Whole-Crop Cereals in Dairy Production

Digestibility, Feed Intake and Milk Production

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Cover: Barley in the sunset
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Abstract

The four studies summarised and discussed in this thesis evaluate the use of whole-crop cereal silage (WCCS) for cattle in dairy production. The dry matter (DM) yield, chemical composition, digestibility, feed intake and milk production for WCCS were evaluated for different cereal species and maturity stages at harvest.

The DM yield increased from milk to dough stages of maturity and was higher in winter triticale and rye than in spring barley and oats. Delayed harvest until early dough stage decreased the crude protein (CP) and neutral detergent fibre (NDF) concentrations in barley, oats and triticale. The concentration of water soluble carbohydrates (WSC) of the fresh crop was highest at the early milk stage, but these carbohydrates were to a large extent polymerised to starch by the early dough stage of maturity. Both WSC and starch concentrations were lower in oats than in barley, triticale and rye.

When fed to dairy heifers the DM intake (DMI) of six-rowed barley was reduced at early milk and early dough stages most likely due to the development of sharp awns on the crop. The DMI of six-rowed barley silage also decreased with delayed maturity stage when fed to dairy cows. The DMI of oats was reduced at the heading and early milk stages of maturity due to low DM content of the silages. The DM digestibilities and organic matter digestibilities (OMD) of oats and winter rye were lower than for barley and winter triticale, as a combined effect of higher NDF concentrations and lower NDF digestibilities in the two former crops. When six-rowed barley silage harvested at the early dough stage was fed to dairy cows in mid-late lactation the daily energy-corrected milk (ECM) yield was 3 kg lower than when barley silage at heading was fed, due to reductions in milk yield, and both protein and fat concentrations in the milk. This decrease in ECM yield was due to lower DMI and OMD of the ration containing barley silage at early dough stage than of the ration including barley silage at the heading stage of maturity.

In conclusion, spring barley and winter triticale appear to have the best feed values when chemical composition and digestibility are considered. When WCCS harvested at early dough stage is fed to dairy cows, milk production may decrease.

Keywords: Hordeum vulgare, *Avena sativa*, *Triticosecale*, *Secale cereale*, fat, protein, NDF, starch, yield, forage

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Dedication

In memory of my father, Henry Wallsten (1942–1999)

Henrys sång - Det luktar hav och den våta gatan längtar dit.
Carolina Thorell

Contents

List of Publications

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

I J. Wallsten, L. Ericson and K. Martinsson. Influence of variety, time of harvest and temperature on chemical composition and *in vitro* degradation of whole-crop barley, oat, rye and triticale (manuscript).

II J. Wallsten, E. Nadeau, J. Bertilsson and K. Martinsson (2008). Voluntary intake and diet selection by dairy heifers fed ensiled whole-crop barley and oats harvested at different stages of maturity. *Livestock Science* (accepted).

III J. Wallsten, J. Bertilsson, E. Nadeau and K. Martinsson. Digestibility of whole-crop barley and oat silages in dairy heifers (Submitted).

IV J. Wallsten and K. Martinsson (2008). Effects of maturity stage and feeding strategy of whole crop barley silage on intake, digestibility and milk production in dairy cows. *Livestock Science* (corrected proof).

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Abbreviations

ADF	Acid detergent fibre
DM	Dry matter
DMD	Dry matter digestibility
DMI	Dry matter intake
OM	Organic matter
OMD	Organic matter digestibility
NDF	Neutral detergent fibre
NDFD	Neutral detergent fibre digestibility
WCCS	Whole-crop cereal silage
WSC	Water soluble carbohydrates

1 Introduction

1.1 Dairy production in Sweden

Dairy production in Sweden is based on a long period of indoor feeding with grass silage and concentrate during the winter, and a shorter period on pasture during summer. The average milk production in Sweden is high, and the level of production demands high-quality forages for the cows, especially when they are in early lactation. However, some animals on the farms have lower nutritional demands, e.g. dry cows and heifers. Composing suitable rations for all of the types of animals is therefore difficult. As the farms are increasing in size, the use of total mixed rations is becoming increasingly common. This system facilitates the creation of different rations for animals with different nutritional demands and the use of forages of different qualities. In addition to grass silage, whole-crop silages of various annual crops, (e.g. maize, peas, horse beans and cereals) are used in feed rations.

Most of the forage for dairy cows in northern Sweden is based on silage mixtures of different grasses (timothy, meadow fescue) and clover (red and white clover). As the quality of grass silage, especially in terms of energy and protein concentrations, decreases with increasing maturity stage, high-quality grass silage has to be harvested at early maturity stages (Rinne and Nykänän, 2000; Bernes et al., 2008). Hence the dry matter (DM) yield/ha is low (Rinne and Nykänen, 2000). In northern Sweden the leys usually are harvested twice per year, although some farmers are attempting to harvest three times, aiming to obtain high-quality forage rather than high quantities at each harvest. The most common additional forage is whole crop cereals and mixtures of cereals and legumes such as peas or horse beans. These crops can be harvested at late maturity stages and at high DM yields without the large reductions in quality that affect grass silages. The focus in this thesis is on the quality of whole-crop silage made from small grain cereals, as an effect of cereal species and maturity stage at harvest.

1.2 Cereals on the farm

1.2.1 Crop rotation

Cereals have an important place in the crop rotations applied on beef and dairy farms in Sweden. Rotations on the farms usually are dominated by grass and clover leys for grazing or silage production. However, including an annual crop such as cereals can reduce weeds and plant diseases. Another benefit of including cereals in a crop rotation is related to hygiene, as it is safer to add slurry to a cereal crop rather than to a grass crop for silage production, as the slurry can be applied before seeding and the risk for microbial contamination is reduced. Leys are often established undersown in cereals and the main advantage of this is the guaranteed harvest of whole-crop silage or grains from the field during the year the leys are established.

1.2.2 Grains or whole-crop

Cereals can be harvested either as forage (whole-crop silage) or as concentrate (grains) and bedding (straw). The choice of harvesting method depends on several different farm-specific considerations. A farmer who uses cheap sawdust from a local sawmill as bedding and can buy cereal grains from a neighbour might be better off using a cereal crop as forage. However, in cases where prices of cereals are high, as they are today, and it is not easy to acquire material for bedding, harvesting cereals as grains and straw may be a better option. An economic advantage of harvesting cereals as whole-crops is that farmers can use the same machines they use for making grass silage. Grains, on the other hand, need different types of machines and the investment costs involved may be high. Furthermore, drying and storage of grains can be a costly for the farmer. Harvesting cereals at an early maturity stage compared to grain maturity increases the radiation to the developing ley, and can be beneficial for weed control reasons (Fogelfors and Hansson, 1998).

1.2.3 Cereal species

The cereal species most commonly grown in Sweden are oats (*Avena sativa*, L.), barley (*Hordeum vulgare*, L.), rye (*Secale cereale*, L.), wheat (*Triticum aestivum,* L.) and triticale (*X Triticosecale,* Wittmack), a cross between rye and wheat. Barley, oats and some cultivars of wheat are seeded in the spring, whereas rye and most of the triticale and the wheat are winter cultivars, seeded in the autumn. In northern Sweden a problem associated with the winter cereals is that their mortality rates during the winter often can be substantial. Moreover, the vegetation period is rather short, extending from seeding in mid/end of May to grain harvest in mid/late September. Fast maturing cultivars are therefore required and the crops available for grain harvest in northern Sweden are all cultivars of two-rowed barley (*H.v.*, var. *Distichum*), six-rowed barley (*H.v.*, var. *vulgare*) or oats. Whenever these cultivars are used the farmer can choose whether to harvest them as a whole-crop or as grains, even after the crop has been established. However, the problem often is that harvest of the whole-crop may occur at the same time as the second harvest of grass silage. If the crop is to be used as a whole-crop the farmers can use cultivars and species that mature more slowly and can be harvested after the second grass silage cut, but then the possibility to harvest it as grain is lost.

1.2.4 Maturation of cereals

Several methods for describing the maturity process of cereals have been proposed. In this thesis the decimal code first published by Zadoks et al. (1974) and later modified by Tottman (1987) will be used. The decimal code is a scale with nine stages (10, 20...90) each of which is divided in nine steps (1, 2...9). Whole-crop cereals are harvested during the stages that occur after heading (stage 50-59). After heading comes anthesis (stage 60-69), milk stage (stage 70-79) and dough stage (80-89). Sometimes two different stages may occur simultaneously, for example barley plants often start the anthesis already during heading. After full heading (59) the barley then continues directly to the milk stage (71), having already completed the anthesis stage (Zadoks et al., 1974; Tottman, 1987). The beginning of the milk stage is the initiation of the kernel development. Figure 1 shows the appearance of kernels of the six-rowed barley (A) and oats (B) harvested at the early milk stage in studies II and III.

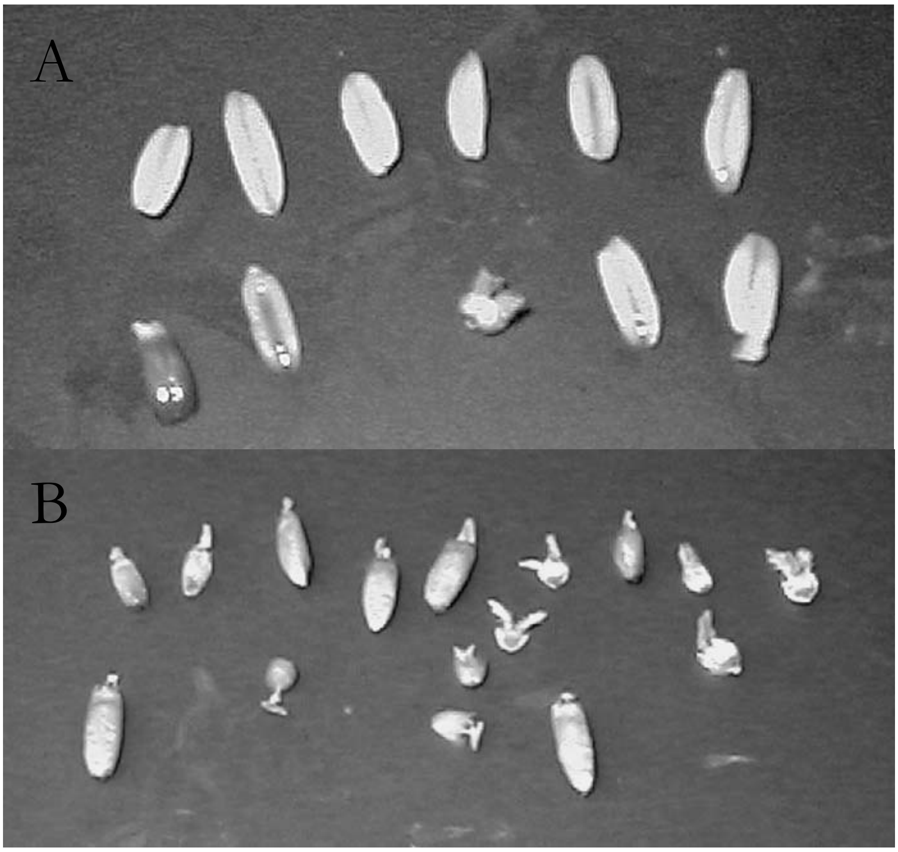

Figure 1. Kernels from six-rowed barley (A) and oat (B) plants at early milk stage (photo J. Wallsten).

The very small kernels are regarded as caryopsis water ripe (stage 71) in the decimal code, whereas the larger kernels represent stage 73, early milk (Tottman, 1987). The rapidity of crop maturation varies both among species, and among cultivars within species. Figure 2 shows the kernel development of eight different spring triticale cultivars, and a six-rowed barley cultivar grown in Umeå, Sweden and harvested at the same date. Even though all of the triticale cultivars were in the milk stage (70-79) there were differences in their maturity. Cultivar 2 was only at the very beginning of the milk stage, whereas cultivars 7 and 8 were in the middle of the milk stage. In comparison the barley in the picture was in mid-dough stage. In the end of dough stage, the maximum dry weight of the grain has been reached and the crop is turning completely yellow, marking the end of carbon assimilation (Tottman, 1987).

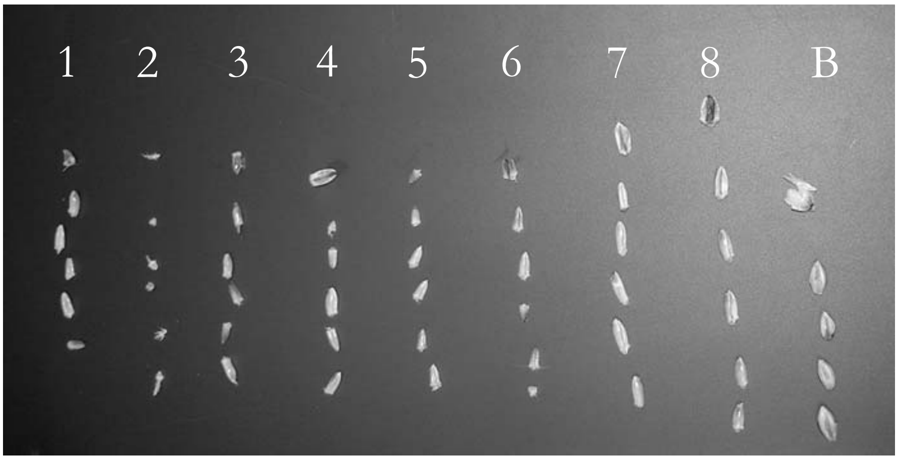

Figure 2. Kernels from eight (1, 2-8) different cultivars of spring triticale and one six-rowed barley (B) harvested at 2007-08-17 (photo J. Wallsten)

1.2.5 Harvest of whole crop cereal silages

Whole-crop cereals can be harvested for ensiling with conventional grass silage machinery at maturity stages from heading to early dough stages. The crop is usually cut with a mower conditioner and ensiled as big bales, although it is sometimes chopped and ensiled in bunker silos. Ensiling at the milk stage is usually easy due to the high concentrations of water-soluble carbohydrates (WSC) in the crop at that stage (Knický, 2005). Nevertheless, the DM yield/ha of the crop continues to increase during the milk and dough stages, so delaying the harvest can therefore be of economical interest (Nadeau, 2007). Furthermore, delaying harvest until the dough stage of maturity has another advantage as the DM concentration in the crop is high, and wilting is therefore unnecessary. Excluding wilting reduces losses due to plant respiration and the harvest will proceed faster, and becomes less dependent on the weather (Williams et al., 1995). However, delaying harvests is not without problems, as it leads to reductions in the WSC concentrations in the plants and increases the stiffness of their stalks. These two factors can reduce the fermentation activities by lactic acid bacteria and increase the production of unwanted microbes in the silage. Mechanical processing at harvest is an alternative that may increase the availability of WSC to the microbes (Knický, 2005). Moreover, the density of the crop in the silo or in the bale also increases (Lingvall et al., 2005). However, increased mechanical processing also will increase the grain losses at harvest (Knický, 2005; Lingvall et al., 2005). Delaying harvest until the late dough stage may decrease the grain utilisation by the cows due to associated increases of the hardness of the grains. The grain is the most nutritious part of the whole-crop and there is therefore desirable to minimise all grain losses. One possibility to avoid the problems associated with late harvests is to use direct harvesting methods and to equip the harvester with a processor that damages the grains at harvest (Jackson et al., 2004). However, this equipment is not very common on farms, as yet at least, and their investment costs may be high. Nevertheless, use of this type of harvesting technique is increasing in southern Sweden as the cultivation of maize for forage production is becoming more common.

2 Objectives

The main objective for the studies described in this thesis was to investigate the feed quality of whole-crop cereals with regard to cereal crops and maturity stage at harvest. The feed quality was evaluated on the basis of hectare yield (Paper I), chemical composition (Papers I-IV), digestibility (Papers I, III and IV), feed intake (Papers II and IV), diet selection (Paper II) and milk production (Paper IV). The main focus was on the use of whole-crop cereal silage (WCCS) in dairy production, but most results also can be applied for growing cattle.

3 Materials and Methods

All of the study sites mentioned below are located in Sweden, and for convenience the studies reported in papers I-IV are referred to as studies I-IV.

3.1 Paper I

Two-rowed barley (cv. Barbro) was sown in Öjebyn, Norrbotten and Ås, Jämtland, and six-rowed barley (cv. Rolfi) was sown in Ås, Jämtland. Winter rye (cvs. Amilo and Kaskelot), and triticale (cv. Fidelio) were sown in Offer, Västernorrland, and oats (cvs. Cilla and Stork) were sown in Umeå, Västerbotten. Weather data for the four sites is presented in table 1. All cultivars were harvested as whole crops 1, 3, 4, 5 and 7 weeks after heading, but the oat and barley crops harvested at 7 weeks after heading were not analysed. The experimental design was a split-plot with cultivars as the main plots and harvest as sub-plots. There were four replicates of the cultivars within each year.

Table 1. *Latitude, and mean (1960-1990) and annual (2003 and 2004) July temperature and precipitation for the four sites used in studies I-IV (data from the Swedish Meteorological and Hydrological Institute, SMHI)*

		Temperature			Precipitation		
Site	Latitude	Mean	2003	2004	Mean	2003	2004
Offer	63°08'	15.6	18.5	14.0	61	33	89
Ås	63°14'	13.9	17.2	13.8	86	44	38
Röbäcksdalen	63°48'	15.2	18.7	15.3	54	43	62
Öjebyn	65°21'	15.0	18.4	14.9	57	43	73

3.2 Papers II and III

Whole crops of oats (cv. Cilla) and six-rowed barley (cv. Olsok) were harvested and ensiled at heading, early milk and early dough stages of maturity, while two-rowed barley (cv. Pasadena) was harvested and ensiled at early milk and early dough stages. The silages were fed to 32 heifers in a change-over design with three periods and eight treatments. During the first 17 days of each period the heifers were fed the silages *ad libitum* and their voluntary feed intake and diet selection was measured. In the remaining eleven days of each period the heifers were fed restricted levels of WCCS (95% of *ad libitum* levels) and in the last five days digestibility was measured with a total faecal collections.

3.3 Paper IV

The same six-rowed barley silages as those used in the studies II and III were fed to 15 dairy cows in mid-lactation as parts of five different rations, in which the WCCS and grass silage were fed along with two different concentrates (Table 2). The experiment was conducted as a change-over design during three periods, each four weeks long. *Ad libitum* intake was measured during the last 14 days of each period. Milk production was measured weekly during the morning and evening milking on two consecutive days during the final two weeks of each period. Two faecal samples per day and cow were collected during the last five days of each period and diet digestibility was measured, using acid-insoluble ash as an internal marker.

Table 2. *Composition (kg dry matter) of the five diets used in study IV*

	Diet B1	Diet B2	Diet B3	Diet M1	Diet M2
Concentrate	10.7	10.7	10.7	10.7	10.7
Grass silage (GS)	4	4	4		
Barley silage at heading (BSH)	*Ad libitum*				
Barley silage at early milk		*Ad libitum*			
Barley silage at early dough			*Ad libitum*		
Mix1 0.7:0.3 GS:BSH				*Ad libitum*	
Mix2 0.3:0.7 GS:BSH					*Ad libitum*

4 Results and Discussion

As the maturity stage at harvest was not determined in study I it is difficult to compare the results of that study to those reported in the other papers, in which the crop was harvested at specific maturity stages. However, the oat cultivar Cilla was not only used in studies I, II and III, but was, in addition, cultivated at the same site in all experiments. Furthermore, the six-rowed barley Rolfi used in study I and Olsok used in studies II, III and IV are similar cultivars in terms of maturation. The time between harvests of six-rowed barley (13 days from heading to early milk stage, eight days from early milk stage to early dough stage) and oats (eight days from heading to early milk stage, 18 days from early milk stage to early dough stage) in study III were therefore used to decide which of the harvests in study I corresponded most closely to the early milk and early dough stages. The starch and WSC concentrations were also taken into consideration; a peak in WSC concentration is indicative of the early milk stage and a starch concentration of 15-20% of DM is indicative of the early dough stage (Nadeau, 2007). Since these indicators provide quite rough estimates, the values presented in the tables based on these data are averages of both years in study I. In addition for oats and rye, average values for both cultivars were used; for the two-rowed barley cv. Barbro, average values from the two sites were used. Since estimating the maturity stage in this way is rather crude, the two maturity stages will be referred to as milk and dough stages rather than early milk and early dough stages. The chosen harvests are presented in Table 3. The rye cultivars were not sufficiently mature at the last harvest in 2004 to be regarded as being in the dough stage since their starch concentrations were too low. For the rye cultivars in 2003 and the triticale cultivar in 2004 the dough stage seemed to occur some time between 5 and 7 weeks after heading. In those cases the later harvest was regarded as the dough stage of maturity, even though the starch concentrations imply that the crops were in the late rather than early dough stage of maturity.

Table 3. *The harvests (weeks after heading) of the eight cereal crops in study I where the maturity of the crop best corresponded to milk and dough stages of maturity*

	2003		2004	
	Milk	Dough	Milk	Dough
Barbro Öjebyn	1	3	1	4
Barbro Ås	1	3	1	4
Rolfi	1	3	1	4
Cilla	1	3	3	5
Stork	1	4	3	5
Fidelio	3	4	4	7
Amilo	4	7	5	–
Kaskelot	4	7	5	–

4.1 Maturation of whole-crop cereals

The two summers covered in study I differed strongly in terms of temperature and rainfall, the summer of 2004 being both cooler and wetter (Table 1). Hence, all crops matured more slowly in 2004 than in 2003, as manifested in the changes in WSC and starch concentrations (Paper I). This confirms that harvesting a specific number of weeks after heading can be highly inappropriate if harvest at a specific maturity stage is desired. Most of the crops took about a week longer to mature in 2004 than in 2003. Barley (both six-rowed and two-rowed) matured most rapidly, and, in 2003, within three weeks post-heading the crop was close to maximum yield and starch concentration. One reason for the rapid maturation is that there is usually no anthesis stage (stage 60-69 in the decimal code; Zadoks et al., 1974) in barley, and consequently the milk stage follows directly after the heading stage (Tottman, 1987). Oats took about a week longer post-heading to mature to early dough stage than barley in studies II and III, and this seem to correspond to the maturity rate in study I. However, in studies II and III the days between harvest at heading stage and early milk stage was shorter in oats than in barley.

The winter crops were already in the full heading stage in June. The triticale reached full heading 10-14 days after the rye cultivars, in accordance with the reported lag between rye and triticale cultivars grown in Canada (Juskiw et al., 2000). After heading there were minor changes in the triticale and rye crops for two and three weeks, respectively. Part of the delay in maturity between the heading and milk stages could be attributed to anthesis, especially for rye, which is a cross-pollinating cereal. Maturation can also be dependent on the day length, e.g. tassel initiation in maize is delayed when the day length is increased (Hunter et al., 1974). The rye and triticale cultivars reached full heading during the lightest time of year, when there were more than 20 hours between sunrise and sunset at the experimental site. Neither the rye cultivars nor the triticale cultivar used in study I were bred for cultivation in northern Sweden, but the two-rowed barley, the six-rowed barley and the oat cultivar Cilla were all cultivars that can be used for grain production in northern Sweden. This could mean two things: 1) further south the winter crop starts to grow earlier in the spring when the days are shorter; 2) at the same date the days are shorter the farther south the crop is cultivated. If the winter cereals are sensitive to day length during anthesis the maturation of the winter cereals may be prolonged when cultivated as far north as in study I.

4.2 Yield

At the experimental sites used in study I the greatest problem usually associated with the climate is that autumn-sown crops may not survive the winter. For the triticale cultivar Fidelio grown at Offer, there was about 30-40% winter kills in spring 2003 and the total DM yield was therefore lower at all harvests than in 2004 (Paper I). None of the rye cultivars suffered from winter kills, although they were cultivated in the same experimental fields. Even with the reduced DM yield, the winter triticale in study I had a higher yield potential than the spring-sown cereals (Paper I). While maximum yields for both the oats and barley cultivars were around 8000-10000 kg DM/ha, the winter crops yielded up to 16000 kg DM/ha, similar to the values reported for winter wheat (Filya, 2003; Paper I). However, the crop that gives the highest DM yield/ha is not necessarily the best. For a farm with a small cultivation area it is important to maximise yield, but one must also consider the quality of the crop that is harvested. In table 4 yields (per hectare) are listed in terms of a number of quality parameters, based on the results at the harvests corresponding most closely to the milk and dough stages of maturity in study I. One of the most interesting parameters in table 4 is, perhaps, the yield of digestible DM. The digestible DM yield is the part of the forage that the animals can utilise potentially, and is therefore very important. Rye has a very high DM yield and, because the lack of winter kills in 2003 for that crop, the DM yield was higher than for triticale at both milk and dough stages. However, the triticale yielded more digestible DM per hectare than rye, because the DM digestibility (DMD) of rye is lower (Paper I). Even so, rye yielded almost twice as much digestible DM/ha as the spring-sown cereals barley and oats at the same maturity stage (Table 4). Nadeau (2007) reported yields of digestible OM that were similar to the yields of digestible DM in table 4 for barley and oats, whereas the yield of digestible DM of winter triticale in table 4 was higher than that of digestible OM in the study by Nadeau (2007). A shared feature of all species, except oats, was that at early dough stage the yield of starch approximately equalled the yield of digestible neutral detergent fibre (NDF). If the digestibility of starch at this maturity stage is considered to be close to 100% (as the results in Paper III indicate for barley and oats), then one can assume that the contributions to energy yields provided by starch and NDF are roughly equal at the dough stage, but the NDF provides more energy than starch at the milk stage. The crude protein (CP) yields for the spring-sown crops were lower than that reported by McCartney and Vaage (1994) for spring-sown barley (953 kg/ha), oats (868 kg/ha) and triticale (978 kg/ha). However, their data were the result of higher CP concentrations in the crops rather than a higher DM yield (McCartney and Vaage, 1994).

Table 4. *Whole-crop cereal yield (kg/ha) of dry matter (DM), crude protein (CP), starch, digestible DM (DDM) and digestible neutral detergent fibre (DNDF) at the harvests representing milk and dough stages of maturity (modified from the results in Paper I)*

	Barley Barbro		Barley Rolfi		Oats		Triticale		Rye	
	Milk	Dough	Milk	Dough	Milk	Dough	Milk	Dough	Milk	Dough
DM	6401	9058	5833	8715	6341	8362	10191	12900	12326	13493
CP	682	738	621	695	636	761	888	1040	867	817
Starch	84	1957	74	2139	321	1215	234	2716	142	2884
DDM	4733	6792	4425	6454	4522	5896	8179	10146	8766	9126
DNDF	2161	1988	2069	1900	1960	1908	2959	2991	3298	2923

4.3 Chemical content of fresh crop and silages

4.3.1 Water-soluble carbohydrates and starch

The WSC concentration is an important parameter of forage crops that are to be used for ensiling since the readily soluble carbohydrates are the primary sources of energy for the microbes (Knický, 2005). The concentration of WSC in grass leys can vary with maturity of the plants, but also according to the time of day (Syrjälä-Qvist and Alaruikka, 1992). The WSC concentration in the fresh crop of six-rowed barley in study III harvested at early milk stage was lower than that of the corresponding crop in 2003 in study I, probably due to respiration of the plants since the crop in study III was wilted, unlike the crop in study I (Williams et al., 1995). The WSC concentration in fresh matter is usually higher at the early milk stage than at the early dough stage (Bergen et al., 1991; Filya, 2003; Nadeau, 2007; Paper III). However, Borowiec et al. (1998) found higher WSC concentrations in barley harvested at the dough stage than at the milk stage. For the oat cultivars in study I the WSC concentration peaked around one week after heading in 2003 and this corresponds in time to the harvesting of oats at early milk stage in study III.

The average WSC concentrations in triticale and rye are higher than those of oats and barley (Nadeau, 2007; Table 5). Oats seem to have the lowest WSC concentration among cereal species (Bergen et al., 1991; Nadeau, 2007; Papers I and III). At early dough stage of maturity the DM concentration in the crop is so high that wilting is not necessary. If the crop is harvested without wilting, the WSC concentrations in Table 3 are all sufficient to ensure good ensiling, assuming that an oxygen-free environment is maintained. However, Knický (2005) suggested that the main components of the WSC in cereals at dough stage are sucrose and fructan and these are less available to the lactic acid bacteria as they have to be hydrolysed into monosaccharides before they can be utilised by the microbes. Hence, the desired rapid reduction in pH may not occur and undesired fermentation of e.g. clostridia, can take place. The WSC of the fresh whole-crop of six-rowed barley and oats examined in study III consisted mainly of free glucose and fructose, whereas that of the two-rowed barley also had considerable amounts of fructan and sucrose (Table 6). The two-rowed barley silage at early dough stage also had the highest pH, despite higher WSC concentration in the fresh matter than oats and six-rowed barley (Paper II).

Table 5. *Chemical composition (g/kg dry matter if not else stated) and* in vitro *digestibility (g/kg) of whole-crop cereals representing milk and dough stages of maturity (modified from the results in Paper I)*

	Barley Barbro		Barley Rolfi		Oats		Triticale		Rye	
	Milk	Dough	Milk	Dough	Milk	Dough	Milk	Dough	Milk	Dough
Composition										
Dry matter (g/kg)	227	334	227	443	196	261	323	384	345	456
Ash	74	54	69	50	97	83	52	48	40	37
Crude protein	110	82	107	80	102	91	89	81	67	61
Water soluble carbohydrates	172	107	166	54	98	71	303	158	242	60
Starch	13	210	13	247	44	146	26	202	51	216
Neutral detergent fibre	596	470	595	478	605	521	489	446	539	540
In vitro digestibility										
Dry matter	743	753	760	740	718	705	800	790	713	680
Neutral detergent fibre	570	470	595	455	525	433	590	530	485	400

Table 6. *Composition of water-soluble carbohydrates in the fresh crops of the eight whole-crop cereals in study III*

	Glucose	Fructose	Sucrose	Fructan
Six-rowed barley				
Heading	36	39	8	5
Early milk	21	35	16	20
Early dough	8	12	6	12
Oats				
Heading	29	22	5	2
Early milk	37	28	10	6
Early dough	17	15	5	9
Two-rowed barley				
Early milk	40	57	56	64
Early dough	22	38	27	30

The WSC are polymerised to starch as maturation proceeds through the milk and dough stages. The accumulation of starch during maturation is highly dependent on temperature and will go faster at high temperatures (Herrmann, 2006; Paper I). Starch is not generally fermented by the microbes during ensiling, but may be hydrolysed into simple sugars when the pH of the crop drops (Nadeau, 2007). This seemed to have happened in the six-rowed barley harvested at early dough stage in study III; the starch concentration was around 200 g/kg DM in the fresh crop, but only 160 g/kg DM in the silage (Paper III). Oats have a lower starch concentration than barley at early dough stage, which may be related to a lower ear: stalk ratio in oats (Nadeau, 2007; Paper III).

4.3.2 Ash, crude protein and fibre

The ash concentrations in the silages analysed in studies II, III and IV were very high compared to those in Table 5; this was due to soil contamination at harvest in studies II, III and IV, which can be a problem when harvesting WCCS. When a grass ley has been undersown beneath cereals, the sward of the grass crop may prevent soil contamination at harvest. Generally, the advice is to set cutting heights at harvest sufficiently high to avoid fresh soil mingling with the crop when it is picked up. Williams et al. (1995) reported higher ash concentrations in whole-crop wheat that was wilted than in unwilted crop. The wilted silages were raked in the study by Williams et al.

(1995), unlike in studies II–IV, and the raking was suggested to be the cause of the soil contamination in their paper. The contamination of the crops harvested in 2003 did not arise from contamination by fresh soil when the crop was picked up, but rather from dust due to the lack of rain in the weeks preceding the first two harvests (Papers II-IV).

The CP concentrations in WCCS usually are lower than those that are gained with grass and clover silages (Hameleers, 1998; Ahvenjärvi, 2006; paper IV). Moreover, there is a decrease in CP concentration with increased maturity stage at harvest (Crovetto et al., 1998; Nadeau, 2007; Papers I and III). The CP concentration was lower in rye than in the other cereal crops, which could be because of higher stem content in rye, as the stem fraction has the lowest CP concentration (Cherney and Marten, 1982). The NDF concentrations also decrease during maturation as a dilution effect of the increased starch contents (Bergen et al., 1991; Nadeau, 2007; Paper I and III). Triticale and rye had lower NDF concentrations than the other crops at the milk stage, probably because of the high WSC concentrations, whereas oats and rye had the highest NDF concentrations at the dough stage (Table 5). The NDF concentrations in study III were rather low compared to those in table 5, partly because of the high ash concentrations of the crops in study III. The ADF concentrations in study III changed in a similar way as the NDF concentration during maturation. According to results by Cherney and Marten (1982), the acid detergent fibre (ADF) and lignin concentrations increase during maturation in a linear fashion for the stem, leaf blade and leaf sheath fractions. The major part of the increase in lignin during maturation takes place in the stem, as a response to the increased ear weight (Cherney and Marten, 1982).

4.4 Digestibility of whole-crop cereal silage

4.4.1 Effect of maturity stage at harvest

In study III the *in vivo* organic matter digestibility (OMD) of six-rowed barley was similar at all maturity stages. Neither did Borowiec et al. (1998) or Mannerkorpi and Brandt (1995) find any significant differences in *in vivo* OMD of barley silages with regard to maturity stage. However, Acosta et al. (1991) recorded a 10 percent reduction in *in vivo* OMD in barley from the boot stage (the stage of stem elongation, preceding the heading stage) to early dough stage. The OMD in oats decreased between the heading and early milk stages, but the OMD of six-rowed barley and oats did not significantly change from the early milk to early dough stages (Paper III). In study I the first harvest occurred one week after heading and no significant decrease in DMD was detected in oats and barley between one and three weeks after heading. In fact, delaying the harvest of WCCS post-heading had little effect on the *in vitro* DMD of the crops in study I, except for the two rye cultivars, for which there was a decrease in DMD between one and three weeks after heading corresponding to an increase in NDF concentration (Paper I).

The mean *in vivo* DMD values of the crops analysed in study III ranged from 585 to 611 g/kg for oats, from 601 to 661 g/kg for six-rowed barley and from 648 to 687 g/kg for two-rowed barley, which is lower (around 100 g/kg) than the *in vitro* DMD values obtained in study I (Table 5). However, the DMD values in table 3 correspond rather well to the *in vitro* OMD values reported for oats and barley at early milk and early dough stages in Paper II. The digestibilities that are measured *in vivo* are usually lower than *in vitro* values due to faecal contamination by endogenous matter, e.g. microbes and intestinal cells. These substances have already been digested once, but because they end up in the faeces they are regarded as undigested, and thus reduce *in vivo* digestibility values. The digestibilities most affected by this are the DMD, OMD and CP digestibility. It is very likely that the difference between *in vitro* and *in vivo* DMD can be attributed to a large extent to these endogenous matters. Another source of error is that there is no passage of undigested material from the "rumen" in an *in vitro* analysis.

The NDF digestibility (NDFD) decreases during post-heading maturation for all cereal crops (Borowiec et al., 1998; Crovetto et al., 1998; Mustafa and Seguin, 2003; Papers I and III). However, the results in study I indicate that NDFD also is influenced by year, and Chow et al. (2008) concluded that delaying the sowing date in spring increased the NDFD at the same maturity stage. For the oats in study III *in vivo* NDFD declined continuously from the heading to the early dough stage and the decrease between the early milk and early dough stages was similar to the decrease in *in vitro* NDF digestibility from the milk to dough stage shown in table 5. The *in vivo* NDFD of the two barley varieties examined in study III differed, in that NDFD values decreased between the early milk and early dough stages in the two-rowed barley, but not in the six-rowed barley. The *in vitro* NDFD values in table 5 show similar reductions to those found for the two-rowed barley in study III. The time when the reduction in NDFD occurs corresponds to the time when the starch concentration increases in the grain. According to Tottman (1987) the wet weight of the ear peaks at around the early dough stage of maturity. It is not surprising that the largest decrease in NDFD should have occurred at the same time.

The reductions in NDFD contents are partly due to increased concentrations of lignin in proportion to the rest of the NDF, and partly to reductions in the digestibility of the hemicelluloses and cellulose due to linkages between the lignin and hemicelluloses (Cherney and Marten, 1982; Paper III). This lignification process is the response by the plant to the increased weight of the ear, and should therefore occur at the same time as the increase in ear weight. Even if the decrease in *in vivo* NDFD from the heading to the early dough stage was rather large (between 150 and 200 g/kg), the lack of a decrease in *in vivo* OMD shows that the increase in starch concentration, together with high starch digestibility, could compensate for the reduced NDFD (Paper III). The changes in the proportions of the various constituents of the digestible OM of whole-crop cereal silages during maturation, based on the results presented in Paper III, are summarised in figure 3. The change from digestible NDF to digestible starch is clearly the main difference between the OMD at the heading and early dough stages. It is important to remember this as these differences may affect the production of animals fed the silages, even if the energy contents of the silages are similar.

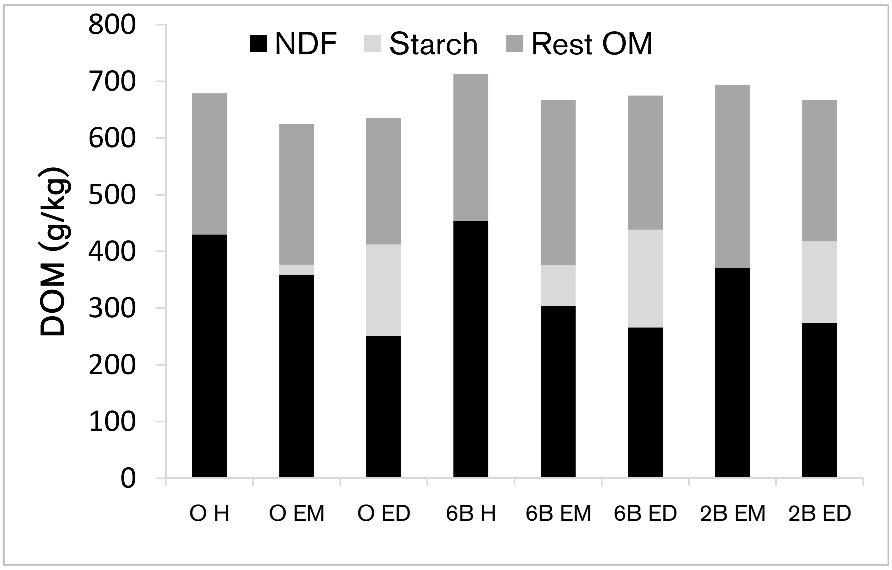

Figure 3. Composition of digestible organic matter (DOM) as digestible neutral detergent fibre (NDF), digestible starch and the rest of the digestible organic matter (OM) for the silages used in study III (O=oats, 6B=six-rowed barley, 2B=two-rowed barley, H=heading, EM=early milk stage and ED=early dough stage).

The digestibility of CP varied little with maturity stage when whole-crop oats and barley were fed to heifers (Paper III). However, including WCCS in dairy cow rations containing other forages high in CP may increase the nitrogen efficiency of the diet (Bertilsson and Knický, 2005).

When the six-rowed barley silages were fed to dairy cows, the *in vivo* OMD of the diet decreased with delayed maturity stage of the fed barley silage (Paper IV). The decrease in diet OMD from heading to early dough stage was larger than the results from the heifer trial in study III suggested. The results of study IV therefore indicated that the utilisation of the whole diet fed to the dairy cows changed more than expected from the differences in digestibility of the whole-crop barley silages. In order to determine how the concentrate + grass silage part of the diets in study IV were affected by the maturity of the barley silages, the whole-crop barley silage part of the diet was assumed to have the same digestibility as the corresponding silage in study III. The original digestibility data (not the LS means) from the digestibility trial in study III were used to calculate the amount of faeces that would have originated from the undigested barley silages, and the remaining faeces were used to calculated the digestibility of the diets without the whole-crop barley silages. The *in vivo* OMD values for the concentrate + grass silage parts of diets B1, B2 and B3 were 818, 808 and 744 g/kg, and the *in vivo* NDFD values were 695, 673 and 578 g/kg, respectively. Consequently, it seems that feeding the barley silage harvested at early dough stage reduced the OMD of the whole diet by reducing the NDFD. It is likely that the amount of starch in the diet (around 20%) reduced the utilisation of NDF when the diet with barley silage harvested at early dough stage was fed. Soita et al. (2003) found a decrease in both NDF and ADF digestibilities when the concentrate level in rations fed to steers was increased from 50 to 80% of DM on behalf of barley silage. When Beckman and Weiss (2005) fed dairy cows maize-based diets with different NDF: starch ratios, they did not find any differences in NDFD of the diets with increased starch concentrations. However, the starch concentrations in their study ranged from 25.4-33.3% of DM, compared to 14.8-20.0% of DM in paper IV (Beckman and Weiss, 2005). Moreover, the NDFD (450-460g/kg) of the diets were much lower than of the diets (600-740g/kg) in paper IV (Beckman and Weiss, 2005). In order to reduce the impact of high starch intakes in study IV, the concentrates were fed four times daily and a small proportion of the starch in the concentrates was maize starch, which is digested more slowly in the rumen than wheat or barley starch. However, these measures were clearly not sufficient to prevent reductions in the NDFD of the diets. Normally, it is not possible to reduce the amount of concentrate in the diet when feeding WCCS with a high starch concentration without reducing milk production (Keady et al., 2005). However, increasing numbers of Swedish farmers are using mixer wagons, which supply concentrate and forage simultaneously at all times; even if it may be possible for the cows to select grains and concentrates from the mixtures, this system reduces the risk of occasional high starch intakes during the day. Another option would be to use a concentrate that is lower in starch and higher in highly digestible fibres.

4.4.2 Effect of cereal species

The statistical design applied in study I did not allow comparisons among species unless they were cultivated at the same site. However, numerically the *in vitro* DMD values of rye and oats were lower than those of barley and triticale in both years in study I (see also table 5). Similarly, both Christensen et al. (1977) and Nadeau (2007) found *in vitro* OMD levels of oats to be lower than those of barley. Winter triticale seems to have DMD and OMD similar to barley (Nadeau, 2007; Paper I); however, McCartney and Vaage (1994) reported lower *in vivo* OMD of spring triticale than barley when the silages were fed to sheep. The *in vivo* OMD values of oats in study III were lower than those of barley. As the starch digestibility of oats were slightly higher than that of barley in study III, the lower OMD of oats was presumably due to lower NDFD.

The changes in digestibility of the fibre components in oats differed from those of the two barley cultivars in study III. The digestibilities of cellulose and hemicelluloses decreased in both oats and barley during maturation, but while the digestibility of cellulose was similar in oats and barley at each stage of maturity, the digestibility of hemicelluloses was lower in oats, and this seemed to be the main reason to the lower NDFD in oats than in barley (McCartney and Vaage, 1994; Paper III). In contrast to the DMD, the *in vivo* NDFD was higher in study III than the *in vitro* NDFD in study I. The NDFD is not affected by endogenous matters, because there are no fibres in its constituents and the apparent and the real *in vivo* NDFD values can therefore be assumed to be equal. However, the *in vitro* digestibility analysis used in study I only provided estimates of changes to material that occurred in the rumen during 30 hours, but the *in vivo* digestibility reflects changes that occur to the material during its passage through the entire gastro-intestinal tract.

4.5 Voluntary feed intake and feed selection

4.5.1 Intake of whole-crop cereal silage vs. grass silage

The DM intake (DMI) of grass silage can be affected by its DM content, fermentation characteristics, NDF concentration, OMD and NDFD, all of which can also be assumed to affect intake of WCCS (Steen, et al., 1998; Hetta et al., 2007; Huhtanen et al., 2007; Krizsan and Randby, 2007). While the first two factors can be controlled by wilting and use of appropriate additives at the time of ensiling the others depend on maturity stage at harvest and choice of cereal species. Typically, for grass silage an increase in NDF concentration due to delayed harvest is correlated to reductions in OMD and NDFD. For WCCS, on the other hand, the NDF concentration is positively correlated to NDF digestibility, while DMD and OMD changes little during maturation (Papers I and III). Thus, assuming that DMI will decrease if WCCS harvests are delayed, as one could assume for grass silage, is not entirely valid.

Huhtanen et al. (2007) have shown that including WCCS in the diet of dairy cows increases the DMI of the diet. Moreover, Keady (2005) concludes in a review that intake of WCCS made of wheat is often higher than that of grass silage. Two possible reasons for this are that WCCS usually (but not always) has higher DM contents and lower NDF concentrations than grass silage (Keady, 2005; Ahvenjärvi, 2006; Paper IV). However, including WCCS does not always result in higher intake. Ahvenjärvi et al. (2006) reportedly found no increase in DMI when barley silage harvested at the early dough stage was exchanged for grass silage in the diets of dairy cows, despite the barley silage having a higher DM content and lower NDF concentration than the grass silage. This corroborates the findings in study IV, in which no significant difference in DMI was detected between diets M1 and M2, although the grass silage accounted for 70% of forage DM in the former and only 30% of forage DM in the latter. In both the study by Ahvenjärvi et al. (2006) and study IV the forages were mixed before feeding, which may have reduced the impact of the low DM contents of grass silage on DMI.

4.5.2 Effects of maturity stage at harvest and cereal species on silage intake

In study II intake of oats increased with maturity stage corresponding to an increase in DM content of the silages. Consequently, the DMI was lower for oats at heading than at early dough stage, even though the *in vivo* OMD was lower at early dough stage (Papers II and III). In contrast to the oats there was a reduction in DMI between six-rowed barley at heading and the two later harvests despite no significant decrease in OMD. Furthermore, in study IV, where the whole-crop barley was fed as part of a diet to dairy cows, there was a linear decrease in intake of whole-crop barely silage with increasing maturity stage from heading to early dough stage. Christensen et al. (1977) found that awned varieties of wheat and barley had lower DMI values than oats and wheat without awns when the crop was harvested at the dough stage. This could therefore explain the difference in DMI between oats and barley at early dough stage (Paper II). The awns on the barley crop seem to become harder as the crop matures and might bother the animals more at later maturity stages, hence the higher intakes of barley at heading (Papers II and IV). The two-rowed barley used in study II was also awned, but did not seem to bother the heifers as much as the six-rowed barley.

The heifers seemed to be able to select grains from the more mature two-rowed barley silage, as was the case with oats, but not from six-rowed barley; this could be seen as evidence that the awns on the two-rowed barley were less troublesome (Paper II). Whether this is due to variations in the hardness of awns among barley cultivars or merely to the lower number of awns on two-rowed barley is difficult to say. Generally, the feed value of barley as a whole-crop is regarded to be higher than that of oats, but the problem with awns reduces the usage of the forage, especially since WCCS is regarded as a good forage for young, low producing animals such as dairy heifers. Triticale has a similar digestibility and chemical composition as barley, and is on those terms a good alternative for whole-crop silage (Nadeau, 2007; Paper I). However, intake of triticale has been reported to be lower than that of barley and oats when fed to heifers (McCartney and Vaage, 1994).

4.6 Milk production

When grass silage is exchanged for WCCS the results are expected to depend on the quality of the grass silage. Replacing a grass silage with an energy content of 11 MJ metabolisable energy (ME) should be more difficult than replacing one with an energy content of 10 MJ ME. However, when feeding a ration composed of several different feeds, as in the case of dairy cows, the utilisation of the diet is not necessarily the sum of the single feeds that the diet is composed of. In study IV, feeding barley silage at the early dough stage of maturity lowered the OM and NDF digestibility of the other diet components. Such interaction effects make it difficult to evaluate the effects of including WCCS rather than grass silage, especially in diets high in starch. Keady (2005) have reviewed the effects of replacing grass silage with whole crop wheat silage, and concluded that in most studies the intake of forage increased when whole-crop wheat silage was used, but there was a lack of corresponding increases in milk yields. In study IV there was no comparison with a grass silage only diet. However, there was little difference in milk yield between diets with 70% or 30% grass silage in forage DM when grass silage was fed along with barley silage harvested at the heading stage. The differences were instead among the different maturity stages (Paper IV). Considering how small the differences in OM digestibility were amongst the barley silages tested in study III, this difference in milk production was unexpected. The decreasing yield of ECM with advancing maturity of the barley silage in study IV was a combined result of lower milk yield, and lower concentrations of fat and protein in the milk.

A difference in milk production associated to the maturity stage of the fed cereal silage as seen in study IV has not been shown in other studies (Polan et al., 1968; Acosta et al., 1991; Sinclair et al., 2003). There also seem to be no difference in milk production when oats or barley is fed despite the difference in OMD between the crops (Burgess et al., 1973; Khorasani et al., 1993).

4.6.1 Changes in milk fat yield

The lower milk yield and protein concentration recorded in study IV can be explained by the assumed lower energy content of the diet as a result of reduced OMD. Fat concentrations also can be affected by the composition of the diet. The higher starch and lower NDF concentrations in the diet containing barley silage harvested at early dough stage are the most likely reasons for the decrease in milk fat concentration (Beckman and Weiss, 2005). A number of different mechanisms can account for the effects of diet composition. One possible explanation is that a high starch concentration in the diet results in the production of propionate in the rumen, and high amounts of propionate can induce an insulin response in the animal and trigger production of body fat rather than milk fat (DeVisser et al., 1990). It is quite possible that the cows in study IV used energy to produce body reserves (i.e. body fat) rather than milk. Polan et al. (1968) found no difference in milk production when barley silages at bloom, milk and dough stages were fed, despite a higher DMI with the two later harvests. However, the increase in body weight gain was higher when barley was harvested at milk and dough stages than at bloom stage (Polan et al., 1968). Jackson et al. (2004) reported higher body condition scores and lower milk fat concentrations in dairy cows when starch concentration in whole-crop wheat was increased by increasing cutting height at harvest. However, measuring body condition score and weight changes can be problematic when the animals are used in a change-over design with periods only four weeks short. This hypothesis cannot therefore be confirmed for the cows in study IV.

Another possible explanation is that when NDF is degraded in the rumen the main end product is acetate, which is important for synthesis of fatty acids in the mammary gland (Sveinbjörnsson, 2006). A lower concentration and/or utilisation of fibre could therefore reduce milk fat concentrations (Beckman and Weiss, 2005). Both NDF intake and digestible NDF intake was reduced when barley silage at the early dough stage was fed. The amounts of NDF and digestible NDF required to produce 1 kg of milk fat in study IV are presented in figure 4, which shows that, in this study, the total NDF intake rather than digestible NDF intake was important for milk fat production. Rondahl et al. (2007) fed dairy cow rations varying in starch concentration (10-25% of DM) by adding different proportions of concentrate and whole-crop pea-oat silages. Calculations of the amounts of NDF and digestible NDF required for milk fat production based on data from their study corroborate the results of study IV (Figure 5). However, Sinclair et al. (2007) varied starch concentration in rations fed to dairy cows from 6 to 24% of DM by changing the proportion of whole-crop wheat in the diet and the data presented herein contradict the result in the two studies cited, as it is the NDF/kg fat that varies rather than the digestible NDF/kg fat (Figure 6).

Using WCCS harvested at early dough stage should be possible without causing a reduction in milk production if the concentrate is modified. In study IV there were two concentrates: one (9 kg/day) in which all of the starch originated from barley or wheat and one (3 kg/day) in which 2/3 of the starch came from maize and the rest from barley. Had a larger proportion of the starch in the diet originated from maize, the effect on milk production may have been different. The problem with WCCS harvested at later maturity stages also can be seen from another perspective, namely that including such silage reduces the proportion of digestible fibre in the diet. Another solution might therefore be to increase the amount of highly digestible fibre in the concentrate, e.g. with more beet pulp.

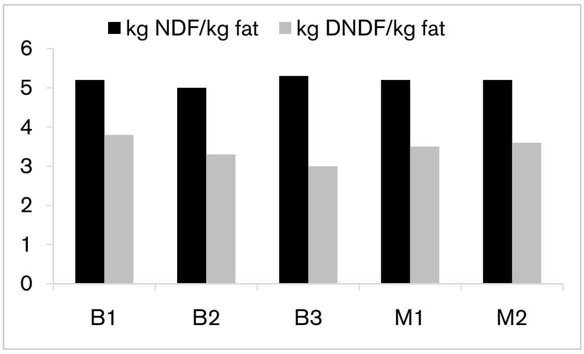

Figure 4. Amounts of neutral detergent fibre (NDF) and digestible NDF (DNDF) needed to produce 1 kg milk fat in paper IV (for diet composition see table 2).

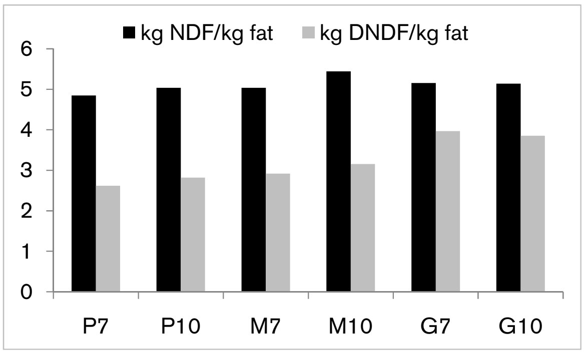

Figure 5. Amounts of neutral detergent fibre (NDF) and digestible NDF (DNDF) needed to produce 1 kg milk fat in the paper by Rondahl et al. (2007). Concentrate levels were 7 or 10 kg/day and forage consisted of pea/oat silage (P), pea/oat silage and grass silage mixed (M), and grass silage only (G).

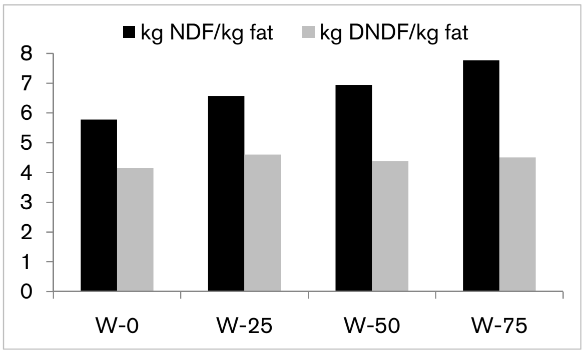

Figure 6. Amounts of neutral detergent fibre (NDF) and digestible NDF (DNDF) needed to produce 1 kg milk fat in the paper by Sinclair et al. (2007). Whole-crop wheat concentration of forage dry matter is 0 in W-0, 25% in W-25, 50% in W-50, and 75% in W-75.

5 Conclusions

The main advantage of using WCCS on the dairy farm is the high yield at one cut compared to grass silage, which makes the crop relatively cheap to produce. To be able to utilise this advantage the crop should be harvested at early dough stage. Nevertheless, care has to be taken to avoid milk fat depression in the cows due to a decreased fibre digestibility as more milk fat generates a higher milk price. Among the spring crops evaluated in this thesis barley is the best when the digestibility and chemical composition are considered. However, the lack of cultivars with smooth awns or no awns reduces the usability of the crop, because the awns reduce the palatability of the silage. Using two-rowed cultivars with fewer awns than the six-rowed might be a solution, though there also might be differences in the hardness of the awns among cultivars. The winter triticale has a good yield and a high digestibility, which makes it very suitable as WCCS. However, more feeding trials with triticale are needed to evaluate its palatability and utilisation by ruminants.

6 Future Research

Farmers in northern Sweden wanting to keep the opportunity to harvest cereals as either whole-crop silage or grain need to use oat and barley cultivars bred for fast maturation. However, when using slower maturing cultivars the harvest of the whole-crop cereals at dough stage can be delayed until the second (or sometimes third) harvest of grass silage is finished. Removing the option to harvest the cereal crop as grain opens three new possibilities when selecting the cereal crops 1) the use of slower maturing cultivars of barley and oats, 2) the use of the slower maturing species such as spring triticale and spring wheat, 3) the use of winter cereal cultivars and 4) the use of fast maturing cultivars with delayed planting date in spring. There are no recommendations as to what cultivar to choose for any of the options as cereal cultivars used in Sweden are bred for improved grain harvest, and there are no cultivars specifically bred for silage production. It is therefore of interest to evaluate different cultivars and species for silage production. This should be done both from crop production aspects by looking at crop establishment, rate of maturation and DM yield, but also from a feed value perspective with emphasis on palatability (and voluntary feed intake), digestibility and utilisation. The results from the Canadian study where delayed planting date increased the NDFD of WCCS are interesting, but need to be tested during Scandinavian climate conditions.

Finding solutions to the problems with awns on the barley crop is important, as barley is a common crop for WCCS in Sweden. One option is to investigate the difference among cultivars and varieties. Another is to continue working with cultivars with soft awns of without awns, as breeding lines of these types already exists. In North America there are cultivars on the market already, but if these are to be used in Sweden, they need to be better evaluated with regard to growth, maturation and DM yield.

The reduction in milk production when WCCS at early dough stage was fed in study IV needs to be investigated further. Few other studies have shown the same decrease in response to delayed maturity stage at harvest, but discussion with dairy farmers indicate that they have experienced the same thing (a drop in milk fat concentration) when they included high-starch WCCS in the diets of dairy cows. The effect of grass silage digestibility, concentrate level, starch source of concentrate (maize or wheat/barley), digestible fibre content of the concentrate, and mixed or not mixed feed rations are some factors that should be investigated.

At last the use of WCCS in organic milk production needs further evaluation. The grass-clover silage on organic farms often can have a high clover portion and, thus high amounts of soluble protein. Mixing this kind of grass-clover silage with WCCS high in starch can increase the protein utilisation by dairy cows, especially for the lower producing animals that need small amounts of concentrate.

7 Populärvetenskaplig sammanfattning

I denna avhandling presenteras resultat från fyra olika studier som undersökt hur val av sort och mognadsstadium vid skörd påverkar fodervärdet och foderutnyttjandet av helsädsensilage av spannmål.

I studie I genomfördes fältförsök under två år (2003 och 2004) som innefattade sexradskorn (Rolfi), tvåradskorn (Barbro), havre (Cilla och Stork), råg (Amilo och Kaskelot) och rågvete (Fidelio). Alla havre- och kornsorter såddes på våren medan rågen och rågvetet såddes på hösten. Avkastningen av torrsubstans (ts) i fält mättes vid samtliga skördetillfällen (1, 3, 4, 5 och 7 veckor efter axgång). Prover från alla spannmålssorter och skördetidpunkter, utom skörd 7 veckor efter axgång för korn- och havresorterna, analyserades för kemisk sammansättning och smältbarhet. I studie II och III studerades om konsumtionen och smältbarheten av helsädsensilage skiljer sig mellan grödor och skördetidpunkter. I utfodringsförsöket ingick 32 mjölkraskvigor som fick helsädsensilage av havre (Cilla) och sexradskorn (Olsok) skördat vid axgång, tidig mjölkmognad och tidig degmognad, samt tvåradskorn (Pasadena) skördat vid tidig mjölkmognad och tidig degmognad. I studie IV utfodrades helsädsensilage av sexradskorn skördat vid axgång, tidig mjölkmognad och tidig degmognad i fem olika foderstater tillsammans med vallensilage och kraftfoder. Femton mjölkkor ingick i studien och konsumtion, foderstatens smältbarhet och mjölkproduktion mättes.

Avkastningen i fält för de höstsådda grödorna kan bli hög om de har övervintrat bra. I studie I uppnåddes en avkastning på 10 000–16 000 kg ts/ha för råg och rågvete, medan avkastningen för korn och havre som mest låg runt 8 000–10 000 kg ts/ha. Resultat från studie I, II och III visar att korn har ett högre fodervärde än havre eftersom totala fiberhalten, mätt som NDF, är lägre, socker- och stärkelsehalterna är högre och smältbarheten av den organiska substansen och NDF är högre. Både studie II och IV visar dock att även om konsumtionen av helsädsensilage av korn är hög vid axgång så sjunker den för ensilage skördat vid senare mognadsstadier (tidig mjölkmognad och degmognad). För helsädsensilage av havre är konsumtionen däremot hög även vid tidig degmognad. Smältbarheten av organisk substans kan sjunka något mellan axgång och tidig degmognad medan NDF-smältbarheten sjunker med 150-200 g/kg under samma tid. Den ökningen av stärkelsehalten som sker under spannmålens mognadsprocess kompenserar alltså till stor del minskningen av NDF-smältbarheten. Konsekvensen av detta är att vid axgång kommer en stor del av energin i fodret från NDF, medan NDF och stärkelse står för ungefär lika stor del av energin i ensilaget vid tidig degmognad. Detta påverkade mjölkproduktionen i studie IV på så sätt att den höga stärkelsehalten i foderstaten med helsäd skördat vid tidig degmognad minskade både NDF-smältbarheten och den organiska substansens smältbarhet av hela foderstaten. Resultatet blev en minskning i produktionen av kg mjölk och även av halterna av fett och protein i mjölken. Mängden energikorrigerad mjölk var därför 3 kg lägre per dag för kor utfodrade med foderstaten som innehöll korn skördat vid tidig degmognad, jämfört med de som fick foderstaten som innehöll helsäd skördat vid axgång.

Slutsatser från dessa försök är att korn och höstrågvete verkar ha ett bättre fodervärde än havre och råg, när fodervärdet baseras på den kemiska sammansättningen och grödans smältbarhet. Dessvärre verkar det som om korn kan uppfattas som osmakliga av djuren pga. borsten, med sänkt foderintag som påföljd. Att skörda helsäd vid degmognad ger en högre ts-avkastning i fält än vid mjölkmognad, men när ensilaget utfodras till mjölkkor kan mjölkproduktionen påverkas negativt och det är viktigt att tänka på att den totala stärkelsehalten i foderstaten inte blir för hög.

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