MTT SCIENCE 1

Concentrate feeding strategies for growing and finishing dairy bulls offered grass silage-based diets

Doctoral Dissertation

Arto Huuskonen

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Concentrate feeding strategies for growing and finishing dairy bulls offered grass silage-based diets

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Abstract

Beef production in Finland is based mainly on raising dairy bulls born on dairy farms. Because the supply of domestic beef has been decreasing during recent years, there is nowadays a clear discrepancy between the demand for and supply of domestic beef. Consequently, slaughterhouse pricing favours heavy carcasses, and the average carcass weights of animals have clearly increased in Finland. The prices of the concentrate feeds can vary dramatically, so it would be valuable to obtain information on the performance of dairy bulls slaughtered at heavy carcass weights when they are fed different concentrate levels and different concentrate components.

The first aim of this thesis was to produce data for evaluating, developing and recommending biologically and economically efficient energy and protein feeding strategies for growing and finishing dairy bulls offered grass silage-based diets and slaughtered at carcass weights above 300 kg. The second aim was to calculate the energy and protein supplies of the dairy bulls fed different grass silage-cereal-based diets and, based on this, to estimate the possible need to revise the current Finnish energy and protein recommendations for growing dairy bulls. The third aim was to demonstrate the P supply of dairy bulls fed grass silage-cereal-based diets with or without protein supplementation in relation to current feeding recommendations for P.

The objectives of the first experiment were to determine the effects on animal performance in various growth periods of (1) the proportion of concentrate in the diet, and (2) the inclusion of rapeseed meal (RSM) in the barley-based concentrate in total mixed ration feeding. The three concentrate proportions were 300, 500 and 700 g/kg dry matter (DM), fed without RSM or with RSM. The live weight gain (LWG) and carcass fat score of the bulls increased linearly with increasing concentrate proportion. Rapeseed meal did not affect animal performance. In order to determine the optimum proportion of concentrate supplementation, estimates of carcass efficiency (kg concentrates per kg carcass), silage substituted (kg DM per kg carcass gain) and true price of concentrates relative to that of forages are required.

The objective of the second experiment was to study the effects of partial replacement of barley grain with barley fibre (BF) on animal performance of dairy bulls. There were four diets with two offered at stage 1 (from initiation of the study to 450 kg live weight) and four at stage 2 (from 450 kg live weight to slaughter). The control diet (BF0) included grass silage (460 g/kg DM) and barley grain (540), the BF25 diet

grass silage (460), barley grain (405) and BF (135), the BF50 diet grass silage (460), barley grain (270) and BF (270), and the BF75 diet grass silage (460), barley grain (135) and BF (405). At stage 1 there were only two treatments (BF0 and BF50); all four treatments were included at stage 2. The experiment indicated that 50% of barley grain can be replaced with BF without affecting growth, but feed efficiency factors may decrease when barley grain is replaced with BF. The rationality of the use of BF in the future will depend on its price in relation to other concentrates.

The objective of the third experiment was to study the need for protein supplementation in the diet of growing dairy bulls fed total mixed ration based on grass silage and barley. The control diet (C) consisted of moderate digestible (653 g digestible organic matter in DM) grass silage (450 g/kg DM), barley grain (275) and barley fibre (275) without protein supplementation. Three isonitrogenous experimental diets included also additional protein, i.e. (1) rapeseed meal (RSM) (supplementation 530 g DM/head/day), (2) wet distillers' solubles (WDS) (600 g) and (3) a mixture of barley protein (90 % of fresh weight) and wet distillers' solubles (10) (BPWDS) (480 g). In all the isonitrogenous diets the crude protein content of the concentrate increased from 137 to 150 g/kg DM (9%) compared with the C diet. Protein supplementation did not affect significantly animal performance. The results indicate that the supply of protein in dairy bulls is most probably adequate with moderate digestible, well-preserved grass silage and barley-based concentrates when the intake of digestible organic matter is high enough to support sufficient microbial protein synthesis in the rumen.

The objectives of the fourth experiment were to determine the effects on animal performance in various growth periods of (1) cereal type (barley versus oats) in the diet and (2) the inclusion of RSM in the grass silage-based diet in separate feeding. The three cereal feeding treatments used were rolled barley, rolled barley + rolled oats (1:1 on DM basis) and rolled oats, fed either without RSM or with RSM. As a consequence of decreased energy intake, the LWG and feed conversion of growing bulls decreased with increasing oats proportion in the diet. Rapeseed meal did not affect animal performance.

During the feeding experiments the calculated supply of energy was 10% higher than in the Finnish feeding recommendations for the present growth rate. This indicates that there is a need to update the Finnish feeding recommendations for dairy-breed growing bulls, and further calculations are needed for the energy supply of growing dairy bulls. The calculated supply of AAT (amino acids absorbed from the small intestine) was 38% higher than in the Finnish feeding recommendations for the present growth. Possibly, the present AAT-PBV system is not an optimal protein evaluation system for growing dairy bulls more than 250 kg live weight.

The calculations based on the feeding experiments and the Finnish feeding recommendations indicate that in most cases the dairy bulls (live weight more than 250 kg) received enough P from the basic grass silage cereal-based diets without additional mineral feeds. Therefore there is no need to add P in the form of mineral mixtures. Also feeding additional protein increases the P excretion to the environment, because the P content of protein supplements is generally high relative to grass silage and cereals.

Key words:
beef production, dairy bulls, feeding, concentrate supplementation, supplementary protein

Maitorotuisten sonnien väkirehuruokintastrategiat nurmisäilörehuun perustuvalla ruokinnalla

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Tiivistelmä

Tämän tutkimuksen ensimmäisenä tavoitteena oli tuottaa tietoa, jonka perusteella voidaan arvioida ja kehittää biologisesti ja taloudellisesti tehokkaita energia- ja valkuaisruokintastrategioita maitorotuisille sonneille, jotka kasvatetaan yli 300 kg:n teuraspainoihin nurmisäilörehuun perustuvalla ruokinnalla. Toisena tavoitteena oli tarkastella Suomessa tällä hetkellä käytössä olevien energia- ja valkuaisruokintasuositusten soveltuvuutta maitorotuisten sonnien ruokintaan. Kolmantena tavoitteena oli selvittää nurmisäilörehu-vilja-pohjaisilla ruokinnoilla ruokittujen sonnien fosforin saantia suhteessa nykyisiin fosforiruokintasuosituksiin.

Ensimmäisen osakokeen tarkoituksena oli määrittää väkirehutason ja valkuaislisän vaikutus maitorotuisten sonnien kasvuun, rehun syöntiin, rehun hyväksikäyttöön ja ruhon laatuun seosrehuruokinnalla. Kokeen sonnit ruokittiin nurmisäilörehulla ja litistetyllä ohralla kolmella eri väkirehutasolla (väkirehua 30, 50 tai 70 % ruokinnan kuiva-aineesta). Kaikilla kolmella väkirehutasolla puolet eläimistä sai väkirehuna pelkkää ohraa ja puolet eläimistä sai myös valkuaislisän (rypsi). Sonnien päiväkasvu ja ruhojen rasvaisuus lisääntyivät lineaarisesti väkirehutason noustessa. Rypsilisällä ei ollut vaikutusta sonnien tuotantotuloksiin.

Toisen osakokeen tavoitteena oli selvittää integroidun tärkkelys-etanoliteollisuuden sivutuotteena syntyvän ohrarehun käyttöä kasvavien sonnien seosrehuruokinnassa. Kontrolliruokinta sisälsi ainoastaan nurmisäilörehua (46 % kuiva-aineesta) ja ohraa (54 %) koko ruokintakokeen ajan. Kolmella muulla ruokinnalla väkirehu sisälsi ohraa 50 % ja ohrarehua 50 % kuiva-aineesta siihen saakka, kunnes sonnit saavuttivat 450 kg elopainon. Tästä elopainosta ylöspäin väkirehussa oli ohraa 75, 50 tai 25 %, ja vastaavasti ohrarehua 25, 50 tai 75 % väkirehun kuiva-aineesta. Kaikilla ruokinnoilla eläimet saivat vapaasti seosrehua, ja väkirehuprosentti oli kaikilla ruokinnoilla sama (54 %) koko kokeen ajan. Sonnien rehun syönti lisääntyi, kun ohrasta 25 tai 50 % korvattiin ohrarehulla, mutta 75 % korvaus vähensi rehun syöntiä. Ohran osittainen korvaaminen ohrarehulla heikensi hieman kasvutuloksia, ja teurasprosentti ja ruhojen rasvaisuus pienenivät. Tulosten perusteella kasvavan sonnin väkirehuannoksesta on mahdollista korvata enintään 50 % ohrarehulla. Ohrarehun käytön ratkaisee kuitenkin viime kädessä sen hinta suhteessa muihin väkirehuihin.

Kolmannen osakokeen tavoitteena oli selvittää maitorotuisten sonnien lisävalkuaisen tarvetta, kun eläimiä ruokitaan kes-

kinkertaisesti sulavaan nurmisäilörehuun (tutkimuksessa oli tavoitteena D-arvo 65) ja ohrapohjaiseen väkirehuun perustuvalla seosrehulla. Koe toteutettiin neljällä erilaisella koeruokinnalla. Koeruokinnat erosivat toisistaan valkuaisruokinnan koostumuksen osalta. Kontrolliruokinta sisälsi syyssadosta korjattua nurmisäilörehua (toteutunut D-arvo 65,3 %) (45 % kuiva-aineesta), ohraa (27,5 %) ja ohrarehua (27,5 %) ilman valkuaislisäystä. Kolme valkuaislisäyksen sisältänyttä koedieettiä olivat (1) rypsirouhe, (2) tiivistetty tärkkelysrankki ja (3) ohravalkuaisrehun (90 % tuorepainosta) ja tiivistetyn tärkkelysrankin (10 %) seos. Kaikilla kolmella valkuaislisäyksen sisältäneellä ruokinnalla raakavalkuaislisäys oli 170 g/pv eläintä kohti, jolloin väkirehun raakavalkuaispitoisuus nousi 9 % kontrolliruokintaan verrattuna. Kaikki eläimet ruokittiin vapaasti seosrehulla. Ruokinnalla ei ollut tilastollisesti merkitsevää vaikutusta sonnien nettokasvuun, rehun hyväksikäyttöön eikä ruhon teuraslaatuun. Tutkimuksen perusteella sulavuudeltaan keskinkertaista nurmisäilörehua käytettäessä valkuaislisälle ei näytä tulevan merkittävää tuotosvastetta yli puolen vuoden ikäisten maitorotuisten sonnien seosrehuruokinnassa, jos säilörehu on säilönnälliseltä laadultaan hyvää ja seoksessa käytetään väkirehua yli puolet kuiva-aineesta.

Neljännen osakokeen tarkoituksena oli määrittää väkirehuna käytettävän viljalajin (ohra vs. kaura) ja valkuaislisän vaikutus maitorotuisten sonnien kasvuun, rehun syöntiin, rehun hyväksikäyttöön ja ruhon laatuun erillisruokinnalla. Kokeessa oli kolme erilaista viljaväkirehua (pelkkä ohra, ohran ja kaura seos sekä pelkkä kaura). Kaikilla kolmella viljaruokinnalla puolet eläimistä sai väkirehuna pelkkää viljaa ja puolet eläimistä sai myös valkuaislisän (rypsi). Kauran ohraa heikommasta energia-arvosta ja sitä kautta eläinten pienemmästä energian saannista johtuen ohran korvaaminen kauralla heikensi hieman sonnien päiväkasvua ja rehun hyväksikäyttöä. Kauran käytön järkevyyden sonnien ruokinnassa ratkaisee sen hinta suhteessa muihin käytettävissä oleviin väkirehuihin. Rypsilisällä ei ollut vaikutusta sonnien tuotantotuloksiin.

Valkuaislisällä ei saavutettu merkittävää tuotosvastetta yhdessäkään osakokeessa. Näin ollen valkuaislisän antaminen yli puolen vuoden ikäiselle maitorotuiselle sonneille on tarpeetonta, kun eläimet ruokitaan hyvälaatuisella säilörehulla (D-arvo yli 65 %, rehun säilönnällinen laatu hyvä) ja viljapohjaisella väkirehulla kohtuullisin väkirehutasoin (väkirehuprosentti 30–70 %).

Ruokintakokeiden aikana sonnien laskennallinen energian saanti oli keskimäärin 10 % suurempi kuin mitä nykyiset ruokintasuositukset edellyttävät kokeissa toteutuneilla kasvutasoilla. Tämän tuloksen perusteella on olemassa tarve päivittää meillä nykyisin käytössä olevat kasvavien sonnien energiaruokintasuositukset. Sonnien laskennallinen ohutsuolesta imeytyvän valkuaisen (OIV) saanti oli kokeiden aikana keskimäärin 38 % korkeampi nykyisiin ruokintasuosituksiin verrattuna. On mahdollista, että nykyisin Suomessa käytössä oleva OIV-PVT –järjestelmä ei ole optimaalinen valkuaisarvojärjestelmä yli puolen vuoden ikäisille kasvaville naudoille. Ruokintakokeiden perusteella tehdyt laskelmat osoittavat, että useimmissa tapauksissa yli puolen vuoden ikäiset sonnit saavat perusrehuista (nurmisäilörehu, vilja) tarpeisiinsa nähden riittävästi fosforia. Näin ollen lisäfosforin tarjoaminen kivennäisrehujen kautta ei ole tarpeen. Myös lisävalkuaisen antaminen lisää fosforin ylijäämää ruokinnassa, koska valkuaisrehujen fosforisisältö on yleensä säilörehua ja viljaa selvästi korkeampi.

Avainsanat:
naudanlihantuotanto, maitorotuiset sonnit, ruokinta, väkirehut, valkuaisruokinta, ruokintasuositukset

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List of original publications

This thesis is based on the following publications:

I **Huuskonen, A., Khalili, H. & Joki-Tokola, E. 2007.** Effects of three different concentrate proportions and rapeseed meal supplement to grass silage on animal performance of dairy-breed bulls with TMR feeding. Livestock Science 110:154–165.

II **Huuskonen, A., Khalili, H. & Joki-Tokola, E. 2007.** Effects of replacing different proportions of barley grain by barley fibre on performance of dairy bulls. Agricultural and Food Science 16:232–244.

III **Huuskonen, A., Khalili, H. & Joki-Tokola, E. 2008.** Need for protein supplementation in the diet of growing dairy bulls fed total mixed ration based on moderate digestible grass silage and barley. Agricultural and Food Science 17:109–120.

IV **Huuskonen, A. 2009.** The effect of cereal type (barley versus oats) and rapeseed meal supplementation on the performance of growing and finishing dairy bulls offered grass silage-based diets. Livestock Science 122:53–62.

The publications are referred to in the text by their Roman numerals. The articles are reprinted with the kind permission of the respective copyright owners.

The research was carried out during 2002–2008 in the experimental barn of the North Ostrobothnia Research Station of MTT Agrifood Research Finland.

The corresponding author was responsible for planning and conducting all the experiments. All manuscripts were prepared by the corresponding author and revised according to the comments and suggestions of the respective co-authors and reviewers.

Abbreviations

AA	amino acids
AAT	amino acids absorbed from the small intestine
AIA	acid insoluble ash
BF	barley fibre
BF0	grass silage (460 g/kg DM) and barley grain (540)
BF25	grass silage (460 g/kg DM), barley grain (405) and BF (135)
BF50	grass silage (460 g/kg DM), barley grain (270) and BF (270)
BF75	grass silage (460 g/kg DM), barley grain (135) and BF (405)
BP	barley protein
B RSM -	barley grain as an energy supplement, no protein supplementation
B RSM+	barley grain as an energy supplement, RSM as a protein supplement
BO RSM-	barley grain + oats as an energy supplement, no protein supplementation
BO RSM+	barley grain + oats as an energy supplement, RSM as a protein supplement
O RSM-	oats as an energy supplement, no protein supplementation
O RSM+	oats as an energy supplement, RSM as a protein supplement
CF	crude fat
CP	crude protein
DM	dry matter
DMD	dry matter digestibility
DMI	dry matter intake
DOM	digestible organic matter
D value	digestible organic matter in dry matter
H RSM-	concentrate proportion 700 g/kg DM, without protein supplementation
H RSM+	concentrate proportion 700 g/kg DM, with RSM supplementation
iNDF	indigestible neutral detergent fibre
LW	live weight
LWG	live weight gain
L RSM-	concentrate proportion 300 g/kg DM, without protein supplementation
L RSM +	concentrate proportion 300 g/kg DM, with RSM supplementation
ME	metabolizable energy
MEI	metabolizable energy intake
M RSM-	concentrate proportion 500 g/kg DM, without protein supplementation
M RSM+	concentrate proportion 500 g/kg DM, with RSM supplementation
NDF	neutral detergent fibre
NDFD	neutral detergent fibre digestibility
OM	organic matter
OMD	organic matter digestibility
PBV	protein balance in the rumen
RDP	rumen-degraded protein
RSM	rapeseed meal
RUP	rumen-undegraded protein
SEM	standard error of the mean
TMR	total mixed ration
WDS	wet distillers' solubles
WSC	water-soluble carbohydrates

Contents

1 Introduction

1.1 Background

1.1.1 Beef production in Finland

Beef production in Finland is based mainly on raising dairy-breed bulls born on dairy farms. In 2006, only approximately 13% of Finnish beef meat originated from beef breeds (Manninen 2007). The decrease in the number of dairy cows in Finland has diminished the supply of calves for beef production originating from dairy herds. Because the supply of domestic beef has been decreasing, there is nowadays a clear discrepancy between the demand for and supply of domestic beef. For example in 2006, beef production was 87 million kg whereas consumption was 97 million kg (Finfood 2007). Consequently, slaughterhouse pricing favours heavy carcasses and the average carcass weights of animals have clearly increased in Finland during recent years. For example, the average carcass weight of bulls increased from 275 kg (1996) to 331 kg (2007) in eleven years in Finland (Information Centre of the Ministry of Agriculture and Forestry 2008). Carcass weights have risen also due to changes in beef-producing breeds, and direct or indirect selection for increased adult size of animals (Liinamo 2000).

1.1.2 Energy feeding of dairy bulls

Although many nutrients are required for maintenance and growth, energy is usually chosen as the base requirement and other nutrients are expressed in relation to it (Lawrence and Fowler 2002). The energy expenditure of cattle varies with body weight, breed or genotype, sex, age, season, temperature, physiological state and previous nutrition (McDonald et al. 1988). For example, differences in diet composition and level of intake will cause the composition of the metabolizable energy (ME) (ruminal volatile fatty acids, intestinally digested carbohydrate, and fat) to vary, which can affect the composition of gain (Fox and Black 1984). The UK Agricultural Research Council (ARC) has collected data for large numbers of cattle and sheep that were slaughtered at various ages and weights and subjected to physical dissection and chemical analysis. For both species, the main determinant of the energy content of live weight gain (LWG) was found to be live weight (LW) (ARC 1980). For cattle, additional influences of rate of gain, mature size and sex were recognised and incorporated in feeding standards. For example, in steers of a medium-sized breed growing rapidly, the energy content of the gain rises from 9 MJ/kg at 100 kg LW to 19 MJ/kg at 400 kg LW (ARC 1980). However, steers of the same type growing slowly make gains containing less fat and hence less energy; for example, at 400 kg LW their gains contain 17 MJ/kg.

Grass silage is a basic component of many beef production systems worldwide, particularly in those countries with a temperate climate such as in Northern and Western Europe (McGee 2005). The energy supply to a ruminant from grass silage is primarily influenced by altering the cutting date of the grass crop (i.e. digestibility) (Rinne 2000) and by modifying and restricting fermentation through wilting or the use of additives (Thomas and Thomas 1985). With ruminants there is a positive relationship between the digestibility of forage and the level of voluntary intake, due to physical limitation (Forbes 2007). Increasing the rate of degradation and/or outflow from the rumen increases the voluntary intake. With high-energy diets that are digested quickly, this physical limit is not reached and the animal controls its intake to meet approximately its energy requirements.

The conventional method of overcoming the deficiencies in nutrient supply from grass silage is to supplement with concentrates. In general, the growth response to concentrate supplementation is lower with higher digestibility (Drennan and Keane 1987, Randby 2001) or restricted fermentation (Agnew and Carson 2000) grass silage. In practice, the concentrate level used usually depends on the price of grain relative to that of forage. For example, in the late 1990s and early 2000s, grain was used more in cattle feeding in Finland since the EU policy had reduced the price of grain relative to that of forage. However, it is widely recognized that very high concentrate levels can lead to risks of diseases (like rumen acidosis) due to a high starch load (e.g. Krause and Oetzel 2006). Further, rumen acidosis is known to be related to diseases such as ruminitis, rumen paraketosis, liver abscesses, laminitis and bloat (Nocek 1997, Galyean and Rivera 2003, Krause and Oetzel 2006). Adjusting the ration by increasing the cell wall fraction of the concentrate (Utley et al. 1974) or by increasing the overall roughage intake (Kreikemeier et al. 1990, Zinn and Plascenia 1996) can reduce the risk of rumen acidosis and thereby improve the health and welfare of the animals.

Cereals are the primary source of dietary starch in growing bulls and make up a substantial proportion of cattle feeding stuffs used in North Europe. Traditionally diets for growing cattle were largely based on grass silage and barley (*Hordeum vulgare*) or wheat (*Triticum aestivum*) supplement. The energy value of oats (*Avena sativa*) has been considered inferior to barley and wheat due to the hull content of oats which ranges from 20 to 30% (Crosbie et al. 1985). Oat hulls are a high-fibre feeding stuff containing substantial amounts of indigestible lignin. According to Fuhr (2006), oats is also unique among cereals in that it has both higher lipid levels and the majority of the lipids are in the endosperm. In relation to other cereals, oats is not a predominant grain fed to ruminants. Wheat and barley are the grains of choice, especially in feeding programmes designed for growing and fattening cattle. Therefore, relatively little research has been conducted on oats in ruminant production (Fuhr 2006). However, some studies in dairy cattle (e.g. Moran 1986, Heikkilä et al. 1988, Ekern et al. 2003, Heikkilä and Huida 2004) have shown that oats improve milk production and milk fatty acid composition compared with barley. With growing cattle, Corah et al. (1975) and Dion and Seoane (1992) reported similar growth rates and feed efficiencies between fattening steers receiving oats or barley with hay-based diets.

A feed consisting of concentrates and chopped or ground forage and presented in a form in which it is not possible for the animals to select one ingredient is often termed a *complete diet* or a *Total Mixed Ration* (TMR) (Forbes 2007). With TMR feeding, the possibilities of utilizing different low-priced by-products in cattle feeding have increased. In Finland, an integrated process for production of ethanol and starch from barley creates by-product fractions such as barley fibre (BF), wet distillers' solubles (WDS) and barley protein (BP) (Näsi 1988). Barley fibre is a fibrous product comprised mainly of the cell wall fraction of barley endosperm, WDS is the non-fermentable residue after distillation of ethanol, and BP is obtained as a result of removal of the protein fraction from the cereal cells by separation. These by-products from the barley-based integrated starch-ethanol process have not been studied widely in the feeding of growing bulls. In North America, studies have been made on the thin stillage and distillers' grains derived, for example, from wheat (Fisher et al. 1999, Iwanchysko et al. 1999, Mustafa et al. 2000) and rye (*Secale cereale*)

(Mustafa et al. 2000) in the diet in ruminants. Mustafa et al. (2000) have also studied the nutritive value of distillers' grains derived from barley. However, these feeds are by-products from the traditional yeast fermentation process, making these studies less useful for the Finnish beef sector. The traditional distillers' products contain all the non-fermentables of the raw material in one fraction (Näsi 1988). Barley distillers' grain with solubles has a high fibre content and the heat and other processing treatments cause the protein to react with sugars, thus decreasing its digestibility and utilization (Näsi 1984). Instead, in the integrated production of starch and ethanol, barley by-products can be fractionated into products suitable for use in the diets of both ruminants and monogastrics (Näsi 1988).

The prices of the feeds can vary dramatically and therefore it would be valuable to obtain information on the performance of dairy bulls when they are fed with different concentrate levels and with different alternative feeds. Relative to dairy cows, there are few reports in the literature where a wide range of supplementary concentrate levels in the diet of growing and finishing bulls offered grass silage-based diets were examined (McGee 2005).

1.1.3 Protein feeding of dairy bulls

The N requirements of rumen microorganisms are met by ammonia, amino acids (AA), and peptides, the end products of microbial breakdown of protein and recycled urea (McDonald et al. 1988). Ruminants have two sets of N requirements, the N requirements of ruminal fermentation and the AA requirements of the host animal. Not meeting either set of requirements decreases animal performance and profitability (Schwab et al. 2005). A shortage of rumen-degradable feed protein (RDP) has been shown to reduce microbial digestion of carbohydrates (Griswold et al. 2003, Klevesahl et al. 2003), reduce synthesis of microbial protein (Martin-Orue et al. 2000, Griswold et al. 2003), decrease feed intake (Mehrez and Ørskov 1978, Wheeler et al. 2002) and decrease weight gains of growing cattle (Zinn et al. 1994, 2003). A shortage of absorbed AA by cattle, either because of decreased sythesis of microbial protein or less than required intakes of rumen-undegraded protein (RUP), may decrease weight gains of growing cattle (Pirlo et al. 1997, Lammers and Heinrichs 2000).

In feeding standards for growing animals, protein requirements for growth are usually incorporated into a single value for maintenance and growth combined (McDonald et al. 1988). In the Scandinavian feed protein evaluation system (Madsen et al. 1995), the protein value of the diet is expressed as amino acids absorbed from the small intestine (AAT) and the protein balance value in the rumen (PBV), which describes the balance between the dietary supply of RDP and the microbial requirements for RDP. The modifications made in the Finnish system (MTT 2006) are described in detail by Tuori et al. (1998). The crude protein (CP) of grass silage is characterized by rapid and high (80–90%) degradability in the rumen, which usually results in an excess of RDP for rumen microbes in beef cattle (Aronen 1992). Therefore the protein supplement, if needed, should have lower rumen degradability of CP compared with grass silage. In Finland, rapeseed meal (RSM) is the most important protein feed for cattle. According to the Finnish feed tables and feeding recommendations (MTT 2006), the rumen degradability of the CP in RSM is 60–65%.

The P content of protein supplements (RSM, WDS, and BP) is high relative to silage and barley grain. Therefore feeding additional protein can increase P excretion to the environment, because increasing the P content of the diet will lead to a higher P content of the manure (Satter 2003). Decreasing dietary protein inputs in feeding could potentially decrease environmental concerns related to air and water quality (Cole et al. 2003). According to literature, N and P are routinely overfed to ruminants, which in combination with the continuous trend to concentrate animal units in intensive animal systems, leads to nutrient surpluses at farm and system levels (e.g. Jonker et al. 2002, Ondersteijn et al. 2002, Dou et al. 2003). The crude protein content and composition of the diet can have a profound effect on N losses and ammonia release from manure (Swensson 2003) and should be publicized by nutrition consultants and extension professionals as an immediately available tool for reduction of N losses from cattle operations (Pfeffer and Hristov 2005). Alternatively, N (and P) from animal waste may be converted into value-added products, thus reducing nutrient loads to the soil and atmosphere (Cowling and Galloway 2001). Therefore it is important to know if there is enough protein in the basic diet of dairy bulls to support high growth without protein supplementation.

1.2 Purpose of the study

The first aim of this thesis was to produce data for evaluating, developing and recommending biologically and economically efficient energy and protein feeding strategies for growing and finishing dairy bulls offered grass silage-based diets and slaughtered above 300 kg carcass weight. Experimental feedings were carried out either with conventional or alternative concentrates. The second aim was to calculate energy and protein supplies for dairy bulls fed different grass silage-cereal-based diets and, based on that, to estimate the possible need to revise the current Finnish energy and protein recommendations for growing dairy bulls. The third aim was to demonstrate the P supply of the dairy bulls fed grass silage-cereal-based diets with or without protein supplementation in relation to current Finnish feeding recommendations for P.

2 Materials and methods

The data for this thesis are from four feeding experiments that were performed in the experimental barn of the North Ostrobothnia Research Station of MTT Agrifood Research Finland (Ruukki, 64°44'N, 25°15'E). The experimental procedures were evaluated and approved by the Animal Care and Use Committee of MTT Agrifood Research Finland. The experimental procedures are described in detail in publications I-IV; a short summary is presented here.

2.1 Housing

All the experimental animals were purchased from local dairy farms when they were two weeks old, on average. Before the beginning of the feeding experiments the animals were housed on peat bedding in six pens (3.0 x 3.5 m; 5 calves in each) providing 2.1 m^2 per calf.

During the feeding experiments the bulls were placed in an insulated barn in adjacent tie-stalls and fed individually. The bulls were tied with a collar around the neck and with a chain of 50 cm, which was attached to a horizontal bar 40–55 cm above the floor. The floor surface was solid concrete under the forelegs and metal grids under the hind legs. No bedding was used on the floor. The bulls had free access to water from an open water bowl during the experiments.

2.2 Animals, diets and experimental designs

The first experiment (I) was performed in 2002–2004 and included three feeding trials. The objectives of this experiment were to determine the effects on animal performance in various growth periods of (1) the proportion of concentrate in the diet, and (2) the inclusion of RSM in the barley-based concentrate in TMR feeding. The first trial started in March 2002, the second in October 2002 and the third in May 2003. The first trial comprised 30 Finnish Ayshire bulls; the second 29 Finnish Ayrshire bulls and one Holstein-Friesian bull, and the third 25 Finnish Ayrshire bulls and five Holstein-Friesian bulls. The whole experiment comprised in total 84 Finnish Ayrshire bulls and 6 Holstein-Friesian bulls. At the start of the trials the average LW of the animals was 251±27.6 (mean ± SD) kg. They were divided into five blocks by LW and randomly assigned to six treatments within each block. The bulls were fed TMR *ad libitum* twice a day. A 3×2 factorial design was used to study the effects of concentrate proportion and RSM inclusion in the barley-based concentrate. The three concentrate proportions were 300 (L), 500 (M) and 700 (H) g/kg dry matter (DM), fed without RSM (RSM–) or with RSM (RSM+). The concentrate used was rolled barley. The crude protein (CP) content of the concentrate was 128 g/kg DM in the RSM– diets and 160 g/kg DM in the RSM+ diets.

The second experiment (II) was performed in 2005–2006. The objective of the experiment was to study the effects of partial replacement of barley grain with barley fibre on animal performance, carcass traits and diet digestibility. The experiment comprised 20 Finnish Ayrshire bulls and 12 Holstein-Friesian bulls. At the beginning of the experiment the animals (initial LW 261±34.0 kg) were divided into four blocks of 8 animals by LW and breed. Two randomly selected animals in each block were assigned to four treatments. The animals were fed total mixed ration *ad libitum* three times per day. There were four diets with two offered at stage 1 (from the initiation of the study to 450 kg live weight) and four at stage 2 (from 450 kg live weight to slaughter). The control diet (BF0) included grass silage (460 g/kg dry matter) and barley grain (540), the BF25 diet grass silage (460), barley grain (405) and BF (135), the BF50 diet grass silage (460), barley grain (270) and BF (270), and the BF75 diet grass silage (460), barley grain (135) and BF (405). At stage 1 there were only two treatments (BF0 and BF50); all four treatments were included at stage 2. The commercial BF (produced by Altia Ltd., Finland) used in the experiment included BF (950 g/kg DM), wet distillers' solubles (25) and molasses (25).

The third experiment (III) was performed in 2005–2006. This experiment was conducted to study the need for protein supplementation in the diet of growing dairy bulls fed a moderately digestible grass silage-barley-based TMR. The experiment comprised 24 Finnish Ayrshire bulls and 8 Holstein-Friesian bulls. At the beginning of the experiment the animals (initial LW 272±28.5 kg) were divided into eight blocks of four animals by LW and breed. The experiment included four treatments, and one randomly selected animal in each block was assigned to each treatment. The control diet (C) consisted of moderately digestible (653 g digestible organic matter in DM) grass silage (450 g/kg DM), barley grain (275) and barley fibre (275) without protein supplementation. Three isonitrogenous experimental diets included also additional protein, i.e. (1) rapeseed meal (RSM) (supplementation 530 g DM/head/day), (2) wet distillers' solubles (WDS) (600 g) and (3) a mixture of barley protein (90 % of fresh weight) and wet distillers' solubles (10) (BPWDS) (480 g). In all the isonitrogenous diets the crude protein content of the concentrate increased from 137 to 150 g/kg DM (9%) compared with the C diet. All the bulls were fed total mixed ration *ad libitum*. The energy content of all the diets was 11.6 MJ/kg DM.

The fourth experiment (IV) was performed in 2006–2008. The objectives of this experiment were to determine the effects on animal performance in various growth periods of (1) cereal type (barley *versus* oats), and (2) the inclusion of RSM in the grass silage-based diet in separate feeding. The experiment included two feeding trials. The first trial started in April 2006 and the second in December 2006. The first trial comprised 18 Finnish Ayrshire bulls and 12 Holstein-Friesian bulls, the second trial 24 Finnish Ayrshire bulls and 6 Holstein-Friesian bulls. The experiment comprised in total 42 Finnish Ayrshire bulls and 18 Holstein-Friesian bulls. At the start of the experiment the animals (initial LW 257±26.6 kg) were divided into five blocks of six animals by LW and breed within trials. Within each block one randomly selected animal was chosen for each treatment. A 3 x 2 factorial design was used to study the effects on animal performance of cereal type and inclusion of RSM. All bulls were offered grass silage *ad libitum*. The three cereal feeding treatments were rolled barley, rolled barley + rolled oats (1:1 on DM basis) and rolled oats, fed without RSM (RSM-) or with RSM (RSM+). The animals were individually fed twice a day. The amount of concentrate supplementation was 37 g/$W^{0.75}$/animal/day for all treatments, and the target for average concentrate level during the experiment was 400 g/kg DM. In the RSM– diets the CP content of the concentrate was 132 g/kg DM and in the RSM+ diets 160 g/kg DM. The amount of RSM supplement depended on the CP content of the grain, which was measured by chemical analyses. The average RSM supplementation during the experiment was 440 g DM/ animal/day.

The rapeseed meal used (I, III, IV) was solvent-extracted RSM and it was obtained from a commercial source (Rehuraisio Ltd., Raisio, Finland). In addition, in all the experiments (I–IV) the daily concentrate ration included 150 g of a mineral mixture (150 g/head/day). Also a weekly vitamin mixture of 50 g/animal was given. The grass silages used in all the experiments were made from primary (I, II, IV) or secondary growth (III) of timothy (*Phleum pratense*) and meadow fescue (*Festuca pratensis*) sward and ensiled in bunker silos with a formic acid-based additive applied at a rate of 5 L/tonne of fresh grass.

A summary of the experiments is presented in Table 1.

2.3 Experimental measurements and calculations

The animals were individually fed. Refused feed was collected and measured daily. Silage sub-samples for chemical analyses were taken twice a week, pooled over periods of four weeks and stored at –20 °C prior to analyses. Concentrate sub-samples were collected weekly and pooled over periods of eight weeks.

Silage samples were analysed for DM, ash, CP, crude fat (CF) (IV), neutral detergent fibre (NDF), indigestible NDF (iNDF) (IV), starch (II, IV), P, silage fermentation quality (pH, water-soluble carbohydrates (WSC), lactic and formic acids, volatile fatty acids, soluble and ammonia-N content of total N) and digestible organic matter (DOM) in DM (D value). Concentrate sub-samples were analysed for DM, ash, CP, CF (IV), NDF, iNDF (IV), starch (II, IV) and P. The analyses of DM, ash, CP, CF and NDF were made as described by Ahvenjärvi et al. (2000). The P content of samples was determined as described by Luh Huang and Schulte (1985). Starch was analysed according to McCleary et al. (1994) and iNDF as described by Huuskonen et al. 2008. The silage was analysed for fermentation quality by electrometric titration as described by Moisio and Heikonen (1989) and for D value by the meth-

Table 1. Summary of the experiments.

Paper	Number of bulls	Initial LW, kg	Final LW, kg	Feeding method	Treatments	Abbreviation
I	15	252	641	Total mixed ration	Concentrate proportion 300 g/kg DM, without protein supplementation	L RSM-
	15	250	658	*ad libitum*	Concentrate proportion 300 g/kg DM, with RSM supplementation	L RSM+
	15	252	671		Concentrate proportion 500 g/kg DM, without protein supplementation	M RSM-
	15	250	648		Concentrate proportion 500 g/kg DM, with RSM supplementation	M RSM+
	15	249	652		Concentrate proportion 700 g/kg DM, without protein supplementation	H RSM-
	15	250	660		Concentrate proportion 700 g/kg DM, with RSM supplementation	H RSM+
II	8	260	659	Total mixed ration	Grass silage (460 g/kg DM) and barley grain (540)	BF0
	8	260	644	*ad libitum*	Grass silage (460 g/kg DM), barley grain (405) and BF (135)	BF25
	8	261	659		Grass silage (460 g/kg DM), barley grain (270) and BF (270)	BF50
	8	265	637		Grass silage (460 g/kg DM), barley grain (135) and BF (405)	BF75
III	8	271	653	Total mixed ration	Grass silage, barley grain and BF without protein supplementation	C
	8	261	660	*ad libitum*	Grass silage, barley grain and BF + RSM as a protein supplement	RSM
	8	275	696		Grass silage, barley grain and BF + WDS as a protein supplement	WDS
	8	279	699		Grass silage, barley grain and BF + a mixture of BP and WDS as a protein supplement	BPWDS
IV	10	264	694	Separate feeding.	Barley grain as an energy supplement, no protein supplementation	B RSM-
	10	254	696	Grass silage	Barley grain as an energy supplement, RSM as a protein supplement	B RSM+
	10	256	693	*ad libitum.*	Barley grain + oats as an energy supplement, no protein supplementation	BO RSM-
	10	262	682		Barley grain + oats as an energy supplement, RSM as a protein supplement	BO RSM+
	10	260	673		Oats as an energy supplement, no protein supplementation	O RSM-
	10	254	679		Oats as an energy supplement, RSM as a protein supplement	O RSM+

od described by Nousiainen et al. (2003). The D value results were calculated using correction equations to convert pepsincellulase solubility values into *in vivo* digestibility based on a data set comprising Finnish *in vivo* digestibility trials (Huhtanen et al. 2006).

The diet digestibility was estimated using acid insoluble ash (AIA) as internal marker (Van Keulen and Young 1977). Feed and faecal samples were collected twice a day during the collection period (5 days) and stored frozen prior to analyses. The samples were analyzed for DM, ash, CP and NDF as described above.

The ME contents of the feeds were calculated according to the Finnish feed tables (MTT 2006). The ME value of the silage was calculated as 0.16 × D value (MAFF 1981). The ME values of the concentrates were calculated as described by Schiemann et al. (1972) and MAFF (1984). The digestibility coefficients of the concentrates were taken from the Finnish feed tables (MTT 2006). The supply of AAT and PBV were calculated according to the Finnish feed tables (MTT 2006).

The average energy, AAT and P intakes of the bulls from I–IV were compared with the current Finnish feeding recommendations (MTT 2006). The Finnish energy feeding recommendations for growing cattle are calculated according to the ARC (1980, 1990) and ARFC (1990) so that the q value (metabolizable energy/gross energy) used was 0.60. The Finnish protein and phosphorus feeding recommendations for growing cattle are based on the recommend allowances and feed tables of INRA (Geay and Micol 1989, Meschy 2003) and are calculated based on the LW and LWG of the animals.

The animals were weighed on two consecutive days at the beginning of the experiment. After that the animals were weighed approximately every 28 days. Before slaughter they were weighed on two consecutive days. The LWG was calculated as the difference between the means of initial and final weights. Dressing proportion, carcass conformation and carcass fat score were determined according to the EUROP classification (Commission of the European Communities 1982). For conformation, the development of carcass profiles, in particular the essential parts (round, back, shoulder), was taken into consideration according to the EUROP classification (E: excellent, U: very good, R: good, O: fair, P: poor), and for fat cover degree the amount of fat on the outside of the carcass and in the thoracic cavity was taken into account using a classification range from 1 to 5 (1: low, 2: slight, 3: average, 4: high, 5: very high).

2.4 Statistical procedures

The bulls were placed in an insulated barn in adjacent tie-stalls and were individually fed. All experiments used a randomized block design with the animal as the experimental unit. The statistical analyses were performed using the SAS/GLM (I, IV) and SAS/MIXED (II, III) procedures (SAS 1999). Using the SAS/GLM procedure, the error term for each comparison had to be defined by the user as well as when the standard error of the mean (SEM) was calculated. The results were expressed as LS means with SEM. The normality of residuals was checked for each analysis using graphical methods: box plot and scatter plot of residuals and fitted values.

In addition, data from I–IV were used for the meta-analyses of the feed intake and growth data. Relationships and regression curves between LW and feed intake, growth and feed efficiency are presented in this thesis. The meta-analyses were conducted with a mixed model (St-Pierre 2001). The fixed effects of the linear mixed model were the intercept and slope. The model involves a random intercept and slope for each cluster of data (treatment-by-experiment combination). The covariance parameter between intercept and slope was also added to the model. Regression curves are presented based on predicted values of dependent variables vs. independent variables. Adjusted individual observations are also plotted (St-Pierre 2001).

3 Results and discussion

3.1 Feeds

The D value of the grass silages used varied between the experiments, being 653 g/kg DM in III and 701 g/kg DM in the second trial of IV. The CP content of silages was quite high (153–174 g/kg DM) and the NDF content varied between 519 and 551 g/kg DM. The fermentation quality of the silages, as indicated by low pH values and low contents of ammonia-N and volatile fatty acids, was good. The silages used were restrictively fermented with high residual WSC concentrations and low lactic acid concentrations. The grass silages used were representative of the average silage produced in Finland. For example, according to statistics by Valio Ltd., the mean pH and concentrations of DM, CP, NDF, ammonia N and WSC as well as the D value of grass silages in 2007-2008 (calculated by Valio Ltd. from their national statistics for forage properties) were 4.24, 323 g/kg fresh, 150 g/kg DM, 545 g/kg DM, 44 g/kg N, 55 g/kg DM and 680 g/kg DM, respectively. Mean values of the grass silages analysed by Valio Ltd. in Finland in 2002-2008 are given in Table 2.

Table 2. Mean values of grass silages analysed by Valio Ltd. in Finland in 2002-2008 (calculated from the national statistics for forage properties owned by Valio Ltd.). Available at: https://portal.mtt.fi/portal/page/portal/Artturi

Period	1.8.2002–1.7.2003	1.8.2003–1.7.2004	1.8.2004–1.7.2005	1.8.2005–1.7.2006	1.8.2006–1.7.2007	1.8.2007–1.7.2008
Total n	18 743	22 202	26 055	23 200	21 014	24 398
Dry matter (DM), g/kg feed	334	329	276	318	374	323
Crude protein, g/kg DM	152	156	142	149	154	150
Neutral detergent fibre (NDF), g/kg DM	546	531	562	549	520	545
D value[1], g/kg DM	677	671	660	674	689	680
Metabolizable energy, MJ/kg DM	10.9	10.8	10.5	10.8	11.0	10.9
AAT[2], g/kg DM	82	82	81	83	85	84
PBV[3], g/kg DM	11	16	4	7	9	7
pH	4.28	4.20	4.17	4.22	4.38	4.24
Volatile fatty acids, g/kg DM	12	12	16	12	9	13
Lactic + formic acid, g/kg DM	42	46	48	44	35	43
Water-soluble carbohydrates, g/kg DM	47	56	48	52	83	55
In total N, g/kg N						
NH_4N	46	47	60	48	38	44
Soluble N	390	410	470	420	360	420

1) Digestible organic matter in DM.
2) Amino acids absorbed from small intestine.
3) Protein balance in the rumen.

3.2 Diet digestion

In all experiments the diet digestibility was estimated using AIA as an internal marker. Research has shown AIA in feeds to be an acceptable natural marker for the determination of dry matter digestibility in sheep and cattle (Van Keulen and Young 1977, Thonney et al. 1979, Block et al. 1981). For example, Block et al. (1981) reported correlation coefficients for digestibility determined by total collection versus AIA for wethers fed corn plants, cows fed hay plus grain diets and wethers fed hay diets to be 0.96, 0.95 and 0.40, respectively. The low correlation for wethers fed hay was apparently due to a high quantity of orts with a variable AIA content. The range of total recovery of AIA from all animals was 98 to 102% when ort AIA was taken into account and 91 to 121% when ort AIA was not taken into account (Block et al. 1981). Block et al. (1981) concluded that the use of AIA as a natural marker for the estimation of digestibility when diets are fed *ad libitum* has potential, provided that a sufficient number of animals is used and diets are adequately mixed to limit feed selection and sorting, or intake is determined and feed and orts are sampled.

3.2.1 Effects of energy feeding

The apparent digestibility of DM and OM increased curvilinearly with an increasing proportion of barley-based concentrate in the diet (I). The substitution of silage with barley improved the digestibility, because the digestibility of barley was higher than that of silage. The increased organic matter digestibility (OMD) of grass silage-based diets due to increasing concentrate supplementation has been extensively documented (Steen et al. 2002, Keady and Gordon 2006, Keady and Kilpatrick 2006, Keady et al. 2007, 2008). However, a reduced forage intake due to increased concentrate intake may be related to a reduced rate of OM digestion (e.g. Colucci et al., 1982, 1990). Effects of forage: concentrate ratio on the rate of digestion have been observed by Poore et al. (1990), while the extent of ruminal digestion has also been shown to decrease as the inclusion level of concentrates in the diet increases (Mould et al. 1983, Carro et al. 2000). In study I, the effect of concentrate on the OM digestibility was quadratic. The digestibility increased considerably more when the concentrate proportion increased from 300 to 500 g/kg DM than from 500 to 700 g/kg DM. This curvilinear effect suggests changes in fibre digestion.

The NDF digestibility (NDFD) decreased with increasing concentrate proportion in the diet (I). The reduction in fibre digestibility due to increased concentrate proportion has been well documented (e.g. Vadiveloo and Holmes 1979, Udén 1984, Huhtanen and Jaakkola 1993, Steen et al. 2002, Keady and Kilpatrick 2006). The quadratic effect of the concentrate level on NDFD (I) indicates negative associative effects from a combination of silage and barley-based concentrate. The results (I) suggest that the effect of barley-based concentrate on NDF digestion is limited if the level does not exceed 500 g/kg DM which is also suggested by Huhtanen and Jaakkola (1993). In contrast, Ørskov (1986) concluded that only 200 – 300 g/kg total DM of concentrate can be used without adverse effects on forage digestibility and Udén (1984) reported that NDFD started to decrease when the concentrate level exceeded 300 g/kg DM.

The negative associative effect is attributed to a depression in fibre digestibility in the rumen and in the total digestive tract from inclusion of rapidly fermentable carbohydrates such as barley-based (starch) concentrate (Huhtanen and Jaakkola 1993) and sucrose (Khalili and Huhtanen 1991) in grass silage-based diets. When cattle are fed diets containing cereal grains, the presence of starch and sugars reduces fibre digestion (Mould et al. 1983, Mould and Ørskov 1984). According to Hoover

(1985), added starch reduced fibre digestion through a series of events involving carbohydrate preference, reduced rumen pH and decreased cellulolytic organisms. A moderately reduced pH, to about 6.2, exacerbated the depression in the fibre digestion brought about by added starch; a more severe pH decrease, to 6.0, reduced cellulolytic microbes and severely limited fibre digestion. The initial reduction in fibre digestion, which was not pH-related, was referred to as "carbohydrate effect", and suggests that an alternate, readily digested carbohydrate, can inhibit cellulose digestion (Hoover 1985).

Mulligan et al. (2002) concluded that for diets based on grass silage and high fibre concentrate supplements, the depressive effect of the feeding level *per se* on diet digestibility was greater for high (0.85 dietary DM) than for moderate (0.50 dietary DM) concentrate diets. For moderate concentrate diets, the reduction in digestibility was attributed to an increased fractional rumen outflow rate for the concentrate component while for high concentrate diets, decreased rumen pH and a decreased rate of concentrate and forage digestion were deemed to be important components (Mulligan et al. 2002). As a result of the negative associative effects, contrary to expectations from published feed table values, increasing the concentrate proportion in the diet of growing cattle does not necessarily increase the digestible energy value of the total diet (Patterson et al. 2000, Steen and Kilpatrick 2000, Caplis 2005), particularly where grass silage of higher digestibility is fed (Drennan and Keane 1987, Steen et al. 2002).

In the present thesis, the apparent digestibility of OM and NDF decreased with replacing barley grain by BF (II) or oats (IV). Both oats and BF contain much more NDF and iNDF and less starch than barley grain, so the difference in OMD can be attributed to a lower digestibility of cell wall components of oats and BF compared with barley starch. Similar results were observed by Huhtanen (1992) and Huuskonen et al. (2008) in bulls and by Huhtanen et al. (1988) in dairy cows. The reduction in NDFD, when replacing barley grain with BF or oats, was partly a consequence of decreasing the proportion of silage NDF in the total NDF intake. The silage fibre was more digestible than the fibre fraction of grains (IV) and replacing barley with BF or oats increased the proportion of grain NDF in the total NDF intake.

3.2.2 Effects of protein feeding

Rapeseed meal supplementation had no effect on diet apparent OMD when barley grain (I, IV), barley grain + BF mixture (III) or oats (IV) was partly replaced by RSM. Similarly, WDS had no effect on OMD (III), but BPWDS had a small but significant positive effect (III). In III and IV, protein supplementation had no significant effects on diet apparent NDFD, but in I, diet apparent NDFD slightly improved with RSM supplementation. In general, the positive effect of protein supplementation on diet OMD or fibre digestion has been most notable when the digestibility of the roughage has been low (Stokes et al. 1988, Delcurto et al. 1990). Nocek and Russel (1988) suggested that increased DMI and OMD with protein supplementation were mediated by the increased fibre digestibility in the rumen. Most of the experiments in which protein supplementation resulted in positive effects on fibre digestion, have been conducted with medium or poor quality roughages (e.g. McAllan and Griffith 1987, McAllan et al. 1988, Olsson et al. 1991). The positive response to protein supplementation has been related to low rumen degradability of feed protein and a more gradual release of NH_3-N, peptides and branched-chain VFA, allowing the essential growth factors to remain available in the rumen for a longer period of time after feeding (Hussein et al. 1991).

With grass silage-based diets, inclusion of a protein feed has been found to improve OMD when poor fermentation quality silages have been used (e.g. Gill and England 1984, England and Gill 1985). With well-preserved silages, the inclusion of a protein feed in the diet had only a small effect (Steen 1992, Aronen et al. 1992) or no effect at all (Gill et al. 1987, Steen 1988a, 1989a, Aronen 1990, Jaakkola et al. 1990, Aronen and Vanhatalo 1992a,b). In I and IV, the quality of the grass silages used, both in terms of digestibility (*D* value 670-700 g/kg DM) and fermentation characteristics, was good, and inclusion of a protein feed had no effect on diet OMD. In III, in which the digestibility of grass silage was lower (*D* value 650 g/kg DM), the inclusion of BPWDS had a small positive effect on diet OMD.

In accordance with earlier studies (Aronen 1990, Aronen and Vanhatalo 1992a, Aronen et al. 1992), the apparent CP digestibility increased with protein supplementation (I, III, IV). Some of the increased apparent digestibility of the CP in the RSM supplemented diets may have reflected the better digestibility of RSM protein. Most of this increase was, probably, only apparent, related to the decreased proportion of faecal metabolic nitrogen recovered in faeces when the CP content increased. This hypothesis is supported by Minson (1982).

3.3 Feed intake

3.3.1 Effects of energy feeding

The total DMI (kg/day) in I–IV was related to the LW of the bulls and was described by the equation: Y = 0.0116X + 3.7445 (R^2=0.80) where Y=DMI (kg/day) and X=LW (kg) (Figure 1). However, generally the intake tends to plateau as the animals get heavier and also in this data the intake/kg metabolic LW was negative-

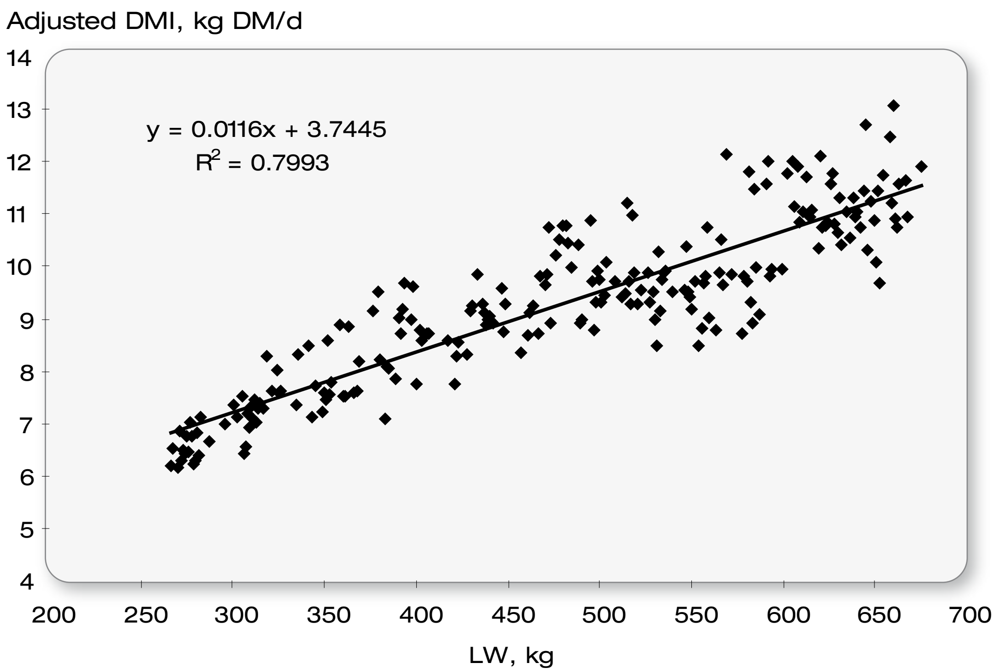

Figure 1. Relationships between live weight (LW, kg) and adjusted total dry matter intake (DMI, kg/d) of the bulls (data in I–IV).

ly related to the LW of the bulls and was described by the equation: Y = -0.0317X + 107.13 (R^2=0.25) where Y=DMI (g/kg metabolic LW) and X=LW (kg) (Figure 2).

The concentrate proportion had no significant effects on the total average DMI in experiment I. This is in contrast to many studies in which increasing the level of supplementary concentrates in the diet of growing cattle has reduced grass silage intake but increased total DMI with TMR (Caplis et al. 2005, Keane et al. 2006) or with separate (Drennan and Keane 1987, Dawson et al. 2002) feeding. The magnitude of the decrease in silage intake is usually greater with silage of higher digestibility (Drennan and Keane 1987, Steen 1998). For diets containing low to moderate levels of concentrate (<0.47 of dietary DMI), substitution rates have ranged from 0.29 to 0.64 kg silage DM/kg concentrate DM with high digestibility grass silage (Agnew and Carson 2000, Steen and Kilpatrick 2000, Patterson et al. 2000, Dawson et al. 2002, Caplis et al. 2005).

At the beginning of experiment I, the relationship between concentrate proportion and total DMI was curvilinear. The total DMI increased up to the medium concentrate proportion (500 g/kg DM), but after that a further increase in concentrate did not increase the DMI. Probably the capacity to use energy was the limiting factor in intake regulation of dairy bulls with the highest concentrate proportion. Also recent studies have reported a curvilinear increase in DMI with increasing concentrate proportion (Steen 1998, Keane 2001, Caplis et al. 2005), implying a progressively decreasing intake of grass silage with increasing concentrate proportion. From a series of experiments with high digestibility grass silage, Steen (1998) calculated substitution rates of 0.33, 0.64, 0.90 and 1.15 kg silage DM/kg concentrate DM for successive in-

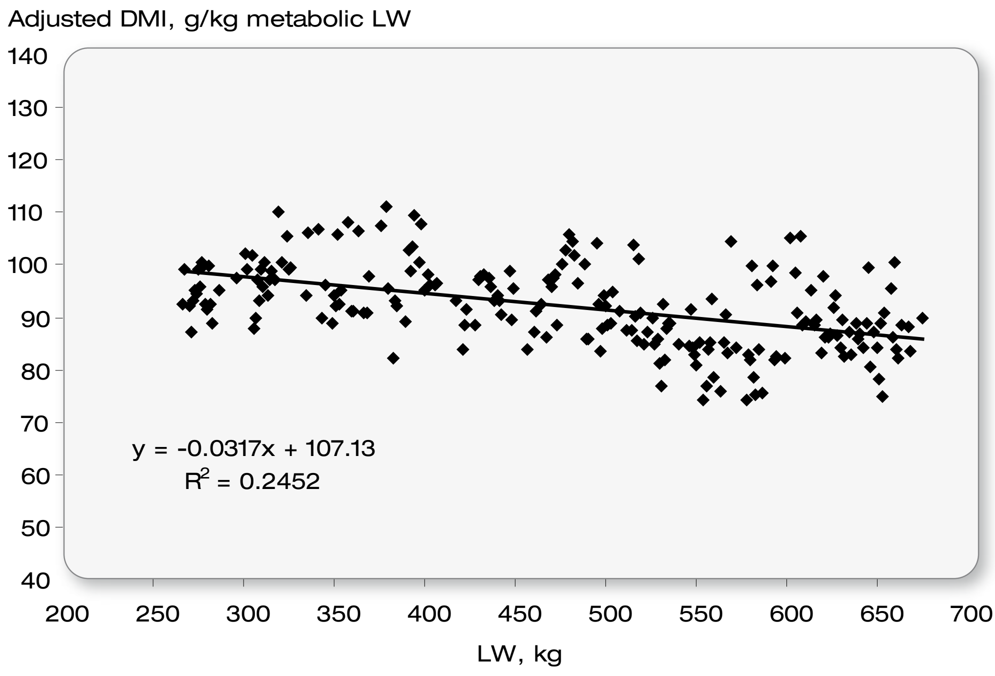

Figure 2. Relationships between live weight (LW, kg) and adjusted dry matter intake (DMI, g/metabolic LW) of the bulls (data in I–IV).

crements of concentrates equating to 0.22, 0.42, 0.62 and 0.85 of total DMI, respectively. Caplis et al. (2005) found substitution rates for high digestibility silage of 0.29, 0.65 and 1.10 kg silage DM/kg concentrate DM for successive increments of concentrate equating to 0.31, 0.55 and 0.85 of total DMI, respectively.

Based on literature reports the effect of energy supplement type on the intake is complicated and partly unclear (McGee 2005). Mayne et al. (1995) reported that starch or fibre supplements had no significant difference in mean substitution rate in growing cattle when considered across a range of silage compositions, but there were interactions between supplement type and silage type. With extensively fermented silages characterised by high lactic acid concentrations, substitution rates were lower with high starch than with high fibre supplements. It was suggested that this difference might reflect better synchronisation of nitrogen and fermentable energy (Mayne et al. 1995). Steen (1993) reported that silage intake was higher for fibre than starch-based concentrate for growing cattle. However, the silage intake of growing and finishing cattle was shown not to be differentially affected by starch, fibre or sugar-based concentrates (Moloney et al. 1993) or by fibre or starch-based concentrates (O'Kiely and Moloney 1994, Steen 1995). Surprisingly, there are relatively few reports in the literature where different supplementary concentrate types in the diet of growing and finishing cattle offered grass silage-based TMR feeding were examined.

With TMR feeding, DMI increased with the BF25 and BF50 diets but decreased with BF75 as compared with the control diet (II). The increased DMI with the BF25 and BF50 diets to the same level of ME supply as with the control diet suggested a physiological regulation of feed intake. When cattle are fed high-energy rations that are palatable, low in fill and readily digested, feed intake is regulated to meet the energy demands of the animal, unless the diet is fermented too rapidly and digestive disorders occur (Baile and Forbes 1974). This was not likely to occur in experiment II in which the concentrate proportion was 540 g/kg DM and barley grain was replaced partly by BF. It is suggested that, when the energy content of the diet decreases (usually with increasing NDF content), the animal can increase its DMI until rumen fill (Forbes 2007). In experiment II, the silage used was of good nutritional quality and the concentrates were not high in bulk. Therefore the bulls could increase DMI when the energy content of the rations decreased with BF25 and BF50 diets compared with the B diet. Similarly, Jorgensen et al. (2007) reported that substitution of dietary starch by fibre resulted in an increased total DMI, which compensated for the reduced energy content, when young dairy bulls were fed one of the two concentrates: high starch (43% of DM) or low starch (25% of DM). In addition, replacing starch by fibrous concentrate may change rumen fermentation by more efficient cellulolysis in the rumen, especially with high concentrate proportions (Huhtanen et al. 1988). This may partly explain the increased DMI observed with the BF25 and BF50 diets compared with the control diet. However, DMI decreased clearly when 75% of the barley grain concentrate was replaced with BF in experiment II. This suggests that on the BF75 diet the bulls could not compensate the lower energy content of TMR by increasing DMI. This was probably partly due to the palatability of BF which was not very good. Also Huhtanen et al. (1989) reported that the palatability of BF was not good in the study with growing bulls.

In contrast to some other studies (II, Huuskonen et al. 2008) there were no significant treatment differences in the DMI of the bulls in experiment IV, so the bulls did not compensate the lower energy content of oats by increasing silage intake.

In the earlier studies with growing dairy bulls, partial (50%) replacement of barley grain with BF increased feed intake (II, Huuskonen et al. 2008). In these experiments, TMR feeding was used and the average concentrate proportions were higher (II: 540 g/kg DM, Huuskonen et al. 2008: 570 g/kg DM) than in experiment IV (400 g/kg). Therefore, different feeding methods and concentrate proportions may partly explain the differences in feed intake.

3.3.2 Effects of protein feeding

Rapeseed meal supplementation had no effect on feed intake (I, III, IV) which is in accordance with results by Huhtanen et al. (1985, 1989), Aronen (1990) and Steen (1996a). However, in some experiments partial replacement of cereal grains by protein feeds had a small positive effect (3–5%) on intake (e.g. Aronen and Vanhatalo 1992a, Aronen et al. 1992). According to Forbes (2007), supplementation of low-protein roughage with high-protein concentrates stimulates roughage intake. Bandyk et al. (1999) reported that casein infusion in the rumen in steers fed very low-quality tallgrass prairie hay increased intake more than duodenal infusion of casein. Anyway, supplementation of low-protein forage with high-protein concentrates is not always effective in increasing intake (Forbes 2007). If the primary cause of the low-forage intake is not protein deficiency, then no benefit from supplementation with protein may be evident.

The frequently advanced explanation for the positive relationship between feed protein content and voluntary intake is the effect of the CP on microbial activity and the digestion of N in the rumen (Faverdin 1999). Feed digestibility and microbial activity are improved when CP that is degradable in the rumen is added to the diet. Faster and more complete digestion apparently reduces rumen fill and thus enables an increase in feed intake. While this hypothesis is plausible with very poor roughage, it is not convincing for other diets (Forbes 2007). According to Faverdin (1999), adding protein directly to the abomasum or to the duodenum by continuous infusion generally has no significant effect on feed intake, except in a few cases with very poor roughage, grass or grass silage.

With dairy cows, protein supplements have improved milk production of cows fed grass silage-based diets (Huhtanen 1998) through ruminal (Tuori 1992) or postruminal effects (Choung and Chamberlain 1993, Huhtanen et al. 1997). Increased protein (AA) supply has in some, but not all, cases increased forage DMI. For example, Choung and Chamberlain (1992) reported that postruminal casein infusion improved grass silage DMI, but, inversely, Choung and Chamberlain (1993) and Huhtanen et al. (1997) did not observe this. Feeding casein as seven equal meals per day has also been shown to increase alfalfa silage DMI (Robinson et al. 1992). Obviously, the mechanisms by which increased protein (AA) supply increases forage DMI are not completely understood. For example, it is unclear whether postruminal protein supply could affect chewing time, mastication efficiency, digesta flow or ruminal capacity to facilitate higher feed intakes. Khalili and Huhtanen (2002) reported that ruminal casein infusion increased microbial protein synthesis in the rumen, the rate of rumen potentially digestible NDF digestion, and passage of iNDF from the rumen. Duodenal casein infusion increased silage DMI, which was mediated most plausibly as an improved ratio of AA and energy at the tissue level, which enhanced milk production. Cows were able to adjust the time spent eating and chewing accordingly. Khalili and Huhtanen (2002) concluded that silage DMI and milk yield were greatest with a combination of ruminal and duodenal infusion. Increase in silage DMI was mediated as an increase in the rate of passage of potentially digestible NDF. It can be concluded that most of the positive effects of protein supplementation on intake have been observed with dairy cows at higher intakes than with bulls or steers.

3.4 Live weight gain and feed efficiency

3.4.1 Effects of energy feeding

Increasing concentrate proportion led to linearly improved LWG and feed conversion when the D value of the grass silage was 670 g/kg DM (I). The LWG response to concentrate supplementation was 27 g LWG/kg DM additional concentrate, on average (I). When the concentrate proportion increased from 0.3 to 0.5, the LWG response was 33 g LWG/kg DM additional concentrate and from 0.5 to 0.7 the response was 20 g, respectively. The improved LWG was probably due to improved diet digestibility, because DM and energy intakes did not increase with increasing concentrate proportion. However, with silage of higher digestibility, the differences in growth between the concentrate levels might have been smaller, because the optimum input of concentrates is higher with lower digestibility silage (McGee 2005). According to literature, the growth response to concentrate supplementation is generally lower with higher digestibility grass silage (e.g. Drennan and Keane 1987, Steen 1998, Randby 2001), because with high digestibility grass silages there are only slight differences in intake responses between concentrate levels. The relation between concentrate proportion and LWG of bulls or steers fed with silages of different digestibilities is illustrated in Figure 3.

Responses to increasing amounts of concentrate (2-11 kg/d) in terms of carcass gain or LWG have increased linearly (52 and 58 g/kg, Drennan and Keane 1987, Steen 1998, respectively) with moderate quality of silages (DMD 725 g/kg or 625 g/kg DM, respectively), while the respective responses have decreased curvilinearly (130-23 and 93-4 g/kg additional concentrate DM, Caplis et al. 2005, Steen 1998, respectively) with high quality silages (DMD 758 g/kg and 733 g/kg DM, respectively). Martinsson (1990) concluded that increasing the digestibility of grass silage, by harvesting earlier, results in a substantial increase in feed intake and daily gain. Martinsson (1990) also reported that the response in animal performance declines with increasing level of concentrate supplementation and this effect also emerges from Figure 3.

With high-quality silage, a reasonable LWG for dairy bulls (above 0.9 kg/d) can be achieved even when the silage is given alone (Lampila et al. 1988). Where silages were offered as the sole feed, the carcass weight gain was increased by 33 g/d per 10 g/kg increase in silage digestibility (Steen 1988b). Keane (2001) concluded that in order to determine the optimum or break-even level of concentrate supplementation *per se*, estimates of carcass efficiency (kg concentrates per kg carcass), silage substituted (kg DM per kg carcass gain) and the true costs of grass silage and concentrates are required.

Adjusting the ration by increasing the cell wall fraction of the concentrate (Utley et al. 1974) or by increasing the overall roughage intake (Kreikemeier et al. 1990, Zinn and Plascenia 1996) can reduce the risk of liver abscesses and thereby increase the health and welfare of the animals. However, there is a possibility of a reduction in growth when the cell wall or roughage fraction exceeds a certain level and this level is highly dependent on the feed sources used (Utley et al. 1974, Kreikemeier et al. 1990, Zinn and Plascenia 1996). In the present experiments, BF and oats were studied as fibre-rich concentrates. According to experiment II, BF is a suitable energy supplement with good-quality silage for growing dairy bulls. The results indicate that 50% of barley grain can be replaced with BF without affecting growth. However, feed efficiency may decrease when barley grain is replaced with BF because the bulls increase DMI when the energy content of the ration decreases. At 75% replacement DMI decreased, resulting in 8% lower ME intake and a 14% reduction in LWG. In experiment IV, the LWG of the bulls fell 8% as a consequence of decreased energy intake when barley grain was replaced by oats in the diet.

Root and Huhtanen (1998) and Huuskonen et al. (2008) reported no significant differences when replacing barley grain partly with BF in feeding of growing bulls. On the contrary, Huhtanen et al. (1989) reported that replacing barley grain with BF tended to decrease the LWG of growing bulls. This might be explained by the slightly lower energy and protein contents of BF as compared with the BF used in II or in the studies of Root and Huhtanen (1998) and Huuskonen et al. (2008). In the study of Jorgensen et al. (2007), no negative effects of increased fibre content of the concentrate on performance of young dairy bulls were observed. In Irish studies, replacing starch with digestible fibre in the concentrate increased the LWG of cattle offered grass silage-based diets in some studies (Moloney et al. 1993, O'Kiely and Moloney 1994), but not in others (Steen 1995, Moloney 1996, Moloney et al. 2001). In these studies, the concentrate feeding level and silage quality differed widely.

Differences between concentrate energy sources should be more evident at higher concentrate feeding levels (McGee 2005). Ultimately, the rationality of the use of BF

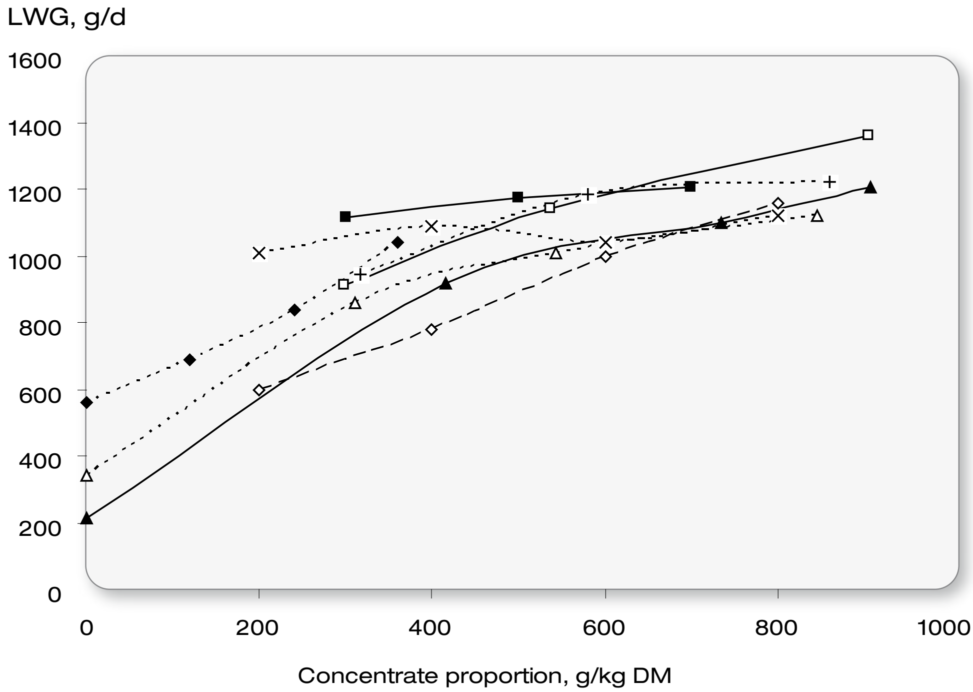

Figure 3. Relationships between concentrate proportion (g/kg DM) and live weight gain (g/d) in I (■), Keane and Fallon (2001 exp. 1, □ , in vitro DM digestibility of silage was 688 g/kg), Keane and Fallon (2001 exp. 2, +, 726 g/kg), Steen et al. (2002 exp. 1, ◊, 643 g/kg), Steen et al. (2002 exp. 2, x, 743 g/kg), Steen and Kilpatrick (2000, ◆ , 734 g/kg), Caplis et al. 2005, Δ, 758 g/kg) and Keane et al. (2006, ▲ , 698 g/kg).

and oats will depend on the price in relation to other concentrates, especially to barley grain. With competition from biofuel production, the relative price and value of grains for animal feeding will change and there may be an economic advantage to use more oats rather than barley for beef production in the future.

The average LWG in I–IV was negatively related to the LW of the bulls and was described by the equation: y = -0.7361X + 1.544.5 (R^2 = 0.30) where Y=LWG (g/day) and X=LW (kg) (Figure 4). Generally, the bulls grew faster during the first months and growth slowed as the animals grew older. It is well established that the performance of growing cattle slows as the animals grow older if they receive feeds evenly throughout the growing period (e.g. Carstens et al. 1991, Ryan et al. 1993).

The average feed conversion rate (kg DM/kg LWG) in I to IV was related to the LW of the bulls and was described by the equation: Y=0.0155X + 0.8932 (R^2 = 0.79) where Y=feed conversion (kg DM/kg LWG) and X=LW (kg) (Figure 5). As a consequence of decreased gain and increased DMI the feed conversion rate fell clearly as the animals grew older. So it is biologically inefficient to raise dairy bulls to heavy carcass weights. However, the average carcass weight of bulls has increased clearly in recent years in Finland (Information Centre of the Ministry of Agriculture and Forestry 2008) because of the pricing principles used for beef. In order to estimate the economically optimum slaughter weight of dairy bulls, it is also necessary to know the slaughterhouse pricing principles as well as the EU and national agricultural support systems.

3.4.2 Effects of protein feeding

There was no growth or feed efficiency response (I, III, IV, RSM and WDS in experi-

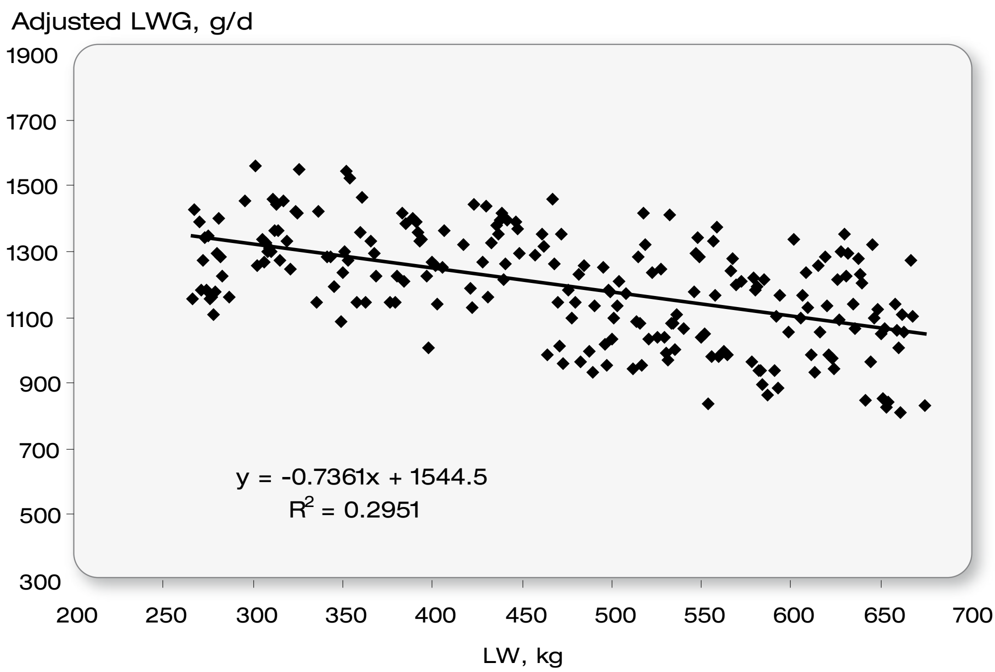

Figure 4. Relationships between live weight (LW, kg) and adjusted live weight gain (LWG, g/d) of the bulls (data in I–IV).

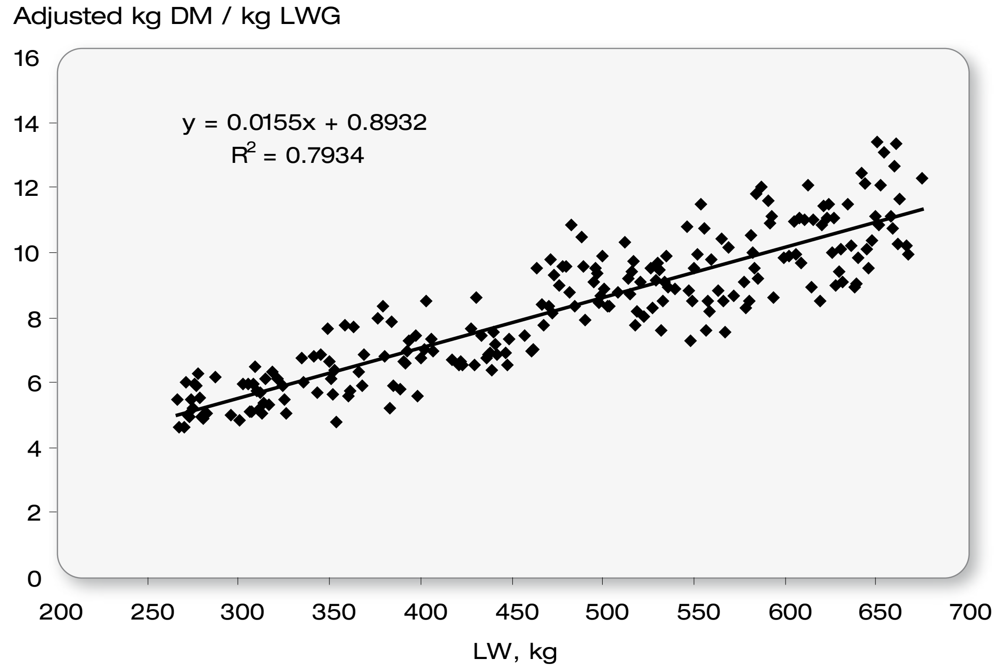

Figure 5. Relationships between live weight (LW, kg) and adjusted feed efficiency (kg DM/kg LWG) of the bulls (data in I–IV).

ment III) or only minor response (BPWDS in experiment III) to protein supplementation. The effect of protein supplementation on LWG has been rather inconsistent in various feeding experiments. In general, the greatest responses have been measured with young cattle (Huhtanen et al. 1985, Veira et al. 1990, Steen 1992) and often the positive effect of protein supplementation on LWG was restricted to only the early phase of the growth period (i.e., LW below 300 kg) (e.g. Huhtanen et al. 1989, Aronen 1990). Also in experiment IV, RSM had a positive effect on LWG during the first sub-experimental period. Similarly, calculations by Titgemeyer and Löest (2001) showed that while amino acids were the limiting factor with lighter weight calves offered grass silage, energy availability was the limiting factor with heavier steers. This shift in the most limiting nutrients as the steers become larger is related to a greater energy to protein requirement for growth by heavier animals. According to Steen (1989b) and Hussein and Jordan (1991), bulls have benefited more from protein supplementation than steers and heifers.

There is evidence that finishing cattle are likely to respond to supplementary protein in barley-based concentrates in situations where the animals are of very high growth potential (late maturing beef breeds) (Steen 1996b). Protein requirements are relatively higher for growing bulls of late maturing breeds (Simmental, Charolais or Limousin) than early maturing breeds (Hereford or Aberdeen Angus) (Geay and Robelin 1979, Geay 1984). For early maturing growing steers the net protein requirements seem to be less important than the energy requirements, because they retain only 12 to 15% of their energy as protein and have only 12% protein in their LWG (Garret 1977). Growing bulls of late maturing breeds retain 35 to 45% of their energy as protein (Rohr and Daenicke 1978, Geay and Robelin 1979). The model of Robelin and Daenicke (1980) showed that protein deposition increases with daily gain regardless of LW. However, with greater LW, the increase was slower. Protein deposition decreases with increasing LW, the decrease being faster with higher daily gain.

The responses to protein supplements seem to be related to the level of concentrate supplement. This concept is confirmed in Figure 6, which presents the effect of protein supplementation on LWG as a function of the concentrate proportion in the diet. In the experiments included in Figure 6, RSM (I, III, IV, Huhtanen et al. 1985, Huhtanen et al. 1989, Aronen 1990, Aronen and Vanhatalo 1992a, Aronen et al. 1992, Scollan et al. 2001), WDS (III, Root and Huhtanen 1998), BP (Aronen 1990), BPWDS (III), soyabean meal (Steen 1991, 1996a, Veira et al. 1994, 1995) or fishmeal (Veira et al. 1985, 1994, 1995, Scollan et al. 2001) was fed to growing cattle. Growing cattle fed grass silage alone respond to protein supplementation with ruminally undegraded protein with relatively large improvements in LWG (Titgemeyer and Löest 2001). Supplementation of grass silage alone with a rumen-degradable source of protein has also increased the gain of growing steers (Veira et al. 1995, Scollan et al. 2001). Including rumen-undegradable protein increased the LWG of young steers offered grass silage plus low levels of concentrate (Moloney 1991, 1993, Rouzbehan et al. 1996). Where young growing cattle are offered grass silage *ad libitum* and a low-level barley-based concentrate, the inclusion of rumen-degradable protein increased (Moloney 1991) or had no significant effect (Keane 2002) on the growth

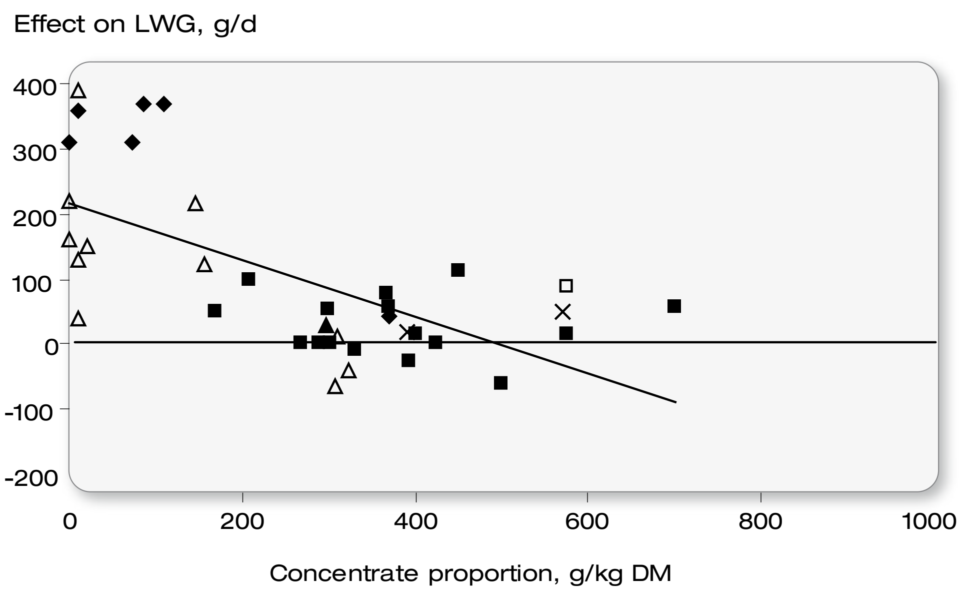

Figure 6. Effect of protein supplementation on the rate of live weight gain (LWG, g/d) as a function of concentrate proportion (g/kg DM). In the experiments included RSM (■) (I, III, IV, Huhtanen et al. 1985, Huhtanen et al. 1989, Aronen 1990, Aronen and Vanhatalo 1992a, Aronen et al. 1992, Scollan et al. 2001), WDS (X) (III, Root and Huhtanen 1998), BP(▲) (Aronen 1990), BPWDS (□) (III), soyabean meal (Δ)(Steen 1991, 1996a, Veira et al. 1994, 1995) or fishmeal (◆) (Veira et al. 1985, 1994, 1995, Scollan et al. 2001) was fed to growing cattle.

rate. In addition, in several studies a major part of the advantage of protein supplementation of young cattle was lost during the finishing period due to compensatory growth (Seoane et al. 1993, Titgemeyer and Löest 2001, McGee 2005). However, in the studies mentioned earlier, the age of the animals and the silage quality (CP concentration, fermentation quality) differed widely, which could affect the conclusions.

The rate of protein synthesis in the rumen improved with a moderate addition of barley-based concentrate to a silage diet (Thomas et al. 1980, Rooke et al. 1985), whereas further substitution gradually reduced the efficiency of synthesis (Harstad and Vik-Mo 1985). Hagemeister et al. (1980) reported a tendency towards lower protein synthesis with rations containing very low (0–20%) or very high (70–100 %) proportions of concentrate. According to Aronen (1992), a medium level of concentrates together with well preserved grass silage may sustain efficient microbial protein production. Therefore, it is likely that a greater response to protein supplementation is to be expected when small rather than large amounts of concentrates are fed to growing cattle on grass silage-based feeding.

The responses to protein supplements are related to the quality of grass silage used. There is evidence that growing cattle are likely to respond to supplementary protein in barley-based concentrates when the digestibility of the grass silage is moderate to low (Waterhouse et al. 1985, Steen 1988b). With poorly preserved silage the response in animal performance to protein supplementation is greater than with well-preserved silage (Hussein and Jordan 1991). There are also differences between extensively and restrictively fermented silages, which both may be well-preserved. Jaakkola et al. (1990) reported that the gain response of growing cattle to fishmeal was greater when enzyme solution (cellulose–glucose oxidase) was used as a silage additive instead of formic acid.

Grass silage generally contains high levels of CP, but much of this protein is either non-protein N or is extensively degraded during the silage fermentation (McDonald et al. 1991). Thus, the rumen-undegraded protein content of grass silages is usually quite low. Additionally, the energy available for fermentation by ruminal microbes is low in silages due to its utilization by microbes during the silage fermentation (Titgemeyer and Löest 2001). This leads to lower amounts of microbial protein production in the rumen when cattle are fed silage rather than fresh or dried forage. These factors taken together account for the greater energy to metabolizable protein ratios supplied by silage and, thus, the greater ability of cattle fed silage to respond to rumen-undegraded protein supplementation. Therefore, in contrast to the situation for grazing cattle, cattle fed grass silage have responded to RUP supplementation with relatively large improvements in some feeding studies. For example, Veira et al. (1985, 1988, 1990, 1995), Petit and Flipot (1992), Sanderson et al. (1992) and Nelson (1997) all observed improvements in gain ranging from 0.2 to 0.45 kg/d when growing cattle fed grass silage were supplemented with fishmeal or other RUP sources. However, most of these studies were based on the performance of cattle fed only grass silage with or without RUP supplementation. Supposedly, there would have been less response to protein supplementation if there were also concentrate available. In addition, results with grass silage are dependent on the quality of silage that may vary considerably with the ensiling technique. Jaakkola et al. (2006) observed that restriction of silage fermentation by formic acid is positively related to the synthesis of microbial protein in the rumen.

In I and IV, the D value of the silages was high (IV: 686 g/kg DM, on average) or moderate (I: 668 g/kg DM, on average), the fermentation quality of the silages was good and the silages were restrictively fermented with high residual WSC concentration and low lactic acid concentration. In addition, there were at least 30% concentrates in all the treatments, so the microbial protein synthesis can be assumed to have been high. These factors may explain that RSM supplementation had no effect on animal performance. In experiment III, the D value of the silage was lower (653 g/kg DM) than in I and IV, and the silage had a slightly lower residual WSC concentration and a higher lactic acid concentration than the silages in I and IV. However, the microbial protein synthesis can be assumed to have been relatively high also in experiment III because of the lack of response (RSM and WDS) or only minor response (BPWDS) to protein supplementation.

3.5 Carcass characteristics

3.5.1 Effects of energy feeding

The dressing proportion was not affected by either the concentrate proportion or the composition (I, III, IV), except in experiment II where the dressing proportion decreased linearly with partial replacement of barley grain with BF. Also Root and Huhtanen (1998) reported that the dressing proportion tended to be lower for BF than for barley grain diets. It was assumed that this might be due to differences in rumen fill. Root and Huhtanen (1998) supposed that compared with bulls fed BF, bulls fed barley grain may have stopped eating with a smaller rumen fill for metabolic reasons, mainly due to feedback caused by an increased amount of rumen fermentation end products, leading to lighter weight of rumen contents with barley grain. However, the effect of fibrous concentrate on the dressing proportion is not very clear. For example, no effects on dressing proportion were reported when barley grain was replaced with BF (Huhtanen et al. 1989) or sugar beet pulp (Jaakkola and Huhtanen 1990). Contrary to earlier results by Drennan and Keane (1987), Keane and Drennan (1994), Caplis et al. (2005) and Keane et al. (2008), concentrate proportion had no effect on the dressing proportion (I).

The carcass conformation score was not affected by the treatments (I, III, IV), except in experiment II. Increasing the proportion of BF had a significant quadratic effect with the BF25 and BF50 diets inducing the highest scores. The explanation for this quadratic effect is not clear. Higher energy intake probably partly explains the increased conformation score with the BF25 and BF50 diets. Caplis et al. (2005) reported that carcass conformation of finishing steers increased with increasing concentrate level and energy intake. In previous studies with barley by-products (Huhtanen et al. 1989, Root and Huhtanen 1998), the carcass conformation or fat score of bulls was not significantly affected by BF replacement. However, in the studies by Huhtanen et al. (1989) and Root and Huhtanen (1998), the carcass weights were considerably lower (224 kg and 260 kg, respectively) than in experiment II (342 kg).

The carcass fat score increased linearly with increasing concentrate proportion (I) and decreased linearly with partial replacement of barley grain with BF (II). According to literature, reducing energy intake usually decreases carcass fat content (Bowling et al. 1978, Harrison et al. 1978, McCartor and Smith 1978, Fishell et al. 1985, Patil et al. 1993, Schaake et al. 1993), which could explain the lower fat classification on the BF75 diet. Similarly, increasing the concentrate level has usually increased the carcass fat content (Thomas et al. 1988, Martinsson 1990, Aronen et al. 1994, Aronen and Toivonen 1995, Joki-Tokola et al. 1995, Keane et al. 2008), although the animals were slaughtered at the same carcass weights. In experiment II, the slaughter weight decreased with increasing level of BF, which probably also explained the decreasing fat score because measures of fatness generally increase with increasing carcass weight (Keane and Allen 1998). For cattle finished on grass silage and concentrates, Steen and Kilpatrick (2000) concluded that reducing slaughter weights is likely to be a more effective strategy to control carcass fat content than reducing energy intake either by diet restriction or concentrate proportion.

3.5.2 Effects of protein feeding

In accordance with many earlier studies (Huhtanen et al. 1985, 1989, Gill et al. 1987, Bailey 1989, Aronen 1990, Solomon and Elsasser 1991, McKinnon et al. 1993, Fiems et al. 1995, Root and Huhtanen 1998), there were no effects of protein supplementation on the dressing proportion, carcass conformation score or carcass fat score (I, III, IV). However, Berge et al. (1993) reported that steers which were given protein supplementation have leaner carcasses than steers which were not given protein supplementation. On the contrary, Steen (1996a) reported that there was a tendency for steers given concentrates containing soyabean meal to produce fatter carcasses than those given barley alone. Also Steen (1988c) and Steen and Moore (1988, 1989) found that similar increases in protein intake tended to increase carcass fatness, although the effects only reached significance when the combined results of a series of experiments were analysed together (Steen 1988b). Lowman et al. (1985) also found that supplementing grass silage with a mixture of barley and fishmeal rather than with barley alone produced a reduction of 3% in the lean content of the fore-rib joint of steers. There would appear to be no information on the reasons for increased fat deposition in cattle with higher intakes of protein. However, Waghorn et al. (1987) found that increasing the protein intake of wether sheep reduced circulating growth hormone concentrations and increased fat synthesis. The effects of protein intake on carcass fatness may also be related to the growth potential of the cattle as higher protein intakes have increased carcass fatness in animals of lower growth potential, but not in those of higher growth potential (Lowman et al. 1985, Steen 1988b, 1991). So the possible effects of protein supplementation on carcass characteristics were found in most cases with steers and heifers, but not with bulls.

In some old studies (e.g. McCarrick 1966, Lonsdale 1976), cattle given grass silage produced fatter carcasses than those given dried forage. This has been attributed to the low nitrogen retention from silage (Lonsdale 1976). However, Steen (1996a) reported that the dried forage-based and isonitrogenous well-preserved-silage-based diets produced carcasses of similar fatness. In addition, Steen (1988b) concluded that supplementing well-preserved grass silages with mixtures of barley and soyabean meal or barley and fishmeal rather than with barley alone did not affect the performance of finishing steers, but tended to increase carcass fatness. So it can be concluded that also the carcass fatness results with grass silage-based feeding are dependent on the quality of the silage that may vary considerably with the ensiling technique.

3.6 Nutrient supply in relation to current feeding recommendations

3.6.1 Metabolizable energy

The current Finnish daily energy recommendations (ME, MJ/d) for dairy bulls (MTT 2006), and the average energy intake from I to IV are presented in Figure 7 and Table 3. During the feeding experiments the calculated supply of energy was on average 10% higher than in the Finnish feeding recommendations (MTT 2006) for the present growth rate. The calculated supply of energy was higher than the recommendations throughout the experiments, but the difference between the calculated supply and the recommendations was greatest during the experimental periods 2 to 4 (Table 3, Figure 7) when the LW of the bulls was 300-400 kg. Experiments I-IV indicate that there is a need to revise the current Finnish energy recommendations and also a need for further calculations of the energy supply for growing dairy bulls.

3.6.1.1 Total mixed ration vs. separate feeding

The difference between recommended and calculated energy supplies tended to be slightly smaller with separate feeding (7.5% in IV, on average) than with TMR feeding (8.5% in I, 12% in II and III, on average). Some earlier studies have shown changes in DMI due to feeding method. A small positive effect (4–5%) of TMR feeding on the DMI of finishing steers was noted by Caplis et al. (2005), Keane et al. (2006) and Keane et al. (2008). Before the advent of mixer wagons, Petchey and Broadbent (1980) compared separate or mixed (in the trough) feeding of silage and concentrates for finishing cattle on silage, concentrate ratios ranging from 0 to 1.0. Mixing increased DMI proportionately by 0.09 with no evidence of an interaction between feeding method and silage:concentrate ratio. Studies with dairy cows have shown both increased (e.g. Gill and Castle 1983) and decreased (e.g. Gaynor et al. 1989) intakes due to TMR feeding. Gordon et al. (1995) summarised 13 studies with dairy cows and reported a mean intake increase due to TMR of proportionately 0.06, while Patterson and Mayne (1997), who also compiled results from a series of experiments, concluded that TMR had no effect on intake. The explanation for the contrasting conclusions was that the latter studies involved out-of-parlour feeding in which the concentrates were offered up to four times daily, whereas in the former concentrates were fed twice a day. According to Phipps et al. (1984), some intake increases with TMR can be explained by the rejection of unpalatable feeds in unmixed rations, something that is not possible with TMR feeding. Otherwise, intake increases could be due to the extra processing that occurs during the preparation and mixing of the TMR or to the fact that whole diet is constantly available (Keane et al. 2006)

Caplis et al. (2005) reported no effect of feeding method (separate vs. TMR) on the LWG of steers despite a small positive effect of TMR feeding on DMI. Instead, Keane et al. (2006) reported that there was a small positive effect of mixing on the LWG of finishing steers on the first 41 days at the low concentrate level (400 g/kg DM). However, there was no effect of mixing on the overall LWG (Keane et al. 2006). This is not consistent with the findings of Cooke et al. (2004) who reported that mixing of maize silage, grass silage, straw and concentrates resulted in a LWG response of proportionately 0.15 for an intake increase of proportionately 0.04. The contrasting results between studies may be due to differences in the silages used in the diets. Maize silage plus grass silage was used in the study by Cooke et al. (2004), but only grass silage in the studies by Caplis et al. (2005) and Keane et al. (2006). It has been observed with dairy cows that when a benefit was obtained from TMR feeding, forages other than grass silage were used (Yan et al. 1998).

3.6.2 Protein

The current daily protein recommendations (AAT, g/d) for dairy bulls (MTT 2006) and the average AAT intake from I to IV are presented in Figure 8 and Table 3. During the feeding experiments the calculated supply of AAT was on average 38% higher than in the Finnish feeding recommendations (MTT 2006) for the present growth rate. The difference between the calculated AAT supply and the recommendations was lowest at the beginning of the

Table 3. Daily metabolizable energy (ME, MJ/d), protein (AAT, g/d) and phosphorus (P, g/d) recommendations for bulls (MTT 2006) and intake/recommendation ratio from I-IV during different experimental periods, on average.

Period	1	2	3	4	5	6	7	8	9	10	11	12
Total n	208	208	208	208	208	208	208	207	207	199	132	83
Average LW, kg	277	315	354	394	433	472	507	540	572	599	633	658
Average LWG, g/d	1266	1357	1332	1349	1305	1252	1084	1176	1052	1092	1119	961
ME recommendation, MJ/d	72	77	84	90	97	102	106	110	113	116	121	123
AAT recommendation, g/d	535	569	594	619	638	657	669	679	690	696	704	706
P recommendation, g/d	23	24	25	25	25	26	26	27	27	28	29	29
Intake/recommendation												
ME whole data [1]	1.06	1.12	1.12	1.12	1.08	1.10	1.06	1.04	1.05	1.05	1.07	1.09
ME TMR [2]	1.07	1.11	1.14	1.12	1.09	1.07	1.07	1.06	1.07	1.03	1.08	1.09
ME separate [3]	1.04	1.16	1.06	1.11	1.07	1.17	1.04	1.00	1.01	1.11	1.06	1.10
AAT whole data [4]	1.14	1.24	1.32	1.36	1.37	1.44	1.40	1.39	1.45	1.46	1.52	1.54
AAT without PS [5]	1.12	1.24	1.26	1.30	1.31	1.38	1.32	1.37	1.42	1.45	1.49	1.47
AAT with PS [6]	1.17	1.25	1.39	1.43	1.44	1.51	1.50	1.42	1.47	1.48	1.55	1.60
P whole data [7]	1.02	1.13	1.20	1.26	1.27	1.33	1.29	1.27	1.28	1.30	1.33	1.36
P without PS [8]	1.00	1.09	1.16	1.22	1.24	1.29	1.24	1.25	1.26	1.28	1.31	1.32
P with PS [9]	1.03	1.13	1.24	1.30	1.31	1.37	1.34	1.29	1.30	1.32	1.35	1.43

[1] ME of whole data from I-IV.
[2] ME of TMR feedings (I-III).
[3] ME of separate feedings (IV).
[4] AAT of whole data from I-IV.
[5] AAT of feedings without protein supplementation.
[6] AAT of feedings with protein supplementation.
[7] P of whole data from I-IV.
[8] P of feedings without protein supplementation.
[9] P of feedings with protein supplementation.

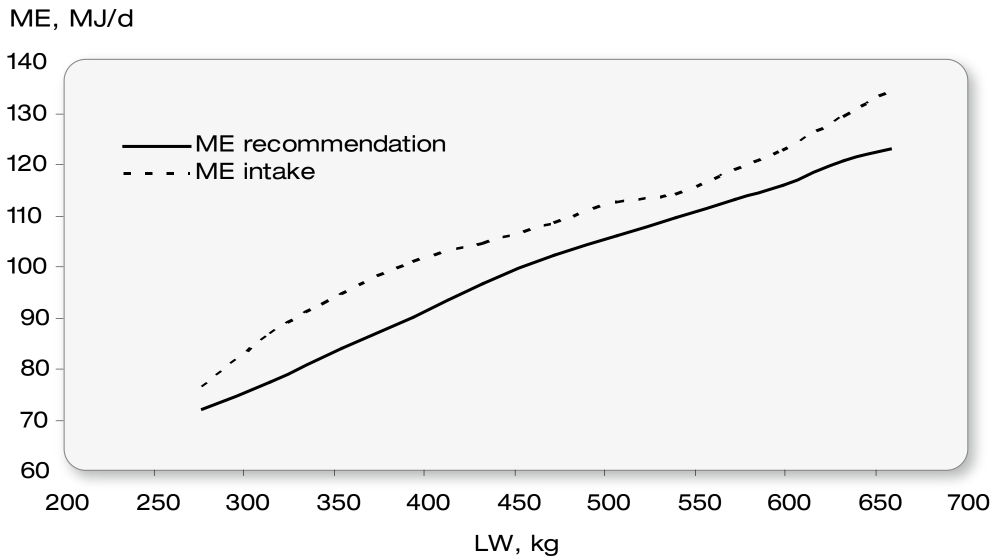

Figure 7. Finnish feeding recommendations for metabolizable energy (ME, MJ/d) (MTT 2006) for the present growth in experiments I-IV, on average (ME recommendation), and calculated supply of ME during the feeding experiments (data from I-IV) (ME intake).

feeding experiments (14% during the first experimental period), but the difference increased clearly as the bulls grew older, even exceeding 50% at the end of the feeding experiments (Table 3, Figure 8). The difference between the calculated AAT supply and the feeding recommendations was naturally greater when supplementary protein was used than with feedings without protein supplementation (Table 3). The calculated supply of AAT was higher than in the Finnish feeding recommendations in almost all feeding groups and all periods. Only for LW less than 400 kg in H RSM feeding (concentrate proportion 700 g/kg DM, without protein supplementation) was the supply of AAT slightly lower than in the recommendations for the present growth.

It is concluded that in most cases the dairy bulls (LW more than 250 kg) received enough protein from the basic diet without protein supplementation. Protein supplementation did not affect animal performance. Thus, protein supplement is not needed for growing and finishing dairy bulls when they are fed good-quality grass silage and grain-based concentrate with a moderate (300-700 g/kg DM) proportion of concentrate. Feeding additional protein puts an unnecessary load on the animal's metabolism and also causes significant water pollution when discharged into surface water through runoff or deposited in water from aerial emissions (e.g. Klopfenstein and Erickson 2002). Decreasing dietary protein inputs in feeding could potentially decrease environmental concerns related to air and water quality (Cole et al. 2003).

The great difference between the calculated AAT supply and current Finnish protein feeding recommendations could indicate that the present AAT-PBV system is not an optimal protein evaluation system for growing dairy bulls of more than 250 kg LW. However, in order to establish superior protein feeding standards for growing dairy bulls, further calculations and comparisons between different systems should be carried out.

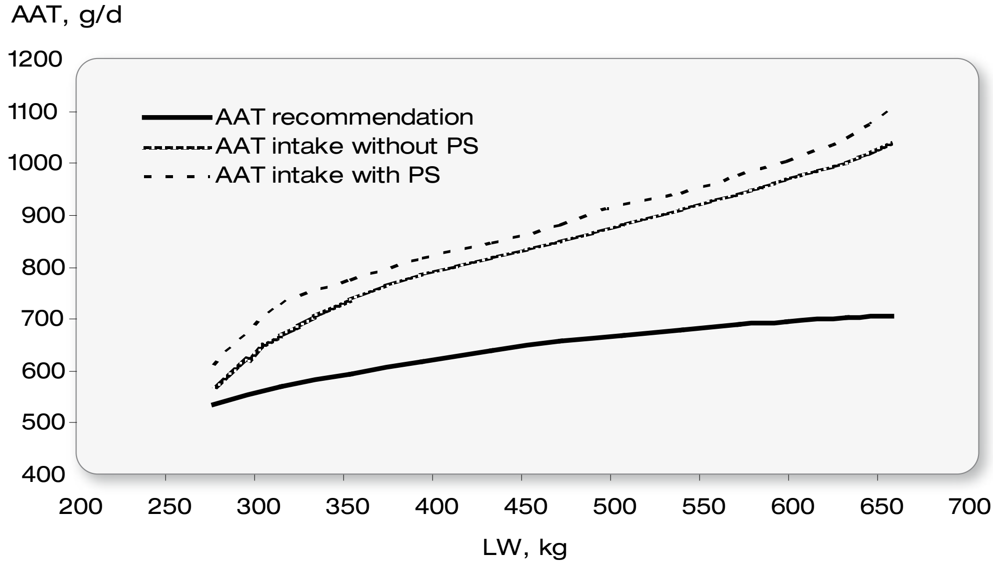

Figure 8. Finnish feeding recommendations for AAT (g/d) (MTT 2006) for the present growth in experiments I-IV, on average (AAT recommendation), and calculated supply of AAT during the feeding experiments with (AAT intake with PS) or without (AAT intake without PS) protein supplementation (data from I-IV).

3.6.3 Phosphorus

The current daily P recommendations (g/d) for the dairy bulls (MTT 2006) and the average P supply from I to IV are presented in Figure 9 and Table 3. During the feeding experiments the calculated supply of P was on average 25% higher than in the Finnish feeding recommendations (MTT 2006). During the first experimental period (when the LW of the bulls was under 300 kg), the calculated supply of P was almost at the same level as the recommendations (Table 3). The difference between the supply and the recommendation increased clearly as the bulls grew older, even exceeding 30% at the end of the feeding experiments (Table 3, Figure 9). The difference between the calculated P supply and the feeding recommendations was greater when supplementary protein was used than with the feedings without protein supplementation (Table 3). During the feeding experiments the calculated supply of P was on average 22% higher than in the Finnish feeding recommendations for the feedings without supplementary protein. Correspondingly, for the feedings with supplementary protein the supply was 28% higher than the recommendations.

The P content of all protein supplements (especially WDS) used in the present feeding experiments was high relative to silage, barley and BF. However, the supply of P was sufficient also with the diets without protein supplementation throughout the feeding experiments although mineral feeds of low P content were used throughout the experiment. This indicates that in most cases the dairy bulls (LW more than 250 kg) received enough P from the basic grass silage-cereal-based diets without additional mineral feeds.

Considerable attention has been paid to the availability of P. Presumably, non-phytate P in forages and other feeds is readily available for absorption by ruminants (Kincaid and Rodehutscord 2005). For example, Lofgreen and Kleiber (1954) reported about 94% of the P in lucerne to be absorbed by sheep. However, although the leaves and stems of plants contain only trace amounts of phytin (phytic acid [myo-inositol hexakisphosphate] and its salts), about two-thirds of P is present as phytin-P in cereal grains, oilseeds and grain by-products (Nelson et al. 1976, Eeckhout and De Paepe 1994). Phosphorus in phytin form cannot be absorbed by animals unless the P is hydrolysed (Kincaid and Rodehutscord 2005). For example, experiments with chicks have shown that the P of calcium phytate is utilized only 10% as effectively as disodium phosphate (McDonald et al. 1988). In pigs, some of the phytate P is made available in the stomach by the action of plant phytase enzymes present in the food (McDonald et al. 1988). It has also been shown with sheep that hydrolysis of phytates by bacterial phytases occurs in the rumen (Kincaid and Rodehutscord 2005). Phytase activity in the rumen is largely of bacterial origin and associated with the cell pellet, not the ruminal fluid supernatant (Yanke et al. 1998). The highest phytase activity is produced by those strains of ruminal bacteria associated with starch fermentation and not with protozoa and fungi. The implication is that for myo-inositol hexakisphosphate to be hydrolysed, the phytate must be consumed by the bacteria (Yanke et al. 1998, Kincaid and Rodehutscord 2005). It can be concluded that dietary phytin can be efficiently hydrolysed in the rumen in the presence of the enzyme phytase produced by rumen bacteria and that this contributes to the overall high level of P availability found in ruminants. Therefore there is no need to add P in the form of mineral mixtures. Feeding additional protein increases the P excretion to the environment, because increasing the P content of the diet will lead to higher P content of manure (Satter 2003).

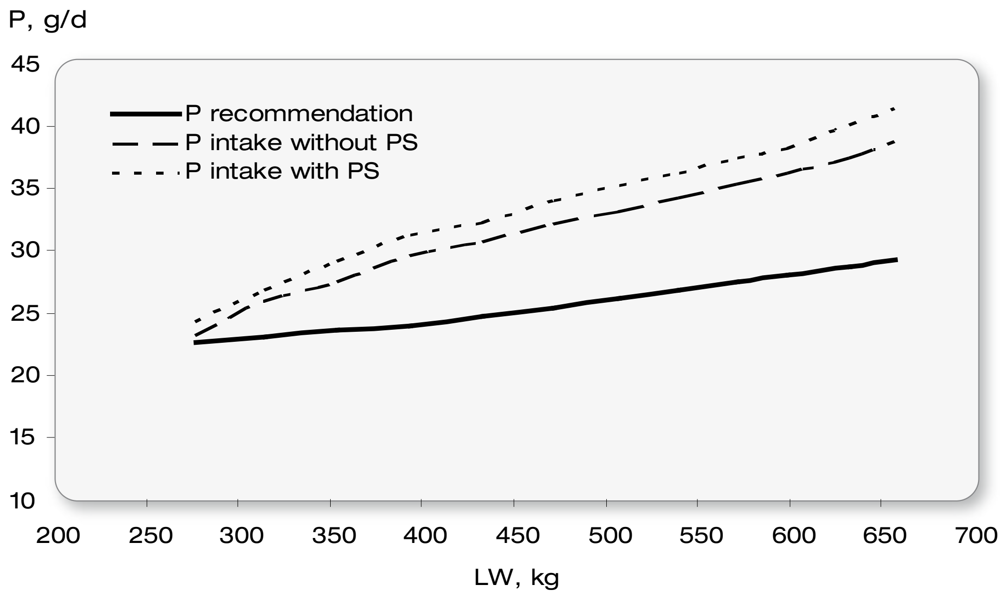

Figure 9. Finnish feeding recommendations for P (g/d) (MTT 2006) for the present growth in experiments I-IV, on average (P recommendation), and calculated supply of P during the feeding experiments with (P intake with PS) or without (P intake without PS) protein supplementation (data from I-IV).

4 General conclusions and practical applications of the results

1. With TMR feeding it is possible to use rather high concentrate proportions (700 g/kg DM) in feeding dairy bulls. In the present study, the LWG response to concentrate supplementation was 27 g LWG/kg DM additional concentrate, on average, when the concentrate proportion increased from 300 to 700 g/kg DM. In order to determine the optimum proportion of concentrate supplementation, estimates of carcass efficiency (kg concentrates per kg carcass), silage substituted (kg DM per kg carcass gain) and true price of concentrates relative to that of forages are required.

2. Protein supplementation did not affect animal performance in the present study. Thus, protein supplement is not needed for finishing dairy bulls (LW more than 250 kg) when they are fed good-quality grass silage (D value more than 650 g/kg DM, restricted fermentation with low concentrations of fermentation acids and ammonia N) and grain-based concentrate with a moderate (300-700 g/kg DM) concentrate level.

3. Barley fibre is a suitable energy supplement with good-quality silage for growing dairy bulls. The results suggest that 50% of barley grain can be replaced with BF without affecting growth. As a consequence of decreased energy intake, the LWG and feed conversion of the bulls were slightly reduced when barley grain was replaced by oats in the diet. Ultimately, the rationality of the use of BF and oats in the future will depend on the price in relation to other concentrates.

4. During the feeding experiments the calculated supply of energy was 10% higher than in the Finnish feeding recommendations for the present growth rate. This indicates that there is a need to update the Finnish feeding recommendations for dairy-breed growing bulls, and further calculations are needed for the energy supply of growing dairy bulls.

5. The calculated supply of AAT was 38% higher than in the Finnish feeding recommendations for the present growth. Possibly, the present AAT-PBV system is not an optimal protein evaluation system for growing bulls of more than 250 kg LW. In order to establish superior protein feeding standards for growing dairy bulls, further calculations and comparisons between different systems should be carried out.

6. The calculations based on the feeding experiments indicate that in most cases the dairy bulls (LW more than 250 kg) received enough P from the basic grass silage-cereal-based diets without additional mineral feeds. Therefore there is no need to add P in the form of mineral mixtures. Also feeding additional protein increased the P excretion to the environment, because the P content of protein supplements is generally high relative to that of grass silage and cereals.

7. As a consequence of the decreased gain and increased intake the feed conversion rate declined clearly as the bulls grew older. It is biologically very inefficient to raise dairy bulls to heavy carcass weights. In order to estimate

the economically optimum slaughter weight for dairy bulls, information is also required on the pricing principles of the slaughterhouses and the EU and national agricultural support systems.

Further research:

1. Re-evaluation of the Finnish feeding recommendations for energy and protein for dairy bulls (LW more than 250 kg) should be considered.

2. Economic evaluation of different feeding strategies for growing and finishing bulls should be carried out.

3. In the future there is need to develop models of the production responses of bulls to changes in nutrient supply as an aid to decision making on farms. A large data set from beef production trials based on grass silage feeding should be collected for meta-analysis. The data set should be used to predict the production responses and changes in feed intake for various dietary manipulation methods. The models should be used to evaluate different feeding regime choices on a farm level based on their economic perfomance and nutrient balances.

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Effects of three different concentrate proportions and rapeseed meal supplement to grass silage on animal performance of dairy-breed bulls with TMR feeding

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Abstract

A 3×2 factorial design with growing dairy-breed bulls was used to study the effects on animal performance of (1) proportion of concentrate (rolled barley) in the diet, and (2) inclusion of rapeseed meal (RSM) in the barley-based concentrate in a total mixed ration (TMR). The interactions between concentrate proportion and RSM supplement were also examined.

Three feeding experiments comprised in total of 84 Finnish Ayrshire bulls and 6 Friesian bulls. The bulls were fed TMR *ad libitum*. The three concentrate proportions were 300 (L), 500 (M) and 700 (H) g/kg dry matter (DM), fed without RSM (RSM−) or with RSM (RSM+). Rapeseed meal was given so that the crude protein (CP) content of the concentrate was raised to 160 g/kg DM in the RSM+ diets. In the RSM− diets the CP content of the concentrate was 128 g/kg DM, so the CP content increased 25% with RSM supplementation. Increasing the proportion of concentrate led to a linear improvement in daily live weight gain (LWG) ($P<0.05$), but there were no significant treatment differences in the DM intake (kg/d). Increasing the proportion of concentrate also led to significantly higher CP ($P<0.001$) and phosphorus (P) ($P<0.001$) supply and significantly improved DM and organic matter (OM) digestibility ($P<0.001$). However, the digestibility of neutral detergent fibre (NDF) decreased ($P<0.001$) as the proportion of concentrate increased. The feed conversion rate (kg DM/kg LWG) decreased significantly with increasing concentrate proportion ($P<0.001$). Rapeseed meal supplement had no effect on animal performance, but the supply of CP ($P<0.01$) and P ($P<0.001$) was higher when RSM was included in the diet. The CP ($P<0.001$) and NDF ($P<0.05$) digestibilities were also higher for the RSM+ diets than for the RSM− diets. Because RSM at the concentration used did not affect animal performance, there is no reason to use RSM supplementation for finishing dairy bulls when there is good quality grass silage and barley-based concentrate in the TMR ration. This study also shows that there is a need to update the Finnish feeding recommendations for dairy-breed growing bulls, and extra calculations are needed for the energy and protein supply of growing dairy bulls.

Keywords: Beef production; Dairy-breed bulls; Total mixed ration; Supplementary protein; Concentrate supplementation

1. Introduction

Beef production in Finland is based mainly on raising Finnish Ayrshire and Friesian bulls born on dairy farms. The supply of domestic beef has been decreasing in

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Finland during recent years, giving rise to a clear discrepancy between the demand for and supply of domestic beef. Because of this trend the average carcass weight of bulls has increased from 270 kg (1999) to 320 kg (2004) in five years. However, there exist no data from feeding trials about the performance of dairy-breed bulls when the carcass weight is over 300 kg.

Previously livestock production in Finland was largely based on grass silage feeding, but in recent years barley has been used more in cattle feeding since the European Union policy has reduced the price of grain relatively to that of forages. Nowadays grain is such an inexpensive source of energy that it may be economically advantageous to feed cattle grain-based diets rather than silage-based diets. A number of studies have examined the response to concentrate feeding level with grass silage in growing cattle (Drennan and Keane, 1987b; Martinsson, 1990; Agnew and Carson, 2000). Increasing the amount of concentrates usually increases the total feed intake but decreases the forage intake in separate feeding. However, the use of total mixed ration (TMR) in beef production systems is receiving considerable attention although only a few studies (e.g. Caplis et al., 2005; Keane et al., 2006) have been published on different proportions of concentrates in TMR feeding. Relative to the dairy cow, much less research has been carried out on the TMR feeding of beef cattle and there is lack of information on the effects of different proportions of concentrates in TMR feeding on the performance of dairy-breed bulls with high carcass weights.

In Finland, rapeseed meal (RSM) is the most important protein feed used in concentrates for cattle, and the need for supplementary RSM in growing cattle has been studied in a series of four research trials (Aronen, 1990; Aronen and Vanhatalo, 1992a,b; Aronen et al., 1992). The initial live weight (LW) of these bulls was 100 kg and the final LW 500 kg, on the average. Inclusion of RSM in the diet was found to have a positive effect on animal performance in some feeding experiments (Aronen and Vanhatalo, 1992a; Aronen et al., 1992). This positive effect was often mediated by increasing grass silage intake, but the effect is possible only with separate feeding. Thus it is of interest to obtain more information concerning animal performance when growing cattle are fed a TMR diet. Besides, the possibility that the enhanced animal performance was caused by an increased amount of amino acids flowing to the intestines could not be excluded. There are also experiments in which increasing protein intake by using either a rumen undegradable (fish meal) (Drennan et al., 1994) or degradable (soybean meal) (Drennan et al., 1994; Steen and Robson, 1995; Steen, 1996) protein source did not significantly affect animal growth, so the effect of protein supplementation in different experiments has been rather inconsistent. In addition, there are no data from any study on the performance of dairy-breed bulls when the protein source is RSM with TMR feeding.

The objectives of the present study with growing dairy-breed bulls raised to a final LW of 630 kg were to determine the effects on animal performance in various growth periods of (1) the proportion of concentrate in the diet, and (2) the inclusion of RSM in the barley-based concentrate in TMR feeding. Possible interactions between concentrate proportion and protein supplement were also examined.

2. Materials and methods

2.1. Animals, feeds, housing and diets

The first experiment started in March 2002, the second in October 2002 and the third in May 2003. The trials were conducted in the experimental barn of the North Ostrobothnia Research Station of MTT Agrifood Research Finland. The first experiment comprised 30 Finnish Ayrshire bulls; the second experiment comprised 29 Finnish Ayrshire bulls and one Friesian bull. The third experiment comprised 25 Finnish Ayrshire bulls and five Friesian bulls. Two animals were excluded from the study due to several occurrences of bloat, two animals due to pneumonia and two animals due to hoof problems. There was no reason to suppose that the diets had caused these problems.

All animals were purchased from local dairy farms when they were initially 48 kg LW and 15 d old on average. Before the beginning of the trials the animals were housed on peat bedding in six pens (3.0 × 3.5 m; 5 calves in each) providing 2.1 m^2 per calf. They received milk replacer, grass silage and a commercial pelleted calf starter (12.3 MJ of metabolizable energy (ME)/kg of DM) during the preweaning period (from 0.5 to 2.5 months old). The average dry matter intake (DMI) during the preweaning period was 1.34 kg/d and the average ME intake was 18.4 MJ/d. During the postweaning period (from 2.5 to 6.5 months old) the animals received grass silage and concentrates (commercial pelleted calf starter, barley and RSM). During the postweaning period the average DMI was 4.56 kg/d and ME intake 55.2 MJ/d. All the animals remained generally healthy throughout the preweaning and postweaning periods after the first 2 weeks when there were some incidences of diarrhea with episodes lasting 2 d on average. During the preweaning period, some calves lost hair from their legs and around the mouth, but no real morbidity problems were observed and calves grew normally. The average live-weight gain (LWG) was 739 g/d during the preweaning period and 1227 g/d during the postweaning period. No medications were used in any of the feeds.

At the start of the experiments the animals were 6.5 months old. They were divided into five blocks by LW and randomly assigned to treatments within each block. The animals were housed in a tie-up barn and individually fed twice a day (at 8:00 a.m. and 6:00 p.m.). The bulls had free access to water from an open water bowl during the experiments.

The bulls were fed TMR *ad libitum* (proportionate refusals as 5%). A 3 × 2 factorial design was used to study the effects of concentrate proportion and RSM inclusion in the barley-based concentrate. The three concentrate proportions were 300 (L), 500 (M) and 700 (H) g/kg DM, fed without RSM (RSM−) or with RSM (RSM+). The concentrate used was rolled barley. Rapeseed meal was given so that the crude protein (CP) content of the concentrate was raised to 160 g/kg DM in the RSM+ diets. Therefore the amount of RSM supplement depended on the CP content of the barley, which was measured by chemical analyses. In the RSM− diets the CP content of the concentrate was 128 g/kg DM, so the content increased 25% with RSM supplementation. The daily ration also included 150 g of a mineral mixture (Feedmix Ltd, Finland: Tähkä Apekivennäinen: Ca 235, P 8, Na 74, Mg 40 g/kg). A vitamin mixture (Suomen Rehu, Finland: Xylitol ADE-Vita: A 2,000,000 IU/kg, D_3 400,000 IU/kg, E DL-α-tocopheryl acetate 1,000 mg/kg, E DL-α-tocopheryl 900 mg/kg, Se 10 mg/kg) was given at 50 g per animal weekly. No medications were used in any of the feeds. The grass silages in all three experiments were direct-cut primary growth from a timothy (*Phleum pratense*) and meadow fescue (*Festuca pratensis*) sward and ensiled in bunker silos with a formic acid-based additive applied at a rate of 5L/tonnes of fresh grass.

2.2. Procedures and chemical analyses

Silage sub-samples for chemical analyses were taken twice a week and pooled over periods of four weeks. Concentrate sub-samples for chemical analyses were taken weekly and pooled over periods of eight weeks. Samples were stored frozen prior to analyses. The chemical analyses of feed samples (DM, ash, CP, NDF) were made as described by Ahvenjärvi et al. (2000). The phosphorus (P) content of feed samples was determined using an ICP emission spectrophotometer (Thermo Jarrel Ash/Baird, Franklin, USA) as described by Luh Huang and Schulte (1985). Silage samples were analyzed for water-soluble carbohydrates (WSC), lactic and formic acids, volatile fatty acids (VFA), soluble and ammonia N content of N by electrometric titration (Moisio and Heikonen, 1989) and for digestible organic matter in DM (D value) by the method described by Nousiainen et al. (2003). The *D* value results were calculated with correction equations to convert pepsin-cellulase solubility values into *in vivo* digestibility based on a data set comprising Finnish *in vivo* digestibility trials.

Diet digestibility was determined when the bulls were initially 605 kg live weight. Diet digestibility was determined at late stage of growth because there exist no kind of data about the apparent diet digestibilities of dairy-breed bulls with high LW. Feed and faecal samples were collected twice a day (at 7:00 a.m. and 3:00 p.m.) during the collection period (5 d) and stored frozen prior to analyses. The samples were analyzed as described above. Diet digestibility was determined using acid-insoluble ash (AIA) as an internal marker (Van Keulen and Young, 1977).

2.3. Calculations and statistical methods

The ME contents of the feeds were calculated according to Finnish feed tables (MAFF, 1975, 1981, 1984; Tuori et al., 2002). The ME value of the silage was calculated as 0.16 × *D* value (MAFF, 1981). The ME values of the concentrates were calculated as described by Schiemann et al. (1972) and MAFF (1984). The supply of amino acids absorbed from the small intestine (AAT) was calculated according to Finnish feed tables (Tuori et al., 2002).

The animals were weighed on two consecutive days at the beginning of the experiment. After that the animals were weighed every 28 d. Before slaughter they were weighed on two consecutive days. The target for average carcass weight in the experiment was 340 kg. The LWG was calculated as the difference between the means of initial and final weights. Dressing percentages were calculated from the ratio of hot carcass weight to final live weight. The carcasses were classified for conformation (scale from 1 to 15) and fat cover (scale from 1 to 5) using the EUROP quality classification (Commission of the European Communities, 1982). The feeding trial was divided into four sub-experimental periods: period 1 (age of bulls 195–279 d), period 2 (279–363 d), period 3 (363–447 d) and period 4 (447–555 d). The live weight gains and feed dry matter intakes of the bulls are also presented separately for these different sub-experimental periods.

The experiment used a randomized block design with the animal as the experimental unit. The results are

Table 1
Chemical composition and feeding values of barley, rapeseed meal and grass silages (mean ± S.D.[a])

	Barley	Rapeseed meal	Silage exp. 1	Silage exp. 2	Silage exp. 3	Silage mean (exp.: 1, 2, 3)
N [b]	6	6	12	12	12	36
DM, g/kg feed	892 ± 20.7	880 ± 8.8	274 ± 64.2	316 ± 59.5	261 ± 60.9	284 ± 64.3
OM, g/kg DM	978 ± 19.6	922 ± 5.9	919 ± 183.8	941 ± 188.2	923 ± 184.6	928 ± 185.6
CP, g/kg DM	128 ± 5.9	354 ± 4.6	156 ± 8.7	153 ± 13.3	174 ± 15.3	161 ± 15.6
NDF, g/kg DM	197 ± 6.1	276 ± 3.4	541 ± 12.5	535 ± 15.7	554 ± 18.1	543 ± 17.2
P, g/kg DM	3.97 ± 0.1	10.89 ± 0.2	2.96 ± 0.1	3.13 ± 0.1	2.74 ± 0.1	2.94 ± 0.1
D value [c], g/kg DM	–	–	667 ± 12.9	676 ± 13.1	660 ± 13.2	668 ± 13.1
ME [d], MJ/kg DM	13.46 ± 0.1	11.70 ± 0.1	10.65 ± 0.2	10.76 ± 0.2	10.53 ± 0.2	10.65 ± 0.2
AAT [e], g/kg DM	105 ± 1.6	151 ± 0.1	82 ± 1.1	82 ± 2.1	82 ± 3.8	82 ± 2.5
Fermentation quality of silage						
pH			4.06 ± 0.1	4.08 ± 0.2	4.03 ± 0.2	4.06 ± 0.2
VFA, g/kg DM			23 ± 12.9	10 ± 6.8	17 ± 7.5	17 ± 10.6
LA + FA [f], g/kg DM			52 ± 17.5	40 ± 16.9	52 ± 17.1	48 ± 17.6
WSC [g], g/kg DM			33 ± 7.9	24 ± 5.8	43 ± 10.3	33 ± 8.6
In total N, g/kg N						
NH_4N			67 ± 14.8	51 ± 9.0	57 ± 8.6	58 ± 12.7
Soluble N			496 ± 71.9	423 ± 56.1	435 ± 33.1	451 ± 62.6

[a] Standard deviation.
[b] Silage, one sample/feeding period (4 weeks); concentrates, one sample/two feeding periods.
[c] Digestible OM in DM.
[d] ME value of silage was calculated as 0.16 × *D* value (MAFF, 1981). ME values of concentrates were calculated according to the Finnish feed tables (MAFF, 1984; Tuori et al., 2002).
[e] Amino acids absorbed from small intestine (Tuori et al., 2002).
[f] Lactic + formic acid.
[g] Water-soluble carbohydrates.

calculated across the three experiments and are shown as least squares means because the records from the six animals removed were not replaced. The data were subjected to analysis of variance using the SAS general linear models procedure (Littell et al., 1991). The model was $y_{ijkl} = \mu + C_i + R_j + (CR)_{ij} + E_k + B(E)_{kl} + e_{ijkl}$, where μ is the overall mean and e_{ijkl} is the random error term. C, R, E and B are the effects of concentrate proportion, RSM supplement, experiment and block (blocks are netted within experiment). Because there were no significant interactions between experiment and concentrate proportion or experiment and RSM supplement, these effects were left out of the model. The effect of the concentrate proportion and RSM supplementation was further divided into linear, quadratic and cubic effects using orthogonal polynomial contrasts (Snedecor and Cochran, 1989).

Table 2
Chemical composition and feeding values of total mixed rations

Concentrate proportion (C)	L (300)		M (500)		H (700)	
Rapeseed meal supplement (RSM)	–	+	–	+	–	+
Dry matter, g/kg	357	357	431	431	543	543
In dry matter, g/kg						
OM	943	941	953	950	963	959
CP	151	160	145	157	138	154
NDF	439	442	370	375	301	306
P	3.2	3.5	3.5	3.8	3.7	4.2
ME, MJ/kg DM [a]	11.5	11.4	12.1	12.0	12.6	12.5
AAT, g/kg DM [b]	89	91	94	96	98	101

[a] ME, Metabolizable energy (MAFF, 1975, 1984).
[b] AAT, Amino acids absorbed from small intestine (Tuori et al., 2002).

3. Results

3.1. Feeds

The content of DM, OM, CP, NDF, P and calculated contents of ME and AAT of the different feeds are given in Table 1. Because the silages used in feeding trial came from different harvests, the chemical compositions and feeding values are also given separately for all three silages in Table 1. However, the *D* values and ME and AAT contents of the silages differed only slightly from each other. The preservation quality of silages as indicated by pH values and contents of ammonia-N and fatty acids was good (Table 1). Because the chemical compositions and feeding values of the barley and RSM were very uniform throughout the trial, only one value is given for barley and RSM in Table 1.

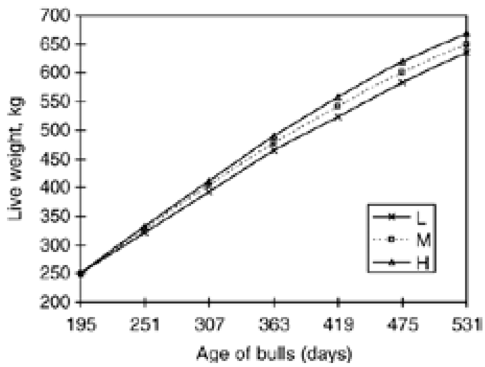

Fig. 1. Live weights of growing dairy bulls given different total mixed rations. The three concentrate proportions were 300 (L), 500 (M) and 700 (H) g/kg dry matter.

The average chemical composition of the TMRs used is presented in Table 2. Because of the higher energy and AAT contents of the concentrate, increasing the proportion of concentrate increased the calculated energy and AAT values of the rations. Increasing the proportion of concentrate also increased the P content but decreased the NDF content of the rations. The RSM supplementation increased the P content and the CP and AAT values of the rations.

3.2. Growth rate

The mean initial LW of the bulls was 252 kg and the mean final LW was 656 kg (Table 3). The live weight curves of the bulls were very similar in all treatments (Fig. 1). Increasing the proportion of concentrate led to a linear improvement of daily LWG ($P<0.05$) as measured over the entire experimental period (Table 3). The rapeseed meal supplement had no effect on LWG. There was no significant concentrate proportion × RSM interaction for the gain variables.

The live weight gains of the bulls during the different sub-experimental periods are presented in Table 4. The live weight gains reflected the live weights (Fig. 1) and increased linearly with increasing concentrate proportion in periods 1 and 2, but in periods 3 and 4 there was no significant difference. The rapeseed meal supplement had no effect on LWG in any sub-experimental period. The live weight gains were clearly greater in periods 1 and 2 than in periods 3 and 4 for all the treatments. There was no significant concentrate proportion × RSM interaction for LWG in any sub-experimental period.

3.3. Feed intake and feed conversion

The average feed DMI and ME intakes during the experiment are presented in Table 5. There were no significant treatment differences in the DMI (kg/d) and the energy intakes were also quite similar. However, DMI (g/kg $W^{0.75}$) decreased linearly with increasing proportion of concentrate feeding. There were also quadratic interactions ($P<0.05$) between the concentrate proportion and the RSM supplement for DMI (kg/d) and ME intake. Where RSM was included in the diet, the DMI (kg/d) and ME intake for the M diet were lower than without RSM supplement. In contrast, in the L and H diets the DMI (kg/d) and ME intakes were greater with RSM supplement.

Table 3
Effects of concentrate proportion (C) and rapeseed meal supplement (RSM) on average daily gains and carcass characteristics of growing bulls

Concentrate proportion (C)	L (300)		M (500)		H (700)		SEM[a]	Polynomial contrasts[b]				
Rapeseed meal supplement (RSM)	−	+	−	+	−	+		1	2	3	4	5
N	13	14	13	15	14	15						
Duration, d	357	356	348	348	338	339						
Initial live weight, kg	252	250	252	250	249	250	3.1					
Final live weight, kg	641	658	671	648	652	660	13.3					
Live weight gain, g/d	1090	1144	1205	1145	1196	1214	38.4		*			
Slaughter data												
Carcass weight, kg	332	338	347	336	340	344	7.3					
Kill-out, g/kg[c]	518	514	517	517	522	521	4.6					
EUROP conformation[d]	3.86	4.18	4.32	4.24	4.24	4.35	0.187					
EUROP fat classification[e]	2.63	2.33	2.97	2.78	2.77	2.94	0.161		*			

[a]Standard error of mean.
[b]Polynomial contrasts: (1 = RSM+ vs. RSM−), (2 = concentrate proportion, linear effect), (3 = concentrate proportion, quadratic effect), (4 = linear interaction between concentrate proportion and rapeseed meal supplement), (5 = quadratic interaction between concentrate proportion and rapeseed meal supplement). Statistical significance: (*$P<0.05$), (**$P<0.01$), (***$P<0.001$).
[c]The ratio of hot carcass weight to final live weight.
[d]Conformation: (1 = poorest, 15 = excellent).
[e]Fat cover (1 = leanest, 5 = fattest).

Table 4
Effects of concentrate proportion (C) and rapeseed meal supplement (RSM) on live weight gain by growing bulls during different experimental periods

Concentrate proportion (C)	L (300)		M (500)		H (700)		SEM[a]	Polynomial contrasts[b]				
Rapeseed meal supplement (RSM)	−	+	−	+	−	+		1	2	3	4	5
Live weight gain, g/d												
Period 1 (age 195–279 d)	1185	1223	1329	1312	1251	1385	51.5		*			
Period 2 (age 279–363 d)	1243	1324	1338	1325	1462	1383	60.7		*			
Period 3 (age 363–447 d)	1013	1102	1114	1039	971	1070	68.2					
Period 4 (age 447–555 d)	951	961	1055	921	1030	937	90.6					

[a]Standard error of mean.
[b]Polynomial contrasts: (1 = RSM+ vs. RSM−), (2 = concentrate proportion, linear effect), (3 = concentrate proportion, quadratic effect), (4 = linear interaction between concentrate proportion and rapeseed meal supplement), (5 = quadratic interaction between concentrate proportion and rapeseed meal supplement). Statistical significance: (*$P<0.05$), (**$P<0.01$), (***$P<0.001$).

Increasing the proportion of concentrate led to linearly higher CP ($P<0.001$) and AAT ($P<0.05$) supply (Table 5). The average supply of CP ($P<0.01$) was higher when RSM was included in the diet, but RSM had no significant effect on the average AAT supply ($P=0.07$) (Table 5).

The average supply of NDF decreased linearly with increasing concentrate proportion ($P<0.001$). The average supply of NDF was 3939, 3333 and 2599 g/d for L, M and H concentrate proportions, respectively. With L feedings 87% of the NDF supply (3430 g/d) came from grass silage and with M and H feedings 74% (2474 g/d) and 55% (1433 g/d), respectively. The supply of NDF was not affected by RSM supplementation, but there was a quadratic interaction ($P<0.05$) between concentrate proportion and RSM supplement for NDF supply.

The feed conversion rate (kg DM/kg LWG) decreased significantly with increasing concentrate proportion ($P<0.001$) (Table 5). Also the feed conversion rate in terms of MJ ME/kg LWG improved linearly with increasing concentrate proportion ($P<0.05$), but

Table 5
Effects of concentrate proportion (C) and rapeseed meal supplement (RSM) on daily feed intake, feed conversion rate and apparent diet digestibility of growing bulls

Concentrate proportion (C)	L (300)		M (500)		H (700)		SEM[a]	Polynomial contrasts[b]				
Rapeseed meal supplement (RSM)	−	+	−	+	−	+		1	2	3	4	5
DMI, kg DM/d												
Silage	6.26	6.37	4.72	4.38	2.61	2.66						
Concentrate	2.45	2.58	4.31	4.19	5.62	5.93						
Total DMI	8.72	8.95	9.03	8.57	8.24	8.59	0.224					*
DMI, g/kg W0.75	89.8	91.0	90.7	87.7	84.3	87.0	1.53		**			
ME intake, MJ/d	100.1	102.4	108.5	102.2	103.7	107.0	2.73					*
CP intake, g/d	1321	1398	1310	1322	1141	1290	32.0	**	***			
AAT intake, g/d	772	809	840	826	806	874	21.2		*			
NDF intake, g/d	3887	3991	3414	3252	2527	2670	82.4		***			*
Feed conversion												
kg DM/kg LW gain	8.02	7.85	7.53	7.55	6.90	7.11	0.138		***			
MJ ME/kg LW gain	92.1	89.8	90.4	90.0	86.8	88.5	1.67		*			
AAT g/kg LW gain	710	710	700	727	675	724	13.2	*				
Apparent digestibility												
DM	0.747	0.747	0.771	0.776	0.786	0.777	0.0048		***	*		
OM	0.765	0.766	0.789	0.796	0.802	0.796	0.0048		***	*		
CP	0.716	0.762	0.717	0.807	0.728	0.795	0.0091	***	*			*
NDF-fibre	0.698	0.705	0.676	0.696	0.612	0.634	0.0086	*	***	**		

[a]Standard error of mean.
[b]Polynomial contrasts: (1 = RSM+ vs. RSM−), (2 = concentrate proportion, linear effect), (3 = concentrate proportion, quadratic effect), (4 = linear interaction between concentrate proportion and rapeseed meal supplement), (5 = quadratic interaction between concentrate proportion and rapeseed meal supplement). Statistical significance: (*$P<0.05$), (**$P<0.01$), (***$P<0.001$).

Table 6
Effects of concentrate proportion (C) and rapeseed meal supplement (RSM) on dry matter intake by growing bulls during different experimental periods

Concentrate proportion (C)	L (300)		M (500)		H (700)		SEM[a]	Polynomial contrasts[b]				
Rapeseed meal supplement (RSM)	−	+	−	+	−	+		1	2	3	4	5
DMI, kg DM/d												
Period 1 (age 195–279 d)	6.98	7.04	7.26	7.11	6.43	6.91	0.183		*	*		
Period 2 (age 279–363 d)	8.57	8.51	8.55	8.35	7.87	8.30	0.235		*			
Period 3 (age 363–447 d)	9.08	9.46	9.64	9.16	8.95	9.14	0.297					
Period 4 (age 447–555 d)	10.03	10.57	10.55	9.51	9.63	9.75	0.422					
DMI, g/kg $W^{0.75}$												
Period 1 (age 195–279 d)	96.0	96.7	98.2	97.1	88.9	93.5	1.90		**	*		
Period 2 (age 279–363 d)	94.9	93.1	91.7	90.2	84.9	90.0	1.96		***			
Period 3 (age 363–447 d)	85.7	87.4	87.6	83.9	81.7	82.2	2.00		*			
Period 4 (age 447–555)	83.4	86.1	84.7	77.5	78.8	78.2	2.75		*			

[a]Standard error of mean.
[b]Polynomial contrasts: (1 = RSM+ vs. RSM−), (2 = concentrate proportion, linear effect), (3 = concentrate proportion, quadratic effect), (4 = linear interaction between concentrate proportion and rapeseed meal supplement), (5 = quadratic interaction between concentrate proportion and rapeseed meal supplement). Statistical significance: (*$P<0.05$), (**$P<0.01$), (***$P<0.001$).

concentrate proportion has no significant effects on the AAT conversion (AAT g/kg LWG). The AAT conversion was higher for the RSM+ diets than for the RSM− diets ($P<0.05$). However, the feed conversion rates in terms of kg DM/kg LWG or MJ ME/kg LWG were not significantly affected by RSM supplementation. There was no significant concentrate proportion × RSM interaction for any of the feed conversion variables.

The dry matter intakes (kg/d and g/kg $W^{0.75}$) during the different sub-experimental periods are presented in Table 6. The dry matter intake (kg/d) increased and the DMI (g/kg $W^{0.75}$) decreased when the bulls were growing. The DMI (g/kg $W^{0.75}$) decreased linearly with increasing proportion of concentrate in all four sub-experimental periods and a quadratic effect was also significant in period 1. Rapeseed meal supplement had no effect on DMI in any sub-experimental period and there was no significant concentrate proportion × RSM interaction for any of the variable presented in Table 6.

3.4. Diet digestibility

The values of the apparent DM, OM, CP and NDF digestibilities are given in Table 5. Increasing the proportion of concentrate led to significantly improved DM and OM digestibilities ($P<0.001$). The apparent digestibility of DM and OM increased linearly with increasing proportion of concentrate. Also a quadratic effect was statistically significant, the increase in the DM and OM digestibilities between the proportions M and H was smaller than the difference between the proportions L and M ($P<0.05$).

The digestibility of CP increased linearly with increasing concentrate proportion ($P<0.05$). The digestibility of NDF decreased with increasing concentrate proportion, with both linear and quadratic effects being significant (Table 5). The crude protein ($P<0.001$) and NDF ($P<0.05$) digestibilities were higher for the RSM+ diets than for the RSM− diets, but RSM had no effect on the DM and OM digestibilities. There was a quadratic interaction ($P<0.05$) between concentrate proportion and RSM supplement for CP digestibility.

3.5. Slaughter parameters

The mean carcass weight of the bulls was 341 kg (Table 3) and very close to the pre-planned carcass weight. There were no significant effects of treatments on the carcass weight, kill-out value (a proportion of hot carcass weight to final live weight) or carcass conformation score, although the kill-out value and carcass conformation score increased slightly with increasing concentrate proportion. The carcass fat score increased linearly with increasing concentrate proportion ($P<0.05$). The RSM supplement had no effect on the carcass fat score. There was no significant concentrate proportion × RSM interaction for any of the carcass traits.

4. Discussion

In our experiment we didn't have possibility to study meat quality aspects. However, meat quality is not probably improved by increased slaughter weight.

While animals get older, the fat and myoglobin contents of muscles will increase and due to increasing myoglobin content beef becomes darker (Lawrie, 1985; Andersen, 1991; Touraille, 1991). The taste of beef will strengthen when animals get older (Lawrie, 1985; Hankey et al., 1988), but according to Andersen (1991) beef will become also tougher due to the strengthening of collagen structure.

4.1. The effect of concentrate proportion

Increasing the proportion of concentrate led to improved LWG in the present experiment. The response in gain to concentrate supplementation was linear. In the present experiment the digestibility of the grass silage was 670 g DOM/kg DM. If the digestibility of the silage had been slightly higher, the differences in growth between the concentrate levels would presumably have been smaller. With high-quality silage, reasonable (above 0.9 kg/d) live weight gains can be achieved even when silage is given alone (Lampila et al., 1988). It is well established that the performance of cattle increases with increasing grass silage digestibility (Flynn, 1981; Martinsson, 1990; Randby, 2001; Steen et al., 2002). Where silages were offered as the sole feed, the carcass weight gain was increased by 33 g/d per 10 g/kg increase in silage digestibility (Steen, 1988a). In many studies with finishing cattle the growth response to concentrate supplementation is generally lower with higher digestibility of grass silage (Drennan and Keane, 1987b; Randby, 2001). Steen (1998) calculated that the response in carcass growth rate to concentrate supplementation within the range 2 to 9 kg/d was curvilinear (decreasing from 93 to 4 g carcass/kg additional concentrate) and linear (58 g carcass/kg additional concentrate) for high (733 g DOM/kg DM) and medium (625 g DOM/kg DM) digestibility silage, respectively.

In the present experiment there were no significant effects of concentrate proportion on the kill-out value or carcass conformation score, but the carcass fat score increased with increasing concentrate proportion. Also Caplis et al. (2005) reported that the carcass fat score increased with increasing concentrate proportion in TMR feeding with steers (Charolais × Friesian and Belgian Blue × Friesian). However, no research has been carried out on TMR feeding of growing dairy-breed bulls. Petchey and Broadbent (1980) and Caplis et al. (2005) compared separate and TMR feeding of finishing steers and Cooke et al. (2004) of finishing heifers (Charolais). Compared with separate feeding, TMR increased the live-weight gain, carcass weight and feed intake with finishing Charolais heifers (Cooke et al., 2004). With finishing steers TMR had no effect on animal performance or carcass traits compared with separate feeding, but for both types of feeding the total DM intake increased with increasing concentrate proportion (Caplis et al., 2005).

In the present experiment the concentrate proportion had no significant effects on the total average DMI. However, at the beginning of the trial (period 1) the relationship between concentrate proportion and total DMI was curvilinear. The total DMI increased up to the medium concentrate proportion, but after that a further increase in concentrate did not increase the DMI. Curvilinear increases in the total DMI with increasing concentrate level have been reported previously by Steen (1998), Keane (2001) and Caplis et al. (2005). There are also a number of reports showing that increasing the level of supplementary concentrates in the diet of beef cattle decreases the silage intake but increases the total DMI in separate feeding (Drennan and Keane, 1987a,b; Dawson et al., 2002). Because the DMI (kg/d) was quite similar for all the concentrate proportions, but an increasing concentrate proportion improved the daily weight gain, also the feed conversion rates were greater with increasing concentrate proportion in the present study.

Increasing the proportion of concentrate led to significantly improved DM and OM digestibilities in the present study. Substitution of silage DM with barley DM caused the improved digestibility, because the digestibility of the barley was higher than the digestibility of the silage. However, a reduced forage intake may be related to a reduced rate of OM digestion (Colucci et al., 1982, 1990). This effect is related to the rumen retention time of concentrate particles (Mulligan et al., 2001) or the negative effects of concentrate inclusion on forage digestibility (Mould et al., 1983). Also in the present experiment there was a quadratic effect on DM and OM digestibilities: the digestibility increased more when the concentrate proportion was increased from 300 to 500 g/kg DM, between 500 to 700 g/kg DM the digestibility increased considerably less. This curvilinear effect comes from changes in fibre digestion.

In the present study the NDF digestibility decreased with increasing concentrate proportion. Decreasing fibre digestibility with increasing concentrate level in the diet is widely recognized (Colucci et al., 1982; Uden, 1984a,b; Huhtanen and Jaakkola, 1993). This decreased digestibility is partly caused by dilution of forage fibre with more slowly digested concentrate fibre (Hoover, 1986). However, there was also a quadratic effect on NDF digestibility in the present study: the digestibility decreased particularly radically when the concentrate proportion was increased from 500 to 700 g/kg DM. This curvilinear effect of concentrates demonstrates that starch adversely affects the cellulolytic activity in the rumen (Uden, 1984a; Hoover, 1986). This negative effect has also been reported by Huhtanen and Jaakkola (1993) and is related to a reduction in ruminal pH (Hoover, 1986). Increasing the concentrate level from 500 to 750 g/kg DM induced a decrease in the rumen pH (0.2 pH-unit) without changes in the lactic acid and VFA concentrations in the rumen (Huhtanen and Jaakkola, 1993).

4.2. The effect of rapeseed meal

In the present experiment, RSM supplementation had no effect on any of the performance parameters. Many earlier studies have reported a positive response of hay (Aronen, 1990) or silage intake (Aronen, 1990; Aronen and Vanhatalo, 1992a; Aronen et al., 1992) to RSM supplementation. According to Aronen et al. (1992), the positive effect of RSM was apparent throughout the experiment and did not depend on the stage of maturity of the grass used for silage or on the level of concentrates. According to Nocek and Russel (1988), the increase in feed intake caused by protein supplementation is mediated by improved microbial activity and thereby increased diet digestibility. However, the reported effects of RSM supplementation on grass silage intake are inconsistent, because for example in the studies by Huhtanen et al. (1985, 1989) RSM had no effect on grass silage intake. In these earlier experiments separate feeding was used, so the feeding method was different compared with the present study. In TMR feeding, animals cannot increase only their silage intake and according to the present study RSM supplementation has no effect on total DMI.

Contrary to some earlier findings (Aronen, 1991; Aronen and Vanhatalo, 1992a), RSM supplementation had no effect on animal growth in the present trial. In earlier reports (Aronen, 1991; Aronen and Vanhatalo, 1992a) the positive effect of RSM on LWG was explained by the increased feed intake and thereby higher energy intake. In some other experiments (Huhtanen et al., 1989; Aronen, 1990) the positive effect of RSM on LWG was restricted only to the early phase of the growth period (i.e., LW below 300 kg). There are several reasons for this discrepancy. First there is a difference between separate and TMR feeding on silage intake. It may also be related to differences in the quality of the grass silage because, according to the literature, protein supplements may have a positive effect on the daily growth rate when the gain without protein supplementation is low, which may be the case with low digestibility silage (Steen, 1988a) or hay (Aronen, 1990; Hennessy et al., 2000) or extensively fermented silage (Jaakkola et al., 1990). It is well established that with poorly preserved silage the response in animal performance to protein supplementation is greater than with well preserved silage (Steen, 1988b; Hussein and Jordan, 1991).

The responses to protein supplements seem to be related also to the level of concentrate supplement and to the LW of the animal, greater effects being observed with small amounts of concentrates and young animals (Pike et al., 1988). According to Aronen (1992), a high level of concentrates together with well preserved grass silage may sustain efficient microbial protein production. Therefore, it is likely that a greater response to RSM supplementation is to be expected when small rather than large amounts of concentrates are fed to growing cattle on a grass silage-based feeding. In the present experiment the *D* value of the silages was quite good (670 g/kg DM, on average) and also the preservation quality of the silages was good. In addition, there were at least 30% concentrate in all the treatments, so the microbial protein synthesis can be assumed to have been high, and therefore there was no positive effect of RSM supplementation on animal performance.

In accordance with earlier studies (Aronen, 1990, 1991; Aronen and Vanhatalo, 1992a) there were no differences in DM or OM digestibility with RSM supplementation. In the present study the apparent CP digestibility increased with RSM supplementation, which is in accordance with earlier studies (Aronen, 1990; Aronen and Vanhatalo, 1992a; Aronen et al., 1992). Some of the increased apparent digestibility of CP of the RSM-supplemented diets may have reflected the better digestibility of RSM protein. Most of this increase was, however, only apparent, related to the decreased proportion of faecal metabolic nitrogen recovered in faeces when the CP content increased (Minson, 1982).

In the present study the average supply of P was higher in the RSM+ diets (34 g/d) than in the RSM− diets (30 g/d) ($P<0.001$). However, according to Finnish feeding recommendations (MTT, 2006), the supply of P was sufficient also in the RSM-diets throughout the feeding experiment. This means that feeding excess RSM increased P excretion to the environment. Similar results are also reported by Steen (1996).

4.3. Energy and protein supply in relation to current recommendations

At the beginning of the experiment (LW 250–400 kg) the calculated supply of energy in all feeding groups was clearly higher than in the Finnish feeding recommendations (MTT, 2006). However, the LWG was in most cases lower than in the recommendations which may suggest that the current Finnish recommendations for energy feeding are insufficient for the live weight range 250–400 kg. After 400 kg live weight the energy supply was close to the recommendations, but at the end of the experiment (live weight 550–650 kg) the LWG was clearly lower than in the recommendations. During the feeding trials the supply of energy was on average 8.5% higher than in Finnish feeding recommendations. There is possibly a need to revise the current energy requirements and also a need for extra calculations for the energy supply of growing dairy-breed bulls.

The calculated supply of AAT was higher than in the Finnish feeding recommendations (MTT, 2006) in almost all feeding groups and all periods. Only for live weight less than 400 kg in H RSM-feeding was the supply of AAT lower than in the recommendations for growth 1200–1300 g/d. This means that in most cases the dairy bulls (LW more than 250 kg) received enough protein from the basic diet without protein supplementation. Extra protein only increased nitrogen and phosphorus excretion to the environment. Extra protein also puts an unnecessary load on the animal's metabolism because the excretion of N increases. It is possible that it may be necessary to revise the current protein requirements for growing dairy-breed bulls, but updating the requirements requires more calculations and more data on protein supply and growth for growing dairy-breed bulls.

5. Conclusion

In conclusion, the LWG of growing dairy-breed bulls increased with increasing concentrate proportion. The carcass fat score also increased with increasing concentrate proportion. With TMR feeding it is possible to use rather high concentrate proportions in feeding beef bulls. However, increasing the proportion of concentrate will increase P excretion to the environment because concentrates generally include more P than grass silage. Rapeseed meal did not affect animal performance, so there is no reason to use protein supplement for finishing dairy bulls when they are fed good quality grass silage and barley-based concentrate. This study also shows that there is need to revise the Finnish feeding recommendations for growing dairy-breed bulls, and there is need for extra calculations for the energy and protein supply of growing dairy-breed bulls.

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Effects of replacing different proportions of barley grain by barley fibre on performance of dairy bulls

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The objective of the present experiment was to study the effects of partial replacement of barley grain with barley fibre (BF) on animal performance, carcass traits and diet digestibility of growing dairy bulls. The feeding experiment comprised 20 Finnish Ayrshire bulls and 12 Holstein-Friesian bulls, and four treatments (8 bulls per treatment). There were four diets with two offered at stage 1 (from the initiation of the study to 450 kg live weight) and four at stage 2 (from 450 kg live weight to slaughter). The control diet (BF0) included grass silage (460 g kg^{-1} dry matter) and barley grain (540), BF25 diet included grass silage (460), barley grain (405) and BF (135), BF50 diet included grass silage (460), barley grain (270) and BF (270), and BF75 diet included grass silage (460), barley grain (135) and BF (405). At stage 1 there were only two treatments (BF0 and BF50) and at stage 2, all four treatments were included. All bulls were fed total mixed ration *ad libitum*. The mean initial live weight of the bulls was 261 kg and the mean final live weight 650 kg. At stage 1 there were no significant treatment differences in dry matter, energy or protein intakes or in live weight gain. At stage 2, replacing barley grain with BF led to a linear decrease of daily live weight gain ($P < 0.05$) and a linearly reduced feed conversion (kg dry matter kg^{-1} live weight gain) ($P < 0.05$). The apparent digestibility of the organic matter and neutral detergent fibre decreased linearly with increasing BF supplementation ($P < 0.001$). The dressing proportion and the carcass fat score decreased linearly ($P < 0.05$) with partial replacement of barley grain with BF. On carcass conformation, treatment had a significant ($P < 0.05$) quadratic effect: the BF25 and BF50 diets were classified highest. The results indicate that 50% of barley starch can be replaced with BF without affecting growth, but feed efficiency factors may decrease when barley starch is replaced with BF. At 75% replacement, feed intake was reduced, which resulted in a lower energy intake and reduced level of performance.

Key-words: Beef production, dairy-breed bulls, total mixed ration, barley fibre, by-products

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Introduction

With increasing oil prices over recent years interest in bio-ethanol production has increased. In Finland, the current integrated production of ethanol and starch creates also barley fibre (BF) as a by-product. Barley fibre is a fibrous product comprised mainly of the cell wall fraction of barley endosperm and is used as energy source in cattle feeding. A detailed description of the integrated starch-ethanol process and the products of the process are given by Näsi (1988). As the integrated starch-ethanol process can be used also for the production of bio-ethanol, it is evident that increasing quantities of by-products will be produced in the future. By-products, such as BF, tend to be low-priced feeds. Therefore, it is important to determine the potential of BF to replace grain in the rations of growing and finishing bulls.

The use of total mixed ration (TMR) in beef production systems is receiving considerable attention in Finland. Total mixed ration feeding and the European Union policy reducing the price of grain in relation to forages have increased the proportion of concentrate in the diet of growing bulls. With increasing concentrate proportion the interest in substituting the starch-rich grain by more fibrous ingredients like BF has increased. In addition, the fact that today BF is 15–20% cheaper than barley grain has increased the interest of beef producers to use BF.

According to Root and Huhtanen (1998), with separate feeding (concentrate proportion 390 g kg^{-1} dry matter (DM)) including BF in the diet of growing bulls (initial live weight (LW) 205 kg and final LW 500 kg) did not affect feed or energy intake markedly. The average live weight gain (LWG) or carcass characteristics were not significantly different for the different BF replacements, but towards the end of the experiment (LW 350 – 500 kg) the LWG of the bulls fed BF tended to decrease compared to barley grain (Root and Huhtanen 1998). With TMR feeding (concentrate proportion 570 g kg^{-1} DM), the LWG of the dairy bulls (initial LW 280 kg and final LW 675 kg) given BF tended to be higher than that of bulls given barley grain diets up to 500 kg LW when replacing half of the barley grain with BF (Huuskonen unpublished data). However, inclusion of BF in the diet decreased the daily gain from 500 kg LW to slaughter. There were no significant treatment effects on carcass characteristics (Huuskonen unpublished data). According to these preliminary findings, the bulls performed well when 50% of the barley grain concentrate was replaced with BF in the early part of the growing period (Root and Huhtanen 1998: 205 to 350 kg LW, Huuskonen unpublished data: 280 to 500 kg LW), but the situation during the final finishing period is still unclear. Therefore, the objective of the present experiment was to study the effects of partial replacement of barley grain with BF on animal performance, carcass traits and diet digestibility of growing dairy bulls.

Materials and methods

Animals and experimental design

The feeding experiment, started in September 2005 and ended in August 2006, was conducted in the experimental barn of North Ostrobothnia Research Station of MTT Agrifood Research Finland (Ruukki, 64°44'N, 25°15'E). The experimental procedures were evaluated and approved by the Animal Care and Use Committee of MTT Agrifood Research Finland. Twenty Finnish Ayrshire bulls and twelve Holstein-Friesian bulls were used in the experiment. All animals were purchased from local dairy farms. Before the feeding experiment they received grass silage and concentrates (commercial pelleted calf starter, barley and rapeseed meal). At the beginning of the present experiment the animals (initial LW 261±34.0 kg and age 195±5.2 days, on average) were divided into four blocks of 8 animals by LW and breed. Age was not taken into account in the blocking, because of the small variations in age. Two randomly selected animals in each block were assigned to each treatment. The animals were housed in a tie-up barn and individually fed three times per day (at 8:00 a.m., 12:00 a.m., and 6:00 p.m.). Refused feed was collected and measured at 7:00 a.m. daily.

The bulls had free access to water from an open water bowl during the experiment.

All the bulls were fed TMR *ad libitum* (proportionate refusals 5%) and the experiment included four treatments and two stages (Table 1):

(1) control (BF0): grass silage (460 g kg^{-1} DM) and flattened barley grain (540)
(2) BF25: grass silage (460), flattened barley grain (405) and BF (135)
(3) BF50: grass silage (460), flattened barley grain (270) and BF (270)
(4) BF75: grass silage (460), flattened barley grain (135) and BF (405)
Stage 1 – from the initiation of the study to 450 kg LW. There were only two treatments (control and BF50).
Stage 2 – from 450 kg LW to slaughter. All four treatments were included. The animals were moved to stage 2 on a treatment mean basis.

The commercial BF (produced by Altia Ltd, Koskenkorva, Finland) used in the experiment included BF (950 g kg^{-1} DM), wet distillers' solubles (25) and molasses (25). The grass silage was direct-cut first-growth from a timothy (*Phleum pratense*) and meadow fescue (*Festuca pratensis*) sward and ensiled in bunker silos with a formic acid-based additive applied at a rate of 5L per tonne of fresh grass. The animals received also a mineral supplementation (150 g per head per day) and vitamin supplement (50 g per head per week). No animals were medicated on any of the treatments.

Table 1. Treatments and total mixed rations (g kg^{-1} DM) used in the feeding experiment in two experimental periods (stage 1 = up to 450 kg live weight, stage 2 = 450 kg live weight to slaughter).

		Treatment			
		BF0	BF25	BF50	BF75
Stage 1	Silage	460	460	460	460
	Barley grain	540	270	270	270
	Barley fibre [a]	0	270	270	270
Stage 2	Silage	460	460	460	460
	Barley grain	540	405	270	135
	Barley fibre	0	135	270	405

[a] Commercial barley fibre (produced by Altia Ltd, Koskenkorva, Finland) included (g kg^{-1} DM) barley fibre (950), wet distillers' solubles (25) and molasses (25).

Measurements

The animals were weighed on two consecutive days at the beginning of the experiment. After that the animals were weighed every 28 days and before slaughter on two consecutive days. The target carcass weight in the experiment was 350 kg, and the bulls were selected for slaughter based on LW and an assumed dressing proportion. The LWG was calculated as the difference between the means of initial and final weights. The estimated rate of carcass gain was calculated by assuming an initial carcass weight of 0.50 of initial LW which was used also in a previous study by Root and Huhtanen (1998). Dressing proportions were calculated from the ratio of hot carcass weight to final LW. For conformation, the development of carcass profiles, in particular the essential parts (round, back, shoulder), was taken into consideration according to the EUROP classification (E: excellent, U: very good, R: good, O: fair, P: poor), and for fat cover degree the amount of fat on the outside of the carcass and in the thoracic cavity was taken into account using a classification range from 1 to 5 (1: low, 2: slight, 3: average, 4: high, 5: very high). Each level of the conformation scale was subdivided into 3 sub-classes (i.e. O+, O and O–) to a transformed scale ranging from 1 to 15, with 15 as the best conformation (Commission of the European Communities 1982).

Diet and sample analyses

Silage samples were analysed for DM (determined at 105 °C for 20 h) at the beginning of the experiment and twice a week thereafter for preparation of TMR. Silage sub-samples for chemical analyses were taken twice a week, pooled over periods of four weeks and stored at –20 ºC. Thawed samples were analysed for DM, ash, crude protein (CP), ether extract, neutral detergent fibre (NDF), starch, silage fermentation quality (pH, water-soluble carbohydrates, lactic and formic acids, volatile fatty acids, soluble and ammonia N content of N) and digestible organic matter (OM) in DM (D value). Concentrate sub-samples were collected weekly, pooled over periods of eight weeks and analysed for DM, ash, CP, ether extract, NDF and starch. The analyses of DM, ash, CP and NDF were made as described by Ahvenjärvi et al. (2000). Starch was analysed according to McCleary et al. (1994). The ether extracts were determined according to procedure 920.39 of AOAC (1990) after acid (HCL) hydrolysis. Silages were analysed for fermentation quality by the methods described by Moisio and Heikonen (1989) and for digestible organic matter in DM by the method described by Nousiainen et al. (2003).

Diet digestibility was determined for all animals at stage 2, when the bulls were initially 512 kg LW. Feed and faecal samples were collected twice a day (at 7:00 a.m. and 3:00 p.m.) during the collection period (5 d), pooled and stored frozen prior to analyses. The samples were analysed for DM, ash, CP and NDF as described above. Diet digestibility was determined using acid-insoluble ash as an internal marker (Van Keulen and Young 1977).

The metabolizable energy (ME) value of the silage was calculated as 0.16 × D value (MAFF 1981). The ME values of the concentrates were calculated as described by Schiemann et al. (1972) and MAFF (1984). The digestibility coefficients of concentrates were taken from Finnish feed tables (MTT 2006). The supply of amino acids absorbed from the small intestine (AAT) was calculated according to Finnish feed tables (MTT 2006).

Statistical analysis

The experiment was set up according to a randomized block design where animal was used as an experimental unit. The results are shown as least squares means, because the records of the one excluded animal were not replaced. The data were subjected to analysis of variance by using the SAS mixed model procedure (SAS 1999). The model used was

$$y_{ijk} = \mu + B_j + E_i + e_{ijk},$$

where μ is the overall mean, B_j is blocking effect (j = 1,…,4) and e_{ijk} is the random error term. E_i is the effect of BF inclusion. Each block includes two animals (k = 1,2) with the same BF inclusion. The effect of the BF inclusion was further divided into linear and quadratic effects using orthogonal polynomial contrasts.

Results

Diet

The chemical compositions and calculated contents of ME and AAT of the different feeds are given in Table 2. The grass silage was of good nutritional quality (*i.e.* D value 693 g kg^{-1} DM and AAT content 87 g kg^{-1} DM). The preservation quality of the silage as indicated by pH values and contents of ammonia-N and fatty acids was good (Table 2). The calculated energy value of barley grain was 14% higher than that of BF, but BF contained slightly more CP (139 vs. 131 g kg^{-1} DM) than barley grain. However, barley grain contained 10% more AAT compared with BF. The starch content of BF was clearly lower (71 vs. 535 g kg^{-1} DM) and the NDF content higher (601 vs. 220 g kg^{-1} DM) compared with barley grain. The average chemical compositions of the TMRs used are presented in Table 3. Replacing barley grain with BF increased the NDF and decreased the starch and energy contents in the diets.

Feed intake and animal performance

One animal (in the BF75 diet) was excluded from the study due to several occurrences of bloat. There was no reason to suppose that the diet had caused this problem. At stage 1 (bulls up to 450 kg LW),

Table 2. Chemical composition and feeding values of concentrates and grass silage.

	Silage	Barley	Barley fibre
Number of samples	11	5	5
Dry matter (DM), g kg^{-1} feed	285	887	921
Organic matter (OM), g kg^{-1} DM	914	977	963
Crude protein, g kg^{-1} DM	170	131	139
Neutral detergent fibre, g kg^{-1} DM	548	220	601
Starch, g kg^{-1} DM	ND[a]	535	71
Ether extract, g kg^{-1} DM	35	22	65
Digestible OM in DM, g kg^{-1} DM	693	ND	ND
Metabolizable energy, MJ kg^{-1} DM	11.1	13.2	11.6
AAT[b], g kg^{-1} DM	87	106	96
Fermentation quality of silage			
pH	4.3		
Volatile fatty acids, g kg^{-1} DM	16		
Lactic + formic acid, g kg^{-1} DM	42		
Water soluble carbohydrates, g kg^{-1} DM	60		
In total nitrogen, g kg^{-1}			
Ammonia N	75		
Soluble N	552		

[a] Not determined.
[b] Amino acids absorbed from the small intestine.

Table 3. Chemical composition and feeding values of total mixed rations.

	Total mixed ration[a]			
	BF0	BF25	BF50	BF75
Dry matter (DM), g kg^{-1}	455	456	457	458
Composition of DM, g kg^{-1}				
Organic matter	949	947	945	943
Crude protein	149	150	151	152
Ether extract	28	34	40	46
Neutral detergent fibre	368	420	472	525
Starch	299	234	170	106
Metabolizable energy, MJ kg^{-1} DM	12.26	12.04	11.82	11.60
AAT[b], g kg^{-1} DM	97	96	95	93

[a] The control diet (BF0) included grass silage and barley grain throughout the experiment. In another three diets (BF25, BF50 and BF75) the concentrate was a mixture (1:1 on DM basis) of barley and barley fibre at stage 1 (up to 450 kg LW). At stage 2 (450 kg live weight to slaughter) the concentrate in BF25 included barley grain (750 g kg^{-1} DM) and barley fibre (250), in BF50 barley grain (500), barley fibre (500) and in BF75 barley grain (250), barley fibre (750). Hence, at stage 1 only BF0 and BF50 rations were used.
[b] Amino acids absorbed from the small intestine.

only BF0 and BF50 rations were used, and there were no statistically significant treatment differences in DM, energy or AAT intakes or in LWG (Table 4). However, the feed conversion rate (kg DM kg^{-1} LWG) tended to be better with the BF0 than with the BF50 diet (5.87 vs. 6.22, $P = 0.10$).

At stage 2 (450 kg LW to slaughter), BF replacement had a significant ($P < 0.05$) quadratic ef-

Table 4. Daily live weight gains, dry matter (DM), energy and AAT[a] intakes and feed conversions of bulls up to 450 kg live weight (stage 1).

	Treatment[b]		SEM[c]	Statistical significance[d]
	BF0	BF50		
N	8	23		
Duration, d	139	139		
Live weight at start, kg	260	262	17.6	NS
Feed intake, kg DM d^{-1}	8.02	8.44	0.451	NS
Metabolizable energy (ME) intake, MJ d^{-1}	99.3	100.7	5.41	NS
AAT intake, g d^{-1}	774	804	43.1	NS
Live weight gain (LWG), g d^{-1}	1365	1358	54.0	NS
Feed conversion				
kg DM kg^{-1} LWG	5.87	6.22	0.209	P = 0.10
MJ ME kg^{-1} LWG	72.7	74.2	2.51	NS
AAT g kg^{-1} LWG	567	593	20.0	NS

[a] Amino acids absorbed from the small intestine. [b] The control diet (BF0) included grass silage and barley grain. In BF50 the concentrate included barley grain (500 g kg^{-1} DM) and barley fibre (500). [c] Standard error of means. [d] Statistical significance: NS, not significant, * p < 0.05, ** p < 0.01, *** p < 0.001.

Table 5. Daily live weight gains, dry matter (DM), energy and AAT[a] intakes, feed conversions and feed digestion data of bulls at stage 2 (450 kg live weight to slaughter).

	Treatment[b]				SEM[c]	Statistical significance[d]	
	BF0	BF25	BF50	BF75		1	2
N	8	8	8	7			
Age at the start, d	334	336	332	333			
Duration, d	174	168	175	190			
Feed intake, kg DM d^{-1}	10.45	10.70	10.98	9.83	0.398	NS	*
Metabolizable energy (ME) intake, MJ d^{-1}	127.8	128.6	129.3	113.0	4.84	*	*
AAT intake, g d^{-1}	1018	1030	1044	919	38.2	P = 0.07	*
Live weight gain (LWG), g d^{-1}	1203	1113	1130	997	50.0	*	NS
Feed conversion							
kg DM kg^{-1} LWG	8.69	9.74	9.78	9.87	0.371	*	NS
MJ ME kg^{-1} LWG	106.3	117.0	115.2	113.9	4.45	NS	P = 0.09
AAT g kg^{-1} LWG	847	937	930	926	35.5	P = 0.08	P = 0.10
Apparent digestibility [e]							
Organic matter	0.832	0.790	0.745	0.712	0.0049	***	NS
Crude protein	0.750	0.752	0.730	0.724	0.0074	**	NS
Neutral detergent fibre	0.752	0.683	0.633	0.609	0.0106	***	*

[a] Amino acids absorbed from small intestine. [b] The control diet (BF0) included grass silage and barley grain throughout the experiment. At stage 2 (450 kg live weight to slaughter) the concentrate in BF25 included barley grain (750 g kg^{-1} DM) and barley fibre (250), in BF50 barley grain (500), barley fibre (500) and in BF75 barley grain (250), barley fibre (750). [c] Standard error of means. [d] Polynomial contrasts: (1 = barley fibre supplementation, linear effect), (2 = barley fibre supplementation, quadratic effect). Statistical significance: NS, not significant, * p < 0.05, ** p < 0.01, *** p < 0.001. [e] Diet digestibility was determined in all animals at 512±30 kg live weight, on average.

fect on DM, ME and AAT intakes (Table 5). Intakes increased in the BF25 and BF50 diets compared with the BF0 diet, but in the BF75 diets intakes decreased clearly. In energy intake also the linear effect was significant (P < 0.05). The apparent digestibility of OM, CP and NDF decreased linearly with increasing BF supplementation (OM, P < 0.001; CP, P < 0.01; NDF, P < 0.001) (Table

5). The apparent digestibility of OM decreased by 17%, CP 3% and NDF by 19% when 75% of barley grain was replaced with BF. With the apparent digestibility of NDF also the quadratic effect of BF supplementation was significant ($P < 0.05$). Replacing barley grain with BF decreased LWG linearly ($P < 0.05$) at stage 2 and resulted in a linear ($P < 0.05$) reduction in efficiency of conversion of feed to LWG. However, there were no significant differences in ME (MJ ME kg^{-1} LWG) or AAT (g kg^{-1} LWG) conversions (Table 5).

The mean final LW of the bulls was 650 kg. Replacing barley grain with BF led to a linear decrease of daily LWG ($P < 0.05$) and carcass gain ($P < 0.01$) and linear reduction of the feed (kg DM per carcass gain, $P < 0.01$), energy (MJ ME kg^{-1} carcass gain, $P < 0.05$) and AAT conversion (g kg^{-1} carcass gain, $P<0.01$) on average during the experiment (as measured over the entire experimental period) (Table 6). The treatments affected also slaughter parameters. The dressing proportion and the carcass fat score decreased linearly ($P < 0.05$) with partial replacement of barley grain with BF. On carcass EUROP conformation, treatment had a significant ($P < 0.05$) quadratic effect: the BF25 and BF50 diets were classified highest (Table 6).

Table 6. Daily feed intake and feed conversion (on average during the experiment), live weights, daily gains and slaughter data.

	Treatment[a]				SEM[b]	Statistical significance[c]	
	BF0	BF25	BF50	BF75		1	2
Duration, d	313	307	314	329			
Age at slaughter, d	508	504	507	523			
Dry matter (DM) intake, kg d^{-1}	9.34	9.76	9.95	9.07	0.359	NS	*
Metabolizable energy (ME) intake, MJ d^{-1}	114.8	116.9	117.7	106.0	4.36	P = 0.10	*
AAT[d] intake, g d^{-1}	907	935	946	856	34.4	NS	*
Initial live weight, kg	260	260	261	265	18.3	NS	NS
Final live weight, kg	659	644	659	637	15.3	NS	NS
Live weight gain, g d^{-1}	1280	1252	1271	1127	50.4	*	NS
Carcass gain, g d^{-1}	721	720	690	612	25.3	**	NS
Feed conversion							
kg DM kg^{-1} carcass gain	12.96	13.55	14.50	14.86	0.416	**	NS
MJ ME kg^{-1} carcass gain	159.3	162.3	171.6	173.5	4.93	*	NS
AAT g kg^{-1} carcass gain	1259	1299	1380	1401	39.6	**	NS
Slaughter data							
Carcass weight, kg	350	346	342	329	7.6	*	NS
Dressing proportion, g kg^{-1}	532	538	519	518	6.3	*	NS
EUROP conformation[e]	4.0	4.5	4.4	3.3	0.34	NS	*
EUROP fat classification[f]	3.3	3.0	3.0	2.7	0.16	*	NS

[a] The control diet (BF0) included grass silage and barley grain throughout the experiment. In another three diets (BF25, BF50 and BF75) the concentrate was a mixture (1:1 on DM basis) of barley and barley fibre at stage 1 (up to 450 kg LW). At stage 2 (450 kg live weight to slaughter) the concentrate in BF25 included barley grain (750 g kg^{-1} DM) and barley fibre (250), in BF50 barley grain (500), barley fibre (500) and in BF75 barley grain (250), barley fibre (750). Hence, at stage 1 only BF0 and BF50 rations were used. [b] Standard error of means. [c] Polynomial contrasts: (1 = barley fibre supplementation, linear effect), (2 = barley fibre supplementation, quadratic effect). Statistical significance: NS, not significant, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. [d] Amino acids absorbed from the small intestine. [e] Conformation: (1 = poorest, 15 = excellent). [f] Fat cover: (1 = leanest, 5 = fattest).

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Discussion

The objective of this trial was to study the effects of partial replacement of barley grain with BF on animal performance, carcass traits and diet digestibility of growing dairy bulls. The trial was separated so that in stage 1 (from the initiation of the study to 450 kg LW) there were only two treatments (control and BF50) and stage 2 (from 450 kg LW to slaughter) included all four treatment groups (control, BF25, BF50 and BF75). There were only two treatments in stage 2 because, according to preliminary findings, the bulls performed well when 50% of the barley grain concentrates was replaced with BF in the early part of the growing period (Root and Huhtanen 1998: LW 205 to 350 kg, Huuskonen unpublished data: LW 280 to 500 kg).

Some by-product feeds can be very variable in nutrient composition, but the chemical and nutritional compositions of commercial BF is fairly constant (Asko Rantanen, personal communication, Altia Ltd, May 7, 2007). The nutrient composition of the BF used in the present experiment was quite similar to, for example, that reported by Mäntysaari et al. (2007).

In the present study there were no treatment differences in LWG (1359±139.9 g d^{-1}, on average) at stage 1, and no differences in DM, energy or AAT intakes. These results are similar to those of Root and Huhtanen (1998) who reported no significant differences when replacing barley grain partly with BF up to 350 kg LW with separate feeding. In the present trial, feed efficiency (kg DM kg^{-1} LWG) tended to be better with the BF0 than with the BF50 diet at stage 1. Root and Huhtanen (1998) reported no difference in feed conversion up to 350 kg LW, but from 350 kg LW to slaughter replacing barley grain by BF reduced the feed conversion. These data indicate that during the early part of the growing period (LW 200 to 400 kg), 50% of barley starch can be replaced with BF without affecting growth or feed efficiency factors.

At stage 2 and also throughout the entire period, replacing barley grain with BF decreased LWG linearly in the present study. Impaired gain of BF75 bulls was a consequence of decreased DM and energy intake, which was possibly partly caused by decreased OM digestibility (OMD). Replacing barley grain with BF in the diet affected the OMD similarly as observed by Huhtanen (1992) in bulls and by Huhtanen et al. (1988) in dairy cows. Barley fibre contains much more NDF and less starch than barley grain, and the difference in OMD can be attributed to a lower digestibility of cell wall components of BF than of those of barley starch. Since NDF digestibility decreased with increasing BF proportion in the present study, the difference in NDF digestibilities reflected the increased proportion of BF. The reduction in NDF digestibility was partly a consequence of decreasing proportion of silage's NDF in the total diet when the BF proportion increased, because silage fibre is more digestible than the fibre fraction of barley (Van Soest 1994, MTT 2006). In addition, this difference between fibre digestibilities is possibly higher in northern latitudes, because grasses grown there exhibited a higher digestibility at the same stage of maturity than those grown at latitudes closer to the equator (Deinum et al. 1968). This is due to temperature and light intensity which influence the lignification of the cell wall, which affects the relationship between fibre and digestibility (Deinum et al. 1968, Van Soest 1994).

It is also possible that the decreasing NDF digestibility with increasing BF proportion was partly due to the fat content of BF which was higher than that of barley grain (65 vs. 22 g kg^{-1} DM). Fat-based concentrates are inferior to starch or fibre-based concentrates as supplements to grass silage which is attributed to a lower organic matter digestibility for the former (e.g. Moloney 1996). Fat supplementation, even at quite low levels (40–50 g kg^{-1} DM), has been shown to depress fibre digestion (e.g. Ikwuegbu and Sutton 1982, Murphy et al. 1987). Therefore, extensive use of fat in ruminant diets has been limited because of the inhibitory effects of fatty acids on ruminal microbial metabolism (Palmquist and Jenkins 1980, Merchen et al. 1997). Apparent total tract digestibilities of fibre components decrease by supplementation of fats, particularly when large amounts of highly unsaturated vegetable oils (Ward et al. 1957), oilseeds (Drackley et al. 1985) or unsaturated animal fats, such as yellow grease (Jenkins and Jenny 1989), are fed. According to Doreau and Chillard (1997), dietary supplementation with fat, especially polyunsaturated fats, of more than 50 g added fat kg^{-1} concentrates, has an increasingly adverse effect on ruminal digestion of fibre. However, disruptions in ruminal fibre digestion with added fat have been observed mostly with sheep or steers fed at or slightly above maintenance intakes (Ikwuegbu and Sutton 1982, Jenkins and Palmquist 1984, Jenkins and Fotouhi 1990). Some recent studies (e.g. Christensen et al. 1996) show that ruminal digestion of structural carbohydrates is not affected by supplementation of fat in dairy cows at higher intakes. Dry matter intake (DMI) has a great effect on ruminal digestion of OM and passage of microbial protein to the duodenum (Clark et al. 1992) and may thus override many of the negative effects of fat supplementation (Merchen et al. 1997). The DMI of bulls is clearly lower than that of high-producing dairy cows. It is therefore possible that the fibre digestion may have been affected in the present trial when the fat content of TMR increased from 28 to 46 g kg^{-1} DM with increasing BF proportion. However, the mechanisms of digestion are complicated and besides intake, there are many other factors that can influence ruminal responses to supplemental fats, including fatty acid profile and chemical form of the fat (Pantoja et al. 1994, 1995), ruminal availability of the fat (Ohajuruka et al. 1991), Ca content of the diet (Bock et al. 1991, Doreau et al. 1993), as well as source, content and particle size of dietary fibre (Ben Salem et al. 1993, Hussein et al. 1995, Tackett et al. 1996).

The reduced gain and lower DM and energy intake of the BF75 diet were not caused only by the reduction in OMD since replacing barley grain with BF had a curvilinear effect on DM, energy and protein intakes at stage 2 and during the entire period. Intakes increased with the BF25 and BF50 diets compared with the control diet, but decreased with BF75 compared with the control diet. In the present study, the increased DMI with the BF25 and BF50 diets to the level of ME supply with the control diet suggested an energetic regulation of feed intake. When cattle are fed high-energy rations that are palatable, low in fill and readily digested, intake is regulated to meet the energy demands of the animal, unless the diet is fermented too rapidly and digestive disorders occur (Montgomery and Baumgardt 1965, Baile and Forbes 1974). It is suggested that, when the energy content of the diet decreased (usually with increasing NDF content), the animal can increase its DMI until rumen fill (Mertens 1994, Forbes 1995). In the present study, the silage used was of good nutritional quality and the concentrates were quite highly digestible. Therefore the bulls could increase DMI when the energy content of the rations decreased with BF25 and BF50 diets compared with the control. In addition, replacing starch with fibrous concentrate may change rumen fermentation by increasing rumen pH, resulting in more efficient cellulolysis in the rumen, especially with high concentrate proportions (Huhtanen et al. 1988), which may partly explain the increased DMI observed with the BF25 and BF50 diets compared with the control. However, DMI decreased when 75% of the barley grain concentrates was replaced with BF, so on the BF75 diet the bulls could not compensate the lower energy content of TMR by increasing DMI. This was probably due to the palatability of BF which was not very good. Subjective observations during the experiment support this conclusion, and also Huhtanen et al. (1989) reported that the palatability of BF was not good in the study with growing bulls. On the other hand, Root and Huhtanen (1998) reported a good palatability of BF in their experiment, but in that trial the highest BF intake was 3.3 kg DM d^{-1}, being at the same level as in the BF50 diet in the present study which was approximately 30% less than the maximum BF intakes in the BF75 diet.

Root and Huhtanen (1998) and Huhtanen et al. (1989) did not report any response of DMI to replacing barley grain with BF in dairy bulls with separate feeding. In these studies by Huhtanen et al. (1989) and Root and Huhtanen (1998), the average concentrate proportions and concentrate intakes were lower (420 g kg^{-1} DM; 2.89 kg DM d^{-1} and 390 g kg^{-1} DM; 3.01 kg DM d^{-1}, respectively) than in the present study (540 g kg^{-1} DM; 5.20 kg DM d^{-1}). Different concentrate proportions, concentrate intakes and feeding methods (separate vs. TMR) probably explain the differences between experiments in feed intake. In the present study linearly depressed feed and energy conversion during the entire period when barley grain was replaced by barley fibre was due to effects on DM and energy intakes and gain. These results are similar to the previous results by Root and Huhtanen (1998) who reported reducing feed conversion when replacing barley grain partly with BF 350 kg LW to slaughter. These data indicate that, during the final part of the growing period (LW 400 to slaughter), 50% of barley starch can be replaced with BF without affecting growth, but feed efficiency factors may decrease when barley starch is replaced with BF. In the course of our trial, the calculated supply of energy was 12% higher than in the Finnish feeding recommendations (MTT 2006) for present growth on average. This is consistent with our earlier findings with dairy bulls fed TMR (Huuskonen et al. 2007) and indicates that the current Finnish energy recommendations are probably too low for dairy bulls of a LW of more than 250 kg.

The dressing proportion decreased with increasing BF proportion in the present study. Also Root and Huhtanen (1998) reported that the dressing proportion tended to be lower for BF than for barley grain diets, assuming that it may be due to differences in rumen fill. Root and Huhtanen (1998) supposed that compared to bulls fed BF, bulls fed barley grain may have stopped eating with smaller rumen fill for metabolic reasons, mainly feedback mechanism of increased amount of rumen fermentation end products, leading to lighter weight of rumen contents with barley grain. However, the effect of fibrous concentrate on the dressing proportion is not very clear. For example, Huhtanen et al. (1989) and Jaakkola and Huhtanen (1990) reported no effect on dressing proportion, when barley grain was replaced with fibrous concentrate (BF or sugar beet pulp). With increasing level of BF in the diet, carcass fat classification decreased by 22% in the present experiment. According to literature, reducing energy intake usually decreases carcass fat content (e.g. Harrison et al. 1978, Fishell et al. 1985), which could explain the lower fat classification on the BF75 diet. On the other hand, measures of fatness increase also with increasing carcass weight (Keane and Allen 1998) and in our trial carcass weight decreased with increasing level of BF, which probably also explained the differences in fatness. For cattle finished on grass silage and concentrates, Steen and Kilpatrick (2000) concluded that reducing slaughter weights is likely to be a more effective strategy to control carcass fat content than reducing energy intake either by diet restriction or concentrate proportion. The explanation for the quadratic effect on carcass conformation in the present experiment is not clear. Probably higher energy intake partly explains the increased conformation score with the BF25 and BF50 diets. Caplis et al. (2005) reported that carcass conformation of finishing steers increased with increasing concentrate level and energy intake. In previous studies with barley by-products (Huhtanen et al. 1989, Root and Huhtanen 1998), the carcass conformation or fat score of bulls was not significantly affected by the BF replacement. However, in the studies by Huhtanen et al. (1989) and Root and Huhtanen (1998), the carcass weights were considerably lower (224 kg and 260 kg, respectively) than in the present study.

In conclusion, barley fibre was a suitable energy supplement with good-quality silage for growing dairy bulls. The results indicate that 50% of barley starch can be replaced with BF without affecting growth, but feed efficiency factors may decrease when barley starch is replaced with BF. At 75% replacement, DMI decreased, resulting in a lower ME intake and reduced level of performance. The rationality of the use of BF in the future will depend on the price in relation to other concentrates.

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SELOSTUS

Ohrarehu maitorotuisten sonnien seosrehuruokinnassa

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ıtkimuksen tarkoituksena oli kartoittaa integroidun rkkelys-etanoliteollisuuden sivutuotteena syntyvän ırarehun käyttöä kasvavien lihanautojen seosrehu- okinnassa. Kokeessa oli mukana 32 maitorotuista ınnia, jotka painoivat kokeen alussa 261 kg ja lopussa ;0 kg. Erilaisia koeruokintoja oli neljä. Kontrolliruo- nta sisälsi ainoastaan nurmisäilörehua (46 %) ja ohraa 4 % kuiva-aineesta) koko kokeen ajan. Kolmessa uussa ruokintaryhmässä väkirehu sisälsi puolet ohraa puolet ohrarehua siihen saakka, kunnes sonnit saavut- ⁄at 450 kg:n elopainon. Tästä eteenpäin väkirehussa i ohraa 75, 50 tai 25 prosenttia, ja vastaavasti ohra- hua 25, 50 tai 75 prosenttia kuiva-aineesta. Kaikki äimet saivat vapaasti seosrehua, ja väkirehuprosentti i kaikilla ruokinnoilla sama (54) koko kokeen ajan. Kun ohraa korvattiin ohrarehulla, orgaanisen aineen ja kuidun näennäinen in vivo -sulavuus heikkeni. Ohraruokintaan verrattuna orgaanisen aineen sulavuus heikkeni 17 prosenttia, kun ohrasta 75 prosenttia oli korvattu ohrarehulla. Ohran osittainen korvaaminen vaikutti myös rehun syöntiin. Syönti lisääntyi, kun ohrasta 25 tai 50 prosenttia oli korvattu ohrarehulla. Sen sijaan 75 prosentin korvaaminen vähensi rehun syöntiä. Ohran osittainen korvaaminen ohrarehulla heikensi hieman kasvutuloksia. Samoin teurasprosentti ja ruhojen rasvaisuus pienenivät. Tulosten perusteella enintään puolet kasvavan sonnin väkirehuannoksesta on mahdollista korvata ohrarehulla. Ohrarehun käytön ratkaisee kuitenkin viime kädessä sen hinta suhteessa muihin väkirehuihin.

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Need for protein supplementation in the diet of growing dairy bulls fed total mixed ration based on moderate digestible grass silage and barley

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The objective of the present experiment was to study the need for the protein supplementation in the diet of growing dairy bulls (initial live weight 272 ± 28.5 kg and final live weight 666 ± 31.2 kg, on average) fed total mixed ration based on moderate digestible grass silage and barley. The experiment comprised 24 Finnish Ayrshire bulls and 8 Holstein-Friesian bulls and included four treatments. The control diet (C) consisted of moderate digestible (653 g digestible organic matter in dry matter (DM) grass silage (450 g kg^{-1} DM), barley grain (275) and barley fibre (275) without protein supplementation. Three isonitrogenous experimental diets included also extra protein, i.e. (1) rapeseed meal (RSM) (supplementation 530 g DM per animal day^{-1}), (2) wet distillers' solubles (WDS) (600 g) and (3) a mixture of barley protein (90% of fresh weight) and wet distillers' solubles (10) (BPWDS) (480 g). In all isonitrogenous diets the crude protein content of concentrate increased from 137 to 150 g kg^{-1} DM (9%) compared with the C diet. All bulls were fed total mixed ration *ad libitum*. The energy content of all diets was 11.6 MJ kg^{-1} DM. The live weight gain of the bulls tended to be higher with the BPWDS diet than with the C diet (C 1214 vs. BPWDS 1301 g d^{-1}; $p = 0.10$), but the treatments had no significant effect on carcass gain, feed conversion or slaughter parameters. Only the BPWDS diet differed significantly from the C diet in DM (C 9.69 vs. BPWDS 10.38 kg DM d^{-1}; $p < 0.01$) and energy intake (C 112.4 vs. BPWDS 120.3 MJ d^{-1}; $p < 0.05$). The apparent organic matter digestibility (OMD) was 5% higher in the BPWDS diet than in the C diet ($p < 0.001$), but the RSM and WDS diets did not differ from the C diet in OMD. The results indicate that the supply of protein in dairy bulls is most probably adequate with moderate digestible, well-preserved grass silage and barley-based concentrates when intake of digestible organic matter is high enough to support microbial protein synthesis in the rumen.

Key-words: Beef production, dairy bulls, protein supplementation, total mixed ration, barley protein, wet distillers' solubles

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Introduction

Beef production in Finland is based mainly on raising dairy bulls by feeding them grass silage and cereal grain-based concentrates. In some feeding experiments (Joki-Tokola 1991, Aronen et al. 1992, Aronen and Vanhatalo 1992a), partial replacement of cereal grains by protein feeds had a positive effect on live weight gain (LWG), while in others the effect was non-existent (Huhtanen et al. 1989, Aronen 1990, Huuskonen et al. 2007a). The improved LWG may have been related either to an increased uptake of amino acids or to improved digestibility of the diet and thereby increased feed intake (Aronen and Vanhatalo 1992b). The Finnish protein evaluation system for ruminants (MTT 2006) takes into account both the nitrogen required for rumen microbes and the supply of amino acids to the animal. The amino acids are of microbial or feed origin. Grass silage is usually cut at an early stage of maturity to obtain silage of high digestibility and, consequently, also the crude protein (CP) content of the grass is high. Grass silage CP is characterized by rapid and high (80-90%) degradability in the rumen, which usually results in an excess of rumen-degradable protein for rumen microbes in beef cattle (Aronen 1992). Therefore, the protein supplement, if needed, should have clearly lower rumen degradability of CP compared to grass silage. In Finland, rapeseed meal (RSM) is the most important protein feed used in concentrates for cattle. According to Harazim et al. (2002) effective degradability of CP in RSM was determined to amount to 68.1%. Similarly, CP degradability of canola meal was 67.3% in the experiment of Boila and Ingalls (1992). According to the literature, a protein supplement may have a positive effect on the daily growth rate of growing cattle when the gain without protein supplementation is low, for example, with low-digestibility silage (Steen 1988) or hay (Aronen 1990, Hennessy et al. 2000), with extensively fermented silage (Jaakkola et al. 1990) or with small amounts of concentrate supplements (Pike et al. 1988). However, it is not clear how low grass silage digestibility should be, for protein supplementation to have a positive effect on the LWG of dairy bulls. There exists no data on the performance of dairy bulls fed with or without protein supplement and moderate digestible grass silage in total mixed ration (TMR) feeding.

Nowadays many beef producers use protein supplements with grass silage-barley-based feedings in Finland (Harri Jalli, personal communication, LSO Foods Ltd., January 10, 2008) even though the price of RSM is very high compared to those of grain or forages. However, there are also some other protein supplements available. For example, an integrated production process of ethanol and starch from barley creates by-product fractions such as barley fibre (BF), wet distillers' solubles (WDS) and barley protein (BP) (Näsi 1988) that are often low-priced feeds. So it would be cost-effective if these by-products can replace grain or more expensive protein supplements in the feeding. With TMR feeding it is easy to use liquid by-products, like BP and WDS. These protein-rich products have been studied earlier in few separate feeding experiments with growing bulls. Root and Huhtanen (1998) reported that increasing WDS to the grass-silage-barley-based diet did not have a significant effect on the LWG of bulls. Huhtanen et al. (1989) and Aronen (1990) studied dried BP with growing cattle and, according to Aronen (1990), dried BP seems to be more suitable as a protein supplement for hay-based than for grass-silage-based diets. However, there exist no published results about liquid protein supplements from the barley-based integrated starch-ethanol process with TMR-fed dairy bulls. In addition, feeding extra protein increased the N and P excretion to the environment (Klopfenstein and Erickson 2002, Satter 2003). Also extra protein puts unnecessary load on the animal's metabolism because of increasing excretion of N. Is there enough protein in the diet to support high growth without protein supplementation is an important question for Finnish beef producers. The present experiment was conducted to study the need for protein supplementation in the diet of growing dairy bulls fed a moderate digestible grass-silage-barley-based TMR. It was hypothesised that the animal performance is lower when protein supplement is not used in moderate digestible grass silage-barley-based TMR.

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Material and methods

Animals, diets and experimental design

A feeding experiment with 24 Finnish Ayrshire bulls and 8 Holstein-Friesian bulls was conducted between March 2005 and February 2006 in the experimental barn of North Ostrobothnia Research Station of MTT Agrifood Research Finland (Ruukki, 64°44'N, 25°15'E). The experimental procedures were evaluated and approved by the Animal Care and Use Committee of MTT Agrifood Research Finland. All animals were purchased from local dairy farms. Before the beginning of the trial the animals received grass silage and concentrates (commercial pelleted calf starter, flattened barley and rapeseed meal). At the beginning of the present experiment the animals (initial live weight (LW) 272 ± 28.5 kg and age 191 ± 6.6 days) were divided into eight blocks of four animals by LW and breed. Age was not taken into account in the blocking because of the small variation in age. The animals were housed in a tie-up barn and individually fed three times per day (at 0800, 1200 and 1800 h). Refused feed was collected and measured at 0700 h daily. The bulls had free access to water from an open water bowl during the experiment.

The experiment included four treatments and each treatment was assigned to one randomly selected animal in each block. Basic TMR (grass silage (450 g kg^{-1} dry matter (DM)), flattened barley grain (275) and BF (275)) was mixed in a mixer wagon (Junkkari Ltd., Ylihärmä, Finland) and fed to all bulls *ad libitum* (proportionate refusals as 5%). In addition, protein supplements were mixed daily in the basic TMR individually for each bull so that the four treatments were:

1. control diet (C): no protein supplementation, but the bulls received barley supplementation (530 g DM per animal d^{-1}) to ensure the same concentrate proportion and energy content for all four treatments
2. rapeseed meal (RSM) 530 g DM per animal d^{-1}
3. wet distillers' solubles (WDS) 600 g DM per animal d^{-1}
4. a mixture of barley protein (90% from fresh weight) and wet distillers' solubles (10) (BPWDS) 480 g DM per animal d^{-1}.

After supplementation the concentrate proportion of the diets was increased to 570–580 g kg^{-1} DM. Treatments 2–4 were isonitrogenous, since each protein supplement provided 170 g CP per animal d^{-1} during the whole study. As compared with the C diet, the CP content of the concentrates in the other diets increased from 137 to 150 g kg^{-1} DM (9%) on average during the experiment. All the bulls received a mineral supplement (150 g per animal d^{-1}) and a vitamin supplement (50 g per animal per week). Grass silage was direct-cut from a second-growth timothy (*Phleum pratense*) and meadow fescue (*Festuca pratensis*) sward and ensiled in bunker silos with a formic acid-based additive applied at a rate of 5 l per tonne of fresh grass. Barley fibre is a fibrous product comprised mainly of the cell wall fraction of barley endosperm. The commercial BF (produced by Altia Ltd., Koskenkorva, Finland) included BF (950 g kg^{-1} DM), wet distillers' solubles (25) and molasses (25). Wet distillers' solubles is the non-fermentable residue after distillation of ethanol, and BP is obtained as a result of removal of the protein fraction from the cereal cells by separation. A detailed description of the integrated starch-ethanol process and the by-products of the process are given by Näsi (1988).

Measurements

The animals were weighed on two consecutive days at the beginning of the experiment, and thereafter every 28 days. Before slaughter they were weighed on two consecutive days. The target carcass weight was 350 kg, and the bulls were selected for slaughter based on LW and an assumed dressing proportion. The LWG was calculated as the difference between the means of initial and final weights. The estimated rate of carcass gain was calculated by assuming an initial carcass weight of 0.50 of initial LW which was used also in previous studies by Root and Huhtanen (1998) and Huuskonen et al. (2007b). Dressing proportions were calculated from the ratio of hot carcass weight to final LW. For conformation, development of carcass profiles, in particular the essential parts (round, back, shoulder), was taken into consideration according to the EUROP classification (E: excellent, U: very good, R: good, O: fair, P: poor), and for fat cover degree the amount of fat on the outside of the carcass and in the thoracic cavity was taken into account using a classification range from 1 to 5 (1: low, 2: slight, 3: average, 4: high, 5: very high). Each level of conformation scale was subdivided into 3 sub-classes (O+, O, O-) to a transformed scale ranging from 1 to 15, 15 being the best conformation (Commission of the European Communities 1982).

Sample Analyses

Silage samples were analysed for DM (determined at 105°C for 20 h) at the beginning of the experiment and twice a week, thereafter for preparation of TMR. Silage sub-samples for chemical analyses were taken twice a week, pooled over periods of four weeks and stored at –20ºC. Thawed samples were analysed for DM, ash, CP, NDF, ether extract, phosphorus (P), silage fermentation quality (pH, water-soluble carbohydrates, lactic and formic acids, volatile fatty acids, soluble and ammonia N content of N) and digestible organic matter (DOM) in DM (D value). Concentrate sub-samples were collected weekly, pooled over periods of eight weeks and analysed for DM, ash, CP, NDF, ether extract and P. The analyses of DM, ash, CP and NDF were made as described by Ahvenjärvi et al. (2000). The ether extracts were determined according to procedure 920.39 of AOAC (1990) after acid (HCL) hydrolysis. Phosphorus was determined using an ICP emission spectrophotometer (Thermo Jarrel Ash/Baird, Franklin, USA) as described by Luh Huang and Schulte (1985). The silage was analysed for fermentation quality by the methods described by Moisio and Heikonen (1989) and for D value by the method described by Nousiainen et al. (2003).

Diet digestibility was determined for all animals when the bulls were 603 ± 39 kg LW. Feed and faecal samples were collected twice a day (at 0700 and 1500 h) during the collection period (5 d), pooled and stored frozen prior to analyses. Thawed samples were analyzed for DM, ash, CP and NDF as described above. Diet digestibility was determined using acid-insoluble ash (AIA) as an internal marker (Van Keulen and Young 1977). The AIA content of the samples was analysed according to the regulations of the European Commission (1971).

The metabolizable energy (ME) value of the silage was calculated as 0.16 × D value (MAFF 1981). The ME values of the concentrates were calculated as described by Schiemann et al. (1972) and MAFF (1984). The digestibility coefficients of concentrates were taken from the Finnish feed tables. The supply of amino acids absorbed from the small intestine (AAT) and protein balance in the rumen (PBV) were calculated according to the Finnish feed tables (MTT 2006).

Statistical analysis

The experiment was set up according to a randomized complete block design with animal as an experimental unit. The results are shown as least squares means, because the records from the excluded animal were not replaced. The data were subjected to analysis of variance using the SAS mixed model procedure. The model used was

$$y_{ij} = \mu + B_j + P_i + e_{ij}$$

where μ is the overall mean, B_j is the random effect of block (j=1,…,8), e_{ij} is the random error term and P_i is the fixed effect of protein supplement. Differences between the diets were compared using an *a priori* test (Dunnett's test) so that comparison of the diets was based on the C diet.

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Results

Diets

The contents of DM, OM, CP, ether extracts, NDF and calculated contents of ME, AAT and PBV of the feeds are given in Table 1. The average D value of silage was 653 g DOM kg^{-1} DM and very close to the pre-planned D value (650). The fermentation characteristics of the silage were good as indicated by the low pH value and the low concentration of ammonia N and total acids. The CP content of BP was 13% higher than that of WDS and 8% higher than the CP content of RSM. The NDF content of RSM was clearly higher than that of BP or WDS. The calculated energy value of BP was 2.5–3.0% higher than the energy values of WDS or RSM. The calculated AAT content of WDS was 28% lower than that of RSM and 40% lower than the AAT content of BP. The calculated PBV content of WDS was clearly lower than that of RSM and BP. The P contents of protein supplements were clearly higher than those of silage, barley and BF (Table 1).

The average chemical compositions of TMR are presented in Table 2. The DM contents of the C and RSM rations were 6% higher than those of WDS and BPWDS rations, because WDS and BP were liquid feeds. The CP content of the C ration was 7% lower than that of the other rations. The P content of the C ration was 27% lower than that of the WDS ration and 15% lower than the P content of the RSM and BPWDS rations. The energy content of all diets was 11.6 MJ kg^{-1} DM.

Feed intake, diet digestibility and animal performance

One animal (in RSM diet) was excluded from the study due to several occurrences of bloat. There

Table 1. Chemical composition and feeding values of concentrates and grass silage.

	Grass silage	Barley grain	Barley fibre	Barley protein	Wet distillers' solubles	Rapeseed meal
Number of samples	11	5	5	5	5	5
Dry matter (DM), g kg^{-1} feed	228	879	920	202	320	880
In the DM, g kg^{-1}						
Organic matter (OM)	937	977	963	946	871	913
Crude protein	167	128	147	360	318	333
Neutral detergent fibre	551	191	599	73	3	254
Ether extract	35	24	63	60	55	42
Phosphorus	2.7	3.8	3.6	9.4	16.0	10.8
Digestible OM in DM, g kg^{-1} DM	653	ND [a]	ND	ND	ND	ND
Metabolizable energy, MJ kg^{-1} DM	10.5	13.1	11.5	13.2	12.9	12.8
AAT[b], g kg^{-1} DM	83	106	98	164	117	150
PBV[c], g kg^{-1} DM	25	-39	-21	127	54	110
Fermentation quality of silage						
pH	4.0					
Volatile fatty acids, g kg^{-1} DM	20					
Lactic + formic acid, g kg^{-1} DM	61					
Water-soluble carbohydrates, g kg^{-1} DM	20					
In total nitrogen, g kg^{-1}						
Ammonia N	60					
Soluble N	490					

[a] Not determined. [b] Amino acids absorbed from small intestine. [c] Protein balance in the rumen.

Table 2. Chemical composition and feeding values of total mixed rations.

	Total mixed ration [a]			
	C	RSM	WDS	BPWDS
Dry matter (DM), g kg^{-1}	402	402	383	373
Composition of DM, g kg^{-1}				
Organic matter	956	953	950	955
Crude protein	150	160	161	161
Ether extract	40	42	43	43
Neutral detergent fibre	461	453	437	444
Phosphorus	3.3	3.8	4.2	3.8
Metabolizable energy, MJ kg^{-1} DM	11.59	11.57	11.58	11.59
AAT[b], g kg^{-1} DM	94	96	95	97
PBV[c], g kg^{-1} DM	-7	0	-2	1

[a] The control diet (C) included only basic ration (grass silage, barley and barley fibre), without protein supplementation. The three isonitrogenous experimental diets were rapeseed meal (RSM), wet distillers' solubles (WDS) and a mixture of barley protein (90 % of fresh weight) and wet distillers' solubles (10) (BPWDS). [b] Amino acids absorbed from small intestine. [c] Protein balance in the rumen.

was no reason to suppose that the diet had caused this problem. The average feed DM, ME and protein intakes during the experiment are presented in Table 3. The total DM intake (DMI) ($p < 0.01$) and ME intake (MEI) ($p < 0.01$) were 7% higher in the BPWDS diet than in the C diet, and DMI kg^{-1} W$^{0.75}$ and MEI kg^{-1} W$^{0.75}$ tended to be higher ($p = 0.06$) in the BPWDS diet than in the C diet. Also in the RSM diet DMI kg^{-1} W$^{0.75}$ and MEI kg^{-1} W$^{0.75}$ tended to be higher ($p = 0.08$) than in the C diet. There were no significant differences in any feed or energy intake parameters between treatments C and WDS. In CP intake, all isonitrogenous diets differed significantly from the C diet, but in AAT intake only the BPWDS diet differed from the C diet (AAT intake was 9.7% higher than that in the C diet; $p < 0.001$).

The apparent organic matter digestibility (OMD) was 5% higher in the BPWDS diet than in the C diet ($p < 0.001$), but RSM and WDS diets did not differ from the C diet in OMD (Table 3). The CP digestibility was significantly higher in the RSM and BPWDS diets than in the C diet ($p < 0.001$). The digestibility of NDF tended to be lower in the BPWDS diet than in the C diet ($p = 0.06$). There were no significant differences in digestibility parameters between treatments C and WDS.

The mean final LW of the bulls was 666 kg (Table 4). The final LW of the bulls fed BPWDS diet was 5% higher compared with the bulls fed C diet ($p < 0.01$). The LWG of the bulls tended to be higher with the BPWDS diet than with the C diet ($p = 0.10$), but treatments had no significant effect on carcass gain or feed conversion rates. The average (all treatments) carcass weight was 344 kg and very close to the pre-planned carcass weight. The carcass weight tended to be higher in the BPWDS diet than in the C diet ($p = 0.06$). Treatments had no significant effect on the dressing proportion, carcass conformation or fat classification (Table 4).

Discussion

Feed intake and diet digestibility

In the present experiment the RSM diet did not differ from the C diet in DMI (kg DM d^{-1}) or MEI (MJ d^{-1}), which is in accordance with the results of Huuskonen et al (2007a) on dairy bulls fed grass silage-barley grain-based TMR. In some earlier studies on growing dairy bulls with separate feeding the RSM supplementation increased the intake of hay (Aronen 1990) or grass silage (Aronen 1990, Aronen and Vanhatalo 1992a, Aronen et al. 1992) but, for example, Huhtanen et al. (1985, 1989)

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Table 3. Daily feed intake and feed digestion.

	Treatment [a]				SEM [b]	Statistical significance [c]		
	C	RSM	WDS	BPWDS		1	2	3
N	8	7	8	8				
Duration, d	319	323	306	319				
Dry matter (DM) intake, kg DM d^{-1}								
Total intake	9.69	9.92	9.88	10.38	0.257	NS	NS	**
Concentrate	5.61	5.74	5.77	5.97	0.142	NS	NS	**
Dry matter intake, g kg^{-1} $W^{0.75}$	97.1	100.3	98.1	100.4	1.41	$p = 0.08$	NS	$p = 0.06$
Metabolizable energy intake, MJ d^{-1}	112.4	114.9	114.4	120.3	2.79	NS	NS	**
Metabolizable energy intake, MJ kg^{-1} $W^{0.75}$	1.13	1.16	1.14	1.16	0.015	$p = 0.08$	NS	$p = 0.06$
Crude protein intake, g d^{-1}	1467	1587	1607	1677	40.5	**	***	***
AAT [d] intake, g d^{-1}	913	946	938	1002	25.2	NS	NS	***
Neutral detergent fibre intake, g d^{-1}	4368	4447	4310	4640	135.7	NS	NS	*
Apparent digestibility [e]								
Organic matter	0.751	0.750	0.756	0.785	0.0056	NS	NS	***
Crude protein	0.760	0.794	0.760	0.836	0.0051	***	NS	***
Neutral detergent fibre	0.635	0.644	0.647	0.611	0.0099	NS	NS	$p = 0.06$

[a] The control diet (C) included only basic ration (silage, barley and barley fibre) without protein supplementation. The three isonitrogenous experimental diets were rapeseed meal (RSM), wet distillers' solubles (WDS) and a mixture of barley protein (90 % of fresh weight) and wet distillers' solubles (10) (BPWDS).

[b] Standard error of means.

[c] Differences between the diets were compared using an *a priori* test (Dunnett's test) so that comparison of the diets was based on the C diet. Contrasts: (1 = C vs. RSM), (2 = C vs. WDS), (3 = C vs. BPWDS). Statistical significance: NS, not significant; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

[d] Amino acids absorbed from small intestine.

[e] Diet digestibility was determined when the bulls were 603±39 kg live weight on average.

Table 4. Live weight, daily gain, feed conversion rate and slaughter data.

	Treatment [a]				SEM [b]	Statistical significance [c]		
	C	RSM	WDS	BPWDS		1	2	3
Initial live weight, kg	271	261	275	279	14.5	NS	NS	NS
Final live weight, kg	655	656	661	691	12.5	NS	NS	**
Live weight gain (LWG), g d^{-1}	1214	1229	1265	1301	44.6	NS	NS	$p = 0.10$
Carcass gain, g d^{-1}	653	660	696	699	27.0	NS	NS	NS
Feed conversion								
MJ kg^{-1} LWG	93	94	91	93	2.5	NS	NS	NS
AAT [d], g kg^{-1} LWG	756	773	744	774	20.9	NS	NS	NS
MJ kg^{-1} carcass gain	173	175	166	174	6.1	NS	NS	NS
AAT, g kg^{-1} carcass gain	1405	1439	1360	1448	50.1	NS	NS	NS
Slaughter data								
Carcass weight, kg	337	338	344	355	7.9	NS	NS	$p = 0.06$
Dressing proportion, g kg^{-1}	515	514	520	514	5.9	NS	NS	NS
EUROP conformation [e]	4.4	4.62	4.1	5.0	0.41	NS	NS	NS
EUROP fat classification [f]	2.9	3.3	3.0	3.3	0.21	NS	NS	NS

[a] The control diet (C) included only basic ration (silage, barley and barley fibre) without protein supplementation. The three isonitrogenous experimental diets were rapeseed meal (RSM), wet distillers' solubles (WDS) and a mixture of barley protein (90% of fresh weight) and wet distillers' solubles (10%) (BPWDS).
[b] Standard error of means.
[c] Differences between the diets were compared using an *a priori* test (Dunnett's test) so that comparison of the diets was based on the C diet. Contrasts: (1 = C vs. RSM), (2 = C vs. WDS), (3 = C vs. BPWDS). Statistical significance: NS, not significant; * $p<0.05$; ** $p<0.01$; *** $p<0.001$.
[d] Amino acids absorbed from small intestine.
[e] Conformation: (1=poor, 15=excellent).
[f] Fat cover: (1=low, 5 = very high).

reported no effect on grass silage intake. On TMR feeding the animals cannot increase only their silage intake and in the study of Huuskonen et al. (2007a) RSM supplementation had no effect on the total DMI. In agreement with Huuskonen et al. (2007a), RSM supplementation had no effect on OMD in the present trial, which is in line with the lack of significant effect on DMI. Inversely, the CP digestibility was slightly higher with the RSM diet than with the C diet, which is in accordance with the results of Huhtanen et al. (1985), Aronen and Vanhatalo (1992), Aronen et al. (1992) and Huuskonen et al. (2007a). Some of the increased apparent digestibility of CP on the protein-supplemented diets may have reflected the better digestibility of protein, while most of the increase is only apparent, being attributable to the decreased proportion of faecal metabolic nitrogen recovered in faeces with increasing CP content (Minson 1982).

Increased total daily DMI (kg DM d^{-1}) in the BPWDS diet compared with the C diet was reflected also as larger daily ME, AAT and NDF intakes. Reasons for higher intake are not totally clear. Increased total DMI (kg DM d^{-1}) in the BPWDS diet can be partly explained by higher LW of BPWDS bulls. Although there was no significant differences in initial LW, the final LW of BPWDS bulls was slightly higher than that of C bulls. The difference in DMI between the C and BPWDS diets was greater in DMI measured as kg d^{-1} (7.1%) than in DMI measured as g kg^{-1} $W^{0.75}$ (3.4%), which supports the previous statement. The good palatability of BPWDS may also partly explain the increased DMI in the BPWDS diet. Subjective observations during the experiment support this conclusion, and Aronen (1990) also reported that the palatability of BP was good in his study with growing bulls. The CP digest-

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ibility was clearly higher with the BPWDS diet than with the C diet, which probably increased the endogenous urinary nitrogen exrection in the BPWDS diet. Because the digestibility of NDF tended to be lower with the BPWDS diet than with the C diet, improved OMD manifests in non-fibre fractions.

Compared with the C diet, WDS increased the CP intake of the bulls, but did not affect DMI, MEI or AAT intake. There were no differences in diet digestibility between the C and WDS diets, which may partly explain why no difference was observed in DMI. Also Root and Huhtanen (1998) reported that the inclusion of distillers' solubles in the diet of growing bulls had no significant effect on silage intake, total DMI as well as AAT or energy intake with separate feeding. Huhtanen (1992) found that despite the increased N intake by the inclusion of distillers' solubles to the diet, the total N or non-ammonia N flow in the duodenum was not changed in growing bulls, which was due to the high rumen degradability of protein in distillers' solubles. Therefore, it can be assumed that due to high rumen degradability of protein, WDS increased little the amino acid supply, but increased the amount of ammonia in the rumen.

The P content of all protein supplements (especially WDS) was high relative to silage, barley and BF. However, according to the Finnish feeding recommendations (MTT 2006), the supply of P was sufficient also in the C diet throughout the feeding experiment. This indicates that feeding extra protein increased the P excretion to the environment, because increasing the P content of the diet will lead to higher P content of manure (Satter 2003). Extra nitrogen also causes significant water pollution when discharged into surface water through runoff or deposited in water from aerial emissions (e.g. Klopfenstein and Erickson 2002). Decreasing dietary protein inputs in feeding could potentially decrease environmental concerns related to air and water quality (Cole et al. 2003). Increased P excretion should be avoided by using mineral feeds of low P content together with these by-products.

Animal performance

In all treatments in the present study the performance of the bulls was good (LWG 1254 g d^{-1}, on average). Also LWG in the C diet (1214 g d^{-1}) was good compared with our earlier study with dairy bulls fed grass silage-barley-based diets (1168 g d^{-1}, Huuskonen et al. 2007a). Albeit the LWG of the bulls fed BPWDS diet tended to be higher compared with the bulls fed C diet, none of the protein supplements had any significant effect on carcass gain or feed conversion in the present experiment. The effect of protein supplementation on daily gain on grass silage-barley-based feedings has been rather inconsistent in various experiments. Much of this variation can be attributed to the differences in the quality of the silage offered. Waterhouse et al. (1985) reported that finishing Friesian steers are likely to respond to supplementary protein in barley-based concentrates where grass silage digestibility is low (*in vitro* digestibility below 0.65). With poorly preserved silage the response in animal performance to protein supplementation is greater than with well-preserved silage (Steen 1988, Jaakkola et al. 1990). There may be differences also between extensively and restrictively fermented silages, which both may be well-preserved, because Jaakkola et al. (1990) reported that the response to fish meal was greater when enzyme solution (cellulose-glucose oxidase) was used as a silage additive instead of formic acid.

The responses to protein supplements seem to be related also to the level of concentrate supplement, greater effects being observed with small amounts of concentrates (Pike et al. 1988). The rate of protein synthesis improved with moderate addition of barley-based concentrate to a silage diet (Thomas et al. 1980, Rooke et al. 1985), whereas further substitution gradually reduced the efficiency of synthesis (Harstad and Vik-Mo 1985). Hagemeister et al. (1980) reported a tendency towards lower protein synthesis with rations containing very low (0–20%) or high (70–100%) proportions of concentrate. In the present study, the silage was of good quality in terms of fermentation characteristics (low concentrations of fermentation acids and ammonia N) and it was treated with formic acid-based silage additive. The D value of the silage was moderate (653 g kg^{-1} DM, on average) and the CP content quite high (167 g kg^{-1} DM), which maintained a high intake of DOM when fed with barley-based concentrate (570-580 g kg^{-1} DM). The lack of response (RSM and WDS) or only minor response (BP-WDS) to protein supplementation may therefore be attributable to high intake of DOM, because the microbial protein synthesis can be assumed to have been relatively high. In accordance with many earlier studies (*e.g.* Huhtanen et al. 1985, 1989, Aronen 1990, Root and Huhtanen 1998, Huuskonen et al. 2007a), protein supplements had no significant effect on dressing proportion, carcass conformation or fat classification in our study. In conclusion, our results indicate that the supply of protein in dairy bulls is most probably adequate with moderate digestible, well-preserved grass silage and barley-based concentrates.

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SELOSTUS

Maitorotuisten sonnien lisävalkuaisen tarve nurmisäilörehuun ja ohraan perustuvalla seosrehuruokinnalla

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Tutkimuksen tavoitteena oli selvittää maitorotuisten sonnien lisävalkuaisen tarvetta, kun eläimiä ruokitaan keskinkertaisesti sulavaan nurmisäilörehuun (tutkimuksessa oli tavoitteena D-arvo 65) ja ohrapohjaiseen väkirehuun perustuvalla seosrehulla. Koe toteutettiin 32 maitorotuisella sonnilla (paino kokeen alussa 272 kg ja lopussa 666 kg) ja neljällä erilaisella koeruokinnalla. Koeruokinnat erosivat toisistaan valkuaisruokinnan koostumuksen osalta. Kontrolliruokinta (C) sisälsi syyssadosta korjattua nurmisäilörehua (toteutunut D-arvo 65,3) (45% kuiva-aineesta), ohraa (27.5) ja ohrarehua (27.5) ilman valkuaislisäystä. Kolme valkuaislisäyksen sisältänyttä koedieettiä olivat (1) rypsirouhe (RSM), (2) tiivistetty tärkkelysrankki (WDS) ja (3) ohravalkuaisrehun (90% tuorepainosta) ja tiivistetyn tärkkelysrankin (10%) seos (BPWDS). Kaikilla kolmella valkuaislisäyksen sisältäneellä ruokinnalla raakavalkuaislisäys oli 170 g d^{-1} eläintä kohti, jolloin väkirehun raakavalkuaispitoisuus nousi 9% kontrolliruokintaan verrattuna. Kaikki eläimet ruokittiin vapaasti seosrehulla. Dieetin energiasisältö oli sama kaikilla koekäsittelyillä (11.6 MJ kg^{-1} ka). Ainoastaan BPWDS-ruokinta erosi merkitsevästi C-ruokinnasta kuiva-aineen syönnin (C 9.69 vs. BPWDS 10.38 kg ka d^{-1}; $p < 0.01$) ja energian saannin (C 112.4 vs. BPWDS 120.3 MJ d^{-1}; $p < 0.05$) osalta. Orgaanisen aineen näennäinen *in vivo* –sulavuus oli 5% korkeampi BPWDS-dieetillä C-dieettiin verrattuna ($p <$ 0.001), mutta RSM- ja WDS-dieeteillä sulavuudet eivät eronneet merkitsevästi C-dieetistä. Ruokinnalla ei ollut tilastollisesti merkitsevää vaikutusta sonnien nettokasvuun, rehun hyväksikäyttöön eikä ruhon teuraslaatuun, mutta eläinten päiväkasvu oli BPWDS-dieetillä hieman kontrolliruokintaa korkeampi (C 1214 vs. BPWDS 1301 g d^{-1}; $p = 0.10$). Sen sijaan RSM ja WDS eivät eronneet tilastollisesti merkitsevästi kontrolliruokinnasta päiväkasvun osalta. Tutkimuksen perusteella sulavuudeltaan keskinkertaista nurmisäilörehua käytettäessä valkuaislisälle ei näytä tulevan merkittävää tuotosvastetta yli puolen vuoden ikäisten maitorotuisten sonnien seosrehuruokinnassa, jos säilörehu on säilönnälliseltä laadultaan hyvää ja seoksessa käytetään väkirehua yli puolet kuiva-aineesta.

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The effect of cereal type (barley versus oats) and rapeseed meal supplementation on the performance of growing and finishing dairy bulls offered grass silage-based diets

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ABSTRACT

A 3 × 2 factorial design with growing dairy bulls offered a grass silage-based diets was used to study the effects on animal performance of (1) cereal type (flattened barley versus flattened oats) and (2) inclusion of rapeseed meal (RSM) in the diet. Two feeding trials comprised a total of 42 Finnish Ayrshire and 18 Holstein-Friesian bulls. The animals were housed in a tie-up barn and fed individually. All bulls were offered grass silage (686 g digestible organic matter in kg dry matter (DM)) ad libitum. The target for average concentrate level during the experiment was 400 g/kg DM for all treatments. Three cereal feeding treatments were flattened barley, flattened barley + flattened oats (1:1 on DM basis) and flattened oats, fed either without RSM (RSM−) or with RSM (RSM+). In the RSM− diets the crude protein (CP) content of the concentrate was 132 g/kg DM. Rapeseed meal was given so that the CP content of the concentrate was raised to 160 g/kg DM in the RSM+ diets, which increased the CP content 21% with RSM supplementation. The mean initial live weight (LW) of the bulls was 257 ± 26.6 kg and the mean final LW 687 ± 30.9 kg. Increasing the proportion of oats in the diet decreased the live weight gain (LWG) ($P<0.05$). Linearly impaired LWG was a consequence of decreased metabolizable energy intake ($P<0.05$) with increasing oats proportion. Because there was no difference in DM intake, also feed conversion efficiency (kg DM/kg LWG) reduced ($P<0.05$) with increasing oats proportion. There were no effects of treatments on the dressing proportion, carcass conformation score or carcass fat score. The RSM supplement had no effect on performance parameters, and there were no significant cereal type x RSM interactions for any of the measured parameters. In conclusion, the LWG and feed conversion of growing dairy bulls reduced with increasing oats proportion. Since rapeseed meal did not affect animal performance, there is no reason to use RSM for finishing dairy bulls when they are fed good-quality grass silage and grain-based concentrate.

1. Introduction

Beef production in Finland is based mainly on raising Finnish Ayrshire and Holstein-Friesian bulls born on dairy farms. Approximately 87% of Finnish beef meat originates from dairy breeds (Manninen, 2007). The supply of domestic beef has decreased in Finland during recent years, giving rise to a clear discrepancy between the demand for and supply of domestic beef. In 2007, for instance, beef production was 87 million kg, whereas the consumption was 99 million kg (Information Centre of the Ministry of Agriculture and Forestry, 2008). Because of this trend the average carcass weight of bulls have increased from 270 kg in 1999 to 331 kg in 2007 (Information Centre of the Ministry of Agriculture and Forestry, 2008). However, there exist only few studies (Huuskonen et al., 2007a,b) on feeding experiments on the performance of dairy bulls with a carcass weight over 320 kg.

Cereals are the primary source of dietary starch in growing bulls and make up a substantial proportion of cattle feeding

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stuffs used in North Europe. Traditionally diets for growing cattle were largely based on grass silage and barley (*Hordeum vulgare*) or corn (*Triticum aestivum*) supplement. As a result of increasing price of barley and corn, oats (*Avena sativa*) has become an economically attractive alternative in cattle rations. With competition from biofuel production, the relative price and value of grains for animal feeding will change and there maybe an economic advantage to use oats rather than barley for beef production. According to Fuhr (2006), oats is also best grown in cool, moist climates and is versatile from a crop production point of view. Oats can provide a desired disease break by limiting the build-up of soilborne pathogens, and grown under certain conditions it may out-yield barley. Nevertheless, the energy value of oats has been considered inferior to barley and corn due to the hull content of oats which ranges from 20 to 30% (Crosbie et al., 1985). Oats hulls are a high-fibre feed stuff containing substantial amounts of indigestible lignin. According to Fuhr (2006), oats is also unique among cereals in that it has both higher lipid levels and the majority of the lipids are in the endosperm. In relation to other cereals, oats is not a predominant grain fed to ruminants. Corn and barley are the grains of choice, especially in feeding programmes designed for growing and fattening cattle. Therefore, little research has been conducted on oats in ruminant production (Fuhr, 2006). However, some studies in dairy cattle (*e.g.* Moran, 1986) have shown that oats is comparable to other cereal grains at maintaining high milk yields. Corah et al. (1975) and Dion and Seoane (1992) reported similar growth rates and feed efficiencies between fattening steers receiving oats or barley with hay-based diets. However, there is paucity of published information on the relative performance of growing dairy bulls offered oats instead of barley as a supplement to grass silage.

In Finland, rapeseed meal (RSM) is the most important protein feed used in concentrates for cattle. Nowadays many beef producers use protein supplements with grass silage-grain-based feedings in Finland even though the price of RSM is very high compared to those of grain or forages and feeding extra protein increased the N and P excretion to the environment (Klopfenstein and Erickson 2002). Also extra protein puts unnecessary load on the animal's metabolism because of increasing excretion of N. Huuskonen et al. (2007b, 2008a) reported that RSM did not affect animal performance of dairy bulls with total mixed ration (TMR) feeding, and concluded that there is no reason to use protein supplement for finishing dairy bulls when they are fed TMR with good-quality (high or medium digestibility, well-preserved) grass silage and barley-based concentrate. However, inclusion of RSM in the diet was found to have a positive effect on performance in some earlier feeding experiments (*e.g.* Aronen and Vanhatalo 1992; Aronen et al., 1992), and this positive effect was mediated by increasing grass silage intake. In these earlier experiments separate feeding was used, so the feeding method was different compared with studies by Huuskonen et al. (2007b, 2008a). With TMR feeding, animals cannot increase only their silage intake and according to Huuskonen et al. (2007b, 2008a) RSM supplementation has no effect on total DMI. Now it is of interest to obtain more information concerning animal performance when finishing dairy bulls are fed with separate feeding. Is there enough protein in the diet to support high growth without protein supplementation is an important question for Finnish beef producers.

The objectives of the present study with growing dairy bulls slaughtered at 350 kg carcass weight were to determine the effects on animal performance in various growth periods of (1) cereal type (barley versus oats) in the diet and (2) the inclusion of RSM in the grass silage-based diet in separate feeding. Possible interactions between cereal type and RSM supplement were also examined.

2. Materials and methods

2.1. Animals, housing and experimental design

The feeding experiment was conducted in the experimental barn of the North Ostrobothnia Research Station of MTT Agrifood Research Finland (Ruukki, 64°44′N, 25°15′E) and it included two feeding trials. The first trial started in April 2006 and the second in December 2006. The experimental procedures were evaluated and approved by the Animal Care and Use Committee of MTT Agrifood Research Finland. The first trial comprised 18 Finnish Ayrshire bulls and 12 Holstein-Friesian bulls, the second trial 24 Finnish Ayrshire bulls and 6 Holstein-Friesian bulls. One animal was excluded from the study due to hoof problems, but there was no reason to assume that the diets had caused these problems.

All animals, initial live weight (LW) 50 ± 5.1 kg and age 15 ± 5.2 days, on average, were purchased from local dairy farms. Before the experiment the animals were housed on peat bedding in six pens (3.0×3.5 m, 5 calves in each) providing 2.1 m^2/calf. They received milk replacer (MR), grass silage and a commercial pelleted calf starter during the preweaning period (from ages 0.5 to 2.5 months). The MR used was delivered by Valio Ltd. (P.O. Box 10, FI-00039 Valio, Finland) and contained 237 g crude protein (CP)/kg dry matter (DM) and 15.8 MJ metabolizable energy (ME)/kg DM. The commercial concentrate delivered by Raisio Nutrition Ltd. (P.O. Box 101, FI-21201 Raisio, Finland) contained 209 g CP/kg DM and 12.3 MJ ME/kg DM. During the postweaning period (from ages 2.5 to 6.5 months) the animals received grass silage and concentrates (commercial pelleted calf starter, barley and RSM). All the animals remained generally healthy throughout the preweaning and postweaning periods and grew normally. The average live weight gain (LWG) was 651 g/day during the preweaning period and 1291 g/day during the postweaning period.

At the start of the experiment the animals (LW 257 ± 26.6 kg) were 6.5 months old. They were divided into five blocks of six animals by LW and breed within trials. Within each block one randomly selected animal was chosen for each treatment. The bulls were placed in an insulated barn in adjacent tie-stalls. The width of the stalls was 70–90 cm for the first four months and 113 cm until the end of the experiment. The bulls were tied with a collar around the neck, and a 50 cm long chain was attached to a horizontal bar 40–55 cm above the floor. The floor surface was solid concrete under the forelegs and metal grids under the hind legs. No bedding was used on the floor.

A 3×2 factorial design was used to study the effects on animal performance of (1) cereal type and (2) inclusion of RSM. The animals were offered grass silage ad libitum (proportionate refusals as 5%) with one of the following concentrate supplement treatments:

1. flattened barley, no protein supplementation (B RSM−)
2. flattened barley, RSM supplementation (B RSM+)
3. flattened barley + flattened oats (1:1 on DM basis), no protein supplementation (BO RSM−)
4. flattened barley + flattened oats (1:1 on DM basis), RSM supplementation (BO RSM+)
5. flattened oats, no protein supplementation (O RSM−)
6. flattened oats, RSM supplementation (O RSM+)

The animals were individually fed twice a day (at 8:00 a.m. and 6:00 p.m.). Refused feed was collected and measured daily at 7:00 a.m. The bulls had free access to water from an open water bowl during the experiment. The amount of the concentrate supplementation was 37 g/$W^{0.75}$/animal/day for all treatments, and the target for average concentrate level during the experiment was 400 g/kg DM. The barley cultivar used in the feeding experiment was Artturi (Boreal Plant Breeding Ltd., Myllytie 10, FI-31600 Jokioinen, Finland) and the oats cultivar was Aslak (Boreal Plant Breeding Ltd., Myllytie 10, FI-31600 Jokioinen, Finland). In the RSM− diets the CP content of the concentrate was 132 g/kg DM, on average. Rapeseed meal (delivered by A-Rehu Ltd., P.O. Box 908, FI-60061 Atria, Finland) was given so that the CP content of the concentrate was raised to 160 g/kg DM in the RSM+ diets. Thereby the CP content increased 21% with RSM supplementation, on average. The amount of RSM supplement depended on the CP content of the grain, which was measured by chemical analyses. The average RSM supplementation during the experiment was 440 g DM/animal/day. The daily concentrate ration also included 150 g of a mineral mixture (Tähkä Apekivennäinen: Ca 235, P 8, Na 74, Mg 40 g/kg; delivered by Feedmix Ltd., Santavuorentie 11, FI-61330 Koskenkorva, Finland). A vitamin mixture contained also Se (Xylitol ADE-Vita: A 2,000,000 IU/kg, D3 400,000 IU/kg, E DL-α-tocopheryl acetate 1000 mg/kg, E DL-α-tocopherol 900 mg/kg, Se 10 mg/kg; delivered by Suomen Rehu Ltd., P.O. Box 401, FI-02601 Espoo, Finland) was given 50 g/animal weekly. No medications were used in any of the feeds. The grass silages in both trials were primary growth from a timothy (*Phleum pratense*) and meadow fescue (*Festuca pratensis*) sward and ensiled in bunker silos with a formic acid-based additive (AIV-2 Plus: 760 g formic acid/kg, 55 g ammonium-formiate/kg; delivered by Kemira Ltd., P.O. Box 171, FI-90101 Oulu, Finland) applied at a rate of 5 L/tonnes of fresh grass.

2.2. Procedures and sample analyses

Silage sub-samples for chemical analyses were taken twice a week, pooled over periods of four weeks and stored at −20 °C. Thawed samples were analysed for DM, ash, CP, crude fat (CF), neutral detergent fibre (NDF), indigestible NDF (iNDF), starch, phosphorus (P), silage fermentation quality (pH, water-soluble carbohydrates (WSC), lactic and formic acids, volatile fatty acids, soluble and ammonia-N content of N) and digestible organic matter (DOM) in DM (*D* value). Concentrate sub-samples were collected weekly, pooled over periods of eight weeks and analysed for DM, ash, CP, CF, NDF, iNDF, starch and P. The analyses of DM, ash, CP, CF and NDF were made as described by Ahvenjärvi et al. (2000). The P content of samples was determined using an ICP emission spectrophotometer (Thermo Jarrel Ash/Baird, Franklin, USA) as described by Luh Huang and Schulte (1985). Starch was analysed according to McCleary et al. (1994). For iNDF analyses, samples of 0.5–1.0 g were weighed into a pre-weighed polyester bag (pore size 17 μm, 60 × 120 mm, Swiss Silk Bolting Cloth Mfg. Co. Ltd., Zurich, Switzerland) which was incubated for 12 day in the cow's rumen (Lippke et al., 1986). After incubation, the bag was rinsed with cold water for 25 min using a household washing machine, boiled for 1 h in NDF solution, rinsed and dried to a constant weight at 60 °C. Finally, the bag was emptied and the residue was ashed at 600 °C for 18 h to determine the organic matter content of the indigestible residue. The silage was analysed for fermentation quality by electrometric titration described by Moisio and Heikonen (1989) and for *D* value by the method described by Nousiainen et al. (2003). The *D* value results were calculated using correction equations to convert pepsin-cellulase solubility values into *in vivo* digestibility based on a data set comprising Finnish *in vivo* digestibility trials.

Diet digestibility was determined for all animals when the bulls were 600 ± 28 kg LW, on average. Feed and faecal samples were collected twice a day (at 7:00 a.m. and 3:00 p.m.) during the collection period (5 day) and stored frozen prior to analyses. The samples were analyzed for DM, ash, CP and NDF as described above. Diet digestibility was determined using acid-insoluble ash (AIA) as an internal marker (Van Keulen and Young, 1977).

2.3. Calculations and carcass measurements

The ME contents of the feeds were calculated according to Finnish feed tables (MTT, 2006). The ME value of the silage was calculated as 0.16 × *D* value (MAFF, 1981). The ME values of the concentrates were calculated as described by Schiemann et al. (1972) and MAFF (1984). The digestibility coefficients of concentrates were taken from Finnish feed tables (MTT, 2006). The supply of amino acids absorbed from the small intestine (AAT) and protein balance in the rumen (PBV) were calculated according to the Finnish feed tables (MTT, 2006).

The animals were weighed on two consecutive days at the beginning of the experiment, thereafter approximately every 28 days. Before slaughter the animals were weighed on two consecutive days. The average target carcass weight in the experiment was 350 kg, and the bulls were selected for slaughter based on LW and an assumed dressing proportion. The LWG was calculated as the difference between the means of initial and final LW. The feeding experiment was divided into four sub-experimental periods of approximately 3 months each. The LWG and feed intakes of the bulls are also presented separately for these different sub-experimental periods.

Dressing proportion, carcass conformation and carcass fat score were determined according to the EUROP classification (Commission of the European Communities, 1982). For conformation, development of carcass profiles, in particular the essential parts (round, back, shoulder), was taken into consideration according to the EUROP classification (E: excellent, U: very good, R: good, O: fair, P: poor). For fat cover degree the amount of fat on the outside of the carcass and in the thoracic cavity was taken into account using a classification range from 1 to 5 (1: low, 2: slight, 3: average, 4: high, 5: very high). Each level of conformation scale was subdivided into 3 sub-classes (O+, O, O−) to a transformed scale ranging from 1 to 15, 15 being the best conformation.

2.4. Statistical methods

The 3×2 factorial feeding experiment used a randomized complete block design. The results were calculated across the two trials and are shown as least squares means. The data was subjected to analysis of variance using the SAS general linear models procedure (Littell et al., 1991). The statistical model used was

$$y_{ijkl} = \mu + \gamma_k + \delta(\gamma)_{kl} + \alpha_i + \beta_j + (\alpha\beta)_{ij} + e_{ijkl}$$

where μ is the overall mean and e_{ijkl} is the random error term. α, β, γ and δ are the effects of cereal type, RSM supplement, trial and block (blocks are nested within trial, i.e. both trials had their own blocks), respectively. Because there were no significant interactions between trial and cereal type or trial and RSM supplement, these effects were not included in the final model. The effect of cereal type and RSM supplementation was further divided into linear and quadratic effects using orthogonal polynomial contrasts (Snedecor and Cochran, 1989). Since the interactions between cereal type and RSM supplement were not statistically significant (P>0.10 for all studied response variables), the results are presented only for the main effects of cereal type and RSM supplement.

3. Results

3.1. Feeds

Because the silages used in the feeding experiment came from two different harvests, the chemical compositions and feeding values are also given separately for two silages in Table 1. However, the D values and ME and AAT contents of the silages differed only slightly (4.7–4.8%). The fermentation quality of silages as indicated by low pH values and low contents of ammonia-N and fatty acids was good (Table 1). The silages used were restricted fermented (high residual WSC concentration and low lactic acid concentration).

Because the chemical compositions and feeding values of barley, oats and RSM were very uniform throughout the experiment, only one value is given for barley, oats and RSM in Table 1. The ME value of barley was 7% higher than that of oats, but oats contained 5% more CP than barley. The AAT content of oats was 6% lower and the NDF content 30% higher compared with barley. The starch content of oats was 27% lower compared with barley and oats contained much more fat than barley. The P content of RSM was clearly higher than those of grass silage, barley and oats.

3.2. Feed intake and diet digestibility

The total DM intake (DMI) (kg/day) during the entire experimental period was related to LW of the bulls and was best described by the equation: $Y = 0.0115X \pm 3.7$ ($R^2 = 0.87$) where Y = DMI (kg/day) and X = LW (kg). There were no significant treatment differences in the DMI as measured over the entire experimental period (Table 2) or during any sub-experimental period (Table 3). However, the ME intake decreased linearly with increasing oats proportion as measured over the entire experimental period (P<0.05). The energy intake also decreased linearly with increasing oats proportion in periods 1 (P<0.05) and 2 (P<0.10), but in periods 3 and 4 there was no significant difference. The RSM supplementation had no effect on the average energy supply,

Table 1
Chemical composition and feeding values of barley, oats, rapeseed meal and grass silages (mean ± S.D. [a])

	Barley	Oats	Rapeseed meal	Silage exp.1	Silage exp. 2
N [b]	12	12	12	12	12
Dry matter (DM), g/kg feed	887 ± 3.6	887 ± 11.5	881 ± 1.8	348 ± 128.1	428 ± 105.4
Organic matter, g/kg DM	975 ± 9.6	971 ± 13.8	920 ± 2.9	917 ± 178.2	923 ± 174.6
Crude protein, g/kg DM	128 ± 11.3	135 ± 6.7	352 ± 2.6	155 ± 14.2	163 ± 15.7
Neutral detergent fibre (NDF), g/kg DM	186 ± 14.1	241 ± 14.5	261 ± 1.4	538 ± 18.9	519 ± 14.6
Indigestible NDF, g/kg DM	27 ± 5.9	100 ± 9.1	114 ± 2.2	49 ± 5.4	43 ± 6.2
Crude fat, g/kg DM	23 ± 0.9	61 ± 1.2	45 ± 0.8	44 ± 0.9	47 ± 0.9
Starch, g/kg DM	573 ± 3.5	450 ± 3.2	26 ± 0.3	8 ± 0.1	9 ± 0.1
Phosphorus, g/kg DM	3.6 ± 0.1	4.0 ± 0.2	9.6 ± 0.2	2.9 ± 0.1	3.8 ± 0.1
D value [c], g/kg DM	–	–	–	669 ± 30.3	701 ± 30.9
Metabolizable energy, MJ/kg DM	13.0 ± 0.1	12.1 ± 0.2	11.7 ± 0.2	10.7 ± 0.5	11.2 ± 0.5
AAT [d], g/kg DM	104 ± 3.5	98 ± 2.7	151 ± 0.1	83 ± 3.2	87 ± 3.9
PBV [e], g/kg DM	−42 ± 6.5	−14 ± 4.3	111 ± 1.3	13 ± 11.7	14 ± 9.7
Fermentation quality of silage					
Ph				4.4 ± 0.3	4.8 ± 0.4
Volatile fatty acids, g/kg DM				12 ± 9.5	6 ± 3.8
Lactic + formic acid, g/kg DM				37 ± 18.8	24 ± 10.4
Water-soluble carbohydrates, g/kg DM				90 ± 63.4	107 ± 50.1
In total N, g/kg N					
NH_4N				51 ± 16.2	51 ± 23.8
Soluble N				416 ± 124.9	409 ± 175.0

[a] Standard deviation.
[b] Silage, one sample/feeding period (4 weeks); concentrates, one sample/two feeding periods.
[c] Digestible organic matter in DM.
[d] Amino acids absorbed from small intestine (MTT, 2006).
[e] Protein balance in the rumen (MTT, 2006).

but the CP intake was higher when RSM was included in the diet ($P<0.05$). There were no treatment effects on the AAT intake, but the PBV intake increased with increasing oats proportion ($P<0.001$) and with RSM supplementation ($P<0.001$). Replacing barley by oats led to a linear increase of NDF intake ($P<0.001$), but RSM supplement had no effect on NDF intake.

The apparent digestibility of DM, OM and NDF decreased linearly ($P<0.001$) with increasing proportion of oats (Table 2). However, replacing barley by oats led to a linear improvement of the apparent digestibility of CP ($P<0.05$). The CP digestibility was 5.6% higher ($P<0.001$) for the RSM+ diet than for the RSM− diet, but RSM had no effect on the DM, OM or NDF digestibilities.

3.3. Growth rate and slaughter parameters

The mean initial LW of the bulls was 257 kg and the mean final LW was 687 kg (Table 4). Replacing barley by oats led to a linear decrease of daily LWG ($P<0.05$) as measured over the entire experimental period. The RSM supplement had no effect on LWG as measured over the entire experimental period.

The LWG decreased linearly with increasing oats proportion in periods 1 ($P<0.10$) and 2 ($P<0.05$), but in periods 3 and 4 there was no significant difference (Table 3). The rapeseed meal supplement had a positive effect on LWG during the first sub-experimental period (1321 vs. 1419 g/day; $P<0.05$), but no effect in any other periods. The average LWG (all treatments) during the entire experimental period was negatively related to LW of the bulls and was best described by the equation: $Y=-0.89X\pm1638$ ($R^2=0.69$) where Y=LWG (g/day) and X=LW (kg).

The mean carcass weight of the bulls was 355 kg (Table 4) and close to the pre-planned carcass weight. There were no significant effects of treatments on the dressing proportion, carcass conformation score or carcass fat score.

3.4. Feed conversion rate

The feed conversion rate (kg DM/kg LWG) reduced significantly with increasing oats proportion ($P<0.05$) (Table 4). There was also a tendency that the protein conversion rate in terms of g AAT/kg LWG increased linearly with increasing oats proportion ($P<0.10$), but cereal type had no significant effect on the energy conversion (MJ/kg LWG). The feed conversion rates in terms of kg DM/kg LWG, MJ ME/kg LWG or g AAT/kg LWG were not significantly affected by RSM supplementation. The average feed conversion rate (kg DM/kg LWG) (all treatments) was related to LW of the bulls and was best described by the equation: $Y=0.0156X+0.33$ ($R^2=0.89$) where Y=feed conversion (kg DM/kg LWG) and X=LW (kg).

4. Discussion

4.1. Effect of cereal type

Oats contains much more NDF and iNDF and less starch than barley, and the difference in DM and OM digestibilities can be attributed to a lower digestibility of cell wall components of oats compared with barley starch. Replacing barley with oats in the diet had a negative effect on the OM digestibility similar to that observed by Huhtanen (1992) and Huuskonen et al. (2007a, 2008b) in growing bulls when they replaced barley grain by barley fibre (a fibrous by-product of integrated starch-ethanol production). Like oats, also barley fibre contains much more

Table 2
Effects of concentrate type and rapeseed meal supplement on daily feed intake and apparent diet digestibility of growing bulls

	Concentrate type (CT) [a]			Rapeseed meal (RSM) supplementation [b]		SEM [c]		Polynomial contrasts [d]				
	B	BO	O	−	+	CT	RSM	1	2	3	4	5
Dry matter (DM) intake, kg DM/day												
Silage	5.76	5.54	5.53	5.60	5.62	0.209	0.171					
Concentrate	3.71	3.71	3.71	3.72	3.70	0.038	0.031					
Total	9.47	9.25	9.24	9.32	9.32	0.239	0.195					
DM intake, g/kg $W^{0.75}$	92.6	91.1	92.0	91.8	91.9	2.09	1.70					
Metabolizable energy intake, MJ/day	113.7	107.2	105.7	108.0	108.1	2.48	2.16		*			
Crude protein intake, g/day	1442	1432	1458	1400	1488	38.2	31.1	*				
AAT [e] intake, g/day	885	855	844	851	873	20.8	16.9					
PBV [f] intake, g/day	−39	4	52	−25	37	4.2	3.4	***	***			
Neutral detergent fibre intake, g/day	3108	3401	3795	3400	3469	113.2	92.2		***			
Apparent digestibility												
Dry matter	0.758	0.741	0.722	0.741	0.739	0.0060	0.0049		***			
Organic matter	0.777	0.760	0.742	0.761	0.759	0.0060	0.0049		***			
Crude protein	0.738	0.753	0.763	0.731	0.772	0.0073	0.0059	***	*			
Neutral detergent fibre	0.705	0.664	0.621	0.660	0.667	0.0103	0.0084		***			

[a] B = flattened barley, BO = flattened barley + flattened oats (1:1 on DM basis), O = flattened oats.
[b] In the RSM− diets the crude protein (CP) content of the concentrate was 132 g/kg DM, on average. The CP content of the concentrate was raised to 160 g/kg DM in the RSM+ diets.
[c] Standard error of mean.
[d] Polynomial contrasts: (1 = RSM+ vs. RSM−), (2 = linear effect of oat supplementation), (3 = quadratic effect of oat supplementation), (4 = linear interaction between concentrate type and rapeseed meal supplement), (5 = quadratic interaction between concentrate type and rapeseed meal supplement). Statistical significance: (o $p<0.10$), (* $p<0.05$), (** $p<0.01$), (*** $p<0.001$).
[e] Amino acids absorbed from small intestine (MTT, 2006).
[f] Protein balance in the rumen (MTT, 2006).

Table 3
Effects of concentrate type and rapeseed meal supplement on live weight gain, feed intake and feed conversion by growing bulls during different experimental periods

	Concentrate type (CT) [a]			Rapeseed meal (RSM) supplementation [b]		SEM [c]		Polynomial contrasts [d]				
	B	BO	O	−	+	CT	RSM	1	2	3	4	5
Live weight gain, g/day												
Period 1 (Age 195–284 days)	1420	1357	1333	1321	1419	36.1	29.4	*	o			
Period 2 (Age 284–373 days)	1298	1235	1171	1255	1213	37.9	30.8		*			
Period 3 (Age 373–462 days)	1198	1138	1127	1148	1160	47.3	38.5					
Period 4 (Age 462–551 days)	1167	1101	1099	1133	1111	57.0	46.4					
Dry matter intake, kg DM/day												
Period 1 (Age 195–284 days)	7.39	7.21	7.06	7.16	7.28	0.204	0.166					
Period 2 (Age 284–373 days)	9.89	9.54	9.45	9.64	9.62	0.329	0.268					
Period 3 (Age 373–462 days)	9.91	9.59	9.60	9.71	9.69	0.253	0.206					
Period 4 (Age 462–551 days)	11.84	11.36	11.35	11.41	11.62	0.377	0.307					
Metabolizable energy intake, MJ/day												
Period 1 (Age 195–284 days)	87.3	83.7	80.4	83.1	84.5	2.32	1.89		*			
Period 2 (Age 284–373 days)	113.1	107.9	105.3	108.8	108.7	3.56	2.90		o			
Period 3 (Age 373–462 days)	117.1	112.3	111.2	113.6	113.5	2.82	2.30					
Period 4 (Age 462–551 days)	140.9	134.0	132.4	134.5	137.0	4.30	3.50					
MJ/kg live weight gain												
Period 1 (Age 195–284 days)	61.8	62.1	60.5	63.4	59.6	1.43	1.17	*				
Period 2 (Age 284–373 days)	87.9	87.7	90.9	88.0	89.7	2.67	2.18					
Period 3 (Age 373–462 days)	99.8	101.1	103.2	104.2	98.5	3.80	3.10					
Period 4 (Age 462–551 days)	130.6	122.6	126.4	122.5	130.6	6.88	5.60				o	

[a] B = flattened barley, BO = flattened barley + flattened oats (1:1 on DM basis), O = flattened oats.
[b] In the RSM− diets the crude protein (CP) content of the concentrate was 132 g/kg DM, on average. The CP content of the concentrate was raised to 160 g/kg DM in the RSM+ diets.
[c] Standard error of mean.
[d] Polynomial contrasts: (1 = RSM+ vs. RSM−), (2 = linear effect of oat supplementation), (3 = quadratic effect of oat supplementation), (4 = linear interaction between concentrate type and rapeseed meal supplement), (5 = quadratic interaction between concentrate type and rapeseed meal supplement). Statistical significance: (o $p<0.10$), (* $p<0.05$), (** $p<0.01$), (*** $p<0.001$).

Table 4
Effects of concentrate type and rapeseed meal supplement on live weight gain, carcass characteristics and feed conversion of growing dairy bulls

	Concentrate type (CT) [a]			Rapeseed meal (RSM) supplementation [b]		SEM [c]		Polynomial contrasts [d]				
	B	BO	O	−	+	CT	RSM	1	2	3	4	5
N	20	20	19	30	29							
Duration, day	346	359	359	355	354							
Initial live weight, kg	259	259	257	260	257	3.5	2.8					
Final live weight, kg	695	688	676	687	686	6.8	5.5		*			
Live weight gain, g/day	1270	1203	1172	1207	1223	31.3	25.5		*			
Slaughter data												
Carcass weight, kg	359	355	350	354	355	4.2	3.4					
Dressing proportion, kg/kg [e]	0.516	0.516	0.517	0.516	0.517	0.0029	0.0023					
EUROP conformation [f]	4.09	3.84	3.86	3.96	3.90	0.167	0.136					
EUROP fat classification [g]	2.95	2.82	2.92	2.94	2.85	0.142	0.116					
Feed conversion												
kg DM/kg live weight gain	7.45	7.71	7.91	7.74	7.64	0.127	0.103		*			
MJ/kg live weight gain	87.6	89.5	90.5	89.7	88.6	1.42	1.16					
AAT [h] g/kg live weight gain	697	713	723	707	716	11.4	9.2		o			

[a] B = flattened barley, BO = flattened barley + flattened oats (1:1 on DM basis), O = flattened oats.
[b] In the RSM− diets the crude protein (CP) content of the concentrate was 132 g/kg DM, on average. The CP content of the concentrate was raised to 160 g/kg DM in the RSM+ diets.
[c] Standard error of mean.
[d] Polynomial contrasts: (1 = RSM+ vs. RSM−), (2 = linear effect of oat supplementation), (3 = quadratic effect of oat supplementation), (4 = linear interaction between concentrate type and rapeseed meal supplement), (5 = quadratic interaction between concentrate type and rapeseed meal supplement). Statistical significance: (o $p<0.10$), (* $p<0.05$), (** $p<0.01$), (*** $p<0.001$).
[e] The ratio of hot carcass weight to final live weight.
[f] Conformation: (1 = poorest, 15 = excellent).
[g] Fat cover (1 = leanest, 5 = fattest).
[h] Amino acids absorbed from small intestine (MTT, 2006).

NDF and less starch than barley grain (Huuskonen et al., 2007a, 2008b). The reduction in NDF digestibility, when replacing barley grain with oats, was partly a consequence of decreasing proportion of silage's NDF in the total NDF intake. The silage fibre was more digestible than the fibre fraction of grains (iNDF proportion of total NDF was 8.7% with silage, 14.5% with barley and 41.5% with oats), and replacing barley with oats increased the proportion of grain NDF in the total NDF intake. It is also possible that the decreasing NDF digestibility with increasing oats proportion may partly have been due to the higher fat content of oats than that of barley (61 vs. 23 g/kg DM). Fat supplementation, even at quite low levels (40–50 g/kg DM), has been shown to depress fibre digestion in ruminants (*e.g.* Ikwuegbu and Sutton, 1982). However, disruptions in ruminal fibre digestion with added fat have been observed mostly with sheep or steers fed at or slightly above maintenance intakes (*e.g.* Ikwuegbu and Sutton, 1982; Jenkins and Fotouhi, 1990). All other indices of digestibility decreased with increasing oats proportion but CP digestibility increased. The explanation for this is not clear. Some of the increased apparent digestibility of CP may have reflected the better digestibility of oats protein than barley protein.

In all treatments in our study the LWG of the bulls was high (1210 g/day, on average) compared with earlier studies with dairy bulls fed grass silage-grain-based diets (*e.g.* Aronen et al., 1992; Huuskonen et al., 2007b). The bulls grew faster during period 1 and the growth slowed down when the animals grew older. It is well established that the performance of growing cattle slows down when animals grow older if they get feeds evenly throughout the growing period (*e.g.* Carstens et al., 1991). Increasing the proportion of oats led to decreased LWG in the present experiment, and a linearly impaired gain was a consequence of decreased energy intake with increasing oats proportion. Because there was no difference in DMI, also feed conversion (kg DM/kg LWG) reduced with increasing oats proportion. My results disagree with those of Corah et al. (1975) and Dion and Seoane (1992) who reported similar growth rates and feed efficiencies between fattening steers receiving oats or barley with hay-based diets. Differences in response to the type of dietary grain could be explained by the energy value of feeds. In the present study the calculated energy value of barley was 7% higher than that of oats, but Dion and Seoane (1992) reported no difference in energy values between barley and oats. In accordance with many earlier trials (*e.g.* Huhtanen et al., 1989; Huuskonen et al., 2008b), carcass quality was not affected by the different concentrate supplement in the present study.

The total DMI of the bulls was linearly related to LW and R-value was high. However, generally intake tends to plateau as animals get heavier and so intake per kg LW declines (*e.g.* Huuskonen et al., 2007b). When cattle are fed high-energy rations that are palatable, low in fill and readily digested, intake is regulated to meet the energy demands of the animal, unless the diet is fermented too rapidly and digestive disorders occur (Forbes, 2007). It is suggested that, when the energy content of the diet decreases (usually with increasing NDF content), the animal can increase its DMI until rumen fill (Forbes, 2007). However, in the present study, the bulls did not compensate the lower energy content of oats by increasing silage intake. In our earlier studies with growing dairy bulls, partial (50%) replacement of barley grain by barley fibre did not affect the LWG of the bulls on TMR feeding, because replacing barley grain with barley fibre increased feed intake (Huuskonen et al., 2007a, 2008b). In these earlier experiments we used TMR feeding and the average concentrate proportions were higher (540 g/kg DM, Huuskonen et al., 2007a and 570 g/kg DM, Huuskonen et al., 2008b) than in the present study (400 g/kg). Therefore different feeding methods and concentrate proportions may partly explain differences in feed intake. To my knowledge, there are only few published reports (Corah et al., 1975; Dion and Seoane, 1992) on the performance of growing cattle offered oats instead of barley. Studies on other grains show that there are differences between grain sources and cattle cannot always compensate the lower energy content by increasing DMI. For example, McEwen et al. (2007) reported that corn-fed steers grew faster than those fed barley and suggested that differences in gain due to grain source may be due to the higher net energy values of corn versus barley. In addition, higher rates of gain for corn-fed cattle might be partially explained by greater DMI versus barley-fed cattle (McEwen et al., 2007). Also Tiffany and Spears (2005) attributed greater gains and better feed conversion for corn- versus barley-fed steers to lower ME in barley diets due to higher NDF concentrations than corn diets. Studies comparing corn versus barley feeding have often found that one grain source improved growth performance to a greater extent than the alternative grain. Koening and Beauchemin (2005) attributed this variation in part to differences in grain processing, sources of CP and roughage, and dietary concentrations of energy, CP and (or) roughage.

4.2. Effect of rapeseed meal

In the present study, RSM supplementation had no effect on the carcass traits or performance parameters during the entire period. Similarly RSM had no effect on the performance of dairy bulls with grass silage-barley-based TMR feedings (Huuskonen et al., 2007b, 2008a). However, in the present study RSM had a positive effect on LWG during the first sub-experimental period. Some earlier feeding experiments have shown a positive response of LWG and hay intake (Aronen, 1990) or LWG and grass silage intake (Aronen, 1990; Aronen and Vanhatalo, 1992; Aronen et al., 1992) of young dairy bulls to RSM supplementation. In these studies the positive effect of RSM on LWG was often explained by the increased feed intake and thereby higher energy intake. However, in the present experiment there were no differences in DMI, so the diets without RSM were likely to provide inadequate supplies of some amino acids for growing bulls on the early phase of growth. In many earlier studies (*e.g.* Huhtanen et al., 1989; Aronen, 1990) the positive effect of RSM was restricted only to the early phase of growth (i.e., LW below 300 kg). Similarly, calculations by Titgemeyer and Löest (2001) showed that, while amino acids were the limiting factor with lighter weight calves offered grass silage, energy availability was the limiting factor with heavier steers. In addition, many times much of the advantage of protein supplementation of young cattle was lost during the finishing period due to compensatory growth (McGee, 2005).

The responses to protein supplements seem to be related to the level of concentrate supplement, greater effects being observed with small amounts of concentrates (Pike et al., 1988). Growing cattle fed grass silage alone respond to supplementation with ruminally undegraded protein with relatively large improvements in gains (Titgemeyer and Löest, 2001). Similarly, including rumen undegradable protein increased the LWG of young steers offered grass silage plus low levels of concentrate (Rouzbehan et al., 1996). When young growing cattle were offered grass silage ad libitum and a low level of barley-based concentrates, the inclusion of rumen-degradable protein increased growth rate (Moloney, 1991) or had no significant effect (Keane, 2002) on it. There are also indications of interactions between grass silage digestibility and crude protein degradability (McGee, 2005). Protein supplements may have a positive effect on the daily growth rate, especially when the gain without protein supplementation is low, which may be the case with low-digestibility silage (Steen, 1988) or hay (Hennessy et al., 2000). According to Aronen (1992), a high level of concentrates together with well-preserved grass silage may sustain efficient microbial protein production. Therefore, it is likely that a greater response to RSM supplementation is to be expected when small rather than large amounts of concentrates are fed to growing cattle on a grass silage-based feeding.

There are also differences between extensively and restrictively fermented silages, which both may be well-preserved. Jaakkola et al. (1990) reported that the gain response of growing cattle to fish meal was greater when enzyme solution (cellulose–glucose oxidase) was used as a silage additive instead of formic acid. Generally, synthesis of microbial protein has been less efficient with silage than with fresh or dried forages (Jaakkola et al., 2006). However, results with grass silage are dependent on the quality of silage that may vary considerably with the ensiling technique. Jaakkola et al. (2006) observed that restriction of silage fermentation by formic acid is positively related to the synthesis of microbial protein in the rumen. In the present experiment the *D* value of the silages was high (686 g/kg DM, on average), the fermentation quality of the silages was good and the silages used were also restricted fermented (high residual WSC concentration and low lactic acid concentration). In addition, there were 40% concentrates in all the treatments, so the microbial protein synthesis can be assumed to have been high. Therefore there was no positive effect of RSM supplementation on animal performance.

In accordance with earlier studies (Aronen, 1990, 1991; Huuskonen et al., 2007b) there were no differences in DM or OM digestibility of diets with RSM supplementation. In the present study the apparent CP digestibility increased with RSM supplementation, which is in accordance with earlier studies (Aronen, 1990; Aronen et al., 1992, Huuskonen et al., 2007b, 2008a). Some of the increased apparent digestibility of CP in the RSM-supplemented diets may have reflected the better digestibility of RSM protein.

5. Conclusion

As a consequence of decreased energy intake, the LWG and feed conversation of growing bulls were reduced with increasing oats proportion in the diet. Carcass quality was not affected by the different grain source. Rapeseed meal did not affect animal performance. Thus, protein supplement is not needed for finishing dairy bulls when they are fed good-quality grass silage and grain-based concentrate. No significant cereal type x RSM interactions was measured.

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