges Lantbruksuniversitet, Uppsala, Sweden.
Pettersson, T., Martinsson, K. & Lingvall, P. 1996. *Ensiling of barley grain*. Swedish. J. Agric. Res. 26:189-197.

Phillips, C. J. C. 1993. *Cattle behavior*. Chapter 5. Nutritional behaviour. Farming press books, Ipswich.

Rustas, B-O., Nadeau, E. & Johnsson, S. 2003. *Feed consumption and performance in young steers fed whole-crop barley silage at different levels of concentrate*. Garmo, T. H. (ed.). Proceedings of the International symposium "Early harvested forage in milk and meat production". 23-24 Oct., Kringler, Nannestad, Norway. Agricultural Univ. of Norway, Dept. of Animal and Agricultural Sci., Ås, Norway.

SAS User´s Guide: Statistics. 1999. Version 8 edn., SAS Inst., Inc., Cary, NC.

Schleisner, C., Nørgaard, P. and Hansen, H. 1999. *Discriminant analyses of pattern of jaw movement during rumination and eating in a cow*. Acta Agric. Scand., Sect. A., Animal Sci. 49:251-259.

Shain, D. H., Stock, R. A., Klopfenstein, T. J. & Herold, D. W. 1999. *The effect of forage source and particle size on finishing yearling steer performance and ruminal metabolism*. J. Anim. Sci. 77:1082-1092.

Sniffen, C. J., Hooper, A. P., Welch, J. G., Randy, H. A. & Thomas, E. V. 1986. *Effect of hay particle size on chewing behavior and rumen mat consistency in steers*. J. Dairy Sci. Suppl. 1. Abstracts.

Soita, H. W., Christensen, D. A. & McKinnon, J. J. 2000. *Influence of particle size on the effectiveness of the fibre in barley silage*. J. Dairy Sci. 83:2295-2300.

Soita, H. W., Christensen, D. A., McKinnon, J. J. & Mustafa, A. F. 2002. *Effects of barley silage of different theoretical cut length on digestion kinetics in ruminants*. Can. J. Anim. Sci. 82:207-213.

Sundberg, M & Olsson, C. 1998. *Skörd och ensilering av helsäd*. Teknik för lantbruket. Nr. 71.

Sutton, J. D., Phipps, R. H., Deaville, E. R, Jones, A. K. & Humphries, D. J. 2002. *Whole-crop wheat for dairy cows: effects of crop maturity, a silage inoculant and an enzyme added before feeding on food intake and digestibility and milk production*. Anim. Sci. 74:307-318.

Teimouri Yansari, A., Valizadeh, R., Naserian, A., Christensen, D. A., Yu, P. & Eftekhari Shahroodi, F. 2004. *Effects of alfalfa particle size and specific gravity on chewing activity, digestibility, and performance of Holstein dairy cows*. J. Dairy Sci. 87:3912-3924.

Vaage, A. S., J. A. Shelford, and G. Moseley. 1984. *Theoretical basis for the measurement of particle length when sieving elongated feed particles*. Pages 76–82 in Techniques in Particle Size Analysis of Feed and Digesta in Ruminants. P. M. Kennedy, ed. Can. Soc. Anim. Sci. Occas. Publ. No. 1. Van Soest, P. J. 1994. Nutritional ecology of the ruminant. 2nd ed. Cornell University Press, New York.

Van Soest, P. J. & Robertson, J. B. 1994. *Systems of analysis for evaluating fibrous feeds*. In: Standardization of Analytical Methodology in Feeds (Pigden, W. J., Balch, C. C. & Graham, M., eds.), pp. 49-60. International Research Development Center, Ottawa, Canada.

Weizong, C. & Udén, P. 1998. *An alternative oven method combined with different detergent strengths in the analysis of neutral detergent fibre*. Anim. Feed Sci. Technol. 74:281-288.

Weidow, B. 1998. *Växtodlingens grunder*. Natur och Kultur, Sverige.

Welch, J. G. & Hooper, A. P. 1988. *Ingestion of feed and water*. In: Church, D. C. (ed.) The ruminant animal. Digestive physiology and nutrition. 2nd ed. Prentice Hall, Englewood Cliffs, New Jersey.

Yang, W. Z., Beauchemin, K. A. & Rode, L. M. 2001. *Barley processing, forage: Concentrate, and forage length effects on chewing and digesta passage in lactating cows*. J. Dairy Sci. 84:2709-2720.

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PICTURES

Front page; Aggie Horticulture. 2006-04-25.
http://aggie-horticulture.tamu.edu/extension/Texascrops/grainsfiberandoilseedcrops/

Figure 1; University of Kentucky, College of Agriculture. 2006-01-25.
http://www.ca.uky.edu/agripedia/Classes/ASC106/media/RUMEN.GIF

Figure 5: Penn State. 2006-05-04.
http://www.das.psu.edu/dairynutrition/forages/particle/

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