Evaluation of whole crop wheat silage as feedstuff to high yielding dairy cows, fed for decreased ammonia emission

Helsädesensilage av höstvete som foder till mjölkkor vid utfodring för reducerat ammoniakutsläpp

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PREFACE

The report is based on a thesis, written as the finishing work for the Master degree in Agricultural Science at The Royal Veterinary- and Agricultural University of Copenhagen. The experimental part, including a feeding experiment with whole-crop silage for dairy cows, has been conducted and performed at the Mellangård Experimental Farm at the Swedish University of Agricultural Sciences in Alnarp. The scientific management was performed by Dr Birgit Frank and the financial support to the feeding experiment was received from the Agricultural Research Programme of Southern Sweden (SSJ).

I would like to express my sincere gratitude to both of my supervisors, Associated Professor Birgit Frank, the Department of Agricultural Biosystems and Technology at the Swedish University of Agricultural Sciences at Alnarp, and Associated Professor Anne-Helene Tauson, The Royal Veterinary- and Agricultural University of Copenhagen. Thank you for all positive support, constructive help, and for always finding the time to answer my questions.

I also want to thank Magnus Nilsson, who helped me with much of the daily practical work and all the measurements during the experimental work.

Finally I would like to give my sincerely thanks to herd manager Nils Bengtsson and the staff at Mellangård for always having time to patiently help me when I needed an extra hand during the daily work with the cows.

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The objective of the first part of the thesis is to review the factors affecting the protein metabolism and nitrogen (N)-excretion of the dairy cow, and discuss the use of whole crop silage as a feedstuff to dairy cows. The second part consists of a presentation of a study performed in order to evaluate the use of whole crop wheat silage as a feedstuff to high yielding dairy cows, fed for decreased ammonia emission.

The composition of the protein reaching the small intestines of the cow depends on several factors, such as, the N and energy contents and the quality of the feed ration, and the type and quantity of the rumen microorganisms and their capacity to synthesise protein. The level of crude protein (CP), AAT and PBV, respectively, in the feed ration affects the milk yield and composition. The N-efficiency increases with increasing milk yield and decreases with increasing levels of CP in the feed ration. The composition of the feed ration affects the form in which N is excreted. The N excretion in the faeces and milk has a modest linear positive relationship to the N intake, but the urinary N increases exponentially with increasing N-intake. Optimising the energy and N contents in the feed ration and securing a good balance between energy and protein can decrease the N-excretion.

Combining whole crop silage with grass silage may result in a more efficient utilization of the dietary CP. Existing methods for estimating the digestibility and the energy value of whole crop silage are insecure, and have to be adjusted.

In the study of the including whole crop silage in the feed ration to dairy cows, a Latin square model was used with 12 Swedish Friesian dairy cows, in the beginning or in the middle of lactation. Four different diets were composed, two with 18 % CP- (HP) and two with 16 % CP (LP) of the total dry matter (DM). The protein levels were combined with whole crop wheat silage (WS) or super-pressed beet pulp silage (BP). The cows were on each diet for four weeks, and the ammonia emission was estimated during the last week of the study period. The planned differences in protein levels were not fully obtained, which probably was the reason for the differences observed between the diets being small. However, significant differences between the diets were found for the milk urea concentrations, total N and NH\textsubscript{4}-N in the manure, and ammonia emission from the manure. The cows given the HP diets had a higher content of milk urea and manure NH\textsubscript{4}-N content than did those given the LP diets. The total N in the manure was significantly higher for cows fed the BPHP than the WSLP. Ammonia emission was significantly higher for the cows fed the WSHP than the WSLP. No significant difference in ammonia emission was observed between the BP-diets, but a tendency to a lower emission was seen for the BPLP diet as a whole. A lower level of CP in the diet seems to result in a decreased ammonia emission, and significant difference was seen between the WS diets. It is therefore conceivable that WS could be used in the feed ration to dairy cows together with other roughage to decrease the emission of ammonia without decreasing the milk yield.
SAMMANFATTNING

Syftet med den första delen av examensarbetet är att undersöka vilka faktorer som påverkar proteinomsättningen i mjölkkon, N-utsöndringen, samt att diskutera användandet av helsädesensilage baserat på spannmål som fodermedel åt mjölkkor. Andra delen är en utvärdering av ett försök med vetehelsädesensilage som fodermedel till högproducerande mjölkkor utfodrade för sänkt ammoniak avgång.


En kombination av helsädesensilage och gräsensilage kan resultera i ett effektivare utnyttjande av RP i foderstaten. Existerande metoder som används för utvärdering av smältbarhet och energiinnehåll är osäkra och behöver förbättras.

1 INTRODUCTION

During the past 20 years, the European Community has taken measures to control the possibility of nitrogen (N) polluting the water. The seepage of nitrates from agricultural sources has placed increased emphasis on determining the environmental effects of the presence of excess N, in particular with respect to eutrophication. In accordance with the EU Nitrate Directive (91/676/EEC), a maximum of 170 kg N storage arising from animal manure spread on the fields is allowed per hectare. Other factors, such as the nutrient balance in the feed, and manure handling and spreading, also have to be considered in order to reduce the N-losses to the environment. The objectives of the EU Nitrate Directive are to reduce water pollution caused or induced by nitrates leaching from agricultural sources and prevent further pollution. In order to achieve this goal, the EU member states have to identify zones vulnerable to nitrate leaching and implement action plans to protect these zones (Anonymous, 2003). The aims of the different countries in Europe are similar, but due to differences in the forms of agricultural production, the emphasis might vary. Even though the deposition of N shall be dealt with on a national level, it has to be considered as an international problem, since a country can only partly affect the deposition within its borders, because a large part of the ammonia emission is transported by the winds between countries (Anonymous, 2004a).

In 1998, Denmark established the Action Plan on the Aquatic Environment II, and in connection with this, an action plan to reduce the amount of ammonia volatilisation from agriculture was drawn up. This plan aims to ensure that a number of different possibilities for reducing ammonia volatilisation are implemented within a short space of time. A further intention is to promote the use of better technology leading to a further reduction in ammonia volatilisation from agriculture. In addition, emphasis is placed on a reduction of ammonia volatilisation in areas where agricultural production takes place in the vicinity of vulnerable natural habitat types (Anonymous, 2001).

If the present action plan is carried out as intended, ammonia volatilisation will be reduced by approximately 9,500 tonnes per year from 2004. The Action Plan on the Aquatic Environment II is expected to reduce ammonia volatilisation by approximately 15,000 to 20,000 tonnes N annually. With respect to ammonia, Denmark has accepted a limit of 69,000 tonnes ammonia volatilisation in 2010, which corresponds to a 43 % reduction in ammonia relative to the 1990 level (Anonymous, 2001).

In Sweden, fifteen national objectives for environmental quality have been established (Wrådhe, 2004). The different objectives describe the quality of the environment, and the qualities that the common natural and cultural resources must have to be ecologically sustainable. Objectives are defined and explained as targets and will function as benchmarks, regardless of where they are implemented or by whom, and it is proposed that the environmental quality objectives shall be achieved within one generation.
Ammonia emission is included in the objectives: No Eutrophication and Natural Acidification Only. The Swedish Environment Protection Agency has proposed the following targets:

- By 2010, the current rates of the increased acidification of forest and soil, in areas affected by human activity, have to be decreased to zero, or even been reversed, so that recovery will have started.
- By 2010, Swedish air emission of ammonia has to be decreased by at least 15 % relative to 1995 levels, i.e., from 61,000 to 52,000 tonnes per year.
- Land-use practices that increase the natural acidification rates of soil and water are to be modified or managed so that their contributions to the acidification processes are neutral (Anonymous, 2004b).

Approximately 90 % of the ammonia emission in Europe comes from agricultural sources, of which 77 % originates from manure and manure handling. In Sweden, the manure from cattle production causes the highest losses of ammonia, because cattle constitute a higher number of animal units than the other animals (Anonymous, 2004c).

Many different actions can be taken to reduce the release of N from agricultural sources, and factors can be influenced both at the farm and the cow levels. When trying to decrease the surplus of N at the cow level, the efficiency of N-utilization is of great interest. An improved efficiency of the N-utilization, means that less N is needed per kg produced milk and the total N-excretion to the environment will be reduced. However, an increase in N-efficiency requires great knowledge about feeding, and more research to determine which feedstuffs will lead to an increase in the N-efficiency and how these feedstuffs will interact with the most commonly used feed.

The use of whole crop silage as feed for cattle has become more interesting in Sweden during the last years, since grain production at present entitles the producer to subsidies from the EU, and the subsidies for grass silage during the last years has been reduced due to over production (Anonymous, 2004d). Whole crop silage is also of interest in countries where the N leakage to the environment is considered to be a large problem, in view of the fact that whole crop silage in combination with other roughages, has previously been shown to increase N utilization and decrease the N excretion from cattle production (Ohlsson and Kristensen, 1998).

It appears to be plausible that whole crop silage should have the above-mentioned effect on N-utilization, due to the fact that whole crop silage can contribute to a more continuous supply of starch than the normal high amounts of concentrate feeds can. This will improve the well being of the cows and achieve N-utilization in the rumen. Producing whole crop silage for use as cattle feed in Sweden should not be a problem, since silage based on the most common cereals (oats, barley and wheat) can be harvested in most parts of the country.

The objective of this thesis for the degree of Master of Agricultural Science was partly to review factors affecting the protein metabolism and N-excretion of dairy cows, and discuss the use of whole crop silage as a feedstuff to dairy cows, and partly to perform and evaluate a study of the use of whole crop wheat silage as a feedstuff to high yielding dairy cows, to achieve a decrease in the ammonia emission from the animals.
2 LITERATURE REVIEW

The surplus of N being produced in agriculture has been a major issue over the past few decades, and many actions have been taken to reduce the impact of agriculture on the environment. A dairy farm is a complex system and different parameters cannot be managed or changed in isolation from each other. Therefore, in general, it is important to consider the whole farm production system, including the soil, crops, animals, feeding, housing and manure management, when considering changes. This review focuses on feeding, but to obtain a better overview, the most important factors affecting the N surplus on farm level are also presented in the following section.

2.1 Factors affecting the N-surplus from animal production

In most cases, the dairy farm comprises a production chain constituting of both plant and animal production. Inputs are in the form of feedstuffs to the animals, often as concentrate, and fertilizer for the plant production. Edible outputs are milk and meat from the animals and crops from the fields; the non-edible output is, of course, manure. As seen in Figure 2.1, a N surplus in production is dependent on the feed used on the farm, and how the manure is stored and spread on the fields. This means that a large part of the farm N flow is an internal exchange between manure from animals in the herd and home produced feedstuffs. This becomes especially important on the organic farms, where the concept is to as great extent as possible, to produce products in a closed ecological system, preferably on farm level. Both the type of feeding system and animal housing system will affect the leaching and volatilization of N, because these factors influence both the amount of N excreted and the amount and type of manure. Improvement in the management of the different parameters shown in Figure 2.1 can contribute to a decrease in the N surplus, but changes in one area may affect the flow somewhere else in the cycle. Therefore, according to Aarts et al. (2000), it is necessary to carry out whole farm interdisciplinary research to find possible methods of reducing N losses without decreasing the productivity.

![Figure 2.1. Model of N flow on a dairy farm (modified after Børsting et al., 2003a).](image-url)
All types of animal husbandry result in ammonia production. Ammonia emission is not desired, because it reduces the value of the manure through N losses, gives off an unpleasant odour in the stable, and because it, in combination with rain can contribute to the acidification and eutrophication of the groundwater, etc. (Aaes et al., 2003). All manure handling causes the production and emission of ammonia, which together with the effect of the feed, means that the factors listed below affect the total emission from the herd (Frank et al., 1997).

- Feed and composition of the feed ration
- Ventilation
- Temperature
- Size of areas where manure is exposed
- Amount of manure and length of time of storage in the stable
- pH of manure
- Water content in the manure
- Area per animal
- Air velocity around surfaces with manure

When evaluating possible methods of decreasing the N losses, each farm should be considered individually, since the losses are related to the farm management. This also means that not all biologically possible solutions will have the expected impact under practical conditions (Børsting et al., 2003a).

2.2 Protein metabolism in dairy cows

Knowledge about the supply and metabolism of protein is of importance in dairy production when trying to optimise the production level and economy. Furthermore, this knowledge is important when the intention is to reduce N-losses from cattle manure.

The protein supply of the cow is a complex system, affected by protein content and digestibility, but most of all affected by the microbial digestion and synthesis of protein occurring in the rumen. Since the cow has to rely on this microbial protein synthesis, the protein supply is also influenced by the other nutrients that affect the growth of rumen microbes (McDonald et al., 1995; Hvelplund et al., 2003).

The amount of protein in the feed ration that is digestible by the microorganisms and will be used for protein synthesis, and the amount of protein that can be produced in the rumen, are the two most limiting processes affecting the protein supply of the dairy cow. However, the microbial protein synthesis not only depends on the available nitrogen, but also on the energy released in the rumen for microbial growth. Carbohydrate fermentation is the most important energy source for these microorganisms. Thus, the available N and energy in the rumen are essential for the amount of protein that eventually reaches the small intestine (Hvelplund et al., 2003).
2.2.1 Protein requirements

Due to the microbial processes in the rumen, the protein requirement of the dairy cow consists partly of the requirements of protein for synthesis in the different tissues of the animal, and partly of the requirements of protein or N sources for protein synthesis by the rumen microorganisms (Madsen et al., 2003).

Protein requirements of rumen microorganisms

The protein need of the microorganisms depends upon the growth of the microorganisms, which in turn depends on the amount of fermentable feed and how effectively the microorganisms can utilize the energy for growth. Microorganisms are continuously being degraded and replaced with new microorganisms. The amount of microbial protein reaching the small intestine will therefore depend on the passage rate of the ingesta out of the rumen and will consequently be smaller than the amount synthesised in the rumen (Madsen et al., 2003).

Protein available in the ingested feed is sufficient for most of the microorganisms’ N requirement for protein synthesis, but the re-circulation of urea via the saliva and blood back to the rumen also contributes to the N-supply. On the other hand, the passage of ammonia via the rumen epithelium decreases the amount of N available for protein synthesis (Madsen et al., 2003). Therefore, the balance between the re-circulation of urea to the rumen and the absorption of ammonia will determine the amount of protein needed in the feed ration to cover the requirements of the rumen microorganisms for protein synthesis.

Even though the microorganisms will digest most of the protein in the feed ration, there will always be a portion that is, for the microorganisms, indigestible. Consequently, the composition of protein reaching the small intestine will be a mixture of ruminally undegraded protein, microbial protein and endogenous protein (Hvelplund et al., 2003). Ruminally undegraded protein can have a lower digestibility than microbial protein in the small intestine, and in that case will be more expensive than that readily degraded in the rumen, because of the lower efficiency (Oba and Allen, 2003). On the other hand, microbial protein is highly digestible in the small intestine, and its composition of amino acids is very close to the requirements of the cow (O’Connor et al., 1993). The ratio between the different protein sources can vary with the composition of the feed ration. In conclusion, the amino acid supply of the cow will depend on the amount, composition of amino acids, rumen digestibility and digestibility in the small intestine of these different protein fractions (Hvelplund et al., 2003).

Protein requirements of the cow

The microbial mass in the rumen provides approximately 20 % of the nutrients absorbed by the cow, and therefore the composition of microorganisms is of great importance (McDonald et al., 1995). Microbial protein has the greatest impact on both the quantity and quality of the metabolizable protein which will be absorbed from the small intestine, and diets promoting high microbial production often also lead to an increase in milk production and a corresponding reduction in diet costs (Oba and Allen, 2003).
The requirement of feed protein for the synthesis of protein in the different tissues of the cow can be divided into the essential and nonessential amino acids. The essential amino acids cannot be synthesised directly in the body tissues, and therefore have to be absorbed from the intestine (Madsen et al., 2003). It can always be discussed if the cow really needs essential amino acids in the feed ration, because the microorganisms in the rumen are capable of synthesising all the amino acids which, theoretically, makes the cow independent of a specific amino acid supply from the feed. However, with respect to the fact that the cows and the other ruminants have the same need on the tissue level as monogastric animals, a division of amino acids into essential and nonessential can be considered to be relevant (Hvelplund et al., 2003).

The majority of the absorbed amino acids are used for the syntheses of the milk proteins, but amino acids are also required for production of digestive enzymes, and a smaller part for growth and foetus production (Madsen et al., 2003). When available energy is too low, amino acids can also be used for glucose production via gluconeogenesis in the liver (Cunningham, 1997).

Different protein evaluation systems exist; the one used in the Scandinavian countries is the AAT-PBV system (Madsen et al., 1995), but even though the same system is used, the recommendations differ between countries. The AAT stands for amino acids absorbed in the small intestine, and PBV for protein balance in the rumen. A comparison of the recommendations given by the different Scandinavian countries is presented in Table 2.1. The AAT and PBV together with the metabolizable energy (ME) constitute the system by which the feed rations for dairy cows are optimised in Sweden (Spörndly, 2003). In Denmark, the feed ration is optimised using the AAT, PBV and net-energy, expressed as the Scandinavian feed unit (FU) (Strudsholm et al., 1999). Calculations of AAT and PBV are described in Appendix A.
Table 2.1. Comparison of recommendations of supply of AAT and PBV to dairy cows in the Nordic countries (modified after Madsen et al., 2003)

<table>
<thead>
<tr>
<th></th>
<th>Denmark</th>
<th>Norway</th>
<th>Sweden</th>
<th>Finland</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AAT – requirement</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk production, g/kg ECM</td>
<td>37</td>
<td>42 – 50</td>
<td>40</td>
<td>45</td>
</tr>
<tr>
<td>Maintenance, g/kg LW0.75</td>
<td>3.0</td>
<td>3.25</td>
<td>3.25</td>
<td>3.25</td>
</tr>
<tr>
<td><strong>Weight change</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight gain, g/kg</td>
<td>188</td>
<td>-</td>
<td>250</td>
<td>233</td>
</tr>
<tr>
<td>Weight loss, g/kg</td>
<td>-112</td>
<td>-</td>
<td>-185</td>
<td>-138</td>
</tr>
<tr>
<td><strong>Stage of lactation, Large breed</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7th month, g/d</td>
<td>95</td>
<td>100</td>
<td>59</td>
<td>75</td>
</tr>
<tr>
<td>8th month, g/d</td>
<td>160</td>
<td>160</td>
<td>98</td>
<td>135</td>
</tr>
<tr>
<td>9th month, g/d</td>
<td>215</td>
<td>230</td>
<td>168</td>
<td>205</td>
</tr>
<tr>
<td><strong>PBV – requirement</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early lactation</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Dry period</td>
<td>-200</td>
<td>-300</td>
<td>-300</td>
<td>-200</td>
</tr>
</tbody>
</table>

According to Spörndly (2003) and the AAT-PBV system, a cow that weighs 600 kg and has a daily milk yield of 25 kg energy corrected milk (ECM), will have a daily need of 187 MJ ME and 1394 g AAT; with the assumption that no weight gain occurs. The optimal PBV is 0 g per day, but it is recommended to feed in the interval from 0 to +300 g per day. Corresponding numbers according to the Danish recommendations are 14.5 FU and 1291 g AAT per day (Strudsholm et al., 1999). The Swedish and Danish standards for energy and protein requirements are presented in Appendix B.

In Table 2.2, a comparison between the Swedish and Danish feed standards is presented. From this, it can be concluded that the Danish energy recommendations are slightly higher than the Swedish, but the AAT requirements are lower. In Denmark, considerations with respect to decreased digestibility and energy utilization with increasing milk yield are included in the standards (Kristensen et al., 2003a), thus giving higher standards because of higher energy requirements. On the other hand, in Sweden, this issue is not considered in the standards, but since it has been observed that the allotted standard of 5.0 MJ ME per kg ECM is not sufficient for preserving a high milk yield, a corrected standard has been established (Spörndly, 2003). This is, however, clumsy to use in practice and that is the reason why a higher standard between 5.2 and 5.4 MJ per kg ECM most often is used for medium and high producing cows (Frank, 2004).

The feed and analyses used for the comparison shown in Table 2.2 are presented in Appendices C and D. The amount of feed was first adjusted to the requirements according the Swedish standards (Spörndly, 2003) presented above. The same feed ration was thereafter used to calculate the corresponding numbers of FU, according to the Danish standards (Møller et al., 2000).
Table 2.2. Requirements of energy and AAT according to standards applied in Sweden and Denmark, respectively, compared with a simulated diet for a cow with a body weight of 600 kg and a milk yield of 25 kg ECM/day. Calculations in Appendices C and D

<table>
<thead>
<tr>
<th>Requirements of energy</th>
<th>Supply from simulated diet</th>
<th>Requirements of AAT</th>
<th>Supply from simulated diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweden</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ME, MJ/d</td>
<td>ME, MJ/d</td>
<td>AAT, g/d</td>
<td>AAT, g/d</td>
</tr>
<tr>
<td>186.5</td>
<td>187.1</td>
<td>1394</td>
<td>1581</td>
</tr>
<tr>
<td>Denmark</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NE, FU/d</td>
<td>NE, FU/d</td>
<td>AAT, g/d</td>
<td>AAT, g/d</td>
</tr>
<tr>
<td>14.5</td>
<td>14.0</td>
<td>1291</td>
<td>1581</td>
</tr>
</tbody>
</table>

Where ME, metabolizable energy; NE, net energy; FU, the Scandinavian feed unit; AAT, amino acids absorbed in the intestine; PBV, protein balance in the rumen.

The protein requirements of the cow can be summarized as a combination of the requirements of the rumen microorganisms and the actual requirement of the cow. The composition of the protein reaching the small intestine depends not only on the N and energy contents and the quality of the feed ration, but also on the type and quantity of rumen microorganisms and their capacity to synthesise protein.

Even though the same protein evaluation system is used in both Sweden and Denmark, it is applied differently. In order for it to be possible to compare given standards between these countries easily, further equations for transmission between the energy systems are needed.

2.2.2 Interactions between energy and protein in the rumen

As mentioned above, the microbial turnover of the feed ration in the rumen will induce a growth of microorganisms, which also equals an induced protein synthesis. This is because 50% of the dry matter of the microbes is protein. The size of this synthesis is primarily determined by the amount of digested carbohydrates in the rumen. Fermentation of carbohydrates into short chain fatty acids (SCFA) provides energy that can be used by the microbes for protein synthesis (Hvelplund et al., 2003). This corresponds well with the findings of Shabi et al. (1998), who found a higher flow of crude protein (CP) into the abomasum for cows fed a high amount of ruminally degradable organic matter and a low amount of ruminally degradable CP. The flow of organic matter into the abomasum was not altered by concentrations of ruminally degradable organic matter nor CP, suggesting that available energy in the rumen is the most limiting factor for ruminal N-utilisation. Although energy supply from organic matter fermentation in the rumen often is the limiting factor for the protein synthesis, it should be noted that the efficiency of microbial protein production varies significantly with the composition of the feed ration (Oba and Allen, 2003).

Increasing the dietary energy content may increase the rumen digestible protein requirements and protein synthesis, provided that enough N-sources are available. However, a high level of concentrate relative to roughage level will have a negative influence on the rumen environment. Rumen pH is strongly affected by the composition of the feed ration,
where an increase in the ratio between concentrate and roughage will decrease the rumen pH, due to a higher production of propionate in relation to the other SCFA (Nørrgaard and Hvelplund, 2003). The optimal function of the rumen is obtained at a pH of 6.0 to 6.2. At levels below 6.0, the rumen microbes will begin to die, and fibre digestion will be depressed (Limin, 1999; Kristensen et al., 2003b).

The rumen digestion of protein only contributes a small amount of energy to the total energy balance. Fat is not fermented and therefore does not contribute any energy to the microbial growth, except for the energy obtained from the fermentation of glycerol (Hvelplund et al., 2003). Fatty acids often affect the microbial metabolism in the rumen. The polyunsaturated fatty acids have a toxic effect on the protozoan and cellulolytic bacteria. Thus, addition of fat, and especially polyunsaturated fatty acids, to the feed ration will reduce the digestibility of rumen neutral detergent fibre (NDF) (Børsting et al., 2003b).

Besides factors such as the chemical composition of each type of feed, and the different physical and/or chemical treatments, ruminal degradation and microbial protein synthesis are also dependent on the rates of digestion and passage. Thus, a high feeding level will increase the passage rate of material leaving the rumen, thus increasing the out-flow of microbes from there (Castillo et al., 2000; Hvelplund et al., 2003). Oba and Allen (2000) have shown that a faster rate of passage was positively related to microbial efficiency.

In conclusion, carbohydrates should be fed to the dairy cow in sufficient quantity to ensure both a good microbial growth and energy to be available for body maintenance and milk production. The main part of the feed ration should be given as roughage to secure a high proportion of the neutral detergent fibre (NDF) in order to create a good rumen environment. An energy rich concentrate, mainly in the form of starch, should be fed as a supplement to the roughage. Protein should be fed to provide the micro organisms with enough N-sources for a good microbial growth and protein synthesis.

2.2.3 Effect of protein content in feed rations on production performance

Milk yield and milk composition

In 1978 Emery (1978) found a small but positive relationship between the intestinal amino acid supply and the milk protein content. The increase in milk protein content was 0.02 % for each percentage increase in the CP between 9 and 17 % of the DM. On the other hand, according to a literature review by Schwab (1994), the protein content in the milk did not increase when the total dietary CP was increased from 16 % up to between 18 to 20 %, using conventional protein sources. These observations might have been due to the presence of a higher amount of rumen-undegraded protein relative to the amount of the microbial protein passing to the intestine. Erasmus et al. (2001) concluded that, while protein deficiency can reduce the milk protein yield, overfeeding with protein will not increase the milk protein contents beyond the genetic capacity of the cow.

In relation to the discussion above, Roseler et al. (1993) concluded that the true milk protein was unaffected by increasing feed protein levels. However, milk non-protein N content increased with increasing protein consumption. These findings correspond well with
those of Frank et al. (2002), Broderick (2003) and Davidson et al. (2003), who all reported that a level of CP above 17 % of the DM in the feed ration did not affect the protein concentration, but led to an increase in the concentration of unwanted urea in the milk. Neither Danfær et al. (1980) or Kristensen et al. (1984) found any differences in the milk composition when the CP varied between 15 and 23 % of the DM, which, however, disagreed with the earlier presented findings.

Recent Danish experiments on milk production levels have shown a good correlation between the AAT content per FU and milk yield, expressed both as ECM and protein yield (Madsen et al., 2003). However, the increase in protein yield is most likely a result of the increase in milk yield rather than an increased content of milk protein (Hermansen et al., 2003). According to Madsen et al. (2003), the production response increases up to 90 g AAT per FU; above this level there is no additional response. This partially agrees with the observations of Ohlsson and Kristensen (1998), since they found an increased milk yield up to 95 g AAT per FU. The decrease in milk yield is between 0.3 to 0.5 kg ECM per g decrease in AAT below 90 g AAT per FU (Madsen et al., 2003). The Danish protein recommendations are 90 g AAT per FU, including the requirements for maintenance, when applying norm feeding, or 37 g per kg ECM, for milk production, when feeding according to strategy feeding (Strudsholm et al., 1999). For a standard cow weighing 600 kg and yielding 25 kg ECM per day, 90 g AAT per FU equals 938 g AAT per day for milk production. This is also in good correspondence with the Swedish protein recommendations of 40 g AAT per kg ECM (Spörndly, 2003), which for the same cow as in the previous example will equal 1000 g AAT per day.

Madsen et al. (2003) also showed a good relationship between the PBV and the ECM and protein yield, with an optimal milk production when the PBV is 0 g per FU or above in the first half of the lactation, and a reduction in milk yield of 0.10 to 0.12 kg ECM per g negative PBV per FU. Ohlsson and Kristensen (1998) found only a marginal decrease in milk production down to −200 g PBV, but at PBV levels below −200 g, the decrease was approximately 1 kg milk per day in late lactation. A low PBV could often decrease the feed intake, which could be due to the lack of N-sources in the rumen, but might also be due to the fact that feed rations with a low PBV often have a high content of starch and sugar, which will decrease the NDF turnover. The requirement level of PBV necessary for obtaining optimal milk production would then also depend upon the capacity of the dairy cow to recycle N to the rumen (Madsen et al., 2003).

It can be concluded that the milk yield and milk composition are affected by the CP-, AAT- and PBV content in the feed ration.

**N-efficiency**

The utilization of N for milk production is often used as an indicator to evaluate how well the feed ration is optimized. If the N-efficiency is high, a larger proportion of the feed N contents is used for milk synthesis, and then less will be excreted in the faeces and urine. Thus, improving the N-efficiency will be one way of decreasing the N-excretion per kg produced milk. Researchers and advisors are also interested in finding a good relationship between the level of CP in the ration and the N-efficiency, but many factors have to be taken into account when evaluating N-efficiency. As an example, the rumen digestibility of protein and the digestibility in the small intestine of rumen-undegraded protein, together with the quality and type of carbohydrates present in the feed ration, can all affect the N-efficiency (Shabi et al., 1998; Gustafsson, 2001; Broderick, 2003).
Different studies have been carried out in order to estimate the N-efficiency, which can be obtained under practical conditions (Kalsheur et al., 1999; Frank and Swensson, 2002; Broderick, 2003; Davidson et al., 2003; Dewhurst et al., 2003; Nadeau et al., 2003 and Eriksson et al., 2004). However, these experiments are often executed over a short period of time, and the observed N-efficiency would only represent a part of the lactation period. Therefore, these results can only be used for comparing cows in the same physiological stage.

In Figure 2.2, data have been combined from seven different experiments where N-efficiency has been calculated (Kalsheur et al., 1999; Frank and Swensson, 2002; Broderick, 2003; Davidson et al., 2003; Dewhurst et al., 2003; Nadeau et al, 2003 and Eriksson et al., 2004). The regression equation is calculated in the Minitab 12 program (Minitab Inc., 1997), and the N-efficiency is expressed as N from true milk protein in percentage of total consumed N. Figure 2.2A illustrates an increase in the N-efficiency with increasing milk yield. According to Gustafsson (2001), a higher milk yield is often directly related to better utilization of nutrients, because the needs for maintenance become lower per kg milk. The graph in Figure 2.2B shows that there is a linear increase in N-efficiency of 0.7 per cent units for each kg increase in ECM or FCM (3.5 % fat corrected milk, calculations are shown in Appendix A).
Figure 2.2. Relationship between N-efficiency and milk yield expressed as energy corrected milk or 3.5 % fat corrected milk, and relationship between N-efficiency and level of CP in the feed ration. Data are combined from 7 different experiments representing values for lactating cows only (Kalsheur et al., 1999; Frank and Swensson, 2002; Broderick, 2003; Davidson et al., 2003; Dewhurst et al., 2003; Nadeau et al., 2003 and Eriksson et al., 2004). Regression equation is calculated in Minitab 12.
Even though the ECM and FCM are not normally considered to be comparable, they are used in the same Figure here since they are expected to give the same picture. The observations noted in Figure 2.2A agree with those of Nadeau et al. (2003), who reported an increase in the N-efficiency with increasing milk yield, although with a linear increase of 0.27 per cent units for each kg produced ECM. These findings are based on 733 observations from a time period of 4 years, and must be considered to be more valid than those shown in Figure 2.2A. This Figure comprises a comparison of data from experiments of varying length, varying from 28 days up to 4 years, and these conditions have not been considered in the regression analysis. However, it is of interest that the shorter experiments also follow the same pattern. Due to the fact that parameters, such as, the level of the CP in the feed ration and the digestibility of protein affect the N utilization, Nadeau et al. (2003) point out that any relationship between the N-efficiency and milk yield should be regarded with caution. However, the relationship can be used as a guideline, explaining that approximately 35 % of the total variation in the N-efficiency between cows is caused by variation in daily milk yield (ECM).

The Figure 2.2B illustrates that the N-efficiency decreases with increasing CP level in the feed ration. The problems is, however, to find a feed ration CP level that gives as high N-efficiency as possible without decreasing the milk yield or levels of milk components. Ohlsson and Kristensen (1998), Frank and Swensson (2002), Broderick (2003), Davidson et al. (2003) and Nadeau et al. (2003) all report that a CP level of 16 to 17 % of DM would be sufficient for sustained milk production, provided that the levels of AAT and PBV are well balanced. An even lower CP level of only 14 % of DM was found by Frank et al. (2002) to be enough for milk production without negatively affecting milk composition or the production of milk protein. However this study was carried out over a short experimental period, and further studies are needed for the evaluation of the long-term effects of these low protein rations.

It can be concluded that the N-efficiency, expressed as the N from true milk protein in percentage of total consumed N, increases with increasing milk yield and decreases with increasing levels of CP in the feed ration.

2.2.4 N-excretion

As already indicated, the N metabolism of the cow is a complex system, and N is excreted in the milk, faeces and urine. Figure 2.3 illustrates schematically this N metabolism. The N-excretion in the urine originates from two sources, the obligatory losses and the facultative losses. The obligatory losses include the N-containing compounds arising from body protein turnover, which has not been reincorporated into body protein. Facultative losses, on the other hand, include the excretion of urea, which is necessary to prevent the plasma urea levels from becoming toxic. This N source originates from body breakdown and excess ammonia absorption from the rumen (Kebreab et al., 2001). The obligatory losses are hard to manipulate, but the facultative losses, especially the excess absorption of ammonia from the rumen, is an area to work with in order to decrease the urinary N excretion (Ohlsson and Kristensen, 1998; Kebreab et al., 2001).

Kebreab et al. (2001) also found a linear relationship between the N-intake and the total amount of excreted N. When measuring the ammonia emission is not an option, it is necessary to know in which form the N is excreted, because the ammonia from the urinary N and urinary urea are known to be important factors for predicting the ammonia emission
(Castillo et al., 2000; Kebreab et al., 2001 and Swensson, 2003). As an example, Lockyer and Whitehead (1990) found the ammonia emission from urinary N to be 5 to 6 times higher than from faecal N.

Figure 2.3. Schematic illustration of the N-flow through the cow (modified after De Boer et al., 2002). AAT is amino acids absorbed in the intestine, and PBV is the protein balance in the rumen.

The N-excretion in the urine varies with the ruminal and metabolic losses of N, and an increased dietary N intake will increase the urinary N-excretion (Castillo et al., 2000). According to both Castillo et al. (2000) and Kebreab et al. (2001), the urinary N increases exponentially with the dietary intake of N, with the point of inflection being around 400 g N per day. This means that the rate of N output per N input begins to increase drastically around 400 g N per day. According to the same experiment, an increase in the N-intake from 400 to 450 g per day will result in an urinary N increase of 50 %, but an increase from 450 to 500 g N per day would result in an increase in the urinary N of 80 %. Figure 2.4 illustrates the relationship between the N intake and the N output in the faeces, urine and milk.
The N excreted in the faeces is a combination of undigested dietary protein, endogenous protein, ammonia and microbial protein (Ohlsson and Kristensen, 1998; Hvelplund, 2003). According to both Tamminga (1992) and Kebreab et al. (2001), the true digestibility of the dietary protein is high, approximately 70 to 80 %. Researchers also report a fairly constant excretion of N in the faeces, which makes it difficult to improve the digestibility and thus difficult to decrease N-excretion by increasing the protein digestibility. Kebreab et al. (2001) report a minimal loss of 200 g N per kg N intake, and a modest linear increase in faecal and milk N output in response to N-intake. Peyraud et al. (1995) have observed a faecal N excretion corresponding to 0.75 % of the DM, and Van Soest (1994) has found 0.6 % of the DM intake as faecal N. However, Kirchgessner et al. (1991) have found a stronger relationship between the faecal N and the N intake than with the DM intake.

Since it is often in practice difficult to measure ammonia emission, different methods for predicting the ammonia emission have been developed. Some are discussed in the following.

De Boer et al. (2002) investigated the relationship between feed characteristics and the urinary urea concentration (UUC). They found an increase in urinary N excretion as the level of rumen degradable balance (OEB), expressed in g per kg DM, in the diet increased, and the N-concentrations in the urine correlated positively with the UUC. Urinary N was calculated as:

\[ N_{\text{urine}} = \frac{(OEB + DVE_{\text{diet}})}{6.25} - N_{\text{milk}} \]

where DVE is the intestinal digestible protein, expressed as g per kg DM.

The variables used in the Dutch protein evaluation system have been described previously by Tamminga et al., 1994. Monteny et al. (2002) used the findings of de Boer et al. (2002) to investigate the relationship between the UUC and ammonia emission. The model used for the prediction of the ammonia emission has previously been described by Monteny et al. (1998). Observations of ammonia emission for a wide range of diets and barn conditions confirmed that a combination of the existing nutrition-emission models could be used to predict the ammonia emission accurately (Monteny et al., 2002).
Castillo et al. (2000) and Kebreab et al. (2001) predict urinary N with the exponential functions:

\[
N_{\text{urine}} = 30.4 * (e^{0.0036 * N_{\text{intake}}}) \quad (\text{Castillo et al., 2000})
\]

\[
N_{\text{urine}} = 0.0052 * (N_{\text{intake}})^{1.7} \quad (\text{Kebreab et al., 2001})
\]

The concentration of urinary N or urea is not the only parameter to use in order to predict the emission of NH₃. A relationship between both the blood and milk urea and the urinary N exists. Blood urea (BUN) is the main end product of protein metabolism in ruminants, and the presence of high concentrations of BUN indicates that there has been an inefficient utilization of the dietary N (Nousiainen et al., 2004). Urea diffuses freely from the blood into the milk (Gustafsson and Palmquist, 1993), and the BUN and milk urea (MUN) equilibrate rapidly. Because of the difficulties in obtaining regular and reliable blood samples for the analysis of the BUN, this method is not used in practice. Instead, the MUN sometimes is used as a diagnostic of the efficiency of N utilization, because milk is easily collected and urea can be accurately determined (Nousiainen et al., 2004).

Since the MUN has been used as a fairly accurate indicator of N-utilization, researchers are now also focusing on the MUN as a parameter for the prediction of ammonia emission. Jonker et al. (1998) has suggested the relationship between urinary N and MUN to be:

\[
N_{\text{urine}} (\text{g/d}) = 12.54 * \text{MUN (mg/dl)}
\]

According to Kohn et al. (2002), the MUN corresponds to milk urea as:

\[
\text{MUN} = \frac{28}{60} * \text{milk urea}
\]

and to urinary N as:

\[
N_{\text{urine}} (\text{g/d}) = 0.026 * \text{BW (kg)} * \text{MUN (mg/dl)}
\]

This equation is almost equivalent to the equation of Kauffman and St-Pierre (2001) that expresses urinary N as:

\[
N_{\text{urine}} (\text{g/d}) = 0.0259 (\pm 0.0006) * \text{BW (kg)} * \text{MUN (mg/dl)}.
\]

Theoretically, this means that a cow weighing 600 kg and having a MUN concentration of 13 mg per dl, will have a daily urinary N excretion of approximately 202 g, according to Kauffman and St-Pierre (2001) and Kohn et al. (2002), but only 163 g according to Jonker et al. (1998). Instead of including BW into the equation, Jonker et al. (1998) correct the urinary N excretion according to breed. This is, however, excluded in the equation by Kauffman and St-Pierre (2001) because the breed effect on the relationship between the urinary N and the MUN lost its significance when BW was included in the model.

Swensson (2003) adjusted the equation from de Boer et al. (2002) to the Nordic protein evaluation system (AAT, PBV) that is based on the same principles, resulting in the following equation:

\[
N_{\text{urine}} = \frac{(\text{PBV}_{\text{diet}} + \text{AAT}_{\text{diet}})}{6.25} - N_{\text{milk}}
\]
When comparing the equations of Castillo et al. (2000), Kebreab et al. (2001), de Boer et al. (2002) and Kohn et al. (2002), Swensson (2003) concludes that the most accurate prediction of the urinary N was made by an equation based on the AAT, PBV and N in milk, and the prediction of ammonia was more precise when using the CP as a parameter for ammonia emission rather than the urinary N. This agrees with the findings of Monteny et al. (2002) and de Boer et al. (2002), who emphasise the greater importance of urea in the urine as compared to the total content of urinary N. This is because cows on a diet with a high mineral content will have a higher urinary volume in order to void the minerals, and thus a lower urinary N concentration. The CP and PBV are, according to Nousiainen et al. (2004), also the main nutritional factors affecting the MUN.

In conclusion, N is excreted in the milk, faeces and urine, and the composition of the feed ration affects the type of N and the form in which it is excreted. The N excretion in the faeces and milk has a modest positive linear relationship to the N intake, but the urinary N increases exponentially with increasing N-intake.

Different methods are used in order to predict the ammonia emission from dairy cows. The most commonly used parameters are the urinary N, the MUN and the CP content of the feed, where the latter has been found to be the most accurate when the parameters are compared to each other.

Possible methods of decreasing nitrogen excretion

In Scandinavia, the introduction of the AAT-PBV system for the evaluation of the protein requirements of dairy cows, together with an increased milk yield per cow, have been the main reasons for the reduction in the excretion of N to the environment per kg milk. A Danish evaluation of the N-excretion based on 25 study-farms in the years from 1996 to 1998 (Aaes et al., 2003), showed a 15 kg lower N-excretion per cow per year for farms with Jersey cows, as compared to farms with a larger breed of dairy cattle. When the data were further analysed, it was found that 86 % of the variation between the farms could be explained by differences in milk yield, breed, N-content of the feed ration and the feed efficiency (Aaes et al., 2003). The effect of breed was probably a combination of a lower milk yield per cow per year in comparison to that obtained with the large breeds, and the higher capacity for protein synthesis in the udder of the Jersey cows. Despite the fact that Jersey cows had a lower CP percentage of milk DM, they produced more CP per kg milk than did the large breed cows, due to a higher DM content, as shown in Table 2.3 (Sehested et al., 2003). However, due to the higher fat and energy content of the milk, the protein content as expressed per kg ECM was lower for the Jersey cows than for cows of larger breeds (Table 2.3). It should also be noted that the BW of Jersey cows is lower, which means that the protein requirement for maintenance is lower in comparison to that of the large breeds. The Danish protein recommendations did not differentiate between the breeds, even though the protein content in the milk does vary. In this respect, Madsen et al. (2003) suggested that the Jersey cows might have a lower AAT requirement per kg ECM in comparison to that of larger breeds cows, but more research is needed in order to determine if this is the case.

Assuming that Jersey cows have a lower AAT requirement per kg produced ECM, one way to decrease the N-excretion to the environment could be to use more Jersey cows, or perhaps to start crossbreeding cows for increased N-efficiency with respect to the ECM. However, when looking at the relationship between the urinary N and the MUN, Kauffman and St-Pierre (2001) found no effect of breed on this relationship, instead, differences between breeds could be explained by the differences in the BW, with the urinary N being shown to be directly proportional to the BW at a constant MUN.
A higher milk yield per cow will decrease the N-excretion per kg produced milk, due to a better utilization of the N. This must, however, be put in relation to the genetic milk potential of the cow.

Table 2.3. Comparison of milk protein content between cows of large breeds and Jersey cows (modified after Sehested et al., 2003 and Madsen et al., 2003)

<table>
<thead>
<tr>
<th></th>
<th>Large Breed</th>
<th>Jersey</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM</td>
<td>13.5 %</td>
<td>15.5%</td>
</tr>
<tr>
<td>Crude protein</td>
<td>3.6 %</td>
<td>4.0 %</td>
</tr>
<tr>
<td>Crude protein</td>
<td>26.5 % DM</td>
<td>25.8 % DM</td>
</tr>
<tr>
<td>Crude protein</td>
<td>35.8 g/kg milk</td>
<td>40.0 g/kg milk</td>
</tr>
<tr>
<td>Crude protein</td>
<td>33.5 g/kg ECM</td>
<td>31.4 g/kg ECM</td>
</tr>
</tbody>
</table>

DM = Dry matter; ECM = Energy corrected milk

Another possible method to reduce N-excretion could be to optimise the energy and N content in the feed ration, through good quality energy and protein sources, and secure a good balance between the energy and the protein. If the protein in the feed ration is of good quality and is highly digestible, the CP-level can be decreased, resulting in a lower N-excretion in both the faeces and the urine. A lower excretion of urinary N will also give a lower ammonia emission. Feeding a higher amount of rumen-indigestible protein, by the use of rumen-protected proteins, may also decrease unnecessary N-excretion (Rotz, 2003).

### 2.3 Whole crop silage as feedstuff

The prospect of using whole crop silage as a feedstuff for cattle has become more interesting in Sweden and the rest of Europe over the past few years. One of the reasons for this is the availability of subsidies from the EU for grain production, and the recent decrease in subsidies for grass silage due to over production (Anonymous, 2004d).

Whole crop silage of, especially, cereals has many advantages as compared to the conventionally produced roughage. The production cost is relatively low because the grain is harvested once during the growing season. DM yields on the fields are often high, and the quality is easier to predict due to a more homogenous composition than for the normal roughage based on grass. The production of whole crop grain is not as weather dependent as are grass products, and the use of whole crop silage as a roughage buffer is eminent. In addition, cereal grains can be harvested either as whole crop silage or as ripened grain, depending on the availability of other roughage sources on the farm (Ohlsson, 1995; Bjergmark et al., 2000; Nadeau and Arnesson, 2002). The high DM-yield in whole cereal crops, harvested on one occasion, lowers the workload, which together with the subsidies might result in economic advantages as compared to the traditional grass silage. Although many advantages exist, one disadvantage with whole crop silage is that it is not as easily conserved as are the grass-based silages. This is due to a rough structure, which might lead to a slow production of lactic acid. Furthermore, the rough material is harder to compact in the
silo and will be easier exposed to air (Lingvall, 1995). This sometimes can result in a poorer hygienic quality compared to the grass silage.

### 2.3.1 Nutritional value and chemical composition

An additional reason for the increasing interest in the use of whole crop silages in cattle production is the positive effect it might have on the utilization of nutrients in the feed ration. In Denmark, where whole crop silage has been used since the 1970’s, the most commonly used cereals are spring barley, winter wheat or a mixture of barley and peas. Other cereal grains give silage with a lower digestibility (Bjergmark et al., 2000).

As shown in Table 2.4, where the nutritive composition of barley, wheat and barley/pea silage is compared, there are only small differences in the composition of silages obtained from the different cereals. The greatest difference in DM content is between wheat silage and barley/pea silage. Wheat silage has the highest DM and starch content, but the lowest ash and CP content.

<table>
<thead>
<tr>
<th>Feed code</th>
<th>Wheat silage</th>
<th>Barley silage</th>
<th>Barley/Peas silage</th>
<th>Wheat grain</th>
<th>Grass silage</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM (%)</td>
<td>41.0</td>
<td>36.0</td>
<td>32.0</td>
<td>85.0</td>
<td>35.0</td>
</tr>
<tr>
<td>Ash (% of DM)</td>
<td>4.8</td>
<td>5.5</td>
<td>6.5</td>
<td>1.8</td>
<td>9.8</td>
</tr>
<tr>
<td>CP (% of DM)</td>
<td>9.4</td>
<td>10.4</td>
<td>13.2</td>
<td>11.9</td>
<td>15.2</td>
</tr>
<tr>
<td>CF (% of DM)</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.2</td>
<td>4.4</td>
</tr>
<tr>
<td>Sugar (% of DM)</td>
<td>2.0</td>
<td>1.8</td>
<td>2.3</td>
<td>3.2</td>
<td>4.3</td>
</tr>
<tr>
<td>Starch (% of DM)</td>
<td>24.7</td>
<td>23.3</td>
<td>19.8</td>
<td>68.0</td>
<td>0</td>
</tr>
<tr>
<td>DCW (% of DM)</td>
<td>33.3</td>
<td>33.0</td>
<td>34.1</td>
<td>8.0</td>
<td>46.7</td>
</tr>
<tr>
<td>DE (MJ/kg DM)</td>
<td>12.1</td>
<td>12.0</td>
<td>12.3</td>
<td>16.0</td>
<td>12.6</td>
</tr>
<tr>
<td>FU/kg DM</td>
<td>0.75</td>
<td>0.74</td>
<td>0.77</td>
<td>1.21</td>
<td>0.78</td>
</tr>
</tbody>
</table>

Where DM = dry matter; CP = crude protein, CF = crude fat; DCW = digestible cell walls; DE = digestible energy, FU = Scandinavian feed unit. Analyses are based on samples from the reference years 1995 to 1999, analysed at Steins Laboratorium A/S, Denmark. If the feed samples had a highly variable composition, the samples were divided after digestible organic matter, into low, moderate and high digestibility. The values presented in this Table are from the moderate section.

With regards to the composition of whole crop silage, the carbohydrates constitute the highest proportion of nutrients, while the CP constitutes only a smaller part. The same is seen for grains, but the composition of the carbohydrates differs between the cereals and the whole crop silage (Møller et al., 2000). As seen in Table 2.4, starch constitutes approximately 68 % of the DM, and the digestible cell walls (DCW) constitute only about 8 % of the wheat grain DM. The corresponding carbohydrate content of the DM for whole crop wheat silage is about 25 % and 33 %, respectively. Grass silage, on the other hand, has in comparison to whole crop silage a higher content of CP, fat, DCW and sugar, but lacks starch.
A more continual supply of easily digested carbohydrates is of importance for the rumen microbes in order to utilize the ammonia arising from the ruminal degraded protein efficiently (Shabi et al., 1998). This has been shown to be especially important when feeding dairy cows to obtain a decrease in the ammonia emission. Frank et al. (2002) have compared the effect of feeding two levels of crude protein (14 and 19 %) to these animals. Feeding the low level of CP in combination with a high amount of beet-pulp silage led to a decrease in the relative level of ammonia emission by 2/3, in comparison to that obtained when feeding the high level of CP.

If the feed ration is composed of both whole crop silage and the traditional grass silage, the stem-rich whole crop silage will add more structure to the ration, and the easily soluble protein in early harvested grass silage will be utilized more efficiently because of a better availability of energy from fibre and starch in the whole crop silage (Nadeau and Arnesson, 2002). In this way, it will be possible to decrease the losses of N from the manure and increase the N efficiency (Ohlsson and Kristensen, 1998).

Table 2.5. The chemical composition of whole crop wheat silages, harvested at different growth stages (modified after Crovetto et al., 1998)

<table>
<thead>
<tr>
<th>Stage of maturity</th>
<th>Boot</th>
<th>Mid-bloom</th>
<th>Milk</th>
<th>Dough</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM (%)</td>
<td>19.7</td>
<td>22.4</td>
<td>29.0</td>
<td>36.0</td>
</tr>
<tr>
<td>OM (% of DM)</td>
<td>93.1</td>
<td>94.4</td>
<td>93.8</td>
<td>94.4</td>
</tr>
<tr>
<td>CP (% of DM)</td>
<td>12.7</td>
<td>9.8</td>
<td>8.3</td>
<td>7.9</td>
</tr>
<tr>
<td>NDF (% of DM)</td>
<td>57.5</td>
<td>59.4</td>
<td>59.4</td>
<td>48.7</td>
</tr>
<tr>
<td>ADF (% of DM)</td>
<td>34.9</td>
<td>34.6</td>
<td>35.0</td>
<td>31.0</td>
</tr>
<tr>
<td>Lignin (% of DM)</td>
<td>3.8</td>
<td>4.7</td>
<td>4.6</td>
<td>6.2</td>
</tr>
<tr>
<td>Starch (% of DM)</td>
<td>2.3</td>
<td>2.6</td>
<td>2.7</td>
<td>18.8</td>
</tr>
</tbody>
</table>

Where DM = dry matter; OM = organic matter; CP = crude protein; NDF = neutral-detergent fibre; ADF = acid detergent fibre

The chemical composition of whole crop silage depends on the growth stage of the grain at harvesting and can therefore vary considerably. Table 2.5 presents an example of the chemical composition of four whole crop wheat silages harvested at different stages of maturity. The DM and starch contents and the amount of lignification increase with increasing maturity, whereas the proportions of CP and NDF decrease (Crovetto et al., 1998). This is in agreement with the findings of Ohlsson (1995), O’Kiely and Moloney (1995), and Sinclair et al. (2003). Sinclair et al. (2003) have observed that an increase in the stubble height led to a decrease in the starch content, but an increase in the NDF contents. The short straw silage (approximately 18 cm) has a starch content of 292 g/kg DM, whereas the long straw silage (approximately 38 cm) has a starch content of 232 g/kg DM. The corresponding levels for the NDF are 384 and 433 g/kg DM, respectively. This agrees with the findings of Ohlsson (1995), who notes the fact that the straw has a higher proportion of cell walls than the ears, which also explains the lower digestibility and energy values.

According to the analyses performed by Crovetto et al. (1998) shown in Table 2.5, the NDF fraction remains more constant during maturation than does the starch, which is due to the deposition of starch. If this can be considered as a general principle, the voluntary feed intake and digestibility of wheat silages should not change radically during maturation, thus giving a long interval for cutting without undesirable effects on the silage quality and
nutritive value. Filya (2003), on the other hand, recommends harvesting at the dough ripening stage, to obtain the highest yield of degradable NDF, which contradicts the findings of Crovetto et al. (1998).

### 2.3.2 Digestibility and energy evaluation

Optimization of the feed ration and meeting the requirements of the dairy cows for maximal milk production, minimal N-excretion and feed costs, and improvement of animal health, requires good knowledge about the chemical composition of the feedstuffs in the ration. Another prerequisite for making trustworthy nutritional calculations is precise analysis methods (De Boever et al., 1999; Søegaard et al., 2001).

Some of the methods used for the determination of the digestibility of whole crop silage are estimated by the use of laboratory techniques, many of which have been developed for the corresponding analyses of grass-based roughage. Few researchers have investigated the accuracy of the methods used for analysing whole crop silages. However, Adesogan et al. (1998) and Søegaard et al. (2001) have evaluated the methods used for the determination of the digestibility of roughage in the United Kingdom and Denmark, respectively. The results from these studies are summarized in the following.

Adesogan et al. (1998) carried out a study of 26 whole crop silages over two years to determine the accuracy of the different methods used for determination of the digestibility of roughage. The chemical composition, the in vitro and in vivo digestibility, the in vitro gas production, the water solubility, and the in situ rumen degradation and the use of near infrared reflectance spectroscopy (NIRS) were compared. Generally, predictions of the in vivo digestible organic matter content from the in vitro digestibility obtained from the traditional laboratory based methods and predictions from chemical composition, were imprecise and inconsistent. Prediction of the in vivo digestibility from the in situ degradability only gave significant predictions for the fine particles fraction, the immediately soluble fraction and the effective degradability, but none were consistent from year to year. The prediction of the in vivo digestibility from the NIRS was tested using two different equations, one for grass silage (Baker et al., 1994), and one for wheat silage. Both equations were developed from calibration graphs from earlier in vivo studies. The grass silage equation gave a poor prediction of the in vivo organic matter digestibility in both years, whereas the equation for the calibration of the wheat silage predicted the digestibility of organic matter and content accurately (Adesogan et al., 1998).

Standard values for the evaluation of the digestibility of different feedstuffs for ruminants in Denmark are based on measurements of the in vivo digestibility in sheep fed at maintenance levels This method is resource demanding and cannot be used in practice. Roughage has a large variance in digestibility, depending on the growth conditions and maturation stage, and because of this, the available feed tables are not adequate for practical use. Thus, at the present time, it is necessary to be able to determine the digestibility of the current feedlot from laboratory methods (Søegaard et al., 2001).

Søegaard et al. (2001) investigated a total of 191 feed samples, with known in vivo digestibility, which had been obtained from Denmark and other European countries. The methods compared were the in vitro dissolvability of organic matter (IVOS) (Titley and Terry, 1963), the enzymatic digestibility of organic matter for cattle (EFOS) (Weisbjerg and Hvelplund, 1993), and the enzymatic digestibility according to De Boever et al. (1986).
The IVOS method depends upon a good microbial activity, which means that parameters such as variation in activity between cows and how rumen fluid is sampled might influence the activity of the rumen fluid used for the digestibility analyses. Another source of error could be that the potential portion that can be dissolved from the maize and barley whole crop silages are not fully dissolved after 48 hours. The EFOS analyses gave approximately 5 percentage units lower values as compared with the \textit{in vivo} digestibility, whereas the De Boever digestibility gave higher values compared with \textit{in vivo} digestibility. No good correlation was found between the IVOS and EFOS analyses for barley- or wheat whole crop silages. Søegaard \textit{et al.} (2001) recommended using the EFOS method for the analyses of maize-, barley or wheat whole crop silage, because this method gave values for the digestibility of roughage that were as good or better as the values determined by the use of the IVOS method. Furthermore, the EFOS method had a lower variation within the laboratory, in comparison to the IVOS method (Søegaard \textit{et al.}, 2001).

The energy evaluation of different feedstuffs is based on the digestibility of organic matter and chemical composition (Møller \textit{et al.}, 2003). Consequently, any insecurity in the determination of the digestibility will be reflected in the energy evaluation. Adesogan \textit{et al.} (1999), ascertained the accuracy with which several laboratory-based measurements predicted the ME value of whole crop wheat. A total of 26 forages differing in variety, maturity at harvest, and treatment applied, were harvested over a period of 2 years, conserved and used for the analyses. Furthermore, the gross energy was analysed through adiabatic bomb calorimeter. All analyses were compared to the ME determined using a balance study, where the ME was calculated using the measured energy losses in the faeces and urine, and predicted energy losses as methane. The authors concluded that many of the techniques used at the present time inaccurately predict the ME value of whole crop wheat, and that the use of these methods can lead to misleading results. However, the NIRS technique appeared to give more stable and accurate predictions of the ME when a calibration was developed using a whole crop wheat sample, than the traditionally used \textit{in vitro} methods did. Further research is needed in order to investigate the validity of the NIRS method for estimating the ME of whole crop wheat.

Grains used for the production of whole crop silages, in comparison to grass products, are very inhomogeneous crops, consisting of the grains, having a high proportion of starch and low proportion of fibre, and a fibrous straw having a low proportion of protein (Ohlsson, 1995; Søegaard \textit{et al.}, 2001). This may be one of the reasons for the problems occurring when analysing the digestibility of whole crop silages. The poorer prediction from the biological techniques used for the determination of the ME, in comparison to the predictions using chemical constitutes, can be related to the fact that the biological techniques do not accurately simulate the whole tract digestibility \textit{in vivo} in whole crop wheat. Therefore, it may be possible to modify the biological techniques for whole crop wheat, so that they better emulate the digestion of the cow. It can also be concluded that the existing methods, used for determination of digestibility and energy content in whole crop silages, have to be adjusted to the characteristics of the whole crop products. Before this is carried out, the method used in this type of research should be evaluated if it is known to give higher or lower digestibility values.
2.4 Conclusions and perspectives from the literature review

Decreasing the N losses from dairy farms requires interdisciplinary research, and farms should be considered individually, because the N-losses are related to the management of the farm. This also means that not all biologically available solutions will have the expected impact under practical conditions.

Knowledge about the protein supply and the metabolism is important when trying to optimise the milk production and decrease the N losses from the cattle manure. The protein supply of the cow is affected by the protein content of the feed ration, and by the digestibility of both the protein and the carbohydrates. The protein requirements of the cow can be summarized as a combination of the requirements of the rumen microorganisms and the actual requirements of the cow. The composition of the protein reaching the small intestine not only depends on the N and energy contents and the quality of the feed ration, but also on the type and quantity of rumen microorganisms and their capacity to synthesise protein. Thus, carbohydrates must be fed in sufficient quantity to ensure a good microbial growth and energy adequate for maintenance and milk production. The main part of the feed ration should be given as roughage, in order to secure a good rumen environment. Protein should be fed to provide the microorganisms with enough N-sources to ensure a good microbial growth and protein synthesis.

The level of CP, AAT and PBV in the feed ration affects the milk yield and its composition. However, researchers do not agree about the CP level that can be considered to be the upper limit for yielding the maximum milk protein, without obtaining an increase in the level of unwanted urea in the milk, suggesting that more research is needed. Giving both AAT and PBV levels below the current Danish standards have been shown to decrease the milk yield.

The N-efficiency, expressed as the N from true milk protein as a percentage of the total consumed N, increases with increasing milk yield and decreases with increasing levels of feed ration CP.

N is excreted in the milk, faeces and urine, and the composition of the feed ration affects the type of N and in which form it is excreted. The N excretion in the faeces and milk has a modest positive linear relationship to the N intake, but the urinary N increases exponentially with increasing N-intake. Different methods have been used to predict the ammonia emission from the dairy cows; the most commonly used parameters are the urinary N, MUN and CP content in the feed, where the last has been found to be the most accurate when the parameters have been compared to each other.

N-excretion in the manure from the dairy cows can be decreased by improving the production efficiency, i.e., increasing the milk yield, and/or optimising the energy and N content in the feed ration, and securing a good balance between the energy and protein. Another possibility is to use rumen-protected proteins.

The use of whole crop silage as a feedstuff to dairy cattle has advantages, such as, higher DM yield, and lower workload as compared to using grass based silages. If whole crop silage is combined with early harvested grass silage, it should be possible to give a more continual supply of easily-digested carbohydrates, and at the same time utilize the soluble protein in the feed ration better. Existing methods used for estimating the digestibility and the energy value of whole crop silage are insecure and not accurate, and have to be adjusted to the characteristics of the whole crop products. Before this is carried out, the method to be
used in these studies has to be evaluated with respect to its tendency to give higher or lower digestibility values.
3 FEEDING EXPERIMENT WITH WHOLE CROP WHEAT SILAGE

3.1 Materials and methods

3.1.1 Design

This study was designed as a Latin square model with 3 replicates, including 12 Swedish Friesian dairy cows, at the beginning or in the middle of lactation (between the 5th and 15th week post calving at the time of the start of the experiment). Four different diets were composed, two with high CP content (18 % of total DM), and two with low CP content (16 % of total DM). The protein levels were combined with two different roughages, whole crop wheat silage (WS) or super-pressed beet pulp silage (BP), given in a high or low amount. The different diets were given to each of the 12 cows for four weeks respectively. The first two weeks of each period were used for adaptation. The last week was used for the estimation of the ammonia emission from the manure. The model that was used for evaluating the different diets is presented in Table 3.1.

Table 3.1. Model used for testing the different diets

<table>
<thead>
<tr>
<th>Groups</th>
<th>Cows in Group 1</th>
<th>Cows in Group 2</th>
<th>Cows in Group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Period</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>170</td>
<td>221</td>
<td>2980</td>
</tr>
<tr>
<td>II</td>
<td>3142</td>
<td>3159</td>
<td>3153</td>
</tr>
<tr>
<td>III</td>
<td>171</td>
<td>3013</td>
<td>3140</td>
</tr>
<tr>
<td>IV</td>
<td>3141</td>
<td>3156</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BPHP</th>
<th>BPLP</th>
<th>WSHP</th>
<th>WSLP</th>
<th>BPHP</th>
<th>BPLP</th>
<th>WSHP</th>
<th>WSLP</th>
<th>BPHP</th>
<th>BPLP</th>
<th>WSHP</th>
<th>WSLP</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSHP</td>
<td>WSHP</td>
<td>BPHP</td>
<td>BPLP</td>
<td>WSHP</td>
<td>WSLP</td>
<td>BPHP</td>
<td>BPLP</td>
<td>WSHP</td>
<td>WSLP</td>
<td>BPHP</td>
<td>BPLP</td>
</tr>
<tr>
<td>WSHP</td>
<td>WSLP</td>
<td>BPHP</td>
<td>BPLP</td>
<td>WSHP</td>
<td>WSLP</td>
<td>BPHP</td>
<td>BPLP</td>
<td>WSHP</td>
<td>WSLP</td>
<td>BPHP</td>
<td>BPLP</td>
</tr>
<tr>
<td>WSLP</td>
<td>BPHP</td>
<td>BPLP</td>
<td>WSLP</td>
<td>BPHP</td>
<td>BPLP</td>
<td>WSLP</td>
<td>BPHP</td>
<td>WSLP</td>
<td>BPHP</td>
<td>WSLP</td>
<td>BPHP</td>
</tr>
</tbody>
</table>

Where the feed rations are: BPHP; BPLP; WSHP; WSLP, and BP = super pressed beet pulp silage; WS = whole crop wheat silage; HP = high level of crude protein; and LP = low level of crude protein.

3.1.2 Forage production

The winter wheat used in the study was of the variety Tarso and it was harvested on the 11th of July, 2003. The crop was still green but the ears had become paler, which according to the scale of Zadoks et al. (1974) was growth stage 87 (hard dough). A JF GMS Crimper mower (JF Fabriken, Sønderborg, Denmark ) conditioner, with low revolutions per minutes, was used to cut and string the crop. Directly after cutting, a Claas Rollant 250, Rotor cut (Claas KGaA mbH Germany ) was used to make round-bales with a diameter of 120 cm. 3.6 l Kofasil Ultra (Hanson and Möring AB, ) were added per ton fresh crop. The round bales were wrapped (12 layers) with plastic of the type Horsewrap 750 (Trioplast AB, Sweden).
The WS was compared to BP silage. The beet pulp, produced by Danisco AS, was hard pressed to about 26 % DM and 5 % beet molasses added, then directly transported to the farm and ensiled in bunker silos.

3.1.3 Animals and feeding

The cows used in this study had an average body weight (BW) of 670 kg and an average body condition score (BC) of 3. All cows were 3 to 5 years of age and in the second or fourth lactation. The cows were kept in individual stalls with rubber mattresses and wood shavings, and fed individually. Concentrate was given in relation to body weight, and milk production at the beginning of each period, and the amounts of concentrate were kept constant throughout each period. For comparison between diets see Tables 3.2 and 3.3. The energy supply followed Swedish standard recommendations (Spörndly, 2003). The feed used were whole crop maize silage, alfalfa silage, straw, grass-hay, BP, WS, minerals and two concentrate mixtures (I and II), one cereal mixture and one protein concentrate. The chemical composition and nutritive values of the different feed-sources are presented in Table 3.4.

Table 3.2. Comparison of feed rations between the different diets. Concentrate was given according to BW and milk yield at the beginning of each period. Quoted values are calculated for a BW of 650 kg

<table>
<thead>
<tr>
<th></th>
<th>BPHP</th>
<th>BPLP</th>
<th>WSHP</th>
<th>WSLP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hay, kg DM</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>MR, kg DM</td>
<td>9.0</td>
<td>9.0</td>
<td>9.0</td>
<td>9.0</td>
</tr>
<tr>
<td>WS, kg DM</td>
<td></td>
<td>2.8</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td>BP, kg DM</td>
<td>2.2</td>
<td>4.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Concentrate (kg/day)

<table>
<thead>
<tr>
<th>Concentrate (kg/day)</th>
<th>I</th>
<th>II</th>
<th>I</th>
<th>II</th>
<th>I</th>
<th>II</th>
<th>I</th>
<th>II</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 kg ECM</td>
<td>0.5</td>
<td>1.0</td>
<td>0.5</td>
<td>1.0</td>
<td>0.5</td>
<td>2.7</td>
<td>0.3</td>
<td>1.2</td>
</tr>
<tr>
<td>30 kg ECM</td>
<td>0.8</td>
<td>3.0</td>
<td>0.8</td>
<td>2.0</td>
<td>0.8</td>
<td>4.3</td>
<td>1.6</td>
<td>2.0</td>
</tr>
<tr>
<td>35 kg ECM</td>
<td>2.0</td>
<td>5.0</td>
<td>2.1</td>
<td>3.0</td>
<td>1.3</td>
<td>6.5</td>
<td>4.3</td>
<td>2.0</td>
</tr>
<tr>
<td>40 kg ECM</td>
<td>4.3</td>
<td>5.4</td>
<td>3.2</td>
<td>4.0</td>
<td>2.0</td>
<td>7.8</td>
<td>5.2</td>
<td>3.3</td>
</tr>
<tr>
<td>45 kg ECM</td>
<td>5.5</td>
<td>5.5</td>
<td>4.5</td>
<td>5.0</td>
<td>3.5</td>
<td>8.5</td>
<td>6.1</td>
<td>4.5</td>
</tr>
<tr>
<td>50 kg ECM</td>
<td>8.0</td>
<td>5.7</td>
<td>6.2</td>
<td>5.5</td>
<td>6.0</td>
<td>8.5</td>
<td>7.1</td>
<td>5.7</td>
</tr>
</tbody>
</table>

Where MR = mixed ration; WS = whole crop wheat silage; BP = super pressed beet pulp silage; HP = high protein; LP = low protein; ECM = energy corrected milk
Table 3.3. Composition of the Mixed ration and Concentrate I

<table>
<thead>
<tr>
<th>MR</th>
<th>Amount, kg DM/day</th>
<th>Concentrate I</th>
<th>Composition, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole crop maize silage</td>
<td>2.3</td>
<td>Wheat</td>
<td>44</td>
</tr>
<tr>
<td>Alfalfa silage</td>
<td>4.9</td>
<td>Barley</td>
<td>32</td>
</tr>
<tr>
<td>Straw</td>
<td>0.2</td>
<td>Soybean meal</td>
<td>12</td>
</tr>
<tr>
<td>Minerals</td>
<td>0.1</td>
<td>Peas</td>
<td>12</td>
</tr>
<tr>
<td>Concentrate I</td>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total kg DM/day</td>
<td>9.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Where MR = mixed ration. Minerals given in the MR contained 96 g Ca, 147 g P, 100 g Mg, and 67 g Na per kg DM.

Table 3.4. Chemical composition and calculated nutritive value of the feeds given to the dairy cows

<table>
<thead>
<tr>
<th>Feed</th>
<th>DM, %</th>
<th>ME, MJ</th>
<th>AAT, g</th>
<th>PBV, g</th>
<th>CP, g</th>
<th>CF, g</th>
<th>NDF, g</th>
<th>Starch, g</th>
</tr>
</thead>
<tbody>
<tr>
<td>C I</td>
<td>87.2</td>
<td>13.9</td>
<td>103.3</td>
<td>10.8</td>
<td>176.6</td>
<td>22.6</td>
<td>157.1</td>
<td>610.1</td>
</tr>
<tr>
<td>C II</td>
<td>86.8</td>
<td>14.6</td>
<td>158.0</td>
<td>25.0</td>
<td>258.0</td>
<td>87.1</td>
<td>309.0</td>
<td>103.0</td>
</tr>
<tr>
<td>Hay</td>
<td>84.0±6.24</td>
<td>9.6±0.15</td>
<td>67.3±0.58</td>
<td>5.7±17.79</td>
<td>121.3±18.15</td>
<td>19.2±1.13</td>
<td>620.0±23.39</td>
<td></td>
</tr>
<tr>
<td>MR</td>
<td>36.2±3.20</td>
<td>10.7±0.01</td>
<td>76.1±0.05</td>
<td>28.5±8.77</td>
<td>160.5±7.79</td>
<td>21.3±0.77</td>
<td>391.2±14.40</td>
<td>161.3±11.62</td>
</tr>
<tr>
<td>BP</td>
<td>23.3±2.08</td>
<td>12.8±0.15</td>
<td>97.0±0.58</td>
<td>-68.0±5.03</td>
<td>100.0±4.16</td>
<td>8.0±0.00</td>
<td>345.0±42.02</td>
<td></td>
</tr>
<tr>
<td>WS</td>
<td>32.7±2.31</td>
<td>9.9±0.20</td>
<td>70.3±0.58</td>
<td>-21.0±6.93</td>
<td>103.0±2.00</td>
<td>17.7±0.85</td>
<td>458.0±14.18</td>
<td>85.7±1.53</td>
</tr>
</tbody>
</table>

Where C I = concentrate I; C II = concentrate II; MR = mixed ration; BP = super pressed beet pulp silage; WS = whole crop wheat silage; ME = metabolizable energy; AAT = amino acids absorbed in the intestine; PBV = protein balance in the rumen; CP = crude protein; CF = crude fat; NDF = neutral detergent fibre. Data presented for hay, MR, BP and WS are calculated means ± standard deviations (SD) from 3 analyses. Data presented for C I are calculated means for 2 analyses, and data presented for C II are from 1 analysis.

3.1.4 Observations

Observations of body weight, feed intake, milk yield and composition, manure and ammonia emission are presented in the following, and the Swedish and Danish standards are shown in Appendix B.

Body weight

While changes in the BW of the animals during each period were considered to be negligible, the individual BW was registered at the start and end of the experiment. The average BW for each cow was used as a base for the final calculation of the maintenance needs of the nutrients. The BC was scored at the start and the end of the experiment. BC was given on a scale from 1 to 5, where 1 is thin, 3 is normal, and 5 is fat. Every cow was assessed at 5
locations (loin, short ribs, pelvic bone, tail-head and pin bone), and a mean BC score was calculated (not shown).

Feed intake

The individual feed consumption was recorded daily during all 16 experimental weeks. Daily feed samples were taken and pooled for every four weeks. Chemical analyses were made on the pooled samples and the nutritive value was calculated according to standard Swedish methods (Spöndly, 2003).

Milk

The cows were milked twice daily. Milk production was registered individually every day and the milk samples were taken on two consecutive days, with an interval of seven days. Samples of morning and evening milk were pooled and analyzed at a commercial dairy laboratory (Steins Laboratorium, Jönköping, Sweden). Analyses from the last two weeks in each period were used in the calculations.

Manure and ammonia

Because all four feed rations were compared at the same time, measurements of ammonia in stable air could not be made. Therefore, estimations were carried out on an individual level. The purpose of the method applied for the estimation of the ammonia emission was mainly to obtain an expression of the relative differences between feed rations, not to give the exact amount of ammonia released per cow and day.

The ammonia release from each cow was determined over the last four consecutive days in each of the different test periods. For these days, the cows were kept in individual stalls with one empty space between them to avoid mixing the manure from the different cows. Three plastic bins (size 400*600*200 mm) were placed in the manure channel behind every cow for the total collection of individual faeces and urine. Every 24th hour, the manure was collected and the full plastic bins were immediately replaced with new empty bins. The collected manure was weighed and mixed thoroughly. Samples were taken and frozen for later chemical analyses.

The mixed manure was placed in a plastic bin up to approximately half of the height of the bin and having a flat surface. The ammonia release was estimated in a ventilated chamber, constructed at the Department. Once started, the chambers were left for equilibration. After 20 minutes of constant ventilation rate in the chambers, equilibrium between the ammonia in the chamber-air and ammonia in the manure was considered to be established. The ammonia concentration in the chamber air was then measured with the Kitagawa reagent tube No 300, (Komyo Rikagakukogyo K. K, Japan) for 1 minute. Before and after the measurements in the chambers, the ammonia in the stable air was measured in the same manner as in the chambers. For the purpose of eliminating errors caused by the variations in ammonia content in the stable air, all determinations were made at a ventilation rate of 79 m³/m²h and at a room
temperature close to 14º C. Calculation of the ventilation rate is presented in Appendix E. This analytical technique to determine ammonia release from a surface covered with faeces and urine has previously been described by Andersson (1995). The Latin square model excluded possible cross-over effects and seasonal effects such as differences in roughage quality.

Photos presenting the housing of the research animals, milking, manure collection, sampling and estimation of ammonia from manure, are shown in Appendix G.

3.1.5 Analyses

The feed and manure samples were analysed at a commercial agricultural laboratory (AnalyCen Nordic AB, Lidköping, Sweden). The feed was analysed for: DM, ash, CP, crude fat, crude fibre, neutral detergent fibre (NDF), starch, metabolizable energy (ME) and minerals. Silage was also analysed for pH, butyric acid, acetic acid, propionic acid and NH4-N. All analyses were made in duplicate and followed procedures according to the Kungliga Lantbruksstyrelsens Kungörelse (1966). For a further description of the analytical procedures, see Appendix F.

The manure was analysed for the contents of the DM (Ref: SS 028113), total N (Ref: SS 028101:1-92 mod), and NH4-N (Ref: KLK 7 1950 mod). The total N and NH4-N were estimated in wet material to avoid ammonia losses.

The milk samples were analysed for fat, true protein, lactose, urea and somatic cell count (SCC) by the infrared technique using the Foss Combi instrument (Foss Electric, AS, Denmark). The analysis methods used for calibration were Röse Gottlieb, IDF standard, 1996 for fat; Kjeldahl IDF standard 20B, 1993 part 3 for protein; and direct count in microscope for SCC, IDF standard 148 A, 1995. Lactose and urea were estimated using national and international ring tests.

3.1.6 Statistical methods

The statistical analyses were performed by using the GLM ANOVA of MEET MINITAB 12 (Minitab Inc., 1997). The applied statistical model for the Latin square experiment included the effects of diet, period, row and replicate, with the assumption that the data were normally distributed. Since the numbers of somatic cells were not normally distributed, they were transformed to logarithmic scale before statistical analysis.

Model:  
\[ y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_{k(i)} + \delta_{l(j)} + \epsilon_{ijkl} \]

Where:  
\( \alpha \) is the effect of diet
\( \beta \) is the effect of period
\( \gamma \) is the effect of cow
\( \delta \) is the effect of replicate
\( \epsilon \) is the random effect
3.2 Results

All results are related to the last two weeks of each period, except for the measurements of ammonia, which relates to the last test week (the fourth week).

3.2.1 Feed consumption

Table 3.5 presents the daily feed consumption of the different feedstuffs, and the total daily consumption of nutrients are presented in Tables 3.5 and 3.6, respectively. The composition of the feed ration did not significantly affect the DM consumption. The DM consumption was between 20.2 and 20.9 kg per day, but the DM intake of the BP and the WS was lower than planned. The BP-consumption was 5 and 20 % lower than expected for diets BPHP and BPLP, respectively, and the WS-consumption was 39 and 42 % lower than expected for diets WSHP and WSLP, respectively. The lower DM intake of BP was partly due to a lower DM content than the expected 26 %, which led to a lower amount of BP being offered to the cows, and they consequently did not have the possibility of fully consuming the planned amounts.

The DM intake of the MR was lowest for diet BPLP, where consumption was 17 % lower than offered. Diets BPHP, WSHP and WSLP had about 8 % lower DM intake of the MR than offered (for comparison between planned and actual daily feed consumption, see also Table 3.2). The differences in the consumed amounts of the concentrates were due to differences in the given feed ration, because concentrate was adjusted according to the current milk yield at the beginning of each period.

Table 3.5. Daily consumption of the feedstuffs, according to diet

<table>
<thead>
<tr>
<th>Diet</th>
<th>BPHP</th>
<th>BPLP</th>
<th>WSHP</th>
<th>WSLP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hay</td>
<td>2.6±0.2</td>
<td>2.5±0.4</td>
<td>2.1±0.4</td>
<td>2.2±0.2</td>
</tr>
<tr>
<td>MR</td>
<td>23.3±1.8</td>
<td>21.1±2.7</td>
<td>7.5±1.6</td>
<td>8.2±1.5</td>
</tr>
<tr>
<td>BP</td>
<td>9.4±0.1</td>
<td>2.1±0.2</td>
<td>16.5±1.3</td>
<td>3.8±0.6</td>
</tr>
<tr>
<td>WS</td>
<td>6.7±0.2</td>
<td>6.7±0.2</td>
<td>1.7±0.4</td>
<td>9.5±2.2</td>
</tr>
<tr>
<td>Concentrate I</td>
<td>3.4±1.1</td>
<td>3.0±1.0</td>
<td>3.0±1.0</td>
<td>2.5±1.2</td>
</tr>
<tr>
<td>Concentrate II</td>
<td>5.4±0.8</td>
<td>4.7±0.7</td>
<td>4.4±1.1</td>
<td>3.8±0.9</td>
</tr>
</tbody>
</table>

Where MR = mixed ration; BP = beet pulp silage; WS = whole crop wheat silage; HP = high protein; LP = low protein. The values quoted are means ± SD, calculated for the last two weeks of each test period.
Table 3.6. Total daily consumption of nutrients, according to diet

<table>
<thead>
<tr>
<th>Diet</th>
<th>DM, kg/d</th>
<th>ME, MJ</th>
<th>CP, g</th>
<th>CF, g</th>
<th>NDF, g</th>
<th>Starch, g</th>
<th>AAT, g</th>
<th>PBV, g</th>
<th>CP, % DM</th>
<th>AAT, g/MJ ME</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPHP</td>
<td>20.3±1.12</td>
<td>248±15.7</td>
<td>3573±205.8a,b</td>
<td>727±68.8a</td>
<td>7335±399.0a</td>
<td>3530±705.8a</td>
<td>2049±141.1a,b</td>
<td>246±101.9a</td>
<td>17.6±0.31</td>
<td>8.3±0.15</td>
</tr>
<tr>
<td>BPLP</td>
<td>20.2±1.95</td>
<td>244±29.3</td>
<td>3367±452.0a</td>
<td>553±111.9b</td>
<td>7238±776.0a</td>
<td>3195±928.7a</td>
<td>1989±245.7a,b</td>
<td>111±116.7b</td>
<td>16.6±1.07</td>
<td>8.2±0.29</td>
</tr>
<tr>
<td>WSHP</td>
<td>20.7±1.42</td>
<td>248±21.79</td>
<td>3742±318.0b</td>
<td>822±117.6c</td>
<td>7753±567.0b</td>
<td>3464±612.9a</td>
<td>2094±229.1a</td>
<td>368±81.5b</td>
<td>18.0±0.54</td>
<td>8.4±0.26</td>
</tr>
<tr>
<td>WSLP</td>
<td>20.9±1.3</td>
<td>244±18.27</td>
<td>3470±226.8b</td>
<td>645±84.2b</td>
<td>7633±545.0b</td>
<td>4457±627.1b</td>
<td>1929±175.6b</td>
<td>293±54.7d</td>
<td>16.6±0.62</td>
<td>7.9±0.22</td>
</tr>
</tbody>
</table>

BP = beet pulp silage; WS = whole crop wheat silage; HP = high protein; LP = low protein; DM = dry matter; ME = metabolizable energy; CP = crude protein; CF = crude fat; NDF = neutral detergent fibre; AAT = amino acids absorbed in the intestine; and PBV = protein balance in the rumen. The values quoted are means ± SD, and P-values between treatments calculated for the last two weeks of each period. Values within rows without common letters differ significantly.

The daily intake of the ME did not differ significantly between the diets (Table 3.6). The CP level of the diets should, according to the experimental design, differ by two percentage units between the high (diets BPHP and WSHP) and the low protein diets (diets BPLP and WSLP), but in reality the difference was only about one percentage unit between diets BPHP and BPLP, and 1.5 percentage unit between diets WSHP and WSLP. A significant difference in daily CP consumption was observed only between diet WSHP when compared to the diets BPLP and WSLP. Thus, the difference in CP intake between cows on the WS-diets was achieved, but not between cows on the BP-diets (Table 3.6).

### 3.2.2 Body weight

The average body weight during the whole experiment was 670 kg, with an individual range from 563 to 754 kg. On average, the cows lost 4 g per day, but the individual differences were large, ranging from a daily weight gain of 188 g to a daily loss of 308 g. The cows had an average BC of 3, with individual variations from 2.1 to 3.4.

### 3.2.3 Milk production

As presented in Table 3.7, the milk production was significantly higher (P = 0.041) for cows on diet BPHP than for those on diet WSLP, but no significant differences in milk production were found when comparing produced kg ECM, content of fat or protein between treatments, nor were any significant differences observed in SCC between diets. However there was a
tendency for the milk production to be higher for those on the HP-diets than LP-diets. This was also observed for the amount of fat produced per day, though it was not significant ($P = 0.053$). The urea concentration in the milk was, however, affected by the diet. The highest concentration was found for diet WSHP; 5.7 mmol/l, as compared to 4.4 mmol/l for diet BPLP, the latter being significantly lower than all the other three diets ($P < 0.001$). Within the type of silage, the milk urea content was lower for those on the low protein dietary level.

Table 3.7. Average daily milk production and composition of the milk, according to diet

<table>
<thead>
<tr>
<th>Diet</th>
<th>BPLP</th>
<th>BPHP</th>
<th>WSHP</th>
<th>WSLP</th>
<th>$P$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk, kg</td>
<td>35.4±4.64&lt;sup&gt;a&lt;/sup&gt;</td>
<td>33.4±7.48&lt;sup&gt;b&lt;/sup&gt;</td>
<td>34.5±4.54&lt;sup&gt;b&lt;/sup&gt;</td>
<td>32.4±5.54&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.041*</td>
</tr>
<tr>
<td>ECM, kg</td>
<td>34.4±3.74</td>
<td>32.2±6.35</td>
<td>33.7±8.82</td>
<td>32.1±4.87</td>
<td>NS</td>
</tr>
<tr>
<td>Fat, g</td>
<td>1337±175.2</td>
<td>1232±238.7</td>
<td>1309±224.7</td>
<td>1257±200.5</td>
<td>NS</td>
</tr>
<tr>
<td>Protein, g</td>
<td>1148±98.8</td>
<td>1102±202.9</td>
<td>1127±139.6</td>
<td>1075±163.7</td>
<td>NS</td>
</tr>
<tr>
<td>Fat, %</td>
<td>3.82±0.567</td>
<td>3.75±0.478</td>
<td>3.80±0.475</td>
<td>3.92±0.538</td>
<td>NS</td>
</tr>
<tr>
<td>Protein, %</td>
<td>3.28±0.308</td>
<td>3.33±0.252</td>
<td>3.25±0.196</td>
<td>3.31±0.222</td>
<td>NS</td>
</tr>
<tr>
<td>Urea, mmol/l</td>
<td>5.4±0.61&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.4±0.78&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.7±0.84&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.5±0.60&lt;sup&gt;b&lt;/sup&gt;</td>
<td>&lt;0.001***</td>
</tr>
<tr>
<td>SCC, log 10/ml</td>
<td>2.0±0.56</td>
<td>2.2±0.64</td>
<td>2.2±0.58</td>
<td>2.0±0.54</td>
<td>NS</td>
</tr>
</tbody>
</table>

Where ECM = Energy corrected milk; SCC = Somatic cell count; BP = super pressed beet pulp silage; WS = whole crop wheat silage; LP = low protein; HP = high protein. The values quoted are means±SD, and $P$-values between treatments. Values within rows without common letters differ significantly. Means are calculated for 12 cows with 2 analyses per treatment.
3.2.4 Feed efficiency

The feed efficiency for milk production is presented in Table 3.8, expressed as ME and the amount of AAT used for the production of one kg ECM, when the requirements for maintenance have been subtracted according to the standard recommendations (Spördly, 2003). No differences in the utilization of the ME or the AAT above maintenance for milk production were seen between the diets. Both the requirements for energy and the AAT for milk production exceeded the Swedish standard recommendations (Spördly, 2003) in all diets.

Table 3.8. Feed consumption above maintenance requirements, according to diet, expressed as metabolizable energy (ME) and amino acids absorbed in the intestine (AAT) per kg energy corrected milk (ECM) and N-efficiency, expressed as nitrogen in milk as a percentage of consumed nitrogen

<table>
<thead>
<tr>
<th>Diet</th>
<th>BPHP</th>
<th>BPLP</th>
<th>WSHP</th>
<th>WSLP</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ME, MJ/kg ECM</td>
<td>5.3±0.42</td>
<td>5.6±0.78</td>
<td>5.4±0.43</td>
<td>5.6±0.70</td>
<td>NS</td>
</tr>
<tr>
<td>AAT, g/kg ECM</td>
<td>47.4±3.69</td>
<td>49.2±5.99</td>
<td>49.7±3.12</td>
<td>47.3±4.87</td>
<td>NS</td>
</tr>
<tr>
<td>N-utilization, %</td>
<td>31.6±2.19&lt;sup&gt;a&lt;/sup&gt;</td>
<td>32.1±4.31&lt;sup&gt;a&lt;/sup&gt;</td>
<td>29.5±2.18&lt;sup&gt;b&lt;/sup&gt;</td>
<td>30.3±3.42&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Where BP = super pressed beet pulp silage; WS = whole crop wheat silage; LP = low protein; HP = high protein. The values quoted are means± SD, and P-values between treatments. Values within rows without common letters differ significantly.

When expressing the protein efficiency as true milk protein in per cent of consumed protein (both calculated as N), the average N-utilization was between 29.5 and 32.1 %, with no significant differences between diets. The N-utilization observed for the different diets is presented in Table 3.8. There was a tendency to an increased N-utilization for the LP-diets in comparison to the respective HP-diets.
3.2.5 Manure

The daily average amount of collected manure and estimated composition of the sampled manure are presented for each treatment in Table 3.9. No differences were found in the amount of manure per cow per day or in the DM content, but the chemical composition differed between the diets. The percentage of total N was highest for diet BPHP and lowest for diet WSLP. The percentage of NH₄-N was significantly higher \((P < 0.001)\) for the high CP diets (BPHP and WSHP), than for the low CP diets (BPLP and WSLP). The level of NH₄-N as percent of total N in the manure was higher for the diets with the high CP level, and was significantly higher for diet BPHP, in comparison to diet BPLP.

Table 3.9. Daily amounts and content of DM, N and NH₄-N, respectively, in the manure from the dairy cows according to the diet

<table>
<thead>
<tr>
<th>Diet</th>
<th>Manure, kg/d</th>
<th>DM, %</th>
<th>DM, kg/d</th>
<th>Total N, % DM</th>
<th>NH₄-N, % DM</th>
<th>NH₄-N:Total-N, %</th>
<th>Total N, g/d</th>
<th>NH₄-N, g/d</th>
<th>Organic-N, g/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPHP</td>
<td>59.1±6.04</td>
<td>13.3±0.66</td>
<td>7.8±0.90</td>
<td>4.9±0.33</td>
<td>2.2±0.30</td>
<td>44.3±4.48</td>
<td>384±48.6</td>
<td>171±31.9</td>
<td>213±25.1</td>
</tr>
<tr>
<td>BPLP</td>
<td>58.6±6.63</td>
<td>13.6±0.87</td>
<td>7.9±0.96</td>
<td>4.4±0.45</td>
<td>1.8±0.34</td>
<td>39.4±4.83</td>
<td>350±44.1</td>
<td>138±27.9</td>
<td>211±25.0</td>
</tr>
<tr>
<td>WSHP</td>
<td>59.5±5.76</td>
<td>13.1±0.64</td>
<td>7.8±0.81</td>
<td>4.7±0.45</td>
<td>2.2±0.37</td>
<td>45.8±4.80</td>
<td>371±53.9</td>
<td>171±35.5</td>
<td>200±26.5</td>
</tr>
<tr>
<td>WSLP</td>
<td>57.7±3.64</td>
<td>13.5±0.60</td>
<td>7.8±0.60</td>
<td>4.4±0.47</td>
<td>1.9±0.34</td>
<td>42.6±3.42</td>
<td>342±46.1</td>
<td>147±30.6</td>
<td>195±17.9</td>
</tr>
</tbody>
</table>

Where BP = super pressed beet pulp silage; WS = whole crop wheat silage; LP = low protein; HP = high protein. Values for organic-N are calculated as difference between total N and NH₄-N. The values are given as means± SD, and \(P\)-values between treatments. Means are calculated for 12 cows with 4 analyses per treatment. Values within rows without common letters differ significantly.

The amount of available N for protein retention in the body tissue, expressed as the N-balance, was calculated as N-intake – (N in milk + N in manure). Fairly large individual differences were seen between the cows, but on average, all cows had a positive N-balance. However, the cows on the BP-diets had a significantly \((P < 0.003)\) lower N-balance than did the cows on the WS-diets. The average N-balance was 7 and 8 g per day for cows on diets BPHP and BPLP, respectively. Corresponding values for diets WSHP and WSLP were 54 g and 52 g, respectively.
3.2.5 Ammonia release

The ammonia release to the chamber air was estimated as parts per million (ppm). Means and standard deviations from the four days of measurements, and the relative values between diets are presented in Table 3.10. Diet composition affected the ammonia emission, which was higher for the high CP diets than the low CP diets. The lowest emission was estimated for diet WSLP, which also differed significantly ($P = 0.045$) from diet WSHP, with a relative difference of 20%.

Table 3.10. Ammonia concentration in the exhausting chamber-air according to diet.
Concentrations are quoted as ppm or as relative numbers between treatments

<table>
<thead>
<tr>
<th>Diet</th>
<th>BPHP</th>
<th>BPLP</th>
<th>WSHP</th>
<th>WSLP</th>
<th>$P$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia, ppm</td>
<td>3.8±0.75a, b</td>
<td>3.3±1.19a, b</td>
<td>4.0±1.50a</td>
<td>3.2±0.95b</td>
<td>0.045*</td>
</tr>
<tr>
<td>Ammonia, %</td>
<td>100</td>
<td>88</td>
<td>105</td>
<td>85</td>
<td>0.045*</td>
</tr>
</tbody>
</table>

Where BP = super pressed beet pulp silage; WS = whole crop wheat silage; LP = low protein; HP = high protein. The values are given as means± SD, and $P$-values between treatments. Means are calculated for 12 cows with 4 measurements per treatment. Values within rows without common letters differ significantly.
4 DISCUSSION AND CONCLUSIONS

Most of the cows found the BP diet very palatable and consumed all of the offered feed. The reason for the lower DM intake of the WS diet was probably due to a lower palatability of the WS in comparison to the MR. As seen in Table 3.5, the DM consumption of the MR was almost equal in diets BPHP, WSHP and WSLP, respectively, while it was lower for diet BPLP. The cows on diet BPLP were offered a higher amount of BP that in most cases was completely consumed. No significant differences in the consumption of ME were observed. However, one weakness could be the Swedish method for calculating the energy value of whole crop silages of barley, oats and wheat. The calculation is based on the digestibility coefficients of barley crops estimated on sheep (Spörndly, 2003). However, research in this area is in progress (Frank, 2004).

The fact that the cows consumed less roughage than expected, meant that the intended protein levels of 18 and 16 % CP of DM, respectively, were not fully reached at the high level in diet BPLP. The observed levels were 17.6 and 16.6 % CP of the DM for the BP-diets, respectively, and 18.0 and 16.6 % CP of the DM for the WS-diets, respectively. This resulted in a lower difference in the CP contents between the diets, i.e. 1.0 for diets BPHP and BPLP, and 1.4 for diets WSHP and WSLP, instead of the 2 percentage units difference as planned.

In order to make the WS more palatable, one solution could be to chop the silage into smaller pieces. In this experiment, the silage was wrapped in a big baler using seven cut-blades, and at first it was offered to the cows without further processing. However, the cows refused to eat the un-chopped WS. When the WS was then offered in a chopped form, they then began to eat it. However, when they had access to both the MR and WS, most of the cows preferred to eat the MR, although individual differences in preferences were observed. This aspect would not easily be observed when experiments are carried out at the production level, since the individual feed intake most often is not recorded. It is difficult to determine under those conditions if a cow has been selecting the feedstuffs it finds most palatable if there is a choice available.

Differences in the weight gain of the cows might be caused by individual differences in the capability to adapt to new feedstuffs, and might due to the fact that the lactation stage varied from 35 to 105 days post calving at the time the experiment started. Because cows were only weighed at the start and end of the experiment, the effect of the diet on weight gain/loss was not possible to evaluate.

Carbohydrates constitute the largest source of energy for the cow (Weisbjerg et al., 2003), with SCFA (short-chained fatty acids) being important components for the production of lactose and milk fat. Since lactose almost alone regulates the osmotic pressure of the milk, the total milk yield follows the lactose production. An increase in lactose synthesis in the mammary gland is followed by an increase in water secretion and hence an increased milk production (Kennelly, 1996).

The cows on the HP-diets had a slightly higher intake of ME, which correlated well with the observed tendency for a higher milk yield for these cows. However, when comparing these findings with the ME required for milk production, it was found that the cows on HP diets had had less ME remaining per kg produced ECM, although this was not significantly different from those on the LP diets. One explanation for this difference could be that the relative difference in energy intake was smaller than the differences in milk yield, thus, giving less ME per kg produced ECM. Other explanations could be that the cows on the HP diets...
had a higher mobilization of the body reserves, or that the nutritional evaluation of the whole crop silage in general was not precise, a weakness of the current feed evaluation system (Adesogan et al., 1998; Adesogan et al., 1999 and Soegaard et al., 2001).

Differences in milk fat content can be caused by a variation in the ratio between concentrate and roughage in the diet (Hermansen et al., 2003). If this were the case, then the difference in fat content between diets BPHP and BPLP, would be the same as between diets WSHP and WSLP. As shown in Table 3.7, this was not observed.

Previous experiments have shown that there is an increase in urea levels with an increasing level of crude protein in the diet (Frank et al., 2002; Frank and Swensson, 2002; Broderick, 2003; Davidson et al., 2003). This was also found in the present experiment between diets BPHP and BPLP. Between diets WSHP and WSLP, only a tendency towards an increased concentration of urea was observed. If the crude protein had been given at the intended level, these differences might have been more evident.

It has previously been observed in similar experiments, that the N-utilization increased with a decreasing level of crude protein in the diet (Frank et al., 2002; Frank and Swensson, 2002; Broderick, 2003; Ohlsson and Kristensen, 1998). Regression equations were calculated in Minitab 12 in order to investigate the relationship between the milk urea and the feed ration CP level, and the relationship between the efficiency of N-utilization and feed ration CP level. Neither of them showed the same pattern that previously has been described. This probably also can be explained by the fact that the planned differences in CP level of 2 percentage units were not reached, giving too small a difference in CP level. Nor were differences observed in relation to the milk yield. When discussing N-utilization, consideration has to be given to both the stage of lactation and the milk yield, since these factors also affect the N-efficiency (Nadeau et al., 2003; Gustafsson, 2001).

As mentioned in the results, the N-balance was calculated to be positive for diets WSHP and WSLP, but negative for diets BPHP and BPLP. Comparing the observations in Table 3.6 with those of Table 3.8, it could be seen that the WS-diets had a higher intake of CP per g produced protein, but almost an equal amount of total N content in the manure.

In previous experiments, it has been observed that lowering the CP-intake also lowered the relative emission of ammonia (Frank et al., 2002; Frank and Swensson, 2002). This meant that diet BPLP should have a lower ammonia emission relative to diet BPHP, and a corresponding relationship between diets WSLP and WSHP. However, a significant difference was only determined between diets WSHP and WSLP, although there was a tendency for the same relation between diets BPHP and BPLP. Due to a fairly large SD, it is difficult to determine if the difference was caused by the diet or by other factors, such as sources of error during analyses.

The temperature of the manure at the time of measurement might influence the release of ammonia, and the temperature of the manure might be affected by the time between sampling and the last urination or defecation. No calculations of the relationship between ammonia emission and manure temperature were conducted, since the differences were considered negligible, and the manure temperature was therefore not considered to be a disturbing factor. The average manure temperature for the diets varied from 15.9 to 16.4 °C. However this might be a source of error, because the ammonia emission, according to Andersson (1995), strongly increased above 15°C. The relationship between the concentration of the ammonia emission and the slurry manure is illustrated in Figure 4.1.
Figure 4.1. Ammonia equilibration concentration as a function of the manure temperature for the cow slurry sample. ● = Calculated $C_{ch, \text{zero}}$ values at zero air flow rate ($C_{ch, \text{zero}}$) as a measure of $C_{eq}$, — = theoretically calculated

Another source of error, when comparing the ammonia emission, would be the temperature of the barn air. An attempt was made to keep the temperature as close to 14°C as possible, but sometimes the weather made it difficult to maintain a constant air temperature. Observations were not conducted if the temperature fell below 14°C. According to calculations of the relationship between air temperature and ammonia emission from cow slurry performed by Andersson (1995), the emission of ammonia would be fairly constant between 10 and 15°C. This relationship is illustrated in Figure 4.2.

Figure 4.2. Ammonia emission from cow slurry sample as a function of the inlet air temperature ■ = 50 m$^3$/m$^2$·h, ● = 100 m$^3$/m$^2$·h (Andersson, 1995)
When the temperature did fall, a heating fan was used to raise the temperature, but some uncertainty might have occurred due to warm air streams from the heating fan heating only portions of the barn air. If the temperature, on the other hand, became higher than 15°C, measurements were not conducted before the air was stabilized again and the temperature was close to 14°C. The Latin square method was applied in this experiment in order to reduce the eventual influence of error sources in the environment. Thus, the ammonia emissions from the cows on all the diets were estimated in parallel.

The health of the animals was followed daily. All cows, except for one, were considered to be healthy during the entire experimental period. The one ill cow was diagnosed with mastitis on two different occasions, but had recovered by the time of each test week.

The starch content in the fresh crop of the whole crop wheat was 186 g per kg DM, which is to be compared with the 211 g per kg DM observed in previous analyses of fresh crop from whole crop wheat harvested at the dough ripening stage (Persson, 2003). However, these previous analyses showed that it also had a starch content of 114 g per kg DM, which was considerably higher than the 86 g per kg DM found in the present experiment. When considering the decrease in starch content within the different studies, the loss was 46 % for the earlier study and 54 % for the present one. Other experiments, where whole crop wheat silage has been used, have reported a starch content of between 188 to 262 g per kg DM at the soft dough or the dough ripening stage (Crovetto et al., 1998; Møller et al., 2000 and Sinclair et al., 2003).

One reason for the large loss in starch might be the handling of the silage during chopping, where many grains fell out of the ears. An effort was made to collect these grains and mix them with the rest of the chopped silage and this treatment might have led to a more inhomogeneous silage composition and feed samples taken. It was therefore difficult to determine whether the samples of chopped silage were unrepresentative in comparison to the whole portions, or if the starch had partly been degraded during the conservation process.

A lower starch content in the diet might affect the utilization of the other nutrients in the rumen, such as the easily soluble protein that is intended for the microbial protein synthesis. This might in turn affect the expected increase in the efficiency of N utilization negatively, and the subsequent N-excretion.

In conclusion, the planned differences in dietary protein levels were not obtained, and that was probably the reason for the small observed differences between the diets. However, in spite of this, significant differences between diets were observed with respect to the urea concentration in the milk, the total N and NH₃-N excretion in the manure, and the ammonia emission from the manure. Feeding the high CP diets resulted in a higher content of milk urea and NH₃-N content in the manure than did the low CP diets. The total amount of N in the manure differed significantly between diet BPHP, where it was highest, and diet WSLP. The Ammonia emission was significantly higher for diet WSHP than for diet WSLP. No significant difference in ammonia emission was observed between diets BPHP and BPLP, but a tendency to a lower emission was seen for the cows on diet BPLP. Therefore it was also possible that the hypothesis that lowering the level of CP in the diet will decrease the ammonia emission, and that whole crop wheat silage can be used in the ration together with other roughage without decreasing the milk yield, can be confirmed. However, this experiment did not provide sufficient proof, and more research is needed to better evaluate the influence of feeding dairy cattle whole crop silage.
The following are some examples, where more information is needed.

- Optimal harvest and conservation techniques for decreasing the nutrient losses and increasing the palatability of the feed.
- Improved methods for the estimation of the nutritive values of whole crop silage.
- Determination of the optimal stage of maturity at harvest.
- Determination of the optimal feeding level and management.
5 REFERENCES


Anonymous. 2004d. Statens Jordbruksverk. [Internet] [2004-05-30] Available at: <http://www.sjv.se/net/SJVV/Startsida%e4mnesomr%e5den/St%f6d%2C+bidrag+%e4mj%f6lkkvoter/Arealers%e4ttning/Ans%f6kan+om+Arealers%e4ttning/Ers%e4ttningsber%e4ttigande+gr%f6do>


Kungliga Lantbruksstyrelsens Kungörelse m.m. 1966. No 15 Stockholm, Sweden.


APPENDIX A

Equations for calculating the AAT and PBV (Spörndly, 2003)

AAT (g amino acids / kg DM) = \( cp \times (1-EPD) \times a \times b + \) digestible carbohydrates \( \times c \times d \times e \)

PBV (g amino acids / kg DM) = \( cp \times EPD - DCHO \times c \)

Where:
- \( cp \) = g crude protein/kg DM
- \( EPD \) = proportion of rumen degradable crude protein
- \( a \) = proportion of amino acids in non-degradable feed crude protein
  - 0.85 for concentrate
  - 0.65 for roughage
- \( b \) = digestibility in the small intestine of amino acids in the feedstuff
- \( DCHO \) = g digestible carbohydrates / kg DM
- \( c \) = factor for amount microbial crude protein
  - 0.70
- \( d \) = proportion of amino acids in microbial crude protein
- \( e \) = digestibility in the small intestine of amino acids of microbial origin
  - 0.85

Equation for calculating the energy corrected milk (ECM) (Sjauna et al., 1990)

\[ \text{kg ECM} = \text{kg milk} \times \frac{(383 \times \text{fat }\% + 242 \times \text{protein }\% + 165 \times \text{lactose }\% + 20.7)}{3,140} \]

ECM expresses the quantity of milk when standardized to an energy value of 3.14 MJ/kg or 750 kcal/kg.
### APPENDIX B

**Recommended Swedish standards for feeding dairy cows (Spörndly, 2003)**

<table>
<thead>
<tr>
<th></th>
<th>Metabolizable Energy</th>
<th>AAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance, per day</td>
<td>0.507 MJ / kg LW$^{0.75}$</td>
<td>3.25 g / kg LW$^{0.75}$</td>
</tr>
<tr>
<td>Milk production, per day</td>
<td>5.0 MJ / kg ECM</td>
<td>40 g / kg ECM</td>
</tr>
</tbody>
</table>

LW=Living Weight

**Recommended Danish standards for feeding dairy cows (Strudsholm et al., 1999)**

<table>
<thead>
<tr>
<th></th>
<th>Feed Units</th>
<th>AAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance, per day</td>
<td>(LW / 200 + 1.5)</td>
<td>3.02 g / kg LW$^{0.75}$</td>
</tr>
<tr>
<td>Milk production, per day</td>
<td>0.4 * kg ECM</td>
<td>37 g / kg ECM</td>
</tr>
</tbody>
</table>

APPENDIX C
Description of the feed ration used for comparing the Danish and Swedish feed standards for dairy cows

Sweden
Requirements, calculated for a cow with BW 600 kg and 25 kg ECM/d

<table>
<thead>
<tr>
<th>Consumption kg/d</th>
<th>ME, MJ/d</th>
<th>AAT, g/d</th>
<th>DM, kg/d</th>
<th>ME, MJ/d</th>
<th>AAT, g/d</th>
<th>PBV, g/d</th>
<th>CP, g/d</th>
<th>Starch, g/d</th>
<th>NDF, g/d</th>
<th>Crude Fat, g/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hay</td>
<td>3.0</td>
<td>186.5</td>
<td>1394</td>
<td>366</td>
<td>0</td>
<td>1669</td>
<td>48</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixed Ration</td>
<td>21.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize silage</td>
<td>6.7</td>
<td>2.6</td>
<td>24.5</td>
<td>173</td>
<td>67</td>
<td>0</td>
<td>1669</td>
<td>48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alfalfa silage</td>
<td>13.1</td>
<td>5.0</td>
<td>43.7</td>
<td>344</td>
<td>444</td>
<td>1043</td>
<td>100</td>
<td>2052</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Straw</td>
<td>0.2</td>
<td>0.1</td>
<td>1.0</td>
<td>8</td>
<td>-9</td>
<td>5</td>
<td>0</td>
<td>113</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Whole crop wheat silage</td>
<td>14.0</td>
<td>4.8</td>
<td>46.6</td>
<td>333</td>
<td>-138</td>
<td>481</td>
<td>400</td>
<td>2232</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>Concentrate I</td>
<td>3.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barley</td>
<td>1.0</td>
<td>0.8</td>
<td>1.13</td>
<td>80</td>
<td>-29</td>
<td>101</td>
<td>541</td>
<td>177</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Soybean meal</td>
<td>0.4</td>
<td>0.3</td>
<td>0.6</td>
<td>52</td>
<td>83</td>
<td>161</td>
<td>54</td>
<td>54</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Peas</td>
<td>0.4</td>
<td>0.3</td>
<td>0.4</td>
<td>31</td>
<td>24</td>
<td>73</td>
<td>181</td>
<td>35</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>1.3</td>
<td>1.1</td>
<td>1.60</td>
<td>108</td>
<td>-43</td>
<td>133</td>
<td>837</td>
<td>152</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Concentrate II (Aminotop)</td>
<td>1.0</td>
<td>0.9</td>
<td>12.7</td>
<td>137</td>
<td>22</td>
<td>224</td>
<td>89</td>
<td>268</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>In Total</td>
<td>18.0</td>
<td>187.1</td>
<td>1581</td>
<td>297</td>
<td>2758</td>
<td>2683</td>
<td>7583</td>
<td>320</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DM Dry matter  DE Digestible energy  AAT Amino acids absorbed in the intestine
DP Digestible protein ME Metabolizable energy
### APPENDIX D

Analyses of the feed ration used for comparing the Danish and Swedish feed standards for dairy cows

**Denmark**

Requirements, calculated for a cow with BW 600 and 25 kg ECM/d

<table>
<thead>
<tr>
<th>Consumption kg/d</th>
<th>NE, g/d</th>
<th>AAT, kg/kg DM</th>
<th>DP, kg/kg DM</th>
<th>DF, kg/kg DM</th>
<th>DOM, kg/kg DM</th>
<th>DCHO, kg/kg DM</th>
<th>DE, MJ/kg DM</th>
<th>FU/kg DM</th>
<th>FFk/k Danish Feed code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hay</td>
<td>3.0</td>
<td>2.6</td>
<td>0.10</td>
<td>0.61</td>
<td>0.50</td>
<td>11.33</td>
<td>0.64</td>
<td>1.65</td>
<td>0.6</td>
</tr>
<tr>
<td>Mixed Ration</td>
<td>21.5</td>
<td>6.41</td>
<td>FFk in 2nd lactation app. 60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize silage</td>
<td>6.7</td>
<td>2.0</td>
<td>0.05</td>
<td>0.71</td>
<td>0.65</td>
<td>12.86</td>
<td>0.84</td>
<td>1.69</td>
<td>0.49</td>
</tr>
<tr>
<td>Alfalfa silage</td>
<td>13.1</td>
<td>5.0</td>
<td>0.16</td>
<td>0.61</td>
<td>0.44</td>
<td>11.90</td>
<td>0.66</td>
<td>3.29</td>
<td>0.47 501 &amp; 502</td>
</tr>
<tr>
<td>Straw</td>
<td>0.2</td>
<td>0.1</td>
<td>0.00</td>
<td>0.41</td>
<td>0.40</td>
<td>7.39</td>
<td>0.21</td>
<td>0.03</td>
<td>4.01 782</td>
</tr>
<tr>
<td>Whole crop wheat silage</td>
<td>14.0</td>
<td>4.8</td>
<td>0.06</td>
<td>0.63</td>
<td>0.56</td>
<td>11.41</td>
<td>0.67</td>
<td>3.18</td>
<td>0.49 591</td>
</tr>
<tr>
<td>Concentrate I</td>
<td>3.0</td>
<td>6.41</td>
<td>DM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barley</td>
<td>1.0</td>
<td>0.8</td>
<td>0.08</td>
<td>0.70</td>
<td>14.68</td>
<td>1.11</td>
<td>0.93</td>
<td>0.2</td>
<td>200</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>0.4</td>
<td>0.3</td>
<td>0.45</td>
<td>0.74</td>
<td>0.28</td>
<td>16.21</td>
<td>1.21</td>
<td>0.38</td>
<td>0.22 214</td>
</tr>
<tr>
<td>Peas</td>
<td>0.4</td>
<td>0.3</td>
<td>0.19</td>
<td>0.87</td>
<td>0.67</td>
<td>16.48</td>
<td>1.27</td>
<td>0.40</td>
<td>0.22 216</td>
</tr>
<tr>
<td>Wheat</td>
<td>1.3</td>
<td>1.1</td>
<td>0.08</td>
<td>0.85</td>
<td>0.76</td>
<td>15.38</td>
<td>1.20</td>
<td>1.37</td>
<td>0.22 203</td>
</tr>
<tr>
<td>Concentrate II</td>
<td>1.0</td>
<td>0.9</td>
<td>0.21</td>
<td>0.79</td>
<td>0.51</td>
<td>16.40</td>
<td>1.18</td>
<td>1.02</td>
<td>0.22 7</td>
</tr>
</tbody>
</table>

In total: 14.0 6.41

<table>
<thead>
<tr>
<th>DM</th>
<th>Dry matter</th>
<th>DE</th>
<th>Digestible energy</th>
<th>AAT</th>
<th>Amino acids absorbed in the intestine</th>
</tr>
</thead>
<tbody>
<tr>
<td>DP</td>
<td>Digestible protein</td>
<td>ME</td>
<td>Metabolizable energy</td>
<td>DCHO</td>
<td>Digestible carbohydrates</td>
</tr>
</tbody>
</table>
APPENDIX E

Calculation of the ventilation air velocity

\[ v \text{ (inlet air): } 1.5 \text{ m/s} \]
\[ r \text{ (tube): 35.3 mm} \]
\[ A \text{ (tube): } 0.0335^2 \pi = 0.00353 \text{ m}^2 \]
\[ v = 0.00353 \text{ m}^2 \cdot 1.5 \text{ m/s} = 0.00529 \text{ m}^3/\text{s} = 19.04 \text{ m}^3/\text{h} \]
\[ A \text{ (plastic bin): } 0.6 \text{ m} \cdot 0.4 \text{ m} = 0.24 \text{ m}^2 \]

\[ v = \frac{19.04 \text{ m}^3}{24 \text{ m}^2 \text{h}} = 79.3 \text{ m}^3/\text{m}^2 \text{h} \]
APPENDIX F

Chemical analyses

The DM content in roughage was determined after 16 hours oven drying at 60º C; the DM of concentrate and faeces was determined after 20 hours evaporation in 105º C; and the ash content was determined by combustion at 550º C for 16 to 18 hours. After the ignition of the sample, the residue is considered to constitute the ash and is taken to represent the inorganic constituents of the feed. The ash may, however, contain material of organic origin, such as, sulphur and phosphorus from proteins, or volatile compounds in the form of sodium, chloride, potassium, phosphorus and sulphur which form during ignition. Thus the ash content does not completely represent the true inorganic matter (McDonald et al., 2002).

The N and NH4-N were determined by the Kjeldahl technique (Nordisk Metodikkommitté, Nr 6, 1976) using a Kjeltec Auto Sampler System 1035 Analyzer. This method determines the total amount of N and NH4-N in the sample. The N of organic origin is calculated as Organic-N = Kjeldahl-N - NH4-N. When organic-N has been calculated, the CP can be calculated as organic-N * 6.25, if it is assumed that all protein contains 16 % N. The total N and NH4-N in the faeces were estimated in the wet material to avoid ammonia losses.

In order to determine the crude fat content, the feed samples were extracted twice with petroleum ether at 122º C using the SOCTEC SYSTEM HT, 1043. Between the two extractions, the samples were dried, weighed and hydrolysed with warm HCl. HCl will hydrolyse Ca-soaps to Ca²⁺-ions and free fatty acids, and the total fat content can then be determined after ether extraction.

The determination of the crude fibre in the feedstuffs, cereals and roughage was made using a gravimetric method. Organic matter and minerals were extracted after boiling with H₂SO₄ and KOH, respectively, and the fat was extracted with acetone. The insoluble remainder represented the crude fibre, which was filtered and dried, then weighed before and after combustion into ash.

The neutral detergent fibre (NDF) is also determined using a gravimetric method, where the sample was boiled with a neutral detergent solution. The insoluble portion remaining after boiling containing cellulose, hemicellulose and lignin, was dried and weighed before and after combustion into ash. A Tecator Fibertecsystem 1010 and 1020 Hot Extractor are used for analyses of both the crude fibre and the NDF. The starch content was determined by an enzymatic colorimetric method as described by Åman and Hesselman (1984). The starch was gelatinised in a boiling water bath under partly degradation with a heat stable α-amylase (Termamyrl 300 L), which hydrolyses internal α-1,4-linkages. The heat stable α-amylase was used to ensure that only the starch and no other carbohydrates source would be degraded, which was possible because the high temperature inactivated all the other enzymes.
Complete degradation to glucose residues was obtained with glycoamylase. This enzyme hydrolysed the terminal α-1,4-linkages between the D-glucose residues from the non-reducing end of the chain, with the release of β-D-glucose. Most forms of the enzyme could rapidly hydrolyse the 1,6-α-D-glucosidic linkages with the next bond in the sequence being a 1,4-linkage. Thus glycoamylase hydrolysed the surplus of di- and oligosaccharides to β-D-glucose (Voet and Voet, 1995). The glucose that was extracted was then analysed by a HPLC (high performance liquid chromatography), with LidVit.0A.26 method. Normally it is not necessary to extract the free sugars from the cereals products, because the concentration was very low (0.1 to 0.5 %) (Knudsen et al., 1987).
APPENDIX G

Photographs from the feeding experiment.

Feed manger for individual feeding

Cow in tie-stall with bins for manure collection behind the cow

Cows in tie-stalls

Milking time

Milking equipment with Tru-test for individual registration
Empty manure bins

Weighing of manure

Sample for chemical analyse

Registration of ammonia release in manure from three cows. Ventilation chambers

Sampling of manure
Ammonia in the barn air

Estimation of ammonia release in the ventilation chamber

Measure stick

Temperature in manure