Whole-crop maize silage for growing dairy bulls – effects of maturity stage at harvest and feeding strategy

Majsensilage till växande mjölkrastjurar
– effekt av utvecklingsstadium vid skörd och utfodringsstrategi

Sofie Johansson

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Main supervisor: Elisabet Nadeau, Department of Animal Environment and Health, Box 234, 532 23 Skara, Sweden
Co-supervisor: Konstantinos Zaralis, Department of Animal Environment and Health, Box 234, 532 23 Skara, Sweden
Examiner: Anna Hessle, Department of Animal Environment and Health, Box 234, 532 23 Skara, Sweden

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Swedish University of Agricultural Sciences
Faculty of Veterinary Medicine and Animal Science
Department of Animal Environment and Health
Section of Production Systems
Box 234, 532 23 SKARA
E-mail: hmh@slu.se, **Homepage:** www.slu.se/husdjurmiljohalsa

FÖRORD

Detta är ett examensarbete som omfattar 30 högskolepoäng inom agronomprogrammet med husdjursinriktning. Arbetet är en del av ett större projekt som pågår 2009-2012. Projektet finansieras av Stiftelsen Lantbruksforskning, AgroVäst, Sveriges Lantbruksuniversitet och LIFE-fakulteten på Köpenhamns Universitet. Dessutom sponsras projektet av Syngenta Seeds, Nya Fagerås Lantbruk, Addcon, Agroetanol och Lantmännen Lantbruk. Syftet med projektet är att öka kunskapen runt användandet av majsensilage inom den svenska nötköttsproduktionen.

I detta arbete diskuteras det om majsplantans utvecklingsstadium vid skörd och inblandningsnivån av majsensilage i foderstaten påverkar foderintag, tillväxt och slaktkroppsegenskaper hos mjölkrastjurar. I arbetet ingår även en del om foderselektion. Min del av arbetet har bestått i att samla in foderprover samt att analysera foder- och tillväxtdata samt slaktkroppsdata.

Jag vill rikta ett varmt tack till alla som hjälpt mig under projektets gång. Främst vill jag tacka mina handledare; Elisabet Nadeau och Konstantinos Zaralis för stöd och vägledning genom hela arbetet. Jag vill också rikta ett tack till min examinator Anna Hessle och opponent Torbjörn Lundborg, Freja Husdjur, för kompletterande kommentarer på arbetet. Slutligen vill jag också tacka Jonas Dahl, David Johansson och Karin Wallin för god hand med tjurarna och för hjälp med insamling av foderprover.

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Sofie Johansson

SUMMARY

Whole-crop maize silage includes both the stover and the grain components of the maize plant and during the last years there have been increased interests for cultivation of whole-crop maize in areas where forage maize has not earlier been cultivated. The Swedish cultivation of forage maize is mainly limited by the cool weather and short growing season, but new early-maturing varieties have increased the cultivation of forage maize during the last years. The stage of maturity at harvest can affect both the composition of the whole-crop maize silage and also the utilization of the nutrients in the silage. In Sweden, whole-crop maize is often harvested in the beginning to the middle of October, at the dent stage of maturity (30-35% dry matter, DM). In diets for growing cattle, whole-crop maize silage is often fed as a complement to grass or grass-clover silage, mainly because of the different sources of energy that is used by the ruminants. In maize silage, a large proportion of the energy is received from starch if the plant is harvested late, while in grass silage much of the energy is received from other fermentable carbohydrates and proteins. The whole-crop maize is also a good complement to grass-clover silage in the cropping system and during warm and dry years when the grass ley is low yielding, the maize crop is often high yielding.

The aim of the study was to investigate the effects of maturity stage at harvest of whole-crop maize and the dietary inclusion rate of whole-crop maize silage on feed intake, feed utilization, diet selection and carcass characteristics of growing dairy bulls. A total number of 64 growing dairy bulls of Swedish Holstein (n = 49) and Swedish Red (n = 15) breeds were raised from an average initial live weight (LW) of 435 kg (standard deviation 38) to a target LW of approximately 630 kg. The bulls were assigned to 16 groups (four bulls per group) and blocked on the basis of their LW, resulting in eight groups of light bulls and eight groups of heavy bulls. Two groups of light bulls and two groups of heavy bulls (four groups in total) were randomly assigned to each dietary treatment, resulting in 16 bulls per dietary treatment in a randomized block design. The treatments were also balanced for breed.

All bulls were fed a total mixed ration (TMR) composed of ca 60% forage on a DM basis. The forage consisted of whole-crop maize harvested at the dough (26% DM) or at the early dent (35% DM) stage of maturity. The whole-crop maize silage was offered as sole forage or in equal proportion (on DM basis) with grass-clover silage (27% DM). The TMR also consisted of rolled barley, cold-pressed rapeseed cake, dried distiller's grains with solubles, minerals and lime stone. All four diets were formulated to the requirement of an average daily gain of 1.50 kg and balanced for concentrations of metabolizable energy, neutral detergent fibre (NDF), starch, crude protein and forage proportion. The bulls were fed *ad libitum* and their TMR intakes were recorded daily on a pen level. The LWs of the bulls were recorded once every second week and the body condition score once every month in addition to the registrations at start of the experiment and just prior to slaughter. At slaughter carcass weight, conformation score and fatness score were registered.

The whole-crop maize silage as the sole forage in the diet tended to result in both higher live weight gain (LWG, 1.69 vs. 1.56 kg/day; P = 0.10) and higher carcass gain (1.04 vs. 0.95 kg/day; P = 0.05) compared to whole-crop maize silage and grass-clover silage in equal proportions of the forage DM in the ration. This resulted in maize-silage fed bulls reaching the target end point of slaughter 13 days faster than bulls offered equal proportions of maize silage and grass-clover silage in the forage portion of the diet. The higher weight gain is probably an effect of the starch quality in maize silage, as a higher proportion of the starch from maize is degraded more slowly in the rumen, resulting in more starch reaching the small

intestine compared to starch from barley, especially at high intakes. The higher weight gains are important results since a shorter rearing period means fewer days of feeding for maintenance, which may decrease the total amount of feed and the feeding cost. Also the labor cost may decrease.

Whole-crop maize harvested at the dough stage of maturity tended to result in a better feed conversion ratio (6.43 vs. 6.94 kg DM intake/kg LWG; $P = 0.07$) and fatter carcasses (8.2 vs. 7.7; $P = 0.003$) compared to whole-crop maize harvested at the early dent stage of maturity. Dough stage maize when fed as the sole forage in the diet, resulted in higher total DM intake (2.08 vs. 1.94% of LW; $P = 0.08$) and heavier carcasses (336 vs. 328 kg; $P = 0.006$) compared to when offered in equal proportion with grass-clover silage, whereas there was no effect of inclusion rate when fed maize harvested at the dent stage.

All feed rations were balanced for NDF, starch and DM contents, resulting in no or very little confounding effects of these variables on the effect of stage of maturity at harvest on DM intake. There were no effects of stage of maturity of the maize plant at harvest or inclusion rate of maize silage in the diet on diet selection according to feed particle size.

In Sweden, whole-crop maize silage can be a good complement or alternative in feed rations for growing cattle as it can result in increased weight gain and, hence, reduced rearing time.

CONTENTS

INTRODUCTION

Maize has the scientific name *Zea mays L*. and the origin of the species is in Central America (Moore, 2003). Maize stover and grain are important feeds for cattle all over the world (Hallauer, 2004). Whole-crop maize silage includes both the stover and the grain components and during the last years, there have been increased interests for cultivation of whole-crop maize in areas where forage maize has not earlier been cultivated (O'Sullivan *et al.,* 2002). The northernmost cultivation zone for forage maize in Europe is found in the south of Sweden (Detmer *et al.,* 1999). The Swedish cultivation of forage maize is mainly limited by the cool weather and short growing season, but new early-maturing varieties have increased the cultivation of forage maize during the last years (Arnesson *et al.,* 2009).

The stage of maturity at harvest can affect both the composition of the whole-crop maize silage and also the utilization of the nutrients in the silage (Browne *et al.,* 2005a; Nadeau *et al.,* 2010). The maturity stage widely accepted as optimal for harvesting whole-crop maize for silage is ⅔-milk line and a dry matter (DM) content of 30-35% (Bal *et al.,* 1997; Collins & Owens, 2003). The milk line can be seen on the endosperms side of the kernel and as the plant matures the milk line progresses from the tip down towards the base of the kernel. Most of the whole-crop maize in Europe is harvested at a maturity stage of nearly 30% DM (Fernandez *et al.,* 2004). In Sweden, harvest at the dough to dent stage (30-35% DM) is desirable to reduce silage effluent during the ensiling but also to increase the proportion of grain in the plant (Frank *et al.,* 1999; Nadeau *et al.,* 2010). The dough stage of maturity often occurs during the beginning of October and the early dent stage in the middle of October in southern Sweden. Because the farmers want a high DM content and a high proportion of cobs, the harvest may be delayed until after the first frost (Detmer *et al.,* 1999). Delay of the harvest is risky as it may cause bad hygienic quality and low feeding value of the whole-crop maize silage. The short growing season, a choice of an inappropriate hybrid for the area and the weather can, on the other hand, force the farmer to harvest the whole-crop maize at an immature stage in Sweden (Arnesson *et al.,* 2009; Nadeau *et al.,* 2010).

The dietary management is one of the most important production factors affecting animal performance as well as meat quality (O'Sullivan *et al.,* 2002). Whole-crop maize silage is often fed as a complement or alternative to grass silage in diets for beef cattle. In addition, maize silage can be a useful alternative to grass silage to finishing cattle (Browne *et al.,* 2004). Maize and grass silages have different chemical composition and the greatest difference is the source of energy that is used by the ruminants. In maize silage, a large proportion of the energy is received from starch if the plant is harvested late, while in grass silage much of the energy is received from other fermentable carbohydrates and protein. Maize silage is often included in dietary rations to increase the digestible energy levels (Balasko & Nelson, 2003). As whole-crop maize silage contains grain, it also substitutes part of the concentrate proportion in the diet (Keady *et al.,* 2007) and in Northern Europe, whole-crop maize silage is one of the main sources of starch for high-producing dairy cows (Fernandez *et al.,* 2004). Maize is a reliable crop with high energy content and a high intake level (Pahl *et al.,* 1987). As such, it has been deemed a good complement to grass silage in the cropping system on the farm. During warm and dry years when the grass ley is low yielding, the maize crop is often high yielding and, as a consequence, the whole-crop maize is equalizing the risks in the cropping system.

There are only a few research projects on whole-crop maize silage under Swedish conditions and most of those involve dairy cattle. As the cultivation of whole-crop maize in Sweden increases, the interest in the effects of maize silage on performance of growing cattle also increases. For that reason, more research is needed in order to determine the effect of the stage of maturity at harvest on the performance of growing cattle. There also is an interest in evaluating the amount of whole-crop maize silage that can be included in the diet for growing cattle and how this affects the performance of the cattle.

Objectives

The aim of the study was to investigate the effects of maturity stage at harvest of whole-crop maize and the dietary inclusion rate of whole-crop maize silage on intake, feed utilization, live weight gain (LWG) and carcass characteristics of growing dairy bulls. The results will give Swedish farmers a base for making strategic decisions on time of harvest and on the feeding strategy for their growing cattle.

Hypotheses

- Silage produced from whole-crop maize harvested at the early dent stage of maturity results in higher feed intake, more diet selection, improved feed utilization and higher LWG compared to silage produced from whole-crop maize harvested at the dough stage of maturity.

- Silage produced from whole-crop maize harvested at the early dent stage of maturity and fed as sole forage results in the highest feed intake, largest diet selection and highest LWG and carcass fatness.

- Silage produced from whole-crop maize harvested at the dough stage of maturity and fed in equal proportions with grass-clover silage, of the dietary forage DM, results in the smallest diet selection and lowest intake and LWG.

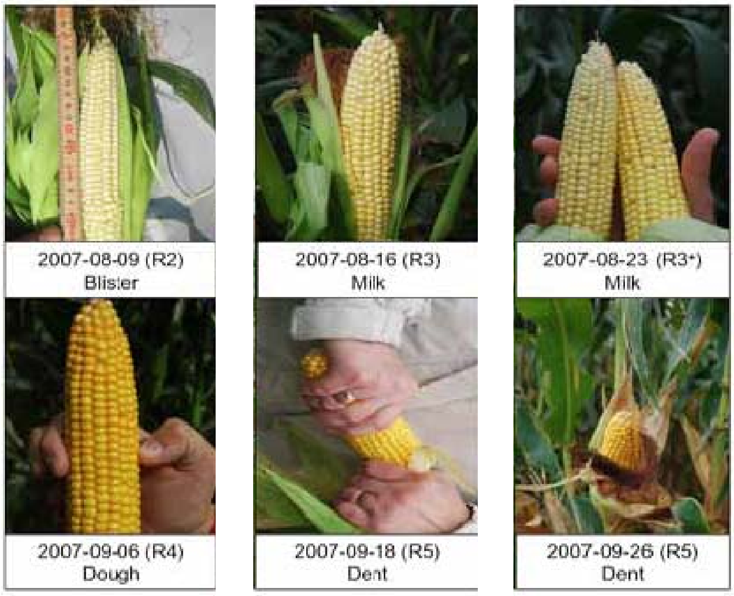
- The whole-crop maize silage as the sole forage in the diet, results in higher intake and LWG compared to a diet containing whole-crop maize silage and grass-clover silage in equal proportions of the forage DM in the ration.

LITERATURE REVIEW

Whole-crop maize harvested at different stages of maturity

The stage of maturity at harvest is a major factor affecting the nutritive value of whole-crop maize silage. After flowering and up until dough stage ripeness, rapid changes of different morphological fractions of the plant occur (Giardini *et al.,* 1976a) and the cob undergoes five different stages of maturity before physiological ripeness; R2-R6 (Swensson *et al.,* 2009; Lantmännen, 2010).

- ***R2*** – blister stage of maturity – white kernels filled with a bright fluid
- ***R3*** – milk stage of maturity – kernels are turning into yellow and filled with a white fluid
- ***R4*** – dough stage of maturity – angular kernels filled with a white and doughy fluid
- ***R5*** – dent stage of maturity – the milkline can be seen on the endosperm side of the kernel and as the plant matures the milkline progresses from the tip down towards the base of the kernel
- ***R6*** – black layer stage of maturity – a dark layer is produced at the base of the kernel



Picture 1. Different maturity stages of the maize cob (Swensson *et al.,* 2009).

The proportion of different plant components influences the chemical composition of the whole-crop maize (Tolera & Sundstøl, 1999). This is affected by the stage of maturity of the crop at harvest. Harvesting too early can result in a low DM yield (Giardini *et al.,* 1976a) and a low DM content of the silage, thus reducing the feed intake and performance of the animals (Hicks & Thomison, 2004). Storage of silage with a low DM content can also result in losses of nutrients from silo run off (McDonald *et al.,* 2002). Bacterial and fungal activity is also higher in wet silage compared to dry silage and DM contents below 30% increase the risk for losses of DM, water-soluble carbohydrates (WSC) and crude protein (CP). Harvesting too late, in the black layer stage of maturity, can in contrast lead to a low nutritive value of the silage because of a poor starch and fibre digestibility (Giardini *et al.,* 1976a). Such silage can have a low palatability, which may restrict the dry matter intake (DMI; McDonald *et al.,* 2002). In addition, late harvesting (for example after frost) can cause problems in fungal activity resulting in heating and bad hygienic quality of the silage. Late harvest, at a high DM content, may also result in heating problems under insufficient packing conditions (Nadeau *et al.,* 2010). There will be a Master thesis published on the effects of maturity stage and additives on the chemical composition, hygienic quality and aerobic stability of maize silage by Emelie Svensson, Department of Animal Environment and Health, Swedish University of Animal Science, Skara.

Chemical composition in different fractions of the maize plant

The maize plant is divided into stover and grain. The stover consists of stalks, leaves and husks and can represent around 50% of total DM content in whole-crop maize silage (Hunt *et al.,* 1992; Balasko & Nelson, 2003). With increasing maturity of the plant, the DM content of the stover proportion increases (Tolera *et al.,* 1998). The stalk has the highest content of lignin, cellulose and hemicellulose and therefore stalk is the most important fraction influencing the chemical composition of the stover (Tolera & Sundstøl, 1999; Masoero *et al.,* 2006). Because of an increasing stalk proportion of the stover the contents of neutral detergent fibre (NDF), hemicellulose, cellulose and lignin increase in the stover with advancing maturity (Tolera *et al.,* 1998; Tolera & Sundstøl, 1999). Contents of CP and ash are especially high in leaves and because the proportion of leaves in the stover decreases with maturity, the contents of ash and CP decrease as the maize plant matures. The proportions of cob, husk and grain increase with ripening and also the starch content in the grain does (Masoero *et al.,* 2006). According to Joanning *et al.* (1981), the grain content can increase from 20% of DM in immature whole-crop maize harvested at milk stage to 46% of DM in mature forage harvested at soft dent stage of maturity. The feeding value of the silage is also affected by the ear (grain and cob) content (Hicks & Thomison, 2004). Silage made from maize plants with no or partly filled ears have only 90-100% of the feeding value, on a DM basis, compared to silage made from well-eared plants (Hicks & Thomison, 2004).

Chemical composition of whole-crop maize

Many studies have reported an increase in DM and starch contents as the maize plant matures from dough stage to black layer stage of maturity (Colovos *et al.,* 1970; Giardini *et al.,* 1976a; Di Marco *et al.,* 2002; Fernandez *et al.,* 2004; Masoero *et al.,* 2006). As maize plants mature, kernels are filled with starch which results in a total increased starch content (Huber *et al.,* 1965). On the other hand, NDF, acid detergent fibre (ADF) and lignin contents often show a declining trend during maize plant ripening (Huber *et al.,* 1965; Gordon *et al.,* 1968; Giardini *et al.,* 1976a; Di Marco *et al.,* 2002; Fernandez *et al.,* 2004). The decline in fibre content and increase in starch content is related to an increased proportion of grain in the plant (Fernandez *et al.,* 2004). The increased grain proportion in mature maize dilutes the fibrous components, resulting in lower contents of NDF and ADF with ripening of the plant (Joanning *et al.,* 1981). The content of NDF is often reported to be 400-450 g/kg DM and the content of starch around 300 g/kg DM (Table 1). Bal *et al.* (1997) found that no further decline in fibre content was detected between the ⅔-milk line stage (35.1% DM) and black layer stage (42.0% DM). This is probably because an increased fibre content of the stover offsets the increased proportion of grain. This was also reported by Browne *et al.* (2004) who found decreasing NDF and ADF contents when DM content increased from 29.1 to 33.9%, but when the DM content increased further, the NDF and ADF content increased. Some studies have also indicated that the lignin content is unaffected by the maturity of the plant at harvest (Gordon *et al.,* 1968; Di Marco *et al.,* 2002).

Table 1. Chemical composition of maize silages harvested at different stages of maturity (g/kg DM, unless stated otherwise)

Harvest date	Location	Stage of maturity	Variety	DM[1] (%)	ME[2] (MJ/kg DM)	GE[3] (MJ/kg DM)	Starch	NDF[4]	ADF[5]	Lignin	CP[6]	References
Sept. 3	Reading,		Hudson	26.7	11.0	18.7	224	499	271	52	74	Browne *et al.*, 2005a
Sept. 19	UK			30.6	11.1	18.7	323	449	243	48	74	
Sept. 24				35.1	10.6	18.6	345	442	237	46	74	
Oct. 6-7			Helix	30.6	-	18.8	291	420	226	-	96	Browne *et al.*, 2005b
Sept. 26			Speedy of	25.7	-	-	195	458	-	-	84	Jensen *et al.,* 2005
Oct. 23			Societe	35.0	-	-	296	401	-	-	89	
Nov. 6			Des Mais	40.3	-	-	334	381	-	-	88	
			Eurorpeens									
Feb. 2	Balcarce,	Silking	Suco®,	20.0	-	-	20	600	360	30	-	Di Marco *et al.,* 2002
March 1	Argentina	Milk stage	Novartis	26.0	-	-	130	550	310	30	-	
March 26		½ milkline		32.0	-	-	280	410	260	30	-	
Aug. 12				31.1	-	-	-	507	317	-	75	Worley *et al.,* 1986
Aug. 27				47.4	-	-	-	545	418	-	75	
Aug. 25		Milk stage	Pioneer	19.9	-	-	75	608	405	-	94	Joanning *et al.,* 1981
Sept. 22		Soft dent	3932A	31.1	-	-	374	449	290	-	76	
	Arlington,	Early dent	4277;	30.1	-	-	182	520	320	33	75	Bal *et al.,* 1997
	Wisconsin,	¼ milkline	Cargill,	32.4	-	-	287	444	271	28	73	
	USA	⅔ milkline	Minneapolis	35.1	-	-	372	405	239	29	71	
		Blacklayer		42.0	-	-	374	413	242	27	70	
		Early	Hudson	29.1	11.1	-	236	440	250	-	80	Browne *et al.,* 2004
		Medium	&	33.9	11.3	-	315	389	221	-	76	
		Late	Advance	39.3	11.3	-	336	398	225	-	75	
	Limagne,	Early	Safrane	24.2	-	-	251	474	278	-	78	Fernandez *et al.,* 2004
	France	Late		31.8	-	-	315	425	234	-	75	

[1]DM = dry matter
[2]ME = metabolisable energy
[3]GE = gross energy
[4]NDF = neutral detergent fibre
[5]ADF = acid detergent fibre
[6]CP = crude protein

The CP content shows a declining trend as the maize plant matures (Colovos *et al.,* 1970; Giardini *et al.,* 1976a; Joanning *et al.,* 1981; Bal *et al.,* 1997; Andrae *et al.,* 2001; Fernandez *et al.,* 2004), but Gordon *et al.* (1968) and Browne *et al.* (2004; 2005a) reported a constant CP content irrespective of the harvest date when maize was harvest between dough stage and full maturity.

The content of metabolizable energy (ME) proves to have an increasing trend as the maize plant matures (Browne *et al.,* 2004), while the gross energy (GE) content has the opposite trend (Browne *et al.,* 2005a). Furthermore, the content of WSC in the whole-crop maize is affected by the harvest date and it is decreasing with increasing plant maturity. In addition, the contents of sugar and ash prove to have a declining trend with increasing maturity of the maize plant at harvest as sugar is converted to starch (Giardini *et al.,* 1976a). Leaves are producing sugar through the photosynthesis and as the plant matures, sugar is transported to the grain, through the stalk (Wilkinson, 1978). The sugar is then stored as starch in the grain. When the maize plant is almost physiologically ripe, the root absorption is ceased and as a result, the content of sugar in the plant is reduced (Giardini *et al.,* 1976a).

Frost effect on the chemical composition of whole-crop maize

The stage of maturity at harvest is a major factor in determining the chemical composition of whole-crop maize. However, the occurrence of frost can also play an important role. In climates with a short growing season, frost can occur before the maize plant has reached the optimum stage of maturity for harvest (Arnesson, *et al.,* 2009). If harvest of the whole-crop maize is delayed until after frost, there would be an increasing risk for decreased nutritive value and palatability of the silage. This was reported by Kwabiah (2005) who harvested maize both before and after frost. The DM content before frost was less than 25%, but after frost the DM content increased up to 33%. The CP content was greatest at the first harvest occasion and declined after frost. In a study by Gordon *et al.* (1968), both the CP and lignin content was unaffected by harvest date. For ADF and NDF the trend was the opposite, the contents were lowest before frost and increased with time (Gordon *et al.,* 1968; Kwabiah, 2005). The increase in fibre content is probably an effect of loss of soft plant tissues, pith of stalks and leaves, which results in an increase of slow decomposable parts. Kwabiah (2005) concluded that a loss in feed quality can be a problem if harvest is delayed until after frost and that the freezing could account for the decreased quality. In general, little or small frost do not cause the described reductions in the nutritive value of the plant in contradiction to large and prolonged frost.

Digestibility of whole-crop maize harvested at different stages of maturity

The digestibility of the silage is of big importance for the animals because it affects feed intake (Masoero *et al.,* 2006). A high digestibility of the components in the silage can increase feed intake and the stage of maturity at harvest is an important factor to determine forage digestibility (Johnson *et al.,* 1999). Compared to other forages, the DM digestibility of whole-crop maize is not reduced with the maturity of the plant (Huber *et al.,* 1965; Collins & Fritz, 2003). This is due to the significant amount of grain in the whole-crop maize. The grain is low in fibre but high in digestible starch, which partially balances the decrease in DM digestibility in the vegetative part of the plant. Because of this, the DM digestibility of the maize crop remains generally constant or slightly increases with advancing maturity of the crop (Giardini *et al.,* 1976a).

Bal *et al.* (1997) reported similar digestibility for DM and organic matter (OM) when whole-crop maize was harvested between early dent stage (30.1% DM) and ⅔-milkline stage (35.1% DM, Table 2). At black layer stage of maturity (42.0% DM) the digestibility of both DM and OM was lower than in younger plants (58 vs. 62% and 60 vs. 64%). Both DM, OM, GE and nitrogen (N) digestibilities were about the same when whole-crop maize was harvested at 27.3 and 31.4% DM (Browne *et al.,* 2005a). Maize harvested at 36.7% DM tended to have lower DM, OM, GE and N digestibilities compared to early harvested maize. This indicates that the digestibility is constant over a range of DM contents, but differs when the DM content exceeds 35%. When whole-crop maize was harvested at 24 and 32% DM there were no effect on total tract digestibility of DM (69%), OM (71%) and NDF (50%) while the digestibility of starch decreased with ripening (from 99.4 to 95.0%; Fernandez *et al.* 2004). Di Marco *et al.* (2002) reported a decline in NDF digestibility when maize plants matured, but it did not affect the DM digestibility because of an equal increase in starch content.

On the other hand, Tolera *et al.* (1998) reported that the degradability of DM declines with maturity. This can be due to a translocation of cell-soluble substances towards grain, resulting in increasing fibre content in the stover. Also Goering *et al.* (1969) found a decrease in the digestibility of DM, energy and CP when DM content of the silage increased from 25% to 45%. In addition, Andrae *et al.* (2001) and Browne *et al.* (2005a) found that total tract digestibilities of DM decreased with maturity. This was an effect of declining starch, NDF and ADF digestibilities. Bal *et al.* (1997) reported decreased digestibilities of CP, starch and ADF between early dent stage and black layer stage of maturity. Total tract digestibilities in maize harvested at different stages of maturity are summarized in Table 2.

The digestibility of whole-crop maize is also affected by the passage of undigested grains, because the kernels become harder and more resistant to physical and chemical breakdown, as the maize crop matures (Browne *et al.,* 2005a). Some studies have indicated that advancing maturity of the plant increases the proportion of starch that is resistant to degradation in the rumen (Cammell *et al.,* 2000; Andrae *et al.,* 2001). This can result in a larger proportion of starch that is bypassing the rumen and instead digested in the small and large intestines (Browne *et al.,* 2004). This can also occur at high feeding levels and is probably due to the fact that starch in maize kernels is more slowly digested in the rumen compared to cereal grains (McDonald *et al.,* 2002). Today, with advanced technology, the kernels can be broken down during harvesting and thus more starch can be available in the feed (Schmidt Detlefsen & Hansson, 2008). A study by Browne *et al.* (2005a) showed that animals could break down the majority of maize kernels during rumination, making use of the starch in the kernels. Jensen *et al.* (2005) reported that, in the fresh crop, the effective degradability of starch in the rumen decreased as maturity increased. On the other hand, after ensiling, the degradability was not altered by stage of maturity. The degradability of starch in the rumen was also higher in the ensiled crop than in the fresh maize crop (Jensen *et al.,* 2005).

Table 2. In vivo total tract digestibility (%) in maize harvested at different stages of maturity

Harvest date	Location	Stage of maturity	Variety	Animal	DM[3] content (%)	DM	OM[4]	GE[5]	Starch	NDF[6]	ADF[7]	CP[8]	References
Sept. 3	Reading,		Hudson	Holstein-	27	70.0	71.5	69.2	99.3	55.5	53.9	-	Browne *et al.,*
Sept. 19	UK			Friesian	31	70.1	71.3	69.5	98.4	50.6	50.2	-	2005a
Sept. 24				steers[1]	35	68.2	69.5	67.5	98.5	47.7	47.0	-	
Oct. 6-7			Helix	Holstein steers[1]	31	70.8	72.6	-	95.5	52.9	48.1	-	Browne *et al.,* 2005b
Sept. 26			Speedy of	Danish	26	-	70.0	-	100.0	56.0	-	-	Jensen *et al.,*
Oct. 23			Societe des	Holstein-	35	-	70.0	-	99.0	51.0	-	-	2005
Nov. 6			Mais Eurorpeens	Friesian cows[2]	40	-	68.0	-	98.0	43.0	-	-	
Sept. 5-7		Soft dough	Wis. 335A	Holstein	24	68.6	-	67.7	-	-	-	56.3	Colovos *et al.,*
Sept. 15		Medium-hard dough		steers[1]	26	69.2	-	68.1	-	-	-	54.7	1970
Sept. 25-27		Early dent			30	67.0	-	65.7	-	-	-	56.3	
Oct. 11		Glazed & frosted			39	66.3	-	65.0	-	-	-	55.0	
Feb. 2	Balcarce,	Silking	Suco®,	Lambs[1]	20	53.0	-	-	-	52.0	-	-	Di Marco *et al.,*
March 1	Argentina	Milk	Novartis		26	53.0	-	-	-	46.0	-	-	2002
March 26		½ milkline			32	53.0	-	-	-	29.0	-	-	
Aug. 25		Milk stage	Pioneer	Hereford	19	68.4	-	69.6	97.8	63.5	59.1	63.4	Joanning *et al.,*
Sept. 22		Soft dent stage	3932A	steers[1]	31	67.2	-	66.0	97.9	48.9	40.8	59.6	1981
		½ milkline	Pioneer 3489	Angus	-	56.5	-	-	97.6	39.1	34.0	-	Andrae *et al.,*
		Black layer	& 3335	steers[2]	-	53.9	-	-	91.1	33.2	26.5	-	2001
	Arlington,	Early dent	4277;	Dairy	30	61.8	65.2	-	94.1	-	45.7	64.9	Bal *et al.,*
	Wisconsin,	¼ milkline	Cargill,	cows[2]	32	62.1	64.9	-	92.9	-	38.3	63.8	1997
	USA	⅔ milkline	Minneapolis		35	61.4	63.8	-	92.2	-	33.6	62.5	
		Black layer			42	58.5	60.4	-	87.7	-	29.4	56.1	
	Limagne,	Early	Safrane	Dairy	24	69.6	71.1	-	99.4	50.6	-	-	Fernandez *et al.,*
	France	Late		cows[1]	32	69.7	71.7	-	95.0	49.3	-	-	2004

[1]*In vivo* with total collection
[2]*In vivo* with marker
[3]DM = dry matter
[4]OM = organic matter
[5]GE = gross energy
[6]NDF = neutral detergent fibre
[7]ADF = acid detergent fibre
[8]CP = crude protein

Effects on diet selection

Whole-crop maize is a heterogeneous crop and the animals can, therefore, select against large and hard particles that are less palatable. Large and hard particles are also more difficult to chew than, for example, the more digestible kernels. Diet selection is expected to occur especially when whole-crop silage is offered *ad libitum* and it should be taken into consideration especially for diets high in starch contents (Wallsten *et al.,* 2009).

Particle size

Limousin bulls (425.9 ± 22 kg) were offered a total mixed ration (TMR) consisting of maize silage (44.9% on DM basis), high moisture maize (16.9%), maize meal (15.2%), soybean meal (13.0%), wheat bran (4.7%) and dried beet pulp (3.5%; Cozzi & Gottardo, 2005). The diet had a DM content of 50.6% and the maize silage a theoretical chop length of 19 mm. Refusal samples taken eight hours after feed distribution showed a chemical and physical composition similar to the TMR delivered, showing no significant selection activity. After 16 hours, there was a selection for particles over eight mm and also a selection for particles over 19 mm, but this selection were not statistically significant. This selection activity, for the more structured particles, was supported by the chemical analysis of the refusals, which showed a significant reduction of NDF and an increase in non-fibrous carbohydrates (NFC) in the refusals. After 17 hours there were no further changes in chemical or physical composition of the refusals. The authors concluded that bulls may select towards more structured particles in order to fulfill the need of sufficient intake of "effective fibre" (Cozzi & Gottardo, 2005).

Silage made from whole-crop cereals is as heterogeneous as whole-crop maize silage and the chemical composition of the plant at harvest affects the quality of the silage in same way as for whole-crop maize. A Swedish study examined the effect of both particle size and maturity stage at harvest of whole-crop barley (Sahlin, 2006). The trial was performed on dairy steers (350 kg) and they were offered four different whole-crop barley silages; harvested at heading and chopped (35.67% DM, 2 cm), harvested at heading and long (37% DM, 70.6 cm), harvested at dough and chopped (41.73% DM, 2 cm) and harvested at dough and long (41.61% DM, 66.1 cm). Each animal also received 0.6 kg of soybean meal/day. At both maturities, sorting was in favor of long particles (> 19 mm) when offered long silages. When fed chopped silages, sorting was in favor of short particles (< 8 mm). The author concluded that there was a tendency for more sorting of chopped silage than of long silage. This was probably due to the easier distribution of the chopped silage in the manger, which made it easier to sort out the sharp awns (Sahlin, 2006).

Chemical composition

Cozzi *et al.* (2005) harvested whole-crop maize silage around ½-milkline and offered it to Limousin bulls (425 ± 20.3 kg). Silages were produced with a theoretical cop length of nine and 19 mm (coarse), respectively. Animals offered nine mm silage was also offered alfalfa hay. All animals received high moisture maize, maize meal, soybean meal, dried beat pulp and wheat bran. All diets were formulated to be isonitrogenous, isofibrous and isocaloric. The silage:concentrate ratio for the coarse silage was 23:68, while it for the other diet was 45:55 on DM basis. Selection indices for CP, NDF and NFC were similar for both diets. This suggests that bulls showed no preference towards specific chemical fractions (Cozzi *et al.,* 2005).

Oat and six-rowed barley were harvested as whole-crop silage at heading (22.6 and 34.7% DM), early milk (25 and 37.4% DM) and early dough (30.7 and 41.1% DM) stage of maturity (Wallsten *et al.,* 2009). Also two-rowed barley were used and harvested at early milk (37.9% DM) and early dough (41.5% DM) stage of maturity. Silages were offered to 32 Swedish Red heifers (244-419 kg) and the diet also included 0.4 kg soybean meal/animal and day. When oat and two-rowed barley, harvested at the early dough stage, were offered, heifers chose to eat part of the silage that had low NDF content (the grain). When six-rowed barley, harvested at the same stage of maturity, was offered, no evidence of selective feeding was observed. The amount of awns is less in two-rowed barley than in six-rowed, which may explain the differences between barley varieties. The authors concluded that diet selection is to be expected and should be taken into considerations when whole-crop cereal silage is offered (Wallsten *et al.,* 2009).

Dairy steers (350 kg) were offered four different whole-crop barley silages; harvested at heading and chopped (36% DM, 2 cm), harvested at heading and long (37.2% DM, 70.6 cm), harvested at dough and chopped (42% DM, 2 cm) and harvested at dough and long (41.6% DM, 66.1 cm; Rustas *et al.,* 2010). Each animal also received 0.6 kg of soybean meal/day. The results indicated that the NDF content in the refusals were significantly higher (98 and 18 g/kg DM) than in the TMR offered for diets containing chopped dough stage silage and long heading stage silage. Furthermore, the starch content in the refusals was significantly lower (84 g/kg DM) than in the TMR for diet containing chopped dough stage silage. This result indicates that the steers were selecting particles low in NDF and high in starch. Steers offered the long dough stage silage had the opportunity to select, but they did not do so. This indicates that ingestion of grains may be restricted in some way, likely by the sharpness of the awns (Rustas *et al.,* 2010).

In a study by Colovos *et al.* (1970), Holstein steers (400 kg) were offered four different whole-crop maize silages. The crop was harvested at soft dough (24% DM), medium dough (27% DM), early dent (32% DM) stage of maturity and after the occurrence of frost (39% DM). Animals were fed urea and cane molasses too. The daily refusals ranged from 5-10% of the weight of the ration but there were only small differences in composition and moisture between the refusals and the silage offered (Colovos *et al.,* 1970).

Effects on animal performance

It is generally accepted that animal performance is largely affected by feed intake. In turn, feed intake is largely dependent on the chemical composition and digestibility of the diet. Therefore, as these parameters are affected by the plant maturity, it is possible that the maturity stage at harvest can affect animal feed intake and thus performance. For beef cattle, advancing crop maturity can have a positive effect on LWG and by that reducing the rearing time (Giardini *et al.* 1976b). On the other hand, very mature maize can reduce LWG and feed conversion ratio (kg DMI/kg LWG) as an effect of reduced intake and reduced nutritional quality of the silage (Chamberlain *et al.,* 1971; Giardini *et al.,* 1976b).

Feed intake

Whole-crop maize was harvested at four different stages of maturity; soft dough (24% DM), medium dough (27% DM), early dent (32% DM) stage of maturity and after the occurrence of frost (39% DM; Colovos *et al.,* 1970). Silages were offered to Holstein steers (400 kg) in combination with a mix of urea and cane molasses (140 g/animal and day). The total DMI was 1.43, 1.70, 1.59 and 1.52 kg/100 kg live weight (LW) for diets containing soft dough, medium dough and early dent maize plus maize harvested after frost. Differences in DMI due to degree of maturity were not statistically significant (Colovos *et al.,* 1970).

Diets containing 90% whole-crop maize silage and 10% concentrate (soybean meal, limestone and trace mineralized salt) were offered to Hereford and Hereford-Angus crossbred steers (250 kg; Joanning *et al.,* 1981). Maize was harvested in milk stage on August 25 (18.1% DM) and in soft dent stage on September 22 (30.9% DM). Diets had a DM content of 24.3 and 36.5%. Differences in intake were not statistically significant (88.8 and 83.9 g silage DM/unit of metabolic LW of milk and soft dough stage silage, respectively) and the feed intake seemed to be bulk-limited in both diets (Joanning *et al.,* 1981).

In another study, whole-crop maize was harvested on September 3 (27.3% DM), 19 (31.4% DM) and 24 (36.7% DM) and ensiled (Browne *et al.,* 2005a). Silages were offered *ad libitum* to Holstein-Friesian steers (352 kg) in combination with 850 g/animal and day of concentrate (soybean meal, rapeseed meal and urea). Diets were formulated to be isonitrogenous. There were no significant differences in total DMI between diets but steers offered diets containing medium silage had a numerically higher DMI than steers offered diets containing early and late maize (9.21 vs.8.28 and 8.88 kg/day, respectively; Browne *et al.,* 2005a).

In a study by Goering *et al.* (1969), Holstein steers (123-281 kg) and Holstein heifers were offered whole-crop maize silage harvested at 24.6, 31.0 and 35.4% DM. All animals had access to bone meal and some of the heifers were offered soybean meal. There were no differences in intake between treatments (1.74 and 1.79% of LW). The experiment was repeated with diet DM contents of 29.8, 40.0 and 45.2% and offered to only Holstein steers (191-245 kg and 284-333 kg). In this trial, the voluntary feed intake was 2.00-2.07% of LW for all steers and unaffected by treatment (Goering *et al.,* 1969).

Andrae *et al.* (2001) reported that there were no significant differences in DMI when Angus steers (322 ± 5.2 kg) were offered maize harvested at two different stages of maturity; ½-milkline (28.4% DM) and blacklayer (42.5% DM). The total DMI was 7.63 kg/day for both diets and the diets contained 60% maize silage and 40% chopped alfalfa (on DM basis; Andrae *et al.,* 2001).

Feed intake, live weight gain, feed conversion ratio and carcass characteristics

Crossbred heifers (Hereford x Angus x Simmental), average initial LW of 239 kg, were offered diets containing 70% maize silage, 20% cracked corn and 7% soybean meal (on diet DM basis; Worley *et al.,* 1986). Whole-crop maize was harvested early, August 12 (31.1% DM) and late, August 27 (47.4% DM). There was no significant effect of harvest date on feed intake (7.79 and 7.82 kg/day for early and late harvested maize, respectively). Harvest date did not significantly affect LWG (1.20 and 1.15 kg/day for early and late harvested maize, respectively; Worley *et al.,* 1986).

Polish Holstein bulls (240 kg) were offered silage from whole-crop maize harvested at milk stage (23.9% DM), dough stage (28.2% DM) and late dough stage (36.9% DM; Giardini *et al.,* 1976b). All animals were offered one kg/animal and day of a protein concentrate, which increased the DM content of the diets to 26.6, 30.8 and 39.8% DM. The total daily DMI was 6.51, 7.15 and 7.49 kg/day for bulls fed milk stage, dough stage and late dough stage maize, respectively. As a consequence of increasing DMI, the LWG also had a linear increase with plant maturity, 0.985, 1.027 and 1.078 kg/day. The feed efficiency decreased with crop maturity, from 6.60 kg DMI/kg LWG (milk stage) to 6.96 kg DMI/kg LWG (dough stage) and 6.95 kg DMI/kg LWG (late dough stage). On the other hand, the dressing percentage increased with crop maturity, from 56.2% for animals fed milk stage maize to 57.2% for bulls fed late dough stage maize (Giardini *et al.,* 1976b). It was not stated in the article if the above described differences were significant or not.

In another study, whole-crop maize silage was harvested at four different stages of maturity; late milk (25.6% DM), early dough (28.7% DM), late dough (30.9% DM) and mealy endosperm (36.9% DM) stage of maturity (Chamberlaine *et al.,* 1971). Silages were offered to heifers (205-227 kg) together with 0.9 kg hay and 0.7 kg cottonseed meal/animal and day. The DMI for heifers offered maize from late milk and mealy endosperm stage of maturity was about the same (5.2 and 5.3 kg/day) and significantly lower than for heifers offered maize from early and late dough stage (5.6 and 5.8 kg/day). The LWG of heifers fed maize silage harvested at late milk, early dough and late dough stage of maturity was similar and significantly higher than of heifers fed maize harvested at mealy endosperm stage of maturity (0.83, 0.86, and 0.81 vs. 0.72 kg/day respectively). There was also a significantly lower DMI requirement/kg of gain for heifers fed early harvested whole-crop maize compared to late harvested maize. Heifers fed silage from maize harvested early (late milk and early dough) had a feed conversion ratio of 6.4 and 6.6 kg DMI/kg gain while heifers fed maize harvested late (late dough and mealy endosperm) had a feed conversion ratio of 7.1 and 7.5 kg DMI/kg gain. On the other hand, there was no significant differences in back fat, loin eye area, length, marbling score or carcass grade due to dietary treatment (Chamberlaine *et al.,* 1971).

According to Browne *et al.* (2004), whole-crop maize harvested with a DM content of 29.1% resulted in a significantly lower total DMI than maize harvested with DM contents of 33.9 and 39.3% (9.39 kg/day vs. 10.61 and 10.48 kg/day). Silages were offered to crossbred (Simmental x Holstein-Friesian) heifers (378 kg) and steers (503 kg) and diets were formulated to be isonitrogenous. All animals were offered a concentrate containing soybean meal, rapeseed meal and food-grade urea. Stage of maturity at harvest did not significantly affect LWG and average LWG for all animals were 1.089-1.094 kg/day. On the other hand, maize maturity stage at harvest affected the feed conversion ratio. Whole-crop maize harvested at 29.1% DM resulted in a significantly better feed conversion ratio than maize harvested at 33.9 and 39.3% DM. Feed conversion ratio was 8.71 vs. 9.99 and 9.84 kg DMI/kg LWG respectively, which equate feed conversion efficiencies of 115, 100 and 102 g LWG/kg DMI. Differences in feed efficiency were probably the result of the different feed intakes. Since forage comprised the majority of the DMI, differences in feed conversion ratio were primarily due to silage DMI. There were no dietary effects on LW at slaughter, carcass weight, killing-out, fatness and conformation. Steers were slaughtered at a minimum LW of 575 kg and heifers at 475 kg, which resulted in an average LW at slaughter for all animals between 535 and 541 kg. The average carcass weight for all animals was 281 to 284 kg. The fat score was 9.3-9.7 and the conformation score 7.5-7.9 as an average for all animals in a 15-point scale (Browne *et al.,* 2004).

High fibre content, reflecting the maturity of the maize plant, is associated with poor digestibility and slow rates of digestion (McDonald *et al.,* 2002). This is related to the filling effect of feeds in the rumen and lowers the DMI (Tjardes *et al.,* 2002a). This is of importance when whole-crop maize silage is offered to beef cattle because the NDF content can vary with maturity of the crop at harvest. In studies by Tjardes *et al.* (2002a; 2002b) the effects of NDF content in whole-crop maize silage on performance by steers was investigated. Holstein steers (198 ± 13 kg) were offered silage containing high fibre and low DM content (567 g NDF/kg DM and 31.0% DM) or silage low in fibre and high in DM (386 g NDF/kg DM and 36.7%

DM; Tjardes *et al.,* 2002a). High fibre silage represented 85.8% in diet DM and the DM content of the diet was 30.3%. For the low fibre silage corresponding numbers were 87.7% in diet DM and 39.3% DM. Diets also contained soybean meal. Animals fed high fibre diets had decreased DMI compared to animals fed diets containing low fibre (4.23 kg/day and 4.92 kg/day, respectively). Similar diets were offered to Holstein (235 ± 15 kg) and Angus (237 ± 13 kg) steers in a study by Tjardes *et al.* (2002b). The DMI decreased with the high fibre diet compared to the low fibre diet in both Holstein (5.85 and 6.76 kg/day) and Angus steers (5.05 and 5.98 kg/day). The decreased DMI with the high fibre diet also resulted in a decreased LWG; 1.03 kg/day compared to 1.25 kg/day for Holstein steers and 0.95 kg/day vs. 1.05 kg/day for Angus steers.

Feeding strategy with whole-crop maize silage

Whole-crop maize silage contains more ME than grass silage, while the grass silage has a higher content of CP than maize silage (Phillips, 2006). This indicates that maize silage can be a good complement in diets for growing cattle. According to Hoving-Bolink *et al.* (1999) and Keady *et al.* (2007), animal performance can be improved when maize silage is included in grass-silage based diets for finishing cattle. Other authors have concluded that replacing grass silage with whole-crop maize silage causes linear responses to the proportion of each forage in the diet (Browne *et al.,* 2005b), which suggests that there is no effect of combining forages. If mixed diets are used, an adjustment of the harvest date of whole-crop maize to the quality of grass silage can be preferred, in order to optimize animal performance (Lantmännen, 2007).

Effects on total diet digestibility

Browne *et al.* (2005b) reported that maize silage often has a higher OM digestibility than grass silage. If grass is harvested early in the season and maize has low starch content, due to immature growth stage at harvest, the opposite response can be observed. This can happen in cool and wet climates. However, the digestibility of NDF in maize silage decreases with advancing maturity. Hence, the higher NDF digestibility of maize silage harvested early counteracts the lower starch content of the crop, resulting in no or only small changes in OM digestibility (Browne *et al.,* 2005a).

In an *in vivo* trial with total collection on crossbred steers (Charolais x Limousin), there were only small differences in DM digestibility between diets containing only grass silage and diets containing both grass and maize silage (Kirkland *et al.,* 2005). The digestibilities of N, NDF and ADF decreased when maize silage was included in the diet. Similar results were found by Browne *et al.* (2005b) and Kirkland & Patterson (2006), who used the same method on steers. In addition, similar results were reported on sheep (*in vivo* with total collection) by Keady *et al.* (2007). In contrast, Browne *et al.* (2005b) and Walsh *et al.* (2008) found a linear increase in DM, OM, energy, starch and total N digestibilities with increasing maize silage inclusions when *in vivo* analyzes where made on steers. For early harvested grass silage, inclusion of maize silage can improve the apparent digestibility of DM, OM, starch and CP in the diet, while the digestibilities of NDF and ADF can decrease (*in vivo* analyze with total collection on Charolais wether sheep; Vranić *et al.,* 2008). For late harvested grass silage, inclusion of maize silage can result in an increased digestibility of all parameters. The digestibility of NDF will decline as a result of increasing lignification of cell walls with increasing maturity of the grass. The positive effect on CP digestibility when maize is included in the diet is probably a result of increased feed intake (Vranić *et al.,* 2008). The higher OM digestibility of diets based on maize silage is probably an effect of a higher starch content of maize silage than grass silage (Browne *et al.,* 2005b). According to Kirkland *et al.* (2006), the quality of the grass silage is the major factor affecting the total diet digestibility both when grass silage is offered alone and in mixtures with whole-crop maize silage.

Effects on animal performance

DMI can be increased by replacing partially or completely the forage grass in the diet with whole-crop maize silage (Aston & Tayler, 1980; Browne *et al.,* 2005b; Kirkland & Patterson*,* 2006; Keady *et al.,* 2007; Vranić *et al.,* 2008; Walsh *et al.,* 2008). This is mainly because whole-crop maize silage has higher DM content than grass silage (Kirkland & Patterson*,* 2006; Keady *et al.,* 2007), but also because it has higher DM digestibility and lower NDF content compared to grass silage (Walsh *et al.,* 2008). Also the final LW and LWG can increase when maize silage is replacing grass silage in the diet, probably as a result of increased DM content of the diet (Forrest, 1982; Forrest & Vanderstoep, 1985; Keady *et al.,* 2007). The lower LWG of animals fed grass silage only is probably due to low DMI in combination with low digestibility of the silage. This is because grass fed animals may spend more time eating and ruminating compared to animals fed whole-crop maize silage only (Walsh *et al.,* 2008). Furthermore, the feed conversion efficiency may be affected by the diet and some studies have indicated that animals fed maize silage only might be more efficient in utilizing energy than animals fed grass silage only (Keady *et al.*, 2007; Walsh *et al.,* 2008). On the other hand, forage type may not significantly affect the carcass conformation, fat classification or dressing percentage (Juniper *et al.,* 2005; Kirkland & Patterson 2006; Keady *et al.,* 2007).

Total DMI increased linearly, from 8.32 kg/day to 9.77 kg/day, as whole-crop maize silage replaced grass silage in the diet for crossbred steers (Simmental x Holstein-Friesian, 424 kg; Juniper *et al.,* 2005). Steers were offered diets containing 100% grass silage, 67% grass:33% maize silage, 33% grass:67% maize silage or 100% maize silage on a DM basis. Each animal also received two kg DM of concentrate daily, consisting of cracked wheat, soybean meal and rapeseed meal. Diets containing high proportions of maize silage (100% or 67% of DM) gave significantly better feed conversion ratios than diets containing grass silage only (7.78, 8.03 vs. 9.12 kg DMI/kg LWG respectively. Furthermore, Juniper *et al.* (2005) showed that both final LW and carcass weight increased linearly with whole-crop maize silage inclusion rate in the diet. Final LW increased from 566 kg to 574 kg, while carcass weight increased from 314.5 to 321.9 kg. The authors concluded that the increased carcass weight was a consequence of better killing-out proportion of cattle on diets containing whole-crop maize silage. The killing-out proportion increased from 55.2% for steers offered grass silage only to 56.5% for steers offered maize silage only, which was significantly different (Juniper *et al.,* 2005).

Walsh *et al.* (2008) showed that crossbred continental steers (424 kg), offered whole-crop maize silage only (9.54 kg DM/day), had significantly higher DMI compared to steers offered grass silage only (7.41 kg DM/day). In addition, steers fed whole-crop maize silage had a significantly better feed conversion efficiency compared to steers fed grass silage only (12.4 kg DMI/kg carcass gain vs. 16 kg DMI/kg carcass gain). As a result, steers offered whole-crop maize silage had significantly higher LWG (1.200 compared to 0.802 kg/day), carcass gain (0.776 compared to 0.479 kg/day) and carcass weight (335 compared to 290 kg) compared to steers fed grass silage only. Steers offered maize silage had an average conformation score of 3.00 (on a 5-point scale) compared to 2.66 for grass silage fed steers, but was not significantly different. On the other hand, there were significant differences in fat score between diets, 3.45 (on a 5-point scale) for maize silage fed steers compared to 3.15 for grass silage fed steers. In this trial, steers were offered grass silage with a DM content of 17.4% and whole-crop maize silage containing 31.5% DM. All steers were also offered three kg of concentrate/animal and day (rolled barley, soybean meal and molasses; Walsh *et al.* 2008).

Continental crossbred steers (523 ± 37.2 kg) were offered ratios containing 100% grass silage (19.2% DM) or 60% grass and 40% maize silage (27.6% DM) on a DM basis (Keady *et al.,* 2007). All steers were also offered three or five kg concentrate/animal and day. The concentrate consisted of barley, maize meal, sugar-beet pulp, soya bean and molasses. Keady *et al.* (2007) reported a significantly increased DMI when steers were offered a mixture of grass and maize silage compared to steers offered grass silage only, 9.08 vs. 8.38 kg DM/day respectively. This resulted in both significantly higher final LW (621 compared to 601 kg) and carcass weight (334 compared to 326 kg) in steers offered a mixed diet compared to steers offered grass silage only. The estimated carcass gain for steers offered a mixed diet was 0.602 kg/day, which was significantly lower in the animals offered grass silage only (0.514 kg/day). Steers offered a mixed diet also had a higher carcass conformation (2.82 vs. 2.75 on a 5-point scale) and higher fat classification (3.77 vs. 3.25 on a 5-point scale), than steers offered grass silage only, but those differences were not significantly different. Inclusion of whole-crop maize silage can also affect the intake of concentrate and the concentrate sparing effect of whole-crop maize silage was more than two kg/animal and day when medium quality grass silage (19.2% DM) was used. This illustrates one of the benefits of including whole-crop maize silage in the forage diet. The producer can maintain animal performance at a lower proportion of concentrate in the diet (Keady *et al.,* 2007).

Also Browne *et al.* (2005b) reported increased forage to concentrate ratio when maize silage was included in the diet. This means that forage contributed to a greater proportion of total digestible energy intake. In this trial, total DMI increased linearly with maize silage inclusion in the diet. The DMI was 7.71, 8.29, 9.06 and 9.54 kg/day for diets containing grass silage only (25.6% DM), 2:1 (27.0% DM) and 1:2 (28.8% DM) of grass and maize silage (on a DM basis) and maize silage only (30.6% DM). Diets were offered to Holstein-Friesian steers (411 ± 20.9 kg) and all diets were formulated to be isonitrogenous. All steers were also offered a concentrate mixture of cracked wheat grain, soybean meal and rapeseed meal (Browne *et al.,* 2005b).

The quality and the DM content of the grass are of major importance for animal performance, either when grass silage is offered alone or in mixtures with whole-crop maize silage. This is mainly illustrated by two similar studies that have been performed by Kirkland *et al.* (2005) and Kirkland & Patterson (2006). In these two studies crossbred steers (Charolais x Limousin, 467 kg) and continental crossbred steers (485 kg) were offered diets containing grass and maize silage of different qualities. In both studies, steers were offered diets containing 100% grass silage, 60% grass and 40% maize silage or 100% maize silage (on a DM basis). All steers were also fed three kg concentrate/animal and day (barley, soybean meal, molassed sugar beet pulp and maize meal). In the study by Kirkland *et al.* (2005) four different grass silages (17.0, 18.8, 26.2 and 25.5% DM) and three different maize silages (25.6, 25.6 and 40.2% DM) were offered. Results indicated that diets containing 100% grass silage with low DM content and low quality gave the lowest DMI (6.93 kg/day). High quality grass silage supplemented with high quality maize silage gave similar DMI as when high quality grass silage was offered alone, 9.67 kg DM/day compared to 10.12 kg DM/day. In mixed diets, maize silage with high DM content gave a higher DMI than diets containing maize silage with low DM content. This was probably due to the DM content and also the digestibility of the

DM. The digestibility of DM increased from 68.9 to 74.5% with increasing DM content of the maize. In contrast, Kirkland & Patterson (2006) concluded that animal intake of mixed diets were similar irrespective of the quality of the maize silage (8.51-9.92 kg DM/day). The intake of mixed diets was also higher than of high quality grass silage alone (9.02 kg/day). A combination of high quality grass and high quality maize silage gave the highest DMI. Diets containing 100% grass silage with low DM content gave the lowest DMI also in this trial (7.72 kg/day). This was probably due to the low DM content and high fibre content in the silage. The total DMI will increase when this type of silage is mixed with whole-crop maize silage. In this study two different grass silages (25.1 and 30.4% DM) and two different maize silages (24.6 and 39.4% DM) were used. Authors of both trials concluded that even when maize silage is included with 40% in the diet, the nutritive value of the grass silage is the key factor affecting total DMI (Kirkland *et al.,* 2005; Kirkland & Patterson, 2006). Kirkland & Patterson (2006) concluded that the feed conversion ratio is not influenced by inclusion of maize silage in the diet and all steers had a feed conversion ratio between 7.6 and 8.5 kg DMI/kg daily LWG. The quality of grass silage significantly affected LW at slaughter and carcass weight. Steers offered high quality grass silage only or in combination with maize silage had higher LW at slaughter and carcass weight (average 599 and 327 kg) than steers offered low quality grass silage only or in combination with maize silage (average 574 and 310 kg). Inclusion of maize silage had no significant effect on LW at slaughter and carcass weight. Steers offered diets with high quality grass silage had significantly higher carcass gain than animals offered low quality grass silage, no matter of the quality of the maize silage (0.858-0.907 kg/day and 0.683-0.715 kg/day respectively). Steers offered high quality grass silage only had higher carcass gain than steers offered low quality grass silage only, 0.808 and 0.699 kg/day respectively. The forage type had no significant effect on carcass conformation and inclusion of maize silage had no effect on fat classification. The fat classification was, however, significantly affected by the quality of the grass silage and steers offered high quality grass silage only or in combination with maize silage, had significantly higher carcass fat class (3.2-3.4 on a 5-point scale) than steers offered diets with low quality grass silage (2.5-3.1; Kirkland & Patterson (2006).

Heifers fed maize silage alone had a significantly higher DMI than heifers fed grass silage only, 9.5 compared to 7.8 kg/day (O'Kiely & Moloney, 2000). On the other hand, compared to maize silage only, there were no significant improvement when grass and maize silage were offered in a mixture (50% grass and 50% maize silage), 9.4 kg/day. LWG increased when whole-crop maize silage was included in the diet in contrast to animals fed on grass silage only, which had the lowest daily LWG, 0.846 kg/day. Animals fed maize silage only had a LWG of around 0.979 kg/day and this was significantly higher than that of animals offered a mixed diet (around 0.950 kg/day). On the other hand, there was no significant difference in feed conversion ratio. Heifers fed grass silage only had a feed conversion ratio of 9.4 kg DMI/kg LWG compared to 9.9 and 10.2 kg DMI/kg LWG for heifers offered maize silage only and a mixed diet. Heifers fed grass silage only had significantly lower LW at slaughter than heifers fed maize silage only or a mixed diet, 589 kg compared to 609 and 604 kg. The same pattern was observed for carcass weight, 324 kg compared to 338 and 330 kg for grass silage only, maize silage only and the mixed diets. Heifers fed maize silage alone had a significantly higher carcass growth rate than heifers fed grass silage only (0.737 vs. 0.653 kg/day, respectively). There was no significant difference in carcass growth rate when grass and maize silage were offered in a mixture (0.698 kg/day). Furthermore, there were no significant differences in carcass conformation between heifers offered grass silage only (2.9), maize silage only (2.9) or a mixed diet (2.9). In contrast, heifers offered diets containing maize silage (only and in a mixture) had significantly fatter carcasses than animals offered grass silage only (4.5 and 4.6 vs. 4.1). This trial was performed on Charolais crossbred heifers (443 kg) and they were offered three different maize silages alone or in mixture with grass silage. Grass silage had a DM content of 18% and maize silages 25.6, 29.7 and 37.5% DM. All heifers were also fed three kg of concentrate/animal and day. The concentrate consisted of barley, soybean meal, citrus pulp and molasses (O'Kiely & Moloney, 2000).

In a study with crossbred (Piemontese x Holstein-Friesian) heifers, Hoving-Bolink *et al.* (1999) found that whole-crop maize silage had significant effects on LWG. Heifers fed on 100% maize silage diet had a significant higher daily LWG (0.876 kg/day) than heifers offered the mixed diet and grass silage diet (0.700 and 0.698 kg/day, respectively). As a result, these heifers reached the slaughter end point 33 days faster than heifers fed the mixed diet and 16 days faster than heifers fed grass silage only. Final LW and carcass weight for heifers fed maize silage were 543 and 298 kg. This means that maize fed heifers were significantly heavier than heifers fed grass silage only (522 and 283 kg) or a mix of grass and maize silage (528 and 287 kg). The study also indicated that maize fed heifers had the significantly best carcass conformation (< R-) compared to heifers fed grass silage and mixed diets (> O+). Maize fed heifers were also significantly fatter (> 3+) compared to heifers fed mixed diet (< 3+) and grass diet (< 3; Hoving-Bolink *et al.,* 1999).

Crossbred bulls (South Devon x British Friesian, 432 kg) were offered maize silage or grass silage in combination with zero, five or ten g barley DM/kg LW daily (Aston & Tayler, 1980). Significant more whole-crop maize silage than grass silage was eaten when silages were offered alone. In the mixed diets of grass and maize silages, animals offered maize silage also had a higher DMI than animals offered grass silage. Furthermore, the LWG was higher for bulls offered maize silage compared to grass silage, 1.26 vs. 0.95 kg/day on average. In contrast, there were no significant differences in carcass conformation (3.2 for maize silage compared to 2.9 for grass silage) and fat score (2.1 compared to 2.0) according to diet (Aston & Tayler, 1980).

Marbling and fat colour

The effects of feeding maize silage on marbling score and fat colour in growing beef cattle has also been investigated. Some studies, Kirkland & Patterson (2006) and Keady *et al.* (2007), found no dietary effects, while Moloney *et al.* (1999), Juniper *et al.* (2005) and Walsh *et al.* (2008) reported that animals fed diets containing whole-crop maize silage had a whiter fat than animals fed grass silage only. Also Hoving-Bolink *et al.* (1999) showed that meat from crossbred (Piemontese x Holstein-Friesian) heifers fed on maize silage was lighter and more tender than meat produced by heifers fed on grass silage or mixed diets. In addition, Forrest (1982) and Forrest & Vanderstoep (1985) reported that Hereford steers fed on maize silage had whiter fat than animals fed on grass silage. Maize fed steers had also lower marbling score than those fed on grass silage. This result can be explained by the large proportion of grain in the whole-crop maize silage. Grains contain less amounts of carotene than grass and the yellow colour of fat from cattle offered grass silage is a result of an accumulation of carotenoids in the fat (Yang *et al.,* 1992).

The colour saturation (colour intensity) is affected by dietary treatments and a diet with 100% whole-crop maize silage gives the lowest colour saturation (Juniper *et al.,* 2005). O'Sullivan *et al.* (2002) found that Charolais crossbred heifers fed grass silage had the greatest colour stability, while heifers fed maize silage had the lowest level of colour stability. Walsh *et al.* (2008) found that muscle fat brightness and muscle yellowness in continental crossbred steers were not affected by the type of the diet. In addition, there were no differences in sensory perception of the meat quality (Moloney *et al.,* 1999) and no differences were reported in aroma, juiciness and tenderness between dietary treatments with maize silage (Hoving-Bolink *et al.,* 1999; Juniper *et al.,* 2005).

The lipid oxidation in meat is affected by the level of α-tocopherol (vitamin E) and an increasing amount of α-tocopherol delays the lipid oxidation (O'Sullivan *et al.,* 2002). Maize silage has lower concentration of α-tocopherol compared to grass silage and therefore, this can be reflected in the α-tocopherol content of the meat, when those forages are fed to growing animals. Meat produced by Charolais crossbred heifers fed on maize silage had a low content of α-tocopherol, and therefore the meat was characterized by a high level of lipid oxidation. In contrast, meat produced by heifers fed on grass silage had a high content of α-tocopherol and thus the lowest level of lipid oxidation (O'Sullivan *et al.,* 2002).

Fatty acid composition

The fatty acid composition of silages can be reflected also in the fatty acid profile of the meat (O'Sullivan *et al.,* 2002). Grass silage contains higher amounts of the fatty acid 18:3 (linolenic acid) than maize silage does. Maize silage, on the other hand, has high content of the fatty acids 18:1 (oleic acid) and 18:2 (linoleic acid). Subsequently, meat produced from animals fed on maize silage can have significantly lower content of 18:3 compared to the meat produced from animals fed on a 50:50 grass:maize silage diet or on a 100% grass silage diet (O'Sullivan *et al.,* 2002).

MATERIALS AND METHODS

Animals and housing

In this experiment, bulls were raised from an average initial LW of 435 kg (standard deviation 38) to a target LW of approximately 630 kg. A total number of 64 growing dairy bulls of Swedish Holstein (n = 49) and Swedish Red (n = 15) breeds were used. The bulls were housed in an insulated barn with, in total, 16 slatted floor pens and remained housed until the end of the experiment. The study took place during the winter of 2009-2010 at the Götala Research Centre of the Swedish University of Agricultural Sciences in Skara, Sweden, after approval of the experimental procedures by the Research Animal Ethics Committee (Swedish Animal Welfare Agency).

Experimental design

The animals were brought indoors approximately ten weeks prior to the start of the experiment in order to adapt to experimental conditions and diets. During the adaptation period, all animals were fed increasing amounts of maize silage and when the inclusion rate of the maize silage reached 75% of forage DM, the animals were allocated to four dietary treatments (Table 3). The bulls were adapted to the treatments for two weeks before the experiment started on December 16, 2009. Prior to the start of the experiment, the bulls were first assigned to 16 groups (four bulls per group) and blocked on the basis of their LW (registered prior to the start of the adaptation period, 2009), resulting in eight groups of light bulls and eight groups of heavy bulls (Table 3). At the time of the allocation to the treatments, two groups of light bulls and two groups of heavy bulls (four groups in total) were randomly assigned to each treatment resulting in 16 bulls per dietary treatment in a randomized block design. As not all the pens had the same floor type (but varied among concrete slats, rubber slats or rubber mats), the groups of four bulls each were allocated to the pens in order for all the treatments to have the same number of animal groups on the same floor type. The treatments were also balanced for breed. The experiment lasted from December 2009 to June 2010, with one intensive collection period in January-February and one in March-April (see Registrations and sample collection). Each intense collection period was divided into four sub periods (four days each) and during each of these sub periods, 16 bulls in four different pens (one per treatment) were studied.

Table 3. Average live weight (LW, kg) and body condition score (BCS) for 64 growing dairy bulls at the beginning of the experiment, standard deviation within parenthesis

Treatment	***n***	**Average group LW**				**Average treatment LW**	**Average treatment BCS**
		Heavy 1	Heavy 2	Light 1	Light 2		
Dough 50[1]	16	454 (20)	460 (42)	409 (48)	408 (26)	433 (41)	3.03 (0.39)
Dough 100[2]	16	467 (24)	462 (23)	409 (32)	408 (9)	436 (36)	3.13 (0.47)
Early dent 50[3]	16	463 (16)	462 (44)	402 (15)	400 (20)	433 (39)	2.98 (0.46)
Early dent 100[4]	16	479 (6)	465 (24)	409 (28)	409 (16)	441 (38)	3.16 (0.40)

[1]50% dough stage maize and 50 % grass of the dietary forage portion
[2]100% dough stage maize of the dietary forage portion
[3]50% early dent stage maize and 50% grass of the dietary forage portion
[4]100% early dent stage maize of the dietary forage portion

Silages and diets

Whole-crop maize silage

Seeds of the early-maturing cultivar Avenir was sown on April 28, 2009 and harvested at two different stages of maturity during the autumn, at the dough stage (September 15th) and at the early dent stage of maturity (October 13th) at Götala Research Centre outside Skara, Sweden. The whole-crop maize was precision chopped to a theoretical length of cut of 14 mm and treated with two litres per ton of fresh herbage of the chemical additive Kofasil Maize N® (sodium benzoate and potassium sorbate; Addcon Europe, GmbH, Bonn Germany). During the second harvest, at early dent stage of maturity, a corn-cracker was used to allow processing of the cob and kernels (Schmidt Detlefsen & Hansson, 2008). The chopped maize was pressed into big round bales and wrapped with eight layers of plastic film. See Table 4 for the chemical composition of the fresh herbages and silages of whole-crop maize. Hygienic qualities of silages are shown in Table 5 and the particle size distribution in Table 6. A composited sample from each harvest was used for analysis of the chemical composition of fresh herbage. For the silages before start of the experiment, a composited sample from two bales was used for each harvest date.

Table 4. Chemical composition of fresh herbages and silages of whole-crop maize (n = 1)

	Dough stage		**Early dent stage**	
	Maize herbage	Maize silage	Maize herbage	Maize silage
DM[1] (%)	25	26	34	35
Ash (g/kg DM)	48	52	36	45
OM[2] disappearance (%)	93	88	88	91
ME[3] (MJ/kg DM)	11.1	11.0	11.2	11.3
Crude protein (g/kg DM)	86	79	72	80
EPD[4] (%)	65	65	65	65
AAT[5] (g/kg DM)	80	80	81	81
PBV[6] (g/kg DM)	-61	-66	-73	-67
Crude fat[7] (g/kg DM)	20	20	20	20
Starch (g/kg DM)	235	196	361	381
Sugar (g/kg DM)	128	37	38	33
NDF[8] (g/kg DM)	383	422	376	352
INDF[9] (g/kg NDF)	141	141	260	260
Calcium (g/kg DM)	2.5	2.2	1.3	1.5
Phosphorous (g/kg DM)	2.6	2.6	2.2	2.5
Magnesium (g/kg DM)	1.0	1.0	0.8	0.9
Potassium (g/kg DM)	12.8	12.2	8.2	8.5
Sulfurous (g/kg DM)	1.1	0.9	0.8	0.8
Sodium (g/kg DM)	< 0.5	0.5	< 0.5	< 0.5

[1]DM = dry matter
[2]OM = organic matter
[3]ME = metabolisable energy
[4]EPD = effective protein degradability in rumen (tabulated value)
[5]AAT = amino acids absorbed in the small intestine (tabulated value)
[6]PBV = protein balance in the rumen (amount of protein degraded in rumen – amount of microbial protein synthesized in rumen) (tabulated value)
[7]tabulated value
[8]NDF = neutral detergent fibre
[9]INDF = indigestible NDF (NIR)

Table 5. Hygienic quality of experimental silages (n = 1)

	Maize silage dough stage	**Maize silage early dent stage**	**Grass-clover silage**
pH	3.9	4.5	4.4
NH_3-N (% of total N)	9.3	6.5	10.0
Lactic acid (g/kg DM)	146	32	91
Acetic acid (g/kg DM)	22	11	16
Butyric acid (g/kg DM)	< 0	< 0	1
Propionic acid (g/kg DM)	< 0	< 0	< 0
Ethanol (g/kg DM)	4	4	4

Table 6. Particle size distribution of silages (%) and standard deviation within parenthesis (n = 4)

	Maize silage dough stage	**Maize silage early dent stage**	**Grass-clover silage**
Top sieve (30 mm)	15.7 (15.5)	5.2 (6.5)	90.5 (1.5)
Upper sieve (19 mm)	32.2 (14.3)	19.2 (9.2)	4.5 (0.8)
Middle sieve (7.9 mm)	48.6 (21.7)	65.0 (7.0)	4.2 (0.6)
Lower sieve (1.8 mm)	3.5 (3.5)	10.6 (10.4)	0.81 (0.5)
Bottom pan	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)

Grass-clover silage and concentrates

The grass-clover ley was harvested as a third cut in 2008 and consisted of timothy, meadow fescue and red clover. The crop was wilted to around 30% DM, precision chopped to a theoretical length of cut of 20 mm and ensiled in a bunker silo with the acidic additive Promyr NT® (formic acid, propionic acid and salts of organic acids, Perstorp Inc., Perstorp, Sweden). See Table 7 for chemical composition of the grass-clover silage. The hygienic quality of the grass-clover silage is shown in Table 5 and the particle size distribution in Table 6.

The concentrates were rolled barley, cold-pressed rapeseed cake and dried distiller's grains with solubles. Chemical composition of the concentrates is shown in Table 8. For the dried distiller's grains with solubles, the content of acid detergent insoluble nitrogen was 21% of total N.

Table 7. Chemical composition of grass-clover silage (n = 1)

	Grass-clover silage
DM[1] (%)	27
Ash (g/kg DM)	88
OM[2] disappearance (%)	87
ME[3] (MJ/kg DM)	10.9
Crude protein (g/kg DM)	167
EPD[4] (%)	80
AAT[5](g/kg DM)	71
PBV[6] (g/kg DM)	51
Crude fat[7] (g/kg DM)	20
Sugar (g/kg DM)	46
NDF[8] (g/kg DM)	464
Calcium (g/kg DM)	6.8
Phosphorous (g/kg DM)	3.0
Magnesium (g/kg DM)	1.9
Potassium (g/kg DM)	27.4
Sulfurous (g/kg DM)	3.0
Sodium (g/kg DM)	1.1

[1]DM = dry matter
[2]OM = organic matter
[3]ME = metabolisable energy
[4]EPD = effective protein degradability in rumen (tabulated value)
[5]AAT = amino acids absorbed in the small intestine (tabulated value)
[6]PBV = protein balance in the rumen (amount of protein degraded in rumen – amount of microbial protein synthesized in rumen) (tabulated value)
[7]tabulated value
[8]NDF = neutral detergent fibre

Table 8. Chemical composition of the concentrates (n = 1)

	Barley	Cold-pressed rapeseed cake	Dried distiller's grains with solubles
DM[1] (%)	86	92	91
Ash (g/kg DM)	26	62	47
ME[2] (MJ/kg DM)	13.3	15.9	13.8
Crude protein (g/kg DM)	119	330	279
AAT[3] (g/kg DM)	93	90	87
PBV[4] (g/kg DM)	-33	193	217
Crude fat[5] (g/kg DM)	29	180	73
Starch (g/kg DM)	611	65	72
NDF[6] (g/kg DM)	189	190	359
Calcium (g/kg DM)	0.6	8.0	1.2
Phosphorous (g/kg DM)	4.9	13.3	11.1
Magnesium (g/kg DM)	1.7	5.8	3.7
Potassium (g/kg DM)	5.5	12.2	11.1
Sodium (g/kg DM)	-	< 0.2	2.2

[1]DM = dry matter
[2]ME = metabolisable energy
[3]AAT = amino acids absorbed in the small intestine (tabulated value)
[4]PBV = protein balance in the rumen (amount of protein degraded in rumen – amount of microbial protein synthesized in rumen) (tabulated value)
[5]tabulated value
[6]NDF = neutral detergent fibre

Total mixed ration

All bulls were fed a TMR composed of ca 60% forage on a DM basis. The forage consisted of whole-crop maize harvested at the dough or at the early dent stage of maturity with or without inclusion of grass-clover silage (in total four treatments, Table 9). All bulls were also fed minerals and lime stone on top of the mix. The animals were feed *ad libitum* on a pen level and the amounts offered were based on 105-110% of the average intake during the previous three days. The diets were formulated to the requirement of an average daily gain of 1.50 kg. The four diets were balanced for forage proportion and concentrations of ME, NDF, starch and CP. See Table 10 for composition of the experimental diets.

Table 9. Ingredients in the experimental diets (kg DM/animal and day)

	Experimental Diets			
	Dough 50[1]	Dough 100[2]	Early dent 50[3]	Early dent 100[4]
Grass-clover silage	3.8	-	3.8	-
Maize silage (dough stage)	3.8	7.6	-	-
Maize silage (early dent stage)	-	-	3.8	7.6
Barley	4.6	2.8	4.1	2.4
Dried distiller's grains with solubles	0.5	1.4	0.5	1.4
Cold pressed rapeseed cake	0.1	0.7	0.1	0.7
Minerals	0.1	0.1	0.1	0.1
Total	12.9	12.6	12.4	12.2

[1]50% dough stage maize and 50 % grass of the dietary forage portion
[2]100% dough stage maize of the dietary forage portion
[3]50% early dent stage maize and 50% grass of the dietary forage portion
[4]100% early dent stage maize of the dietary forage portion

Table 10. Composition of the experimental diets

	Experimental Diets			
	Dough 50[1]	Dough 100[2]	Early dent 50[3]	Early dent 100[4]
Forage proportion (% of DM[5])	59	60	61	62
Feed DM (% of LW[6])	2.4	2.4	2.4	2.3
Forage DM (% of LW)	1.4	1.4	1.4	1.4
ME[7] (MJ/kg DM)	11.8	12.0	11.8	12.1
NDF[8] (g/kg DM)	327	315	327	308
NDF (% of LW)	0.8	0.8	0.8	0.7
Starch (g/kg DM)	279	262	322	365
Crude protein (g/kg DM)	127	123	128	124
Crude fat (g/kg DM)	26	38	26	38

[1]50% dough stage maize and 50 % grass of the dietary forage portion
[2]100% dough stage maize of the dietary forage portion
[3]50% early dent stage maize and 50% grass of the dietary forage portion
[4]100% early dent stage maize of the dietary forage portion
[5]DM = dry matter
[6]LW = live weight
[7]ME = metabolisable energy
[8]NDF = neutral detergent fibre

Registrations and sample collection

The whole finishing period

Feed samples

The amounts of offered TMR were recorded daily on a pen level and the amounts of refusals were recorded three times a week in order to allow calculation of feed intake. One sample of each of the three silages was collected daily and composited to one sample per week in order to determine DM concentration and to calculate DMI. The amount of silage in the TMR was adjusted weekly according to changes in silage DM concentration.

Live weight and body condition score

The LWs of the bulls were recorded on two consecutive days at the beginning of the experiment and just prior to slaughter of the animals at the end of the experiment. During the experiment, the LWs of the bulls were recorded once every second week. The bulls were scored for body condition (BCS, Edmonson *et al.*, 1989) at start of the experiment, once every month and prior to slaughter.

Intensive collection periods

During the two intensive periods, when the bulls averaged 500 kg and 600 kg LW, the amounts of refusals were recorded every morning. Samples of silages, TMR and refusals were taken every day and analyzed for DM content. The daily samples were also composited to one sample per four-day sub period and analyzed for chemical composition and particle size. Samples of the concentrates were taken every new sub period for later analysis of DM and chemical composition.

Analysis of dry matter and chemical composition

To determine the DM content of silages, 200 g of each sample were dried at 60°C for 24 hours, whereas the DM concentration of concentrates were analyzed at 105°C for 24 hours. Analyses of the chemical composition of silages and concentrates conducted before the start of the experiment and shown in tables earlier in the material and method section of this thesis were conducted with conventional methods.

Particle size

Particle size distribution in silages, TMR and refusals was estimated by using the Penn State Particle Separator (Heinrichs & Kononoff, 2002). Approximately 0.473 liters of silage, TMR and refusals were sieved in a Penn State Particle Separator with four different sieves according to the instructions by Heinrichs & Kononoff (2002). The sieves had a pore size of 30 mm, 19 mm, 7.9 mm and 1.8 mm. The top sieve with a pore size of 30 mm was an additional sieve to the Penn State Particle Separator. Diet selection was estimated by comparing particle size distribution in TMR with the particle size distribution in refusals.

Carcass characteristics

The bulls were slaughtered in a commercial abattoir in Skövde at a target LW of around 630 kg. Carcass weight, conformation score and fatness score were registered. The bulls were graded according to the conformation and fatness scores described by the European Union Carcass Schemes (EUROP) modified by the Swedish system in which 15 classes are used (Jordbruksverket, 2004). The EUROP classes were transformed to numerical figures for both conformation (1 = P-, poorest and 15 = E+, best) and fatness (1 = 1-, leanest and 15 = 5+, fattest). Dressing percentage was calculated by dividing the carcass weight with the LW at slaughter. In order to calculate carcass gain, dressing percentage at the beginning of the trial was estimated to be the same as in the study by Hessle *et al.* (2007).

Statistical analyses

Data regarding feed intake and feed conversion ratio were recorded on a pen level and analysed by using the GLM procedure in SAS (SAS system for Windows, release 9.1, SAS Institute Inc., Cary, NC, USA). The statistical model was as follows:

$$Y_{ijkl} = \mu + M_i + I_j + MI_{ij} + B_{k(ij)} + e_{ijkl}$$

where $\mathbf{Y_{ijkl}}$ = observed response, $\boldsymbol{\mu}$ = overall mean, $\mathbf{M_i}$ = effect of maturity stage at harvest (i = 1 to 2), $\mathbf{I_j}$ = effect of dietary inclusion rate of maize silage (j = 1 to 2), $\mathbf{MI_{ij}}$ = interaction between stage of maturity and inclusion rate, $\mathbf{B_{k(ij)}}$ = effect of block within maturity stage and inclusion rate (k = 1 to 2 in light and heavy steers) and $\mathbf{e_{ijkl}}$ = residual error.

LW, BCS, number of days to slaughter, LWG, carcass gain and carcass traits were recorded on each individual animal nested within treatment and block and analysed by using the Mixed procedure of SAS. The statistical model was as follows:

$$Y_{ijklm} = \mu + M_i + I_j + MI_{ij} + B_{k(ij)} + P_{ijkl} + e_{ijklm}$$

where $\mathbf{Y_{ijklm}}$ = observed response, $\boldsymbol{\mu}$ = overall mean, $\mathbf{M_i}$ = effect of maturity stage at harvest (i = 1 to 2), $\mathbf{I_j}$ = effect of dietary inclusion rate of maize silage (j = 1 to 2), $\mathbf{MI_{ij}}$ = interaction between stage of maturity and inclusion rate, $\mathbf{B_{k(ij)}}$ = effect of block within maturity stage and inclusion rate (k = 1 to 2 in light and heavy steers), $\mathbf{P_{ijkl}}$ = effect of pen within block, maturity stage and inclusion rate (l = 1 to 2) and $\mathbf{e_{ijklm}}$ = residual error.

Effects were declared significant at $P \leq 0.05$ and as a tendency to significance at $0.05 < P \leq 0.10$ in the *F* - test. Pair-wise comparisons between treatment means, shown as least square means, were performed with Tukey´s t-test and declared significant at $P \leq 0.05$ and as a tendency to significance at $0.05 < P \leq 0.10$.

Further observations

As this thesis is part of a larger experiment, there were some measurements done during the trial that will not be a part of this thesis. Those measurements are left out since this thesis will be equivalent to 30 credits. For example, all bulls were video recorded during the two intensive periods in order to identify eating and ruminating times. During the intensive periods, faecal samples were taken twice every day (morning and afternoon). The faeces was determined for consistency, DM content, number of undigested/partly digested kernels and number of long particles (> 10 mm). This was done in order to evaluate the effects of dietary treatments on rumen function. Samples of silages, TMR and refusals were collected during the experiment and analysed for chemical composition.

RESULTS

Feed intake

Both total DMI and silage DMI in percentage of LW tended to be affected by the interaction between stage of maturity at harvest and inclusion rate of maize silage in the diet (Table 11). Bulls offered 50% maize harvested at the dough stage of maturity had 7% lower DMI in percentage of LW compared to bulls offered 100% maize harvested at the same stage of maturity, whereas there was no effect of inclusion rate when fed maize silage at the early dent stage. Likewise, silage DMI as percentage of LW was 8% lower for the diet containing 50% dough maize of the dietary forage portion compared to the other three diets, which did not differ in silage DMI.

Silage DMI expressed both as kg DM/day and in percentage of LW was affected by stage of maturity at harvest, when averaged over inclusion rates (Table 11). Bulls offered whole-crop maize silage made from maize harvested at the early dent stage of maturity had 7% higher silage DMI, when expressed as kg DM/day (6.84 vs. 6.40 kg DM/day) and 7% higher silage DMI, when expressed in percentage of LW (1.28 vs. 1.20% of LW), compared to bulls offered silage made from maize harvested at the dough stage of maturity.

The inclusion rate of whole-crop maize silage in the diet affected silage DMI in percentage of LW and bulls offered 100% maize silage had 5% higher silage DMI compared to bulls offered 50% maize silage of the dietary forage portion, when averaged across maturity stages (Table 11). Also, bulls offered 100% maize silage had 5% higher silage DMI in kg DM/day (6.77 vs. 6.47 kg DM/day) compared to bulls offered 50% maize silage of the forage portion in the diet.

Feed conversion ratio

Stage of maturity at harvest tended to have a significant effect on the feed conversion ratio (Table 11). Bulls offered maize harvested at the dough stage of maturity tended to have better feed conversion ratio compared to bulls offered maize harvested at the early dent stage of maturity (6.43 vs. 6.94 kg DMI/kg LWG) as a mean over maize silage inclusion rates. The difference between maturity stages was 7%.

Table 11. Effect of stage of maturity at harvest (H) and inclusion rate of whole-crop maize silage in the forage portion of the diet (I) on feed intake and feed conversion ratio of growing dairy bulls (n = 4)

	Dough stage		**Early dent stage**			**Interaction**	**Main effects**	
	50% maize silage	100% maize silage	50% maize silage	100% maize silage	**SEM**	H * I	H	I
Total feed intake (kg DM[1]/day)	10.38	10.99	10.85	10.97	0.24	NS	NS	NS
Silage intake (kg DM/day	6.18	6.62	6.77	6.92	0.14	NS	**	T
Total DM intake (% of LW[2])	1.94^{b}	2.08^{a}	2.05^{ab}	2.04^{ab}	0.04	T	NS	NS
Silage DM intake (% of LW)	1.15^{b}	1.25^{a}	1.28^{a}	1.29^{a}	0.02	T	**	*
Feed conversion ratio (kg DMI/kg LWG[3])	6.56	6.31	7.07	6.81	0.26	NS	T	NS

SEM = Standard Error of the Mean
NS = Non Significance at $P > 0.10$
T = Tendency to significance at $0.05 < P \leq 0.10$
* Significance at $P \leq 0.05$
** Significance at $P \leq 0.01$
[a,b]Least square means in a row with different superscripts differ significantly at $P < 0.10$
[1]DM = dry matter
[2]LW = live weight
[3]kg DM intake/kg live weight gain

Particle size distribution of total mixed rations and refusals

Standard deviations for most of the treatments were large resulting in no differences in particle size distribution between TMR and refusals for both sizes of the bulls. Diets containing both grass and maize silage had a higher proportion of long particles (> 19 mm) in both TMR and refusals compared to diets containing maize silage only (Tables 12 and 13).

The TMR and refusals containing 100% maize silage had their highest proportion of particles retained on the middle sieve, whereas particles in TMR and refusals containing both grass and maize silage were more evenly distributed between the upper, middle and lower sieves. There was a higher percentage of particles on the middle sieve from diets containing 100% maize silage compared to diets containing 50% maize silage of the forage portion in the diet (Tables 12 and 13).

Table 12. Percentages (standard deviation within parenthesis) of particles in total mixed ration (TMR) and refusals retained on different sieves of the four diets averaged over four sub periods for bulls around 500 kg (n=4)

	Dough 50[1]		**Dough 100**[2]		**Early dent 50**[3]		**Early dent 100**[4]	
	TMR	Refusals	TMR	Refusals	TMR	Refusals	TMR	Refusals
Top sieve	50.6	55.5	13.0	4.8	36.9	55.5	4.1	1.1
(30 mm)	(18.3)	(9.7)	(17.7)	(1.9)	(23.4)	(8.1)	(6.7)	(0.3)
Upper sieve	16.8	19.3	17.0	34.7	20.4	16.8	9.9	7.8
(19 mm)	(6.4)	(6.5)	(7.3)	(16.3)	(7.9)	(3.6)	(8.9)	(2.8)
Middle sieve	22.0	17.5	58.8	52.7	26.1	18.0	62.4	63.6
(7.9 mm)	(8.8)	(4.4)	(14.7)	(12.2)	(10.2)	(3.3)	(6.7)	(3.8)
Lower sieve	10.6	7.8	11.2	7.8	16.3	9.6	22.8	27.1
(1.8 mm)	(3.6)	(1.9)	(6.2)	(7.2)	(5.9)	(1.5)	(10.6)	(6.5)
Bottom pan	0.07	0.00	0.05	0.00	0.21	0.08	0.71	0.35
	(0.1)	(0.0)	(0.1)	(0.0)	(0.3)	(0.2)	(0.8)	(0.1)

[1]50% dough stage maize and 50% grass of the dietary forage portion
[2]100% dough stage maize of the dietary forage portion
[3]50% early dent stage maize and 50% grass of the dietary forage portion
[4]100% early dent stage maize of the dietary forage portion

Table 13. Percentages (standard deviation within parenthesis) of particles in total mixed ration (TMR) and refusals retained on different sieves of the four diets averaged over four sub periods for bulls around 600 kg (n=4)

	Dough 50[1]		**Dough 100**[2]		**Early dent 50**[3]		**Early dent 100**[4]	
	TMR	Refusals	TMR	Refusals	TMR	Refusals	TMR	Refusals
Top sieve	1.9	4.9	0.25	0.59	3.0	4.7	0.41	0.66
(30 mm)	(0.7)	(2.5)	(0.7)	(0.2)	(1.0)	(2.1)	(0.3)	(1.4)
Upper sieve	34.0	33.4	7.3	17.7	26.3	31.8	3.1	4.1
(19 mm)	(15.5)	(2.8)	(2.2)	(6.0)	(2.7)	(7.2)	(0.8)	(1.1)
Middle sieve	27.3	37.4	60.9	57.4	38.8	35.8	50.2	50.0
(7.9 mm)	(27.6)	(1.6)	(1.6)	(2.4)	(2.2)	(3.2)	(3.7)	(2.3)
Lower sieve	36.2	23.6	31.0	24.2	30.2	26.3	40.6	39.7
(1.8 mm)	(11.1)	(3.7)	(2.6)	(4.8)	(1.6)	(4.5)	(1.5)	(3.1)
Bottom pan	0.71	0.65	0.51	0.18	1.7	1.4	5.7	5.5
	(0.7)	(0.3)	(0.5)	(0.2)	(0.3)	(0.8)	(2.4)	(1.2)

[1]50% dough stage maize and 50% grass of the dietary forage portion
[2]100% dough stage maize of the dietary forage portion
[3]50% early dent stage maize and 50% grass of the dietary forage portion
[4]100% early dent stage maize of the dietary forage portion

Live weight gain and carcass gain

Both LWG (1.69 vs. 1.56 kg/day) and carcass weight gain (1.04 vs. 0.95 kg/day) tended to be higher for bulls fed 100% maize silage compared to bulls fed 50% maize silage of the dietary forage portion, when averaged across maturity stages (Table 14). Differences between treatments were 8 and 9% for LWG and carcass weight gain, respectively. In addition, bulls offered 100% maize silage tended to reach the target LW for slaughter 13 days earlier than bulls offered 50% maize silage of the forage portion in the diet (120 vs. 133 days). No differences in BCS were found between treatments.

Carcass characteristics

The interaction between stage of maturity at harvest and inclusion rate of maize silage in the diet had a significant effect on the carcass weight. Bulls offered 100% maize harvested at the dough stage of maturity had 3% higher carcass weight compared to bulls offered diets containing 50% maize harvested at the dough stage and 100% maize harvested at the early dent stage of maturity.

Dressing percentage and carcass conformation did not differ between treatments. The fatness score was significantly affected by stage of maturity at harvest and bulls offered maize harvested at the dough stage of maturity had 6% higher fatness score compared to bulls offered silage made from maize harvested at the early dent stage of maturity, when averaged across inclusion rate of maize silage in the diet (8.2 vs. 7.7).

Table 14. Effect of stage of maturity at harvest (H) and inclusion rate of whole-crop maize silage in the forage portion of the diet (I) on growth rate, body condition score (BCS) and carcass characteristics of growing dairy bulls (n = 16 except for 50% early dent maize silage treatment, where n = 15)

	Dough stage		**Early dent stage**			**Interaction**	**Main effects**	
	50% maize silage	100% maize silage	50% maize silage	100% maize silage	**SEM**	H * I	H	I
No of days to slaughter	131	119	137	121	5.9	NS	NS	T
Live weight gain (kg/day)	1.59	1.75	1.54	1.63	0.07	NS	NS	T
Carcass weight gain (kg/day)	0.97	1.09	0.94	0.99	0.04	NS	NS	T
Final live weight (kg)	635	643	641	634	3.1	*	NS	NS
Final BCS	3.63	3.53	3.50	3.44	0.12	NS	NS	NS
BCS change	0.59	0.41	0.52	0.28	0.13	NS	NS	NS
Mean BCS	3.27	3.24	3.20	3.26	0.07	NS	NS	NS
Dressing percentage (%)	51.7	52.2	51.7	51.6	0.25	NS	NS	NS
Carcass weight (kg)	328^{b}	336^{a}	331^{ab}	327^{b}	1.67	**	NS	NS
Conformation[1]	4.94	4.94	4.72	5.13	0.29	NS	NS	NS
Fatness[2]	8.19	8.25	7.72	7.75	0.13	NS	**	NS

SEM = Standard Error of the Mean
NS = Non Significance at $P > 0.10$
T = Tendency to significance at $0.05 < P \leq 0.10$
*Significance at $P \leq 0.05$
**Significance at $P \leq 0.01$
[a, b]Least square means in a row with different superscripts differ significantly at $P \leq 0.05$
[1]EUROP-system, 4 = O-, 5 = O, 6 = O+
[2]EUROP-system, 7 = 3-, 8 = 3, 9 = 3+

DISCUSSION

Feed intake

Total DMI was unaffected by the stage of maturity at harvest, inclusion rate of maize silage in the diet and interaction between harvest stage and inclusion rate. However, total DMI tended to be affected by the interaction between harvest stage and inclusion rate of maize silage in the forage portion of the diet when expressed in percentage of LW. Feeding 100% maize silage resulted in a higher DMI as percentage of LW compared to feeding 50% maize silage of the dietary forage portion, when the maize was harvested at the dough stage of maturity, whereas no effect of inclusion rate was found when fed maize harvested at the early dent stage of maturity.

Total DMI was unaffected by stage of maturity at harvest, while bulls offered maize harvested at the early dent stage had a significantly higher silage DMI compared to bulls offered maize harvested at the dough stage of maturity. This is probably an effect of diet formulation as diets containing maize harvested at the early dent stage had a higher proportion of forage compared to diets containing maize harvested at the dough stage of maturity (62 vs. 60%). Chamberlaine *et al.* (1971) reported that animals offered maize harvested at 26 and 37% DM had a significantly lower DMI compared to animals offered maize harvested at 29 and 31% DM. This indicates that a DM content of around 30% could be optimal to maximize the total DMI, but on the other hand, Browne *et al.* (2004) found that DMI increased with plant maturity (29, 34 vs. 39% DM). There are also a number of studies indicating that DMI is unaffected by stage of maturity at harvest (Goering *et al.,* 1969; Colovos *et al.,* 1970; Joanning *et al.,* 1981; Worley *et al.,* 1986; Andrae *et al.,* 2001; Browne *et al.,* 2005a).

In the present study, all diets were balanced for DM, NDF and starch contents resulting in no effect of stage of maturity at harvest on total DMI. The DM content of all TMR was around 40% and highest for diets containing 100% early dent maize. For that reason, the effect of different DM contents in maize silages of different maturity stages on total DMI can be excluded. There were only small differences in NDF (422 vs. 352 g/kg DM) content, but large differences in INDF (141 vs. 260 g/kg NDF) content between maize silages. Those differences did not affect the DMI of the bulls as differences between silages were balanced in the diet formulation and all diets had an NDF content of 308-327 g/kg DM. There was also a large difference in starch content between maize silages (196 vs. 381 g/kg DM) but there was an attempt to balance for starch in the diet. The diets differed, though, in starch from 270 g/kg DM for the dough stage maize silage diets to 343 g/kg DM for the dent stage maize silage diets. However, this difference in starch content between diets did not affect DMI.

A number of studies have indicated that total DMI is increasing linearly with increasing amount of maize silage in the diet (Juniper *et al.,* 2005; Browne *et al.,* 2005b; Keady *et al.,* 2007; Walsh *et al.,* 2008) probably as a consequence of higher DM content in the diet. This is not in agreement with the present study, where total DMI was unaffected by inclusion rate of maize silage in the diet, when averaged across maturity stages. However, there was a tendency for higher total DMI in percentage of LW when whole-crop maize, harvested at the dough stage of maturity (26% DM), was offered alone compared to when offered in an equal proportion with grass-clover silage. The unaffected DMI might be an effect of good quality grass silage, as grass silage in the present study had a relatively high DM content and also good chemical composition compared to grass silages in other studies. Kirkland *et al.* (2005) and Kirkland & Patterson (2006) concluded that even when maize silage was included with

40% in the diet, the nutritive value of the grass silage was the key factor affecting total DMI. The quality of the grass silage might be the key factor also when maize silage is included with 50% in the diet. On the other hand, O´Kiely & Moloney (2000) found similar results as in the present study even if the grass silage had a DM content of only 18%. The digestibility is of importance and maize harvested late has a high amount of INDF and need, therefore to be supplemented with grass-clover silage of high NDF digestibility when offered in mixed rations to improve DMI.

Particle size distribution of total mixed rations and refusals

The standard deviations for most of the treatments were large, resulting in no difference in particle size distribution between TMR and refusals. This indicates that bulls were not selecting according to particle size. This is in agreement with Cozzi & Gottardo (2005) who found no selection activity within the first eight hours after feeding. After 16 hours there was a selection activity, although not statistically significant. This difference indicates, though, that maize silage fed bulls may select different particles. Whole-crop maize silage is as heterogeneous as whole-crop cereal silage and diet selection is expected to occur when whole-crop cereal silage is offered *ad libitum* according to Wallsten *et al.* (2009). The authors also concluded that animals were selecting against large and hard particles that were less palatable, but this was not seen in the present study.

TMR and refusals containing both maize and grass silage had a higher proportion of particles over 19 mm compared to TMR and refusals containing maize silage only. This was probably due to the longer particle size of the grass silage compared to the maize silage. As already mentioned, bulls were not selecting according to particle size even if they had the opportunity. Sahlin (2006) concluded that there was more sorting of chopped whole-crop cereal silage (two cm) compared to long silage (70.6 cm). Since the particle size differed between silages a similar tendency could be expected to be seen also in the present trial but it did not occur.

Live weight gain and carcass gain

Both LWG and carcass weight gain tended to be higher for bulls offered 100% maize silage compared to bulls offered only 50% maize silage, when averaged across maturity stages at harvest. As a consequence, bulls offered 100% maize silage tended to reach the target LW for slaughter earlier than bulls offered 50% maize silage. A shorter finishing period means fewer days of feeding for maintenance, which decreases the total amount of feed, the feeding cost and also the labor cost. These are important results for Swedish farmers, since the total economy on the farm may be improved with diets containing 100% whole-crop maize silage compared to grass silage based diets.

The tendency to higher weight gain of the bulls offered 100% maize silage could be due to the source of starch in the diet. In 100% maize silage diets, the highest proportion of starch is derived from maize and a less proportion from barley, but this is not the case in the 50% maize silage diets as the amount of starch derived from maize is much less. Maize kernels are more slowly digested in the rumen compared to cereal grains (McDonald *et al.,* 2002). At high feed intakes as in this experiment, this can result in a higher amount of starch that is bypassing the rumen and instead digested and absorbed in the small intestine (Browne *et al*., 2004), which can increase the weight gain.

There are some studies indicating that both LWG (1.20 and 1.26 vs. 0.80 and 0.95 kg/day) and carcass weight gain (0.479 vs. 0.776 kg/day) are increasing when grass silage is completely replaced by maize silage in diets for crossbred bulls (South Devon x British Friesian) and crossbred continental steers (Aston & Tayler, 1980; Walsh *et al.,* 2008). Furthermore, there are only a few studies demonstrating increasing carcass weight gain when grass silage is partly replaced by maize silage in diets for continental crossbred steers (0.514 vs. 0.602 kg/day; Keady *et al.,* 2007). O´Kiely & Moloney (2000) found that carcass weight gain was similar for heifers (Charolais crossbred) offered a mixed diet and heifers offered maize silage only (0.698 and 0.737 kg/day). However, Hoving-Bolink *et al.* (1999) concluded that crossbred (Piemontese x Holstein-Friesian) heifers fed a mixed diet had lower LWG compared to heifers offered 100% maize silage (0.700 vs. 0.876 kg/day). These studies indicate that the largest improvements in weight gain occur when a 100% grass silage diet is replaced by a mixed or 100% maize silage diet. Differences between mixed diets and 100% maize silage diets are smaller. This is not in agreement with the present study were a 100% maize silage diet tended to give a higher weight gain compared to a mixed diet. In addition, Kirkland & Patterson (2006) found that the quality of the grass silage was of large importance for the weight gain when maize and grass silage was offered in a mixture. The quality of the maize silage was of less importance. This may indicate that the grass-clover silage used in the present study was of moderate quality and therefore bulls did not achieve the same weight gain as those on the diets containing 100% maize silage. A mixed diet with even better quality of the grass may have given the same weight gain as diets containing 100% maize silage of the forage portion. To really investigate the maize silage effect on weight gain it would be interesting to compare a 100% grass silage diet with the present diets and also to compare different qualities of grass silages in the mixed diets.

Neither LWG, nor carcass weight gain were affected by stage of maturity of the maize plant at harvest. This is in agreement with other literature who has concluded a LWG of 1.089-1.094 kg/day (Simmental x Holstein-Friesian heifers; Browne *et al.,* 2004) and 1.15-1.20 kg/day (Hereford x Angus x Simmental heifers; Worley *et al.,* 1986) irrespectively of stage of maturity at harvest. Also Chamberlaine *et al.* (1970) found that LWG of heifers offered maize harvested at late milk (26% DM), early dough (29% DM), and late dough (31% DM) stage of maturity were similar (0.81-0.86 kg/day) but higher than of heifers offered maize harvested at the mealy endosperm stage of maturity (37% DM, 0.72 kg/day). Giardini *et al.* (1976b) concluded the opposite and LWG increased linearly with increasing plant maturity (24-37 % DM; 0.985-1.078 kg/day) when offered to Polish Holstein bulls. All those results indicate that weight gain is most probably unaffected by stage of maturity of the maize plant at harvest but that it might be affected if the maize is harvested late at a DM content above 35%.

Over all, the weight gain is quite high in the present study, which might be a consequence of compensatory growth. The bulls had a low LWG in the summer before the start of the present study, which might have influenced the weight gain in the present study. On the other hand, bulls were brought indoor and fed TMR *ad libitum* with increasing maize silage inclusion rates for ten weeks prior to the start of the experiment, which probably levelled out the effect of the earlier slow growth rates.

Feed conversion ratio

Feed conversion ratio tended to be affected by stage of maturity at harvest and bulls offered maize harvested at the dough stage of maturity had a better feed conversion ratio than bulls offered maize harvested at early dent stage of maturity, when averaged across inclusion rates of maize silage. This is in agreement with Chamberlaine *et al.* (1971), Giardini *et al.* (1976b) and Browne *et al.* (2004) who found less efficient feed conversion ratios with advancing crop maturity. Browne *et al.* (2004) concluded that the improved feed conversion ratio was an effect of lower silage DMI as all animals had a similar daily LWG. Also Chamberlaine *et al.* (1971) concluded that the DMI probably was the main effect on the feed conversion ratio since DMI increased with increasing crop maturity at harvest up until mealy endosperm stage of maturity while LWG was unaffected. At the mealy endosperm stage of maturity, both the DMI and LWG decreased.

Carcass characteristics

Fatness score was significantly affected by stage of maturity of the maize plant at harvest and maize harvested at dough stage resulted in fatter carcasses compared to maize harvested at the early dent stage. These results are difficult to explain but might be an effect of higher LWG, LW at slaughter, carcass weight and dressing percentage. These parameters are not significant different between treatments, although there are numerically differences. Results from the present study are not in agreement with other literature, where carcass characteristics, in terms of dressing percentage, carcass fatness score and carcass conformation score, were unaffected by stage of maturity of the maize plant at harvest (Chamberlaine *et al.,* 1971; Browne *et al.,* 2004). According to Giardini *et al.* (1976b), dressing percentage increased with increasing plant maturity, from 56.2% to 57.2% when maize were harvested between milk stage (24% DM) and late dough stage (37% DM). This type of difference did not occur in the present study.

Inclusion rate of maize silage in the diet did not affect any of the carcass traits, which also have been concluded by others (Aston & Taylor 1980; O´Kiely & Moloney 2000; Keady *et al.,* 2007). On the other hand, both Hoving-Bolink *et al.* (1999) and Walsh *et al.* (2008) concluded that animals offered maize silage as the only forage had fatter carcasses compared to animals offered a mixed diet or grass silage only. Furthermore, Walsh *et al.* (2008) concluded that carcass conformation were unaffected by diet, whereas Hoving-Bolink *et al.* (1999) found that maize fed animals had better carcass conformation compared to animals offered a mixed diet.

CONCLUSIONS

- The whole-crop maize silage as the sole forage in the diet, tended to result in 8% higher LWG, 9% higher carcass weight gain and 13 days less to slaughter compared to a diet containing whole-crop maize silage and grass-clover silage in equal proportions of the forage DM in the ration. In addition, there was a tendency for 7% higher DMI by bulls fed 100% compared to 50% maize silage of the dietary forage portion, when the maize was harvested at the dough stage of maturity.

- Silage produced from whole-crop maize harvested at the dough stage of maturity tended to give a 7% better feed conversion ratio and 6% fatter carcasses compared to silage made from maize harvested at the early dent stage of maturity.

- Stage of maturity of the maize plant at harvest and inclusion rate of whole-crop maize silage in the diet did not affect diet selection according to particle size.

- When the rations are balanced for NDF and starch contents and have similar DM contents, as in the present study, there will be no or very little confounding effects of these variables on the effect of maturity stage at harvest on intake.

SAMMANFATTNING

Vid skörd av majs till helsädesensilage ingår majsplantans alla delar och under senare år har intresset för odling av grovfodermajs ökat i områden där denna typ av odling inte har förekommit tidigare. Den svenska odlingen av majs till ensilage begränsas i första hand av det kalla klimatet och den korta växtsäsongen, men nya majssorter med tidig mognad har ökat odlingen av majs under de senaste åren. Majsplantans utvecklingsstadium vid skörd kan påverka både ensilagets näringsmässiga kvalitet, men också djurens utnyttjande av näringsämnen. I Sverige skördas grovfodermajs oftast i början till mitten av oktober, vid mjölmognad (30-35 % torrsubstans, ts). I foderstater till växande ungnöt ingår ofta majsensilage som ett komplement till gräs- eller gräs- klöverensilage och detta främst på grund av de olika energikällorna i de olika grovfodertyperna. Energin i majsensilage kommer till stor del från stärkelse om majsen är sent skördad. I gräs- klöverensilage kommer istället en stor del av energin från andra smältbara kolhydrater och protein. Majsensilage är också ett bra komplement till gräs- och klövervallen i växtodlingen, eftersom majsen oftast är högavkastande under de torra år då vallen kan ha en lägre avkastning.

Syftet med studien var att utreda om foderintag, foderutnyttjande, foderselektion och slaktkroppsegenskaper hos växande mjölkrastjurar påverkas av majsplantans utvecklingsstadium vid skörd och inblandningsnivån av majsensilage i foderstaten. Totalt användes 64 växande mjölkrastjurar av raserna Holstein (n = 49) och SRB (n = 15) i studien. Tjurarna föddes upp från en medelvikt av 435 kg (standardavvikelse 38) till en målvikt runt 630 kg. Tjurarna var uppdelade i 16 grupper (fyra tjurar per grupp) och grupperade med utgångspunkt på levande vikt, vilket resulterade i åtta grupper med lätta djur och åtta grupper med tunga djur. Två grupper av lätta djur och två grupper av tunga djur (totalt fyra grupper) var sedan slumpmässigt fördelade på de olika behandlingarna, vilket resulterade i 16 tjurar per behandling i en randomiserad blockdesign. Fördelningen av djur mellan behandlingarna var också balanserad med avseende på tjurarnas ras.

Alla tjurar utfodrades med fullfoder (total mixed ration, TMR) bestående av ca 60 % grovfoder på ts-basis. Grovfodret bestod av majs skördad vid degmognad (26 % ts) eller tidig mjölmognad (35 % ts). Majsensilaget utfodrades som enda grovfoder eller i lika proportion (på ts-basis) med gräs- klöverensilage (27 % ts). Fullfodret bestod även av korn, kallpressad rapskaka, agrodrank, mineraler och kalk. De fyra foderstaterna var beräknade för att uppfylla näringsbehovet för en daglig tillväxt på 1,50 kg och foderstaterna var även balanserade för innehåll av omsättbar energi, NDF (neutral detergent fibre), stärkelse, råprotein och grovfoderandel. Tjurarna utfodrades *ad libitum* och konsumtionen av fullfoder registrerades dagligen på boxnivå. Tjurarna vägdes varannan vecka medan hullet bedömdes en gång i månaden. Båda egenskaperna registrerades även innan försökets början samt innan slakt. I samband med slakt registrerades även slaktkroppsvikt, formklass och fettklass.

Majsensilage utfodrat som enda grovfoder resulterade i högre daglig tillväxt (1,69 vs. 1,56 kg/dag; P = 0,10) och högre slaktkroppstillväxt (1,04 vs. 0,95 kg/dag; P = 0.05) jämfört med då majsensilage och gräsensilage utgjorde lika stora delar (på ts-basis) av grovfodergivan. Detta resulterade i att de majsutfodrade tjurarna uppnådde slaktmognad 13 dagar tidigare än de tjurar som utfodrades med lika delar majs- och gräsensilage (på ts-basis). Den högre tillväxten är troligen en effekt av stärkelsekvaliteten i majsensilage. Detta eftersom majsstärkelse bryts ner långsammare i vommen jämfört med stärkelsen i korn, speciellt vid större foderintag. Detta leder till en större andel stärkelse som smälts och absorberas i tunntarmen. De högre tillväxterna är viktiga resultat eftersom de resulterar i en kortare

uppfödningstid. Detta innebär i sin tur att djuren inte behöver utfodras i så många dagar, vilket minskar foderåtgången och foderkostnaden. Dessutom kan arbetskostanden minska något.

Majs skördad vid degmognad gav bättre foderomvandlingsförmåga (6,43 vs. 6,94 kg ts foder/kg tillväxt; P = 0,07) och fetare slaktkroppar (8,2 vs. 7,7; P = 0,003) jämfört med då majsen skördades vid tidig mjölmognad. Majs skördad vid degmognad och utfodrad som enda grovfoder, resulterade i högre totalt dagligt ts-intag (2,08 vs. 1,94 % av levande vikten; P = 0,08) och tyngre slaktkroppar (336 vs. 328 kg; P = 0,006) jämfört med då majs- och gräsensilage utgjorde lika stora delar av grovfodergivan. Däremot fanns det ingen effekt av inblandningsnivån då tjurarna utfodrades med majs skördad vid tidig mjölmognad.

Alla foderstater var balanserade för innehåll av NDF, stärkelse och i viss mån ts-halt. Detta medförde att dessa variabler inte eller endast till en liten del påverkade effekt av utvecklingsstadium vid skörd på det totala foderintaget. I denna studie fanns ingen effekt av majsplantans utvecklingsstadium vid skörd eller andelen majsensilage i foderstaten på tjurarnas foderselektion när selektionen bedömdes utifrån partikelstorleksfördelningen av fodret.

Majsensilage kan vara ett bra komplement eller alternativ till gräs- klöverensilage i foderstater till växande ungnöt i Sverige. Detta eftersom den dagliga tillväxten kan öka och därmed minska uppfödningstiden.

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Faculty of Veterinary Medicine and Animal Science
Department of Animal Environment and Health
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Phone: +46 (0)511 67000
E-mail: hmh@slu.se
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