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Winter feeding strategies for suckler cows in cold climatic conditions

Merja Manninen

Academic dissertation

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Custos:
Professor Matti Näsi
Department of Animal Science
University of Helsinki, Finland

Supervisor:
Docent Seija Jaakkola
Department of Animal Science
University of Helsinki, Finland

Reviewers:
Professor Hannu Saloniemi
Department of Production Animal Medicine
University of Helsinki, Finland

Docent Mikko Tuori
Animal Production Research
MTT Agrifood Research Finland
Hyvinkää, Finland

Opponent:
Associate professor Kjell Martinsson
Agricultural Research for Northern Sweden
Animal Husbandry
Swedish University of Agricultural Sciences
Umeå, Sweden

Photos on the cover:
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Jukalle ja Ilkalle

“Sitä ei koskaan tiedä mihin pystyy ennen kuin yrittää”

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Manninen, M. 2007. Winter feeding strategies for suckler cows in cold climatic conditions

LIST OF ORIGINAL PUBLICATIONS

This thesis consists of a general discussion and the following original publications subsequently referred to in the text as Experiments by their Roman numerals:

I **Manninen, M., Aronen, I. and Huhta, H. 2000.** Effect of feeding level and diet type on the performance of crossbred suckler cows and their calves. *Agricultural and Food Science in Finland* 9: 3-16.

II **Manninen, M. and Taponen, J. 2004.** Influence of feeding accuracy on the performance of Aberdeen Angus × Ayrshire and Charolais × Ayrshire crossbred suckler cows and their progeny. *Livestock Production Science* 85: 65-79.

III **Manninen, M., Saarijärvi, K., Huhta, H., Jauhiainen, L. and Aspila, P. 2004.** Effects of winter feeding strategies with alternative feeds on the performance of mature suckler cows and their progeny. *Agricultural and Food Science* 13: 348-362.

IV **Manninen, M., Virkajärvi, P. and Jauhiainen, L. 2005.** Effect of whole-crop barley and oat silages on the performance of mature suckler cows and their progeny in outdoor winter feeding. *Animal Feed Science and Technology* 121: 227-242.

V **Manninen, M., Sormunen-Cristian, R., Jauhiainen, L., Sankari, S. and Soveri, T. 2006.** Effects of feeding frequency on the performance and welfare of mature Hereford cows and their progeny. *Livestock Science* 100: 203-215.

VI **Manninen, M., Sankari, S., Jauhiainen, L., Kivinen, T., Anttila, P. and Soveri, T. 2007.** Effects of outdoor winter housing and feeding level on performance and blood metabolites of suckler cows fed whole-crop barley silage. *Livestock Science,* in press.

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The research was carried out during 1989-2004 at Tohmajärvi Research Station of MTT, Agrifood Research Finland.

The corresponding author was responsible for planning and conducting all the experiments. Biometrician Lauri Jauhiainen, M.Sc., was responsible for the statistical methods and analysis in all the Experiments. Juha Hurmalainen, DVM, was responsible for collecting the blood samples and Professor Timo Soveri and Docent Satu Sankari were responsible for analysing the blood samples and interpreting the results. All other experimental samples and animal performance data were collected by the suckler cow unit team. All manuscripts were prepared by the corresponding author and revised according to the comments and suggestions of respective co-authors and reviewers.

ABBREVIATIONS

A	Accurate
AAT	Amino acids absorbed in the small intestine
Ab	Aberdeen Angus
AbAy	Aberdeen Angus-Ayrshire
AI	Artificial insemination
AS	Outdoors with a rain shelter having *ad libitum* whole-crop barley silage
ASAT	Aspartate aminotransferase
AT	Outdoors with a three-wall shelter having *ad libitum* whole-crop barley silage
AU	Indoors having *ad libitum* whole-crop barley silage
Ay	Ayrshire
β-HB	β-hydroxybutyrate
BC	Body condition
BCS	Body condition score
BP	Oat hull-based flour-mill by-product
BW	Birth weight
Ch	Charolais
ChAy	Charolais-Ayrshire
CK	Creatine kinase
CP	Crude protein
CS	Calf suckling
D	Daily feeding
D-value	Digestible organic matter in dry matter
DM	Dry matter
DPC	Diet crude protein content
F	Flat-rate feeding strategy
FFU	Fattening feed unit
Fr	Friesian
GS	Grass silage
H	Hay
Hb	Haemoglobin
Hf	Hereford
HfAy	Hereford-Ayrshire
IA	Inaccurate
ICC	Interval from calving to conception
L	Low
LCFA	Long-chain fatty acid
LCT	Lower critical temperature
Li	Limousin
LiAy	Limousin-Ayrshire
LU	Livestock unit

LW	Live weight
LWG	Live weight gain
M	Moderate
ME	Metabolizable energy
MM	Machine milking
OM	Organic matter
OS	Oestrus synchronization
PPI	*Post partum* interval
RH	Relative humidity
RR	Respiration rate
RS	Outdoors with a rain shelter having restricted whole-crop barley silage
RT	Outdoors with a three-wall shelter having restricted whole-crop barley silage
S	Step-up feeding strategy
SH	Sward height
Si	Simmental
US	Urea-treated straw
VWP	Voluntary waiting period
WCBS	Whole-crop barley silage
WCOS	Whole-crop oat silage
3D	Feeding every third day

Manninen, M. 2007. Winter feeding strategies for suckler cows in cold climatic conditions. University of Helsinki, Department of Animal Science. Publications 96 p. + 6 encl.

ABSTRACT

In Finland, suckler cow production is carried out in circumstances characterized by a long winter period and a short grazing period. The traditional winter housing system for suckler cows has been insulated or uninsulated buildings, but there is a demand for developing less expensive housing systems. In addition, more information is needed on new winter feeding strategies, carried out in inexpensive winter facilities with conventional (hay, grass silage, straw) or alternative (treated straw, industrial by-product, whole-crop silage) feeds. The new feeding techniques should not have any detrimental effects on animal welfare in order to be acceptable to both farmers and consumers. Furthermore, no official feeding recommendations for suckler cows are available in Finland and, thus, recommendations for dairy cows have been used. However, this may lead to over- or underfeeding of suckler cows and, finally, to decreased economic output.

In *Experiment I,* second-calf beef-dairy suckler cows were used to compare the effects of diets based on hay (H) or urea-treated straw (US) at two feeding levels (Moderate; M vs. Low; L) on the performance of cows and calves. Live weight (LW) gain during the indoor feeding was lower for cows on level L than on level M. Cows on diet US lost more LW indoors than those on diet H. The cows replenished the LW losses on good pasture. Calf LW gain and cow milk production were unaffected by the treatments. Conception rate was unaffected by the treatments but was only 69%. Urea-treated straw proved to be a suitable winter feed for spring-calving suckler cows.

Experiment II studied the effects of feeding accuracy on the performance of first- and second-calf beef-dairy cows and calves. In II-1, the day-to-day variation in the roughage offered ranged up to ± 40%. In II-2, the same variation was used in two-week periods. Variation of the roughages offered had minor effects on cow performance. Reproduction was unaffected by the feeding accuracy. Accurate feeding is not necessary for young beef-dairy crosses, if the total amount of energy offered over a period of a few weeks fulfills the energy requirements.

Effects of feeding strategies with alternative feeds on the performance of mature beef-dairy and beef cows and calves were evaluated in *Experiment III.* Two studies consisted of two feeding strategies (Step-up vs. Flat-rate) and two diets (Control vs. Alternative). There were no differences between treatments in the cow LW, body condition score (BCS), calf pre-weaning LW gain and cow reproduction. A flat-rate strategy can be practised in the nutrition of mature suckler cows. Oat hull-based flour-mill by-product can partly replace grass silage and straw in the winter diet. Whole-crop barley silage can be offered as a sole feed to suckler cows.

Experiment IV evaluated during the winter feeding period the effects of replacing grass silage with whole-crop barley or oat silage on mature beef cow and calf performance. Both whole-crop silages were suitable winter feeds for suckler cows in cold outdoor winter conditions.

Experiment V aimed at assessing the effects of daily feeding vs. feeding every third day on the performance of mature beef cows and calves. No differences between the treatments were observed in cow LW, BCS, milk production and calf LW. The serum concentrations of urea and long-chain fatty acids were increased on the third day after feeding in the cows fed every third day. Despite of that the feeding every third day is an acceptable feeding strategy for mature suckler cows.

Experiment VI studied the effects of feeding levels and long-term cold climatic conditions on mature beef cows and calves. The cows were overwintered in outdoor facilities or in an uninsulated indoor facility. Whole-crop barley silage was offered either *ad libitum* or restricted. All the facilities offered adequate shelter for the cows. The restricted offering of whole-crop barley silage provided enough energy for the cows.

The Finnish energy recommendations for dairy cows were too high for mature beef breed suckler cows in good body condition at housing, even in cold conditions. Therefore, there is need to determine feeding recommendations for suckler cows in Finland. The results showed that the required amount of energy can be offered to the cows using conventional or alternative feeds provided at a lower feeding level, with an inaccurate feeding, flat-rate feeding or feeding every third day strategy. The cows must have an opportunity to replenish the LW and BCS losses at pasture before the next winter. Production in cold conditions can be practised in inexpensive facilities when shelter against rain and wind, a dry resting place, adequate amounts of feed suitable for cold conditions and water are provided for the animals as was done in the present study.

Manninen, M. Emolehmien sisäruokintakauden ruokintastrategiat kylmissä tuotanto-olosuhteissa. Helsingin yliopisto, Kotieläintiede. Julkaisu 96 p. + 6 liitettä.

SELOSTUS

Suomessa emolehmiä kasvatetaan alueilla, joille on tyypillistä pitkä talviruokintakausi ja lyhyt laidunkausi. Talvella ne pidetään lypsylehmien ja lihanautojen tavoin joko lämpöeristetyissä tai kylmissä tuotantotiloissa. Tuotantokustannusten kasvu on pakottanut etsimään emolehmille entistä taloudellisempia tuotantotiloja ja kasvatusmenetelmiä niiden hyvinvoinnista kuitenkaan tinkimättä. Emolehmätuotannon voimakas kasvu on lisännyt myös tuottajien tarvetta saada tietoa uusista talvikauden ruokintastrategioista, joihin soveltuvat joko perinteiset (heinä, nurmisäilörehu, olki) tai vaihtoehtoiset (käsitelty olki, teollisuuden sivutuote, kokoviljasäilörehu) rehut. Ruokinnan suunnittelua vaikeuttaa se, että Suomessa ei ole emolehmille ruokintasuosituksia. Niiden ruokinta on perustunut kotimaisiin lypsylehmien ruokintasuosituksiin.

Tutkimuksessa I selvitettiin toisaalta heinän ja toisaalta ureoidun oljen soveltuvuutta nuorten risteytysemojen talvirehuksi keskinkertaisessa ja niukassa ruokinnassa. Emot menettivät elopainoaan niukassa ruokinnassa ja ureoitua olkea saadessaan enemmän kuin keskinkertaisessa ruokinnassa ja heinää saadessaan, mutta korvasivat talven aikana tulleet elopainon menetykset hyvällä laitumella. Emän ruokinta ei vaikuttanut vasikoiden kasvuun. Ruokintatavasta riippumatta tiinehtymistulos oli kaikilla heikko. Ureoitu olki soveltui emojen talvirehuksi kylmiin tuotantotiloihin.

Ensimmäistä ja toista kertaa poikivilta risteytysemoilta selvitettiin karkearehujen ruokintatarkkuuden vaikutusta tuotantoon ja tiinehtymiseen (II). Ensimmäisenä talvena ruokintatarkkuus vaihteli päivittäin ±40 %. Toisena talvena vaihtelu oli samansuuruinen, mutta tapahtui kahden viikon jaksoissa. Ruokintatarkkuuden vaihtelut vaikuttivat emojen tuotantoon ja vasikoiden kehitykseen vain hieman. Tiinehtyvyys oli erinomainen. Nuorten risteytysemojen päivittäisen ruokinnan ei tarvitse olla tarkkaa, kunhan eläimet saavat ylläpitoon, tuotantoon ja kasvuun tarvitsemansa energian muutaman viikon aikana.

Kokeessa III tutkittiin kahden sisäruokintakauden aikana teollisuuden kaurankuoripohjaisen sivutuotteen ja ohrakokoviljasäilörehun soveltuvuutta täysikasvuisille risteytys- ja liharotuisille emolehmille tasaisessa ja porrastetussa ruokinnassa. Ruokintastrategia tai rehu ei vaikuttanut emojen elopainoon ja kuntoon, vasikoiden kehitykseen ja emojen tiinehtymiseen. Tulosten perusteella tasaruokinta soveltuu täysikasvuisille emolehmille kylmiin tuotanto-olosuhteisiin. Mikäli saatavilla on hinnaltaan kilpailukykyistä teollisuuden sivutuotetta, voidaan sillä korvata olkea talvikauden ruokinnassa. Kokoviljasäilörehu soveltuu hyvin emolehmille talvikauden ainoaksi rehuksi.

Täysikasvuisten emolehmien talvikauden ruokinnassa nurmisäilörehu voidaan korvata ohrasta tai kaurasta tehdyllä kokoviljasäilörehulla (IV). Molemmilla kokoviljasäilörehuilla saadut tuotantotulokset olivat hyvät, ja kokoviljasäilörehut soveltuivat ulkokasvatustiloihin mm. jäätymättömyytensä ansiosta hyvin.

Tutkimus V selvitti päivittäin tai joka kolmas päivä tapahtuvan ruokinnan vaikutuksia emolehmien tuotantoon. Emolehmien ruokintaa voidaan harventaa joka kolmanteen päivään, kunhan annettu rehumäärä vastaa eläimen tarvetta. Joka kolmas päivä ruokittujen emojen elopaino, kuntoluokka, maidontuotanto ja vasikan kasvu eivät poikenneet päivittäin ruokittujen emojen arvoista. Eläimet käyttäytyivät rauhallisesti ruokintastrategiasta riippumatta. Seerumin urean ja pitkäketjuisten rasvahappojen pitoisuudet olivat hieman kohonneet kolmantena päivänä ruokinnasta.

Tuotantokoe VI selvitti ohrakokoviljasäilörehun vapaan tai rajoitetun saannin vaikutuksia täysikasvuisten emolehmien elopainoon, kuntoon ja veriarvoihin sekä vasikoiden kasvuun erityyppisissä kylmissä tuotanto-olosuhteissa. Rajoitetun ruokinnan vaikutukset emolehmien elopainoon, kuntoon sekä veriarvoihin ja vasikoiden kasvuun olivat pieniä vapaaseen ruokintaan verrattuna. Metsätarhassa ollut sadekatos ja sen ulkopuolinen makuukumpare, kolmiseinäinen kuivitettu katos metsätarhassa ja eristämätön pihatto tarjosivat riittävän suojan hyväkuntoisille emolehmille ja niiden vasikoille talven ajan. Huolellisen hoidon merkitys erityisesti poikimakaudella korostuu ulkokasvatustiloissa. Eläimet saivat riittävästi energiaa rajoitetussakin ruokinnassa.

Kokeiden I - VI tulokset osoittivat, että kotimaiset lypsylehmien ruokintasuositukset ovat täysikasvuisille kevätpoikiville liharotuisille emolehmille kylmissäkin tuotanto-olosuhteissa tarpeeseen nähden liian suuret, jos ne sisäruokintakauden alkaessa ovat hyväkuntoisia. Emolehmille tulee laatia olosuhteisiimme soveltuva, kuntoluokan huomioiva ruokintasuositus. Kokeiden perusteella niiden talviruokintaan soveltuvat perinteiset tai vaihtoehtoiset rehut, suositettua pienempi energiamäärä, epätarkka rehujen annostelu, tasaruokinta ja rehuannoksen jakaminen joka kolmas päivä. Laidunkaudella eläinten on voitava kuntoutua seuraavaa sisäruokintakautta varten. Suomen oloissa emolehmät vasikoineen menestyvät vaatimattomissakin tuotantotiloissa, kunhan eläimille on suoja tuulta ja sadetta vastaan, kuiva makuupaikka, riittävästi olosuhteisiin soveltuvia rehuja ja aina tarjolla vettä.

1. INTRODUCTION

1.1. Background

Throughout the last twenty years beef production has decreased in Finland. In 2006, beef production was 87 million kilogrammes whereas the consumption in 2006 was 97 million kilogrammes (Finfood 2007). Finnish beef production is based on animals originating from dairy herds. Approximately 13% of Finnish beef meat originates from beef breeds. The decrease in the number of dairy cows has diminished the supply of calves for beef production originating from dairy herds. Simultaneously, the number of suckler cows is increasing. In September 2007, the number of adult suckler cows was 46,000 (Kallinen 2007) and the number of heifers reported to have been raised for suckler cows, in May 2007 in total 17,500 animals (TIKE 2007), predicts the enlargement of suckler cow production.

Globally, the primary target of farming beef cows is to convert grazed forage into weaned calves (Petit et al. 1992). In Latin America and Oceania, millions of suckler cows live year-round at pastures without any supplementary feeding. In West Europe and North America, grazed grass supplies 60-80% of the annual nutrient intake. In Finland, suckler cow production is carried out mainly in small herds and circumstances characterized by a long, cold winter period and a rather short, mostly five-month, grazing period. However, published data in suckler cow feeding in these circumstances is fairly scarce. Therefore, new winter feeding strategies carried out in inexpensive winter facilities with alternative feeds (e.g. less expensive, better feeding convenience, local availability) are important for farmers and, thus, should be evaluated.

The effects of cold conditions on the performance and welfare of growing cattle are well-documented. In some cases, cold conditions or absence of shelters have affected animal performance negatively (e.g. Birkelo et al. 1991, Delfino and Mathison 1991, Kubisch et al. 1991) or have changed animal behaviour (Redbo et al. 2001). On the contrary, McCarrick and Drennan (1972a,1972b), Redbo et al. (1996) and Manninen et al. (2007) reported no negative effects. Suckler cows have lower demands for winter housing facilities than growing cattle and dairy cows. Winter housing expenses play a considerable role in Finland where insulated winter buildings are traditionally used for dairy and growing cattle, but also for suckler cows. Rising housing costs have created a demand for less expensive winter housing systems. One method of reducing production costs is to winter suckler cows outdoors. The effects of cold on suckler cows can be evaluated by using the cow and calf performance results or by recording the changes in animal behaviour (e.g. Malechek and Smith 1976, Wassmuth et al. 1999, Olson and Wallander 2002). Blood chemistry gives information on the physiological processes associated with animal welfare.

Suckler cow production is characterized by relatively low nutrient requirements, partly as a consequence of rather low milk production. Nevertheless, feeding is the largest single cost in suckler cow production (Lowman 1997a). The possibility of restricting the amount of winter feed without detrimental effects on cow or calf performance is essential in reducing production costs. The effects of a reduced level of nutrition both *pre* and/or *post partum* have been widely reported (e.g. Somerville et al. 1983, Houghton et al. 1990, Sinclair et al. 1994, Jenkins et al. 2000, Manninen and Huhta 2001). One primary factor influencing the effects of feed restriction on cow performance is the cow body condition score at housing (Martinsson 1983). No official feeding recommendation exists for suckler cows in Finland and, thus, one aim of this study was to define an energy recommendation for winter feeding of suckler cows.

In Finland, winter feeding of suckler cows is based on grass silage and low-energy feeds such as straw or by-products supplemented, if necessary, with small amounts of concentrates. For dry beef cows it is not recommended to offer early-cut grass silage *ad libitum* since the energy content may be too high compared to the requirements. Occasionally there has been increased interest in preserving straw using urea due to its low cost, convenience and safety (Ørskov et al. 1983, Williams et al. 1984, Block et al. 1989). Alaspää (1986) suggested that protection against mould is the most important function of ammonia-based treatments, including urea. The effects of urea treatment on digestibility have been moderate (Alaspää 1986, Aronen 1990).

Harvesting whole-crop cereal silage allows increased use of silage-making equipment, enables crop rotation and manure utilization in the fields, gives relatively high crop yields per hectare harvested in one single operation, produces no effluent and enables the use of grain grown on the farm. Whole-crop cereal silage has proved to be a good alternative feed for dairy and growing cattle. The low protein content and the low digestibility of whole-crop cereal silage may be disadvantages in feeding dairy cows or growing cattle, but are not critical for beef cows. In the dairy cow diet, whole-crop wheat silage increased the dry matter intake without significant increase in milk yield (Hameleers 1998, Sutton et al. 2001). With steers Moloney and O'Kiely (1997) observed that the addition of urea at ensiling increased the nitrogen concentration and digestibility of whole-crop wheat silage but decreased the silage intake. O'Kiely and Moloney (1995) found improved carcass weights when whole-crop barley silage was harvested at later maturity with a high dry matter content ($\geq$ 460 g/kg). In the feeding of suckler cows, whole-crop cereal silages are less common. Therefore, more knowledge is needed of the effects of whole-crop cereal silages on suckler cow production to provide information for producers. The utilization of industrial by-products in the winter feeding of suckler cows varies regionally, but on some farms they may be competitive with home-grown feeds.

Feeding strategies (feed allocation, feeding accuracy, feeding frequency) may give flexibility to organize the feeding routines on farms and diminish the labour requirement and, thus, improve the economic output. With dairy cows the term flat-rate feeding refers to a constant daily allocation of concentrates and *ad libitum* feeding of roughages throughout lactation (e.g. Poole 1987, Andries et al. 1988). With suckler cows the traditional feeding strategy during the indoor feeding period is an allotment of the feeds taking into account the estimated calving date of the cow or the group, i.e. step-up feeding. In many cases the estimated calving date is unknown due to the absence of a pregnancy diagnosis. Step-up feeding is easy for a single cow, but even the best managed beef herds usually calve over an eight to ten weeks period (Broadbent 1984). Pullar and Rigby (1993) reported that flat-rate feeding of spring-calving suckler cows is a well recognized husbandry practice in the

United Kingdom. Although flat-rate feeding for mature beef cows has been successfully practised on some farms in Finland, no comparison of flat-rate to step-up feeding during a long winter feeding period has been available.

The response of suckler cows to changes in feeding accuracy has not been determined. With dairy cows Wiktorsson and Knutsson (1977) observed that a ±15% day-to-day variation of concentrate allocation decreased milk production and increased the calving interval. With growing bulls Aronen (1992) reported inaccurate concentrate feeding caused variation in the contents of fermentation end-products in the rumen, and a break-point in hay degradation was observed when the inaccuracy in concentrate supply exceeded ±30%. Strictly accurate allotment of feed for group-fed suckler cows can seldom be achieved in practical feeding.

Daily supplementation of feed requires a significant commitment of labour and equipment especially when cattle are maintained under extensive grazing conditions but also in indoor feeding facilities. If the supplementation frequency can be diminished without harmful effects on cow and calf performance, savings can be realized via reduced need for labour and equipment. Feeding frequency is well documented with dairy cows (e.g. Phillips and Rind 2001, Dhiman et al. 2002) and beef cattle (e.g. Aronen 1991, Machado et al. 1997) concerning mainly increased daily delivery of concentrates. The feeding frequency is reported in some beef cow studies, generally referring to lessened supplementary feeding of cows offered low-quality forages or grazing native range under extensive conditions (Chase and Hibberd 1989, Beaty et al. 1994, Huston et al. 1999). McCartney et al. (2004) reported that alternate-day winter feeding of barley silage to beef cows in feedlots resulted in large improvements in production efficiency. Results concerning the effects of reduced feeding frequency on suckler cow performance during a long winter period indoors have not been available.

1.2. Purpose of the study

The *first aim* of the present Thesis was to produce data for developing and evaluating new winter feeding strategies for suckler cows in cold nordic conditions, carried out either with conventional feeds or with alternative feeds. The aim was that the new feeding techniques should not have any detrimental effects on animal welfare, performance and fertility in order to be acceptable to both farmers and consumers. In addition, new feeding strategies should not need more labour than the previous techniques; otherwise they will be economically unfeasible.

The *second aim* was to assess the suitability of Finnish dairy cow energy recommendations for suckler cows and, thus, to define energy recommendations for spring-calving immature and mature suckler cows for the entire winter feeding period.

The *third aim* was to evaluate the suitability of different uninsulated or outdoor winter housing facilities for spring-calving suckler cows in cold conditions. The results of animal performance and welfare in cold conditions combined with nutrition give a possibility to offer new technological solutions for suckler cow producers.

The present Thesis combines the aspects of animal nutrition, management, welfare and technology. The effects of new feeding strategies with conventional feeds or with alternative feeds in cold winter housing facilities on feed intake, cow live weight and body condition score, milk production and milk composition, dystocial cases, calf performance, cow blood metabolites, animal health, cow behaviour and rebreeding are reported in this Thesis.

2. MATERIAL AND METHODS

2.1. Experimental animals, design and periods

Tohmajärvi Research Station

All Experiments were carried out at Tohmajärvi Research Station located in Eastern Finland (62°20'N, 30°13'E, Figure 1). The average vegetation growth period at Tohmajärvi is 155 days (base temperature +5°C) and the grazing period 100–120 days. The winter conditions are arctic-continental in nature. The average, the average minimum, maximum and ground minimum temperatures as well as precipitation in the Tohmajärvi zone, 20 km from the Research Station, during the years 1989–2004 are presented in Table 1.

Figure 1. Finland and geographical location of Tohmajärvi Research Station.

Table 1. Temperatures (°C, Average; Average minimum and maximum; Ground minimum) and precipitation (mm/d) during experimental years 1989–2004 in the Tohmajärvi zone.

		Average		Abs.	Abs.	Ground Min. at 10 cm		Precipitation
Month	Average	Min.	Max.	Max.	Min.	Average	Min.	Average
January	-8.5	-16.1	-3.8	5.0	-41.0	-32.9	-42.9	1.63
February	-7.9	-16.9	-0.2	7.4	-38.0	-33.4	-42.6	1.72
March	-3.5	-9.2	0.5	13.0	-30.0	-26.6	-33.6	1.33
April	2.1	-1.1	5.5	24.7	-21.8	-17.6	-27.1	1.02
May	8.4	5.4	11.1	28.4	-11.7	-8.1	-16.6	1.20
June	13.9	10.7	18.3	32.3	-3.4	-2.4	-5.1	2.08
July	16.4	13.8	19.5	31.3	0.4	1.5	-2.0	2.53
August	13.9	12.5	15.2	30.0	-2.4	-0.7	-3.7	2.55
September	8.7	4.2	11.3	25.0	-8.9	-6.7	-11.4	2.13
October	3.1	-2.0	6.2	16.9	-16.4	-12.5	-20.8	2.16
November	-3.6	-7.8	1.6	8.8	-29.3	-21.9	-33.6	1.76
December	-6.8	-14.3	-1.7	5.7	-34.9	-30.7	-38.5	1.83

Experimental arrangements

In I, III, IV and VI, the aim was to study the effects of replacing traditional roughages like hay, straw or grass silage (GS) with alternative feeds like urea-treated straw (US), whole-crop silages or oat hull-based flour-mill by-product (BP). Due to the length of the indoor feeding period and thus high winter feeding costs of suckler cows in Finland, the purpose in I and VI was to study the effects of a lower winter feeding energy level on suckler cow and calf performance. In VI, the purpose of comparing the feeding levels was to study whether suckler cows can be kept in cold conditions on a restricted diet without detrimental effects from the cold.

Suckler cows are generally group-fed with restricted amounts of roughage. Strictly accurate allotment of feed can seldom be achieved and may be unrepresentative of practical feeding conditions. The effects of changes in feeding accuracy on suckler cows and calves were evaluated in II.

The effects of a flat-rate feeding strategy with alternative feeds and feeding every third day instead of daily on the performance of suckler cows and calves during an indoor feeding period and subsequent grazing were evaluated in III and V. One objective was to decrease the labour needed for feeding routines (V).

Suckler cows have lower demands for winter housing facilities than high-producing dairy cows. Therefore, especially VI, but also IV, evaluated whether mature pregnant spring-calving suckler cows can be overwintered outdoors in inexpensive housing facilities without negative effects on animal performance and physiology.

The results of I-VI can be utilized for determination of feeding recommendations for suckler cows.

In I, 32 Hereford-Ayrshire (HfAy) cows and 31 Limousin-Ayrshire (LiAy) cows were used. The animals were second-calf cows except for nine first-calf cows, all of which were the same age and pregnant to Charolais (Ch). The Experiment commenced on 17 November 1989 and consisted of an indoor feeding period averaging 203 days and a grazing period averaging 106 days. Four treatments were evaluated according to a 2×2 factorial design consisting of two feeding levels (Low, L vs. Moderate, M) and two diets (Hay-based, H vs. US-based). The animals were group-fed, once daily in the morning, with eight animals per pen and two pens per treatment. All treatments contained an equal number of cows from each breed. The grazing season commenced on 24 May and ended on 20 September. The calves were weaned on 19 October.

In II, two Experiments (II-1 and II-2) were carried out during two successive years. Thirty-two Aberdeen Angus-Ayrshire (AbAy) cows and 32 Charolais-Ayrshire (ChAy) cows were selected for II-1 and II-2. In II-1, the animals were first-calf heifers and pregnant to Aberdeen Angus (Ab). In II-2, the animals were second-calf cows and in calf to Hereford (Hf). Experiments II-1 and II-2 commenced on 16 October 1992 and 22 October 1993, respectively. Experiments II-1 and II-2 consisted of indoor feeding periods averaging 216 and 227 days and grazing periods averaging 119 and 101 days, respectively. In II-1 and II-2, four treatments in a 2×2 factorial design consisted of two breeds (AbAy vs. ChAy) and two feeding accuracies (Accurate, A vs. Inaccurate, IA). The animals were group-fed, once daily in the morning, with six to eight animals per pen and two pens per treatment. Each pen contained animals of one breed. The grazing season commenced on 20 May and 6 June and ended on 16 September and 15 September in II-1 and II-2, respectively.

In III, two Experiments (III-1 and III-2) were carried out during two years. Twenty-four AbAy cows and 32 ChAy cows were used in III-1. Fifty-six Hf cows were selected for III-2. All animals were mature and pregnant to Limousin (Li, III-1) and Hf (III-2). Experiments III-1 and III-2 commenced on 1 November 1994 and on 1 December 1999, respectively. Experiments III-1 and III-2 consisted of indoor feeding periods averaging 212 and 177 days and grazing periods averaging 74 and 102 days, respectively. In III-1 and III-2, four treatments in a 2×2 factorial design consisted of two feeding strategies (Step-up, S vs. Flat-rate, F) and two diets (Control vs. Alternative). The animals were group-fed, once daily in the morning, with seven animals per pen and two pens per treatment. The grazing season commenced on 1 June and 26 May and ended on 14 August and 5 September in III-1 and III-2, respectively.

In IV, 48 mature Hf cows, pregnant to Hf, were used. The Experiment commenced on 22 November 2000 and consisted of a winter feeding period and a grazing period averaging 188 and 99 days, respectively. The treatments consisted of three winter feeds which were GS as a control, whole-crop barley silage (WCBS) and whole-crop oat silage (WCOS), each as the sole feed. The animals were group-fed, once daily in the morning, with eight animals per pen and two pens per treatment. All pens were outdoors. The grazing season commenced on 29 May and ended on 5 September.

In V, 32 mature Hf cows, pregnant to Hf, were used. The Experiment commenced on 22 October 2003 and consisted of a winter feeding period and a grazing period averaging 225 and 96 days, respectively. The treatments consisted of two winter feeding strategies which were daily feeding (D) and feeding every third day (3D) of GS and hay. The animals were group-fed, eight animals per pen and two pens per treatment. In treatment 3D, the cows received the entire three-day feed portion on the first feeding day except post-calving hay was offered on the second day. The grazing season commenced on 3 June and ended on 7 September.

In VI, 35 mature Hf cows, pregnant to Hf, were used. The Experiment commenced on 3 November 1997 and consisted of a winter feeding period and a grazing period averaging 212 and 94 days, respectively. Five treatments, with seven animals per treatment, were imposed on the cows during the winter period:

a) Outdoors with a rain shelter having *ad libitum* WCBS (AS)
b) Outdoors with a rain shelter having restricted WCBS (RS)
c) Outdoors with a three-wall shelter having *ad libitum* WCBS (AT)
d) Outdoors with a three-wall shelter having restricted WCBS (RT)
e) Indoors having *ad libitum* WCBS (AU)

The animals were group-fed, once daily in the morning. The grazing season commenced on 2 June and ended on 4 September.

2.2. Experimental feeds and feeding

In I, hay, straw, US, barley, rapeseed meal and urea were used during the indoor period. On the MH diet, feed was offered to the cows according to the Finnish recommendations for dairy cows. For the L diets, the amount of feed was restricted to 70% on a dry matter (DM) basis of that on the M diets. On the H diets, feeding was based on hay. On the US diets, hay was replaced by US and barley. The DM intake from hay and US was estimated to be equal for both diets at each feeding level. Barley was included in the US diets to balance the energy intake with respect to the H diets. A urea-solution was given to cows on the H diets to balance the crude protein (CP) intake with respect to the US diets. Untreated straw was offered on all diets. The *pre* and *post partum* concentrate feeding to all cows commenced feeding a barley-rapeseed meal mixture (70:30).

In II, the cows received oats-Italian ryegrass bi-crop and meadow fescue-timothy GSs, hay and straw supplemented with barley. The forage consisted of GS and hay in II-1 with additional straw in II-2. In II-1, GS and hay were offered in the proportions 0.7 and 0.3 and in II-2 in the proportions 0.5, 0.3 and 0.2 (straw) on a DM basis. In II-1 and II-2, barley was offered to all cows *pre* and *post partum*. In II-1, the animals fed diets A and IA were given equal amounts of roughage during the course of one feeding period of 28 days, but with a random daily variation of ±40% around the calculated mean for the animals on diet A. In II-2, the animals fed diets A and IA were given equal amounts of roughage during the course of one feeding period of 28 days, but with a random 14 days variation of ±40% around the calculated mean for the animals on diet A.

In III, wilted GS, WCBS, straw, barley and BP were used for the cows. In III-1, the animals on the Control diet were given GS and straw in the proportions 0.55 and 0.45 and those on the Alternative diet GS and BP in the proportions 0.30 and 0.70 on a DM basis, respectively. On strategy S, milled barley was offered individually with three steps.

On strategy F, the same amount of barley per animal was offered during the entire indoor feeding period. On both strategies, roughages were given at a constant daily level during the indoor period. In III-2, the animals were offered either GS (Control) or WCBS (Alternative). Strategy S involved three steps which were from the onset to 60 days pre-calving, the last 60 days pre-calving and post-calving. On strategy F, roughage was given at a constant daily level during the indoor period. In III-1 and III-2, the aim of strategy F was to offer the cows an equal amount of energy during the entire indoor feeding period as offered on strategy S but at a constant daily level. On strategy S, feed was offered according to the Finnish recommendations for dairy cows.

In IV, GS, WCBS and WCOS were used for the cows during the winter period. The target was to offer the cows an equal amount of energy on the three diets.

In V, GS and hay were offered to the cows during the indoor feeding period in the proportions 1:1 on an energy basis. In treatment 3D, the cows received the entire three-day feed portion on the first feeding day except that post-calving hay was offered on the second day.

In VI, WCBS and oats were offered to the cows. The restricted feeding scheme was based on the Finnish recommendations for dairy cows. In three treatments, WCBS was offered to the cows *ad libitum* during the winter period. In two treatments, the winter feeding period comprised three periods which were from the start to the onset of *pre partum* feeding, *pre partum* and *post partum* feeding. The cows were fed restricted amounts of WCBS supplemented with milled oats *pre* and *post partum*.

In I-VI, the Finnish energy recommendations for dairy cows were used for the suckler cows (Salo et al. 1982, Tuori et al. 1996, Tuori et al. 2002). The energy and crude protein contents of the experimental feeds were evaluated prior to the Experiments to formulate the restricted feeding schemes. The cows received a mineral and a vitamin mixture during the winter and a mineral mixture while on pasture. After the winter feeding period the cows, calves and a bull/bulls grazed as described in Section 3.2.6.1. The feeding arrangements and the main subjects of interest in I-VI are presented in Table 2.

Table 2. Experimental animals, treatments and main subjects of interest in I-VI.

Exp.	Animals	Treatments	Main subjects of interest
I	32 2nd calving HfAy and 31 2nd calving LiAy cows + Ch×calves + Hf bull	*Diet:* Hay- vs. Urea-treated straw-based *Feeding level:* Moderate vs. Low	Feed composition and feed intake Cow and calf LW Milk production Dystocia, oestrus synchronization and conception
II	1: 32 1st calving AbAy and 32 1st calving ChAy cows + Ab×calves + 2 Hf bulls 2: 32 2nd calving AbAy and 32 2nd calving ChAy cows + Hf×calves + 2 Li bulls	*Breed:* AbAy vs. ChAy *Feeding accuracy:* Accurate vs. Inaccurate	Feed composition and feed intake Cow LW, BCS and calf LW Milk production and milk composition Dystocia and conception Ovarian function
III	1: 24 mature AbAy and 32 mature ChAy cows + Li×calves + 2 Hf bulls 2: 56 mature Hf cows + Hf calves + 2 Hf bulls	*Diet:* Control vs. Alternative *Feeding strategy:* Step-up vs. Flat-rate	Feed composition and feed intake Grazing (2) Diet digestibility (2) Cow LW, BCS and calf LW Milk production and milk composition (1) Dystocia and conception
IV	48 mature Hf cows +Hf calves + 2 Hf bulls	*Diet:* GS vs. WCBS vs. WCOS	Feed composition and feed intake Grazing Diet digestibility Cow LW, BCS and calf LW Milk production and milk composition Dystocia and conception
V	32 mature Hf cows + Hf calves + Hf bull	*Feeding strategy:* Daily feeding vs. Feeding every third day	Feed composition and feed intake Grazing Diet digestibility Cow LW, BCS and calf LW Milk production and milk composition Blood parameters and cow behaviour Dystocia and conception
VI	35 mature Hf cows + Hf calves + 2 Hf bulls	*Winter housing and feeding strategy:* *a.* Out, RS, *ad libitum* WCBS *b.* Out, RS, restricted WCBS *c.* Out, TWS, *ad libitum* WCBS *d.* Out, TWS, restricted WCBS *e.* In, *ad libitum* WCBS	Feed composition and feed intake Cow LW, BCS and calf LW Blood parameters Claw health Winter housing facilities Dystocia and conception

Ab, Aberdeen Angus; AbAy, Aberdeen Angus-Ayrshire; BCS, Body condition score; Ch, Charolais; ChAy, Charolais-Ayrshire; GS, Grass silage; Hf, Hereford; HfAy, Hereford-Ayrshire; Li, Limousin; LiAy, Limousin-Ayrshire; LW, Live weight; RS, Rain shelter; TWS, Three-wall shelter; WCBS, Whole-crop barley silage; WCOS, Whole-crop oat silage

2.3. Winter housing facilities

In I-III and V, the cows were housed during the winter period in an uninsulated barn (Figure 2). The barn included nine pens, each with a total area of 74 m^2 comprising 53 m^2 of bedding area and 21 m^2 of passage. The cows had access to a 105 m^2 asphalted exercise area. Peat and straw were used as bedding materials. Water was offered *ad libitum* from heated drinking cups. The barn had natural ventilation with air inlets under the eaves and outlets in the ridge opening.

In IV, the cows spent the winter period outdoors in six pens with a three-wall sheltered bedding area in each pen. Straw was used as bedding material in the three-wall sheltered areas averaging 2.5-5.0 m^2 per cow. Two pens were on average 300 m^2 and four pens on average 1000 m^2. The four pens included a forest area behind the three-wall sheltered area. The forest pens were equipped with L-shaped wind breaks (side lengths 14.0 and 3.5 m, height 2.3 m, with a 3-cm space between boards) in one corner. Water was offered *ad libitum* from heated drinking cups.

In VI, the four outdoor groups (*a-d*) were in the forest pens. A rain shelter with a roof (52 m^2) but without walls or bedding was used for groups *a* and *b* and divided equally between them. Both pens were equipped with an uncovered 56 m^2 sleeping area based on sawmill by-products (mainly bark) and straw as bedding materials. A shelter with three walls and a roof (100 m^2) was offered for groups *c* and *d* and divided equally between them. Straw and sawmill by-products were used as bedding materials in the three-wall shelter. All four forest pens were equipped with L-shaped wind breaks (side lengths 14.0 and 3.5 m, height 2.3 m, with a 3-cm space between boards) in one corner. Group *e* spent the winter in the barn in one pen. Water was offered *ad libitum* from heated drinking cups.

In I-VI, the calves were with the cows in the pens prior to the grazing season and therefore had the opportunity to consume the feeds offered to the cows. In I-II, the calves were creep-fed at pasture pre-weaning in order to facilitate adaptation to the post-weaning diet.

An insulated pen with a total area of 49 m^2 and a target temperature of 10-15°C was used for the milk production measurements in I-V and, occasionally, for difficult parturitions or for cases of illness. The insulated pen was heated by radiators and ventilated by an electrically controlled fan.

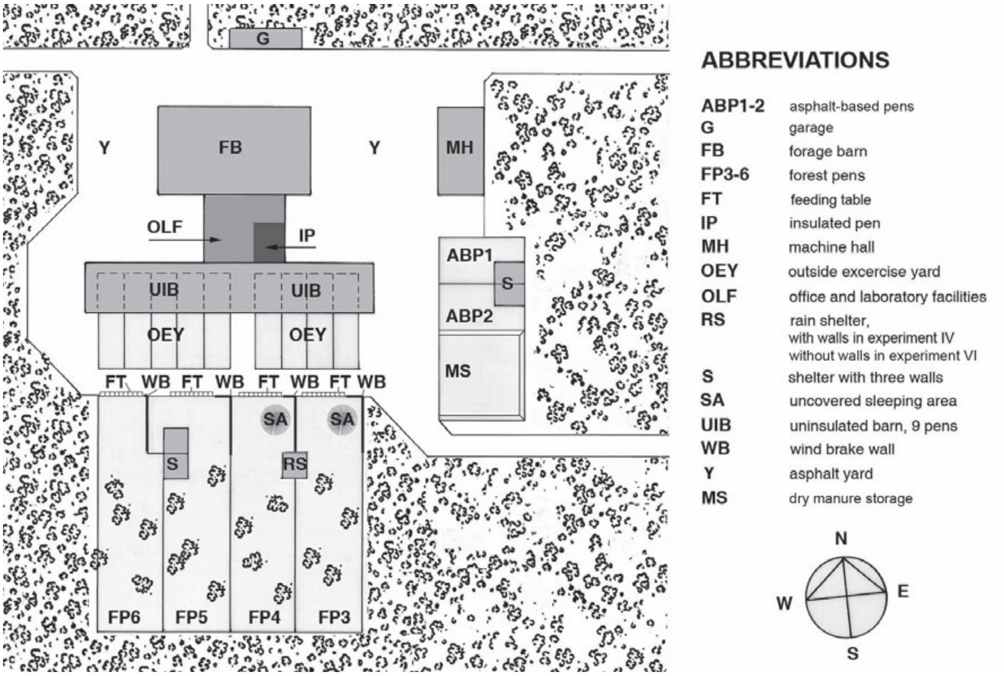

Figure 2. Suckler cow barn and outdoor areas.

2.4. Experimental measurements

In I-VI, the cows' feed intake during the winter period was recorded by pen. The feeds were analysed using standard laboratory methods. The diet digestibility was estimated using indigestible neutral detergent fibre (III-2, Lippke et al. 1986) or acid insoluble ash (IV-V, European Commission 1971) as internal markers. The cows and calves were weighed and the body condition score (BCS) of the cows was measured regularly (Lowman et al. 1976) except in I. The body condition scoring was conducted by 2-4 independent, trained observers on 2-3 successive days. The values reported in the present study are the average values of those observations.

The milk production was measured in I using the calf-suckling technique (Manninen et al. 1998) and in II-V using the machine-milking technique as described in II. The milk composition (fat, protein, lactose, urea) was measured in II-V.

The incidence of calving difficulties was recorded in I-VI using the following classification: easy calving with no assistance (1), calving with slight assistance (2), difficult calving (3) and very difficult calving requiring veterinarian assistance or caesarean section (4). During the indoor feeding period, blood samples were taken in V and VI and analysed using standard laboratory methods. Cow behaviour was observed in V by scan sampling carried out by the same trained person during all the periods. Cow maternal instinct was recorded in I-VI using the following classification: good (1), nonchalant (2) and angry towards her calf (3). The claw health of the outdoor cows was evaluated in VI with monitoring of changes in the sole, haemorrhages and white line rupture using a modified method described by Bergsten (1993). The cleanness of the cows was recorded daily by visual assessment of the group (VI).

In I, at pasture an oestrus synchronization (OS) procedure was carried out using PRID® (Progesterone Releasing Intravaginal Device, ABBOTT Laboratories) with 59 cows, after which artificial insemination (AI) was performed. After the inseminations a bull ran with the cows. In II-VI, natural breeding was used for the cows during the mating period.

Pregnancy and the estimated calving date (I-VI) were evaluated using an ultrasound scanner equipped with a 5.0 MHz rectal linear array transducer. Gestational age was assessed by ultrasonographic foetometry based on measurements of fetal diameter of the external braincase or crown-rump length. Gestational age and, thus, the estimated date of conception were calculated according to Kähn (1989). The interval from calving to estimated conception (ICC) was calculated using the calving date in the experiment and the following calving date, the gestational age measurements and, if available, the services recorded during the mating period. In II, the resumption of ovarian activity and subsequent ovarian function were assessed with milk progesterone (P_4) profiles. The climatic conditions were measured during the winter periods in I and IV-VI.

2.5. Statistical procedures

Group feeding was used in I-VI. Group feeding denoted the practice of placing two or more animals in a single pen and feeding them all from one feed or feeds throughout the winter period. This means that in these kinds of feeding experiments the experimental unit is the pen, not a single animal. This must be taken into account in the statistical modelling. Feed consumption and diet digestibility records for individual cows were not available, the statistical models for these data did not include variation between animals and the selection of the experimental unit was not essential.

The rest of the cow and calf variables were recorded individually and it was possible to make comparisons using animal or pen as an error term. In practice, “pen-nested treatment” effect was used as an error term when treatments were compared in most of the current Experiments. In analysis of the calf data the error term for sex was chosen to be the variation between animals because sex was “set” to animals not to pens.

All the statistical methods used assumed that the response variable analysed was normally distributed. This assumption was checked using a box plot of residuals; also scatter plots of residuals and predicted values were used. The assumption was not valid for some variables of blood data in VI. However, normality was achieved after log transformation.

Most variables were measured several times during the experiments. Typically, the set of observations on one animal tends to be intercorrelated. Two different approaches were used to analyse repeated measurement data. In the first approach all measurement times and changes between times were analysed separately. In the second approach, all measurement times were analysed in the same analysis using a mixed models technique which involved modelling a covariance matrix for repeated measurement (Wolfinger 1996). The latter approach is more complicated and was used only if the interaction between treatment and measurement times was the main subject of interest. The approaches used for different variables and experiments are presented at Table 3.

The statistical analyses were performed using the SAS/GLM and SAS/MIXED 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.

A descriptive analysis was used for feed intake when fixed feeding levels were used. Unnecessary statistical testing was avoided if the differences between treatments were slight (Table 3).

Table 3. Approach chosen for analysis of repeated measurement data: separate analysis for all measurement times (1) or one analysis for whole data (2). Use of descriptive analyses.

Category of response variable	Repeated measurements approach (1)	(2)	No repeated measurement	Descriptive analysis
Feed intake			II, III, V	I, IV, VI
Diet digestibility			III-2, IV, V	
Cow live weight	I, II, III, V	IV, VI		
Cow body condition score	II, III, V	IV, VI		
Calf live weight	I, II, III, V	IV[1], VI		
Milk yield	I, III-1, V	IV	II	
Milk composition	V		II, III-1, IV	
ICC[2]			II, III, IV, V, VI	
Behaviour		V		
Blood		V, VI		

[1] Calves' live weights were analysed in two parts: live weight at 1, 50 and 100 days of age and at the onset of grazing and at the end of the study.
[2] ICC, Interval from calving to conception.

3. RESULTS AND DISCUSSION

3.1. Cold stress and its effects on beef cattle

3.1.1. Background

According to Young (1981), almost two-thirds of all livestock in North-America is raised in areas where the average temperature in January is below 0°C. In these northern agricultural areas average temperatures remain below freezing for up to three months each winter. Those temperatures correspond largely to those measured at Tohmajärvi (Table 1). Conversely, hard winds during cold winter days are fairly uncommon in Finland (Manninen et al. 2007), unlike in Canada and USA. In the other main beef production countries, e.g. Argentina, Brazil, South-Africa, Australia, France and United Kingdom, the adverse effects of the climate mainly rise from other subjects than cold, i.e. hot, dry or wet seasons during the year.

In Scandinavia, the traditional housing system for dairy and beef cattle has been insulated or uninsulated buildings (Mossberg et al. 1992, Mossberg et al. 1993, Redbo et al. 1996, Redbo et al. 2001, Manninen et al. 2007), mainly due to smaller herd sizes, a tradition of keeping cattle indoors during winter, the convenience aspects and, finally, lack of spacious winter ranges. The animal housing and labour costs are increasing continuously and therefore there is a demand for less expensive housing systems. The new winter housing systems, whether using uninsulated buildings or outdoor winter facilities, have to meet the demands of animal welfare, safety at work and expanded public concern with animal welfare issues, as well as complying with the local legislation.

3.1.2. Temperate zones

Impressions of heat and cold are not absolute, since they are uniquely experienced by each individual. The differences between individuals are due to age, breed, nutrition, phase of production, adaptation to cold and management.

Thermoneutral zone

The thermoneutral zone can be defined as an area in which both heat loss and feed energy intake are independent of environmental temperature, i.e. the animal's heat production is independent of the ambient temperature (Webster 1974). Sometimes this zone is referred to as a comfort zone when relating temperature to humans, but thermal comfort for humans is usually different from that for cows. Hence, the animal environment should not be evaluated based on human comfort, since cattle are adapted to a much cooler environment (Webster 1974, Ames 1987). Within this zone, homeothermy is maintained by fluctuations in sensible and evaporative heat loss. At the upper limit of the thermoneutral zone, heat produced in metabolism is dissipated principally by evaporation of water from the skin and from the mucous membranes of the upper respiratory tract. In cattle, the partition of cutaneous and respiratory evaporative losses remain fairly constant at about 60/40 at air temperatures of 0°-40°C and at relative humidities of 30-75% (McLean 1963, McLean and Calvert 1972).

Respiration rate (RR) is a common method of evaluating a cow's state of thermal comfort (Webster 1974). If the RR is higher than 80 per minute, the animal is warm. An RR below 20 per minute indicates the animal is cold, i.e. near or below the lower limit of thermoneutrality. According to Pyykkönen (1991), the growth rate and health of dairy calves were not sensitive enough to measure small changes in the thermal environment, since small thermal fluctuations were effectively balanced by the thermoregulator system of the animal. Tests in the laboratory and on farms showed that the uninsulated heated model was a useful method within a series of measurements for describing the thermal environment, especially under sheltered winter conditions. The measurements on farms showed that the heat loss from the model gives a more diversified description, and therefore a less biassed evaluation of the environment than the dry bulb air temperature (Pyykkönen 1991).

Cold zone and lower critical temperature

The lower limit of the zone of thermoneutrality is called the lower critical temperature (LCT). It can be defined as the temperature below which an animal must increase its rate of heat production to maintain homeothermy (Young 1981, Young 1983). Wagner (1988) expresses the LCT as being the temperature at which the animal begins to feel cold and must increase heat production to stay warm. It is the point at which performance begins to decline as the temperature declines and/or the animal becomes colder. The LCT may be interpreted as an index of cold tolerance and a tool for comparing different species and classes of livestock. The predicted LCT values of large ruminants on high feeding levels are considerably lower than those for e.g. pigs. Christopherson (1985) presents the LCT values for single piglet and single newborn lamb to be +33 and +27°C, while the corresponding values for lactating sow and fleeced lactating lamb are -9 and -70°C, respectively. The LCT varies according to species, age, hair coat, physiological status (e.g. pregnancy, lactation, growth, maintenance) and quality and quantity of diet. In addition, considerable amounts of heat arise as an inevitable consequence of digestion and metabolism at higher levels of intake and production (Young 1981).

The LCT has been determined for most farm animals in rather restricted circumstances, i.e. animals exposed individually in a confined stall or chamber (Christopherson 1985). If animals are kept in groups with opportunity to exercise their behavioural instincts, they may have markedly different LCTs. One limitation to the use of LCT is that changes in the endocrine system and the digestive system seem to occur at temperatures above and below the LCT and thus, they may influence production and feed requirements. Prolonged cold exposure may also result in an increase in resting metabolic rate in many species (Christopherson 1985). Although there are difficulties in the exact determination of LCT, it is used as one means of judging the shelter needs of animals (Table 4).

Table 4. Estimates of the lower critical temperature for cattle (Christopherson 1985).

Animal	Live weight, kg	Lower critical temperature, °C
Beef cow early pregnancy	500	-13
Beef cow late pregnancy	500	-26
Beef cow lactating	500	-47
Growing calves	200	-31
Feedlot steers	400	-45
Newborn calves	35	8
Month-old calf	50	-2
Dairy cow lactating[1]	500	-45

[1] Lactating animals and animals in late pregnancy were assumed to have similar insulation values to non-pregnant and non-lactating animals.

In the present study the Experiments were performed either indoors (I-III, V), outdoors (IV) or both indoors and outdoors (VI). Some additional studies (Manninen et al. 1998, Manninen 2000, Manninen and Huhta 2001, Manninen et al. 2002a, Manninen et al. 2006) were conducted in the same indoor facilities. In other studies (Manninen 1998a, Manninen 1998b, Manninen et al. 2002b), animals were both indoors and outdoors. In one study (Manninen et al. 2007), an indoor, an outdoor and an insulated pen were used for weaned replacement Hf heifers and, thus, only this experiment compares cold winter housing to warm. Therefore, all results reported from Tohmajärvi Research Station should be interpreted as conducted in cold circumstances.

The temperatures were measured in I and IV-VI. The temperature in I was lowest in mid-January when a temperature of -23°C was recorded indoors. In IV, during the winter the temperature at 8:00 a.m. outdoors at a height of 170 cm was below -15°C on 27 days. The temperatures at the surface of the ground must have been considerably lower than the values observed higher up, particularly during the spring months. In V, the temperature indoors was below -20°C on only one day in mid-February. In VI, in February and March the minimum temperature outdoors was -20°C or lower on 19 and 18 days, respectively. In May, the minimum temperature outdoors was below 0°C on 11 days (VI). In an experiment with weaned replacement Hf heifers Manninen et al. (2007) measured the temperature in the uninsulated barn during two winters and reported that it correlated to the amount of heat radiation from the sun and followed the outdoor temperature rather logically during the mid-winter months. When the outdoor temperature was at its lowest, the temperature indoors remained only 5-7°C higher than the outdoor temperature.

Comparing the temperatures measured (I, IV-VI) to the LCT estimates for beef cows in late pregnancy (Table 4) it can be suggested that the cows indoors hardly experienced their LCT. Obviously the LCT was reached occasionally since the cows had in the daytime the possibility to use the outdoor exercise area which they visited frequently on cold sunny days but stayed indoors on rainy and windy days. However, the cows outdoors in IV and VI apparently experienced temperatures below their LCT. On the other hand, it can be assumed that the calves both indoors and outdoors in I-VI were in temperatures below their LCT estimates (Table 4).

The relative humidity (RH) outdoors (VI) at 8:00 a.m. and 2:00 p.m. was on average 95 and 90% in November-March, and indoors 95 and 92%, respectively. Manninen et al. (2007) recorded RH in the uninsulated barn and outdoors during two successive years and reported them to be fairly constant, 90-100% from the beginning of October until the end of February. From the turn of March the RH started to change daily due to increasing solar radiation. A typical daily variation was 50-90% outdoors and 70-95% indoors. Those values may represent typical RH values in the Tohmajärvi experimental conditions.

Hot zone

The heat production increases until the upper limit of the thermoneutral zone, the upper critical temperature. This leads to increased work for thermoregulation (e.g. panting) and an increased body temperature. In tropical conditions, periods of imbalance between heat production and heat loss are normal, but the cattle must maintain homeothermy over successive periods of 24 h without incurring significant losses in production (Webster 1974). At Tohmajärvi during the grazing season, short periods with daytime temperatures of over +25°C were common, but night temperatures were lower, suggesting that heat was not a problem in that region. However, in the experimental conditions during the grazing season the cows and calves did not have an area protected against sunshine, e.g. forest, as is generally recommended.

3.1.3. Responses to cold

The effects of cold on an animal can roughly be divided into *acute* and *chronic* responses. Cold-adapted ruminants on sufficient feed and with substantial thermal insulation are very cold-hardy and have low LCT estimates (Table 4) and, therefore, in dry, cold regions they rarely experience direct cold stress (e.g. Webster et al. 1970, Young 1981, Young 1983).

Acute responses to cold

Moisture and wind may considerably reduce the thermal insulation of the animal's coat and have a stressful effect on the animal. Acute cold exposure can be a practical problem also with cold-adapted animals resulting in death losses (Hutchinson 1968, Blaxter 1977) or the development of secondary complications that affect later performance, i.e. chronic digestive and respiratory disorders, scouring in young animals and pneumonia (Webster 1970, ASAE 1974). Managing acute cold stress involves minimizing the risk and severity of the immediate effects and pre- and early treatment of animals to reduce the probability of development of secondary complications. The risks can be reduced by providing shelters and sufficient bedding, selecting appropriate calving times and ensuring adequate supply of feed which all were satisfied in I-VI. That is probably why no acute responses to cold were observed in the present study. On the other hand, during harsh weather conditions animals tend to temporarily reduce their feed intake and become more cold-susceptible. Reduced feed intake was not observed in the present study, probably because feeding was restricted, the feeds available were well suited to cold conditions and, finally, the weather conditions were not extremely harsh.

Chronic responses to cold

The *first chronic response* of an animal to cold is to increase insulation, i.e. to develop a winter coat. In cattle this is apparently induced and retained by shortening of the daily photoperiod and mild cold stress. It is also suggested that tissue insulation increases as a consequence of prolonged exposure and adaptation to cold (Webster 1976). Wagner (1988) summarized the effects of cattle coat on LCT as being: summer or wet coat, LCT=+15°C; autumn coat, LCT=+7°C; winter coat, LCT=0°C and heavy winter coat, LCT=-8°C, i.e. the LCT for a beef animal might be as high as +15°C for an animal which has a summer coat of hair (short or shed off) or a haircoat which is wet from rain or snow.

The *second chronic response* of metabolic adaptation to cold is an elevated basal metabolic intensity and not simply an acute metabolic response. This is indicative of metabolic adaptation to cold. Cold-adapted animals survive and apparently suffer less in extreme cold than similar non-adapted animals. Therefore, the definition of a static zone of thermoneutrality may be difficult. According to Young (1983), two forms of cold-induced metabolic responses by animals are:

1. Acute metabolic response that compensates directly for an increased rate of loss of body heat to the environment.
2. Chronic adaptive basal metabolic response.
   The latter has been studied with sheep on the basis of changes in heart rate, suggesting that an increase in the resting metabolic intensity was a consequence of prolonged prior exposure to cold (Slee and Sykes 1967). Young and Degen (1981) calculated that the resting metabolic rates of cattle increased by approximately 2.9 $kJ/kg^{0.75}$ for each 1°C decrease in mean ambient temperature.

The *third chronic response* to cold can be expressed as influences of the thermal environment on the intake of animals. Since the feeding was restricted (I-VI, except *ad libitum* treatments in VI) the effect of cold on feed intake could not be evaluated in the present study. Mossberg and Jönsson (1996) studied the effects of temperature and day length on the performance of growing bulls and reported no or very little effect of temperature or housing system on energy intake, but live weight gain (LWG) was improved with increasing day length. Huuskonen and Joki-Tokola (2003) concluded that uninsulated and outdoor winter housing facilities in Finnish cold conditions were appropriate for growing Ayrshire (Ay) bulls compared to an insulated housing facility. However, the LWG was lower and the feed conversion less efficient in the outdoor facility than in the insulated barn or in the uninsulated pen.

Generally, it is assumed that cold stimulates intake and the increase reflects the increase in the metabolic demands of the animal. Earlier studies report that when ruminants are exposed to cold, there is an increase in rumination activity, reticulorumen motility and rate of passage of digesta as well as a reduction in the volume of the reticulorumen (e.g. Kennedy et al. 1976, Kennedy et al. 1977, Gonyou et al. 1979). Due to the changes in the reticulorumen, there is a reduction in digestion, particularly with roughage (Young and Degen 1981), mainly associated with an increased rate of passage of digesta and increased gut motility (Young 1981). Christopherson (1976) studied the effects of prolonged cold and an outdoor winter environment on apparent digestibility in beef calves and concluded that digestive function in young, small animals may be more markedly influenced by environmental temperature than that of older, larger animals.

3.1.4. Impacts on beef cows and calves

Suckler cows are generally overwintered to maintain their live weight (LW) or fed on a slightly sub-maintenance feeding level accepting slight losses in LW (Young 1983). Therefore, it can be assumed that they are more susceptible to cold stress than growing cattle and dairy cows having generally *ad libitum* feeding. According to earlier studies in Canada, the feed requirements may be elevated even by 30-70% due to adverse winter conditions (e.g. Jordan et al. 1968, Hironaka and Peters 1969, Lister et al. 1972). The increased beef cow winter requirements are mainly due to decreased digestion and increased maintenance functions. Pregnancy, the development of the conceptus and subsequently the calf are generally not detrimentally affected by cold stress (e.g. Wiltbank et al. 1962, Jordan et al. 1968, Hironaka and Peters 1969). However, if during pregnancy in cold conditions too much of the body energy reserves is used because the diet is insufficient in energy or protein, complications may arise, such as weak calf syndrome (Bull et al. 1978). If the cows lose too much body condition (BC) due to severe winter conditions, they may have reduced milk production potential and delayed rebreeding (Wiltbank et al. 1962). Using pregnant mature beef cows Young (1975) studied the effects of winter acclimatization on the energy metabolism and concluded that the metabolic rate was not significantly influenced by either the body condition or by the availability of bedding.

3.1.4.1. Animal performance

The calf birth weight (BW) averaged 44.2 and 43.3 kg in IV and VI, respectively, without any treatment effects, suggesting that the cows received enough energy for maintenance and development of the foetus in the cold outdoor conditions. In total, 417 cows calved in I-VI and the occasional calf losses were mainly related to faulty dispositions, premature deliveries originating from various reasons, accidents or death without any specific statement but not due to the experimental treatments or cold conditions, except one in VI due to the somewhat deficient outdoor facility.

The total calf losses were below 4.0% in I-VI, which can be assessed as being an acceptable level. Some calf losses originating from cold conditions were undoubtedly avoided by careful supervision by the technical staff of the Research Station, also at night.

This fact has to be considered, when evaluating the calf survival results observed in the present study, i.e. the continuous supervision of cows during the calving period may be impossible in practice in a large herd with limited labour available. Some calf losses may arise with cows having poor maternal instincts which are important in cold conditions. Therefore, it may be worth arranging for the calving period to occur after the coldest months to reduce the risks rising from cold weather and to organize as compact calving period as possible. To reduce the calf losses which arise from the cold conditions, Lammoglia et al. (1999a, 1999b) described favourable responses to dam *pre partum* supplementary fat feeding in the survival of newborn calves assuming e.g. increased glucose concentrations and heat production in cold-stressed newborns.

In the present study, the average calving season occurred from mid-March to the beginning of May, although some premature deliveries took place in January and February (III-2-V). A calving season beginning in mid-March might be fairly optimal in conditions similar to those of Tohmajärvi since during daytime temperatures in March and April are normally considerably warmer than during nights. However, sudden changes in weather conditions in spring, from plus degrees to zero or below, combined with icy rain and wind, were observed to be more serious for neonatal calves than steady cold conditions. Azzam et al. (1993) studied the environmental effects on the neonatal mortality of beef calves and reported that calves born to two-year-old cows were more susceptible to severe weather conditions than calves born to older cows. They proposed that calving late in spring, compared with earlier calving, would result in decreased mortality especially in calves born to two-year-old dams. The negative effect of precipitation on survival increased with decreasing temperature. In addition, the average ambient temperature and precipitation on the day of calving affected survival non-linearly and the magnitude of the effect depended on the age of the dam, the sex and size of the calf, and the incidence of dystocia. In II-1, the heifers calved mainly indoors under careful supervision and with sufficient bedding which was probably the main reason for the good neonatal calf performance.

In VI, calves born indoors to cows fed WCBS *ad libitum* had a lower daily LWG pre-grazing than those born outdoors to cows fed WCBS *ad libitum* (908 vs. 1183 vs. 1186 g). Afterwards, the calf LWG at pasture and during the entire experiment was unaffected by the winter housing conditions. No particular explanation can be given for the lower LWG pre-grazing indoors, but probably the indoor conditions were not as favourable as the outdoor conditions, e.g. humidity indoors and pen surface area per calf. Jordan et al. (1977) reported that calves born outdoors in northern Ontario were heavier at birth than calves born indoors, but their LWG pre-weaning was lower compared to calves born indoors or indoors-outdoors.

Overwintering mature ChAy, second-calf Hf-cross and first- and second-calf Hf cows either outdoors or indoors did not affect the calf performance (Manninen 1998a, Manninen 1998b, Manninen et al. 2002b). At the Tohmajärvi facilities, no negative effects of cold conditions on calf performance and health were observed, although a comparison to warm housing conditions was not available.

Kauppinen (2000) studied the acclimatization of dairy calves to a cold and variable micro-climate and found the calves in cool (0 - +5°C) and cold (+6 - -22°C) conditions to grow as well as the calves housed in warm (+10 - +16°C) conditions. The growth rate correlated positively with thyroid hormones. An elevated serum cortisol level showed that the calves probably experienced stress from being housed in lower temperatures than recommended. In cold temperatures the calves increased their feed intake to maintain the balance between energy intake and energy expenditure. Finally, Kauppinen (2000) concluded that it is possible to lower the housing temperature of young dairy calves from the recommended temperature (+10 - +16°C) to a cooler ambient temperature in the range ±0 - +5°C if there is draught-free ventilation, dry, thick litter and well-operating feeding and watering methods with daily supervision.

The cow LW losses during winter were rather low in the present study, at the maximum 68 and 61 kg (V, mature cows with good BCS), 58 kg (I, L-US, second-calf cows) and 56 kg (IV, WCOS, mature cows with good BCS). This suggests that the cows did not use extensively the body reserves for heat production.

In the present study, cold conditions did not affect the pregnancy rate, since the mating period occurred during summer. However, environmental effects may affect the pregnancy rate of beef cows. Amundson et al. (2006) studied the effects of temperature (heat stress) and humidity on the pregnancy of crossbred *Bos taurus* cows and concluded that reductions in the pregnancy rate are apparent when the average minimum temperature and temperature-humidity index equal to or exceed 16.7°C and 72.9 when cows are pasture-bred during a 60-day spring-summer period. At Tohmajärvi, the 15-year average temperatures in June and July were 13.9 and 16.4°C, respectively, and thus below the value reported by Amundson et al. (2006), which probably partly explains the pregnancy rates measured in II-VI.

3.1.4.2. Blood values of cows

The use of blood profile tests for farm livestock began as a method to evaluate production diseases in dairy herds such as milk fever, grass tetany and ketosis (Payne and Payne 1987). The difficulties in interpreting and comparing the results of blood chemistry analyses with cattle mainly arise from the facts that differences between herds account for most of the variation, followed by differences between lactational and age groups within herds. In addition, there are seasonal and diurnal variations, and effects due to sampling techniques and analytical methods (Payne and Payne 1987).

In the present study, blood samples were taken from the mature Hf cows. In V, the cows were overwintered in the uninsulated barn and the samples were drawn to evaluate the effects of feeding every third day (3D) versus feeding daily (D). In VI, the cows were in the outdoor pens (AS, RS, AT, RT) and in an indoor pen (AU), and the samples were taken to study the effects of long-term cold conditions in different winter housing facilities when WCBS was offered either *ad libitum* or restricted.

Serum and blood constituents analysed in V and VI are presented in Table 5 as minimum and maximum values for treatments during the winter period. The analysed values were mainly within the reference ranges presented by Payne and Payne (1987), Kaneko et al. (1997) and Moore (1997a, 1997b). The urea concentrations were slightly lower and the long-chain fatty acid (LCFA) concentrations slightly higher compared to those reference ranges which may be due to e.g. differences in feeding.

Table 5. Serum and blood constituents of suckler cows by treatment in V-VI.

	V min-max	VI min-max	Reference range
Leucocyte, $\times 10^9$/l	Nm [1]	6.1 - 10.2	4.0 - 12.0 [2]
Haemoglobin, g/l	Nm	109 - 147	100 - 140 [3]
Glucose, mmol/l	Nm	1.9 - 2.7	2.0 - 3.0 [3]
Long-chain fatty acids, mmol/l	0.17 - 0.63	0.10 - 0.48	0.11 - 0.35 [4]
β-hydroxybutyrate, mmol/l	0.21 - 0.32	0.18 - 0.49	0.04 - 0.84 [5]
Urea, mmol/l	2.8 - 4.8	2.0 - 4.3	3.6 - 7.2 [3]
Total protein, g/l	73 - 78	69 - 79	63 - 85 [5]
Albumin, g/l	40 - 41	Nm	32 - 43 [5]
Aspartate aminotransferase, U/l	63 - 86	53 - 76	49 - 108 [5]
Creatine kinase, U/l	69 - 111	73 - 217	50 - 271 [5]
Leptin, µg/l	Nm	2.7 - 4.5	
Cortisol, nmol/l	Nm	7 - 38	

[1] Not measured.
[2] Moore 1997a.
[3] Payne and Payne 1987.
[4] Kaneko et al. (1997).
[5] Moore 1997b; dry and early lactation.

Minor changes in blood values

On the basis of the blood analyses, no signs of heavy stress, massive consumption of energy stores, frequent muscle injuries or inflammations were observed in V. There were implications of lipolysis and proteolysis in 3D cows on the third day after feeding and, therefore, longer feeding intervals might have a negative effect on the performance of the animals. However, the 3D feeding may give flexibility to organize the feeding routines on farms during the busy periods or diminish the labour requirement and thus improve the economic output (Palva et al. 2004). In accordance, McCartney et al. (2004) found that alternate-day winter feeding of barley silage to beef cows in feedlots resulted in considerable labour and cost savings and, thus, in large improvements in production efficiency. Nevertheless, animal welfare aspects have to be considered if the feeding frequency will be decreased for winter period. Appropriate feeds should be chosen to avoid freezing and behavioural problems (adequately low energy content allowing sufficient time for eating).

In V, the clearest effects of treatment 3D on the blood values were increased serum concentrations of urea and LCFA 72 hours post-feeding, presumably due to activation of lipolysis and proteolysis when animals were prepared to use their own energy stores. In some cattle feeding experiments (Reid et al. 1977, DiMarco et al. 1981) with low-energy diets the concentrations of LCFA were elevated. Serum urea concentrations are known to increase during a high-protein diet, in decreased renal function, dehydration and protein catabolism (Finco 1997). Activation of proteolysis seems to be the most probable reason for the slightly elevated urea values. Blood β-hydroxybutyrate (β-HB) concentrations fluctuated in treatment 3D, possibly reflecting feeding, because the sampling was not synchronized with the fasting. The changes were small and far from the levels found in ketotic cows, suggesting that the general energy balance was good. During the winter period the cows received on average 93-94 metabolizable energy (ME) MJ/d. The treatments had no effects on the activity of creatine kinase (CK) in serum, and only minor effects were observed on the mean activity of aspartate aminotransferase (ASAT). These enzymes are released into the blood stream at times of muscular stress and disorders (Cardinet 1997). It can be suggested that treatment 3D did not cause aggressive behaviour resulting in muscle injuries or clearly increased motility. The observations of cow behaviour support these conclusions.

The cold outdoor conditions seemed to have some minor effects on lipid metabolism (VI). The clearest differences among the treatments were in the values for LCFA, urea, β-HB and haemoglobin (Hb). The differences in concentrations of LCFA among the treatments could have reflected the environment, suggesting that in cold circumstances, particularly in animals in rain shelter groups, some activation of lipolysis occurred. However, the activation was rather small, probably due to the small differences in temperature between the housing conditions. When the outdoor temperature was at its lowest, the temperature in the barn remained 5-7°C higher than the temperature outdoors (Manninen et al. 2007). The differences in urea and β-HB concentrations among the treatments were fairly parallel during the winter which means that the highest values were in the uninsulated barn (AU), then outdoors having a three-wall shelter (AT and RT) and, on the other hand, the lowest values in cows in the harshest conditions, having only a rain shelter (AS and RS). Cold exposure has been reported to increase reticulorumen motility (Kennedy et al. 1976, Kennedy et al. 1977, Gonyou et al. 1979) and reduce digestive efficiency (Young and Degen 1981). Butyrate is metabolized to β-HB in the rumen epithelium, and surplus ammonia from the rumen and intestine is a source for urea synthesis in the liver. One explanation for these differences in β-HB and urea concentrations among the treatments could be the different environmental circumstances which may have been reflected in the digestive functions. However, no β-HB values higher than 1 mmol/l, indicating mildly ketotic cows (Gröhn et al. 1983), were measured. During the winter feeding period the cows received on average 101-134 ME MJ/d energy. The decrease of Hb concentrations of cows on restricted diet is difficult to interpret. This phenomenon could be due to smaller amounts of consumed protein (Payne and Payne 1987), but the concentrations of serum protein and urea do not support this theory. Serum concentrations of leptin have been found to correlate with fat reserves in many animals including sheep and cows (Blache et al. 2000, Erhardt et al. 2000). When the changes in LW or BCS were rather small, only minor changes in the adiposity of the animals seem to have occurred and to be reflected in the leptin values. The serum cortisol concentrations were rather low. The secretion of cortisol shows circadian variation in cattle and may increase during stress (e.g. Rijnberk and Mol 1997). Except for some individual increases in cortisol and CK in very few animals in different treatments, the values of these parameters remained at a low level. Therefore, it can be suggested that the treatments caused neither aggressive behaviour resulting in muscle injuries or clearly increased motility, nor severe stress. All the leucocytes in VI were within the reference range in all animals throughout the Experiment suggesting that no severe inflammations occurred.

Using weaned replacement Hf heifers Manninen et al. (2007) evaluated the effects of cold and warm winter housings on the blood values at Tohmajärvi Research Station. The mean values of all the blood chemistry parameters remained within the physiological range, suggesting that replacement beef heifers on a restricted feeding regimen can be overwintered outdoors in cold conditions or in an uninsulated winter housing facility.

3.1.4.3. Animal health

The health of the cows and calves was good in I-VI and no clinical symptoms were observed, suggesting no negative effects of the feeding strategies or cold conditions. In III-2, three cows offered WCBS with flat-rate feeding had premature deliveries due to an infection by *B. Licheniformis* bacteria. All three cows were in the same pen and probably the infection spread through the afterbirth. The other reasons for removing a cow from a group were mainly uterine torsion or inflammation, prolapses and death of the calf immediate after calving. However, the losses were not related to the treatments or cold conditions. No differences were observed in claw health between the outdoor treatments in VI.

3.1.4.4. Behaviour of cows

Cow behaviour was observed in one Experiment (V) four times during the indoor feeding period on three consecutive days. The purpose was to study how the 3D feeding affected cow behaviour. Behaviour was recorded indoors.

The D cows spent more time outdoors than the 3D cows. All cows were calm and no aggressive behaviour was observed, which is in accordance with the ASAT and CK values. The 3D cows were assumed to be more restless than those fed daily. The calmness of the cows can be explained by their age, breed, sufficient area per cow in the pen and the feeding alley, and the availability of sufficient feed for the cows. Phillips and Rind (2001) compared alternate-day feeding with daily feeding for Friesian (Fr) dairy cows offered total mixed ration. On days when no feed was provided, the cows were less aggressive than when fed daily. The daily fed cows spent more time standing, permitting the assumption that feeding caused disturbance. In accordance with the results by Phillips and Rind (2001), the 3D cows spent more time lying down than the D cows, which can be explained by the feeding routines causing fewer interruptions.

Behavioural studies of suckler cows have mainly focussed on calf suckling behaviour (e.g. Cartwright and Carpenter 1961, Somerville and Lowman 1979, Day et al. 1987), cow grazing behaviour (e.g. Malechek and Smith 1976, Ferrer Cazcarra and Petit 1995a, Ferrer Cazcarra and Petit 1995b, Farruggia et al. 2006), effects of social stress after mixing beef cows (e.g. Mench et al. 1990, Ingrand et al. 1999, Ingrand et al. 2000) and use of differing areas or shelters (e.g. Houseal and Olson 1995, Wassmuth et al. 1999, Olson et al. 2000, Olson and Wallander 2002). The lack of studies concerning the behaviour of beef cows overwintered indoors in cold conditions is natural, since beef cow production occurs mainly in areas with possibilities to graze round-the-year or to provide only minimal shelter during the harshest winter months.

All cows showed good maternal instinct towards their calves, which partly explains the good results in cold conditions. Three AbAy heifers had difficulties in accepting the newborn calf and needed extra handling during the first post-calving day (II-1). One AbAy cow showed hostile behaviour towards her newborn calf, but displayed no negative signs the day after (II-2). The type of behaviour observed may be due mainly to overcare of the calf by the young mother and excessive maternal instincts of the Ab animals. In some cases in I-VI the cow did not take good care of her calf, however, normally without loss of the calf.

3.1.5. Winter housing facilities

3.1.5.1. Feeds and water

All the feeds used in the present study proved to be suitable for cold conditions. The grass silages (II-V) and whole-crop silages (III-2, IV, VI) did not freeze, mainly due to the rather high DM content and the restricted feeding regimen used, except in VI. The urea-treated straw (I) caused a minor freezing problem during the first weeks of experimental feeding, but the problem was eliminated by incubating bales in warm technical storage the day before feeding. The hay, straw, BP (I-III-1, V) and concentrates (I-III-1, VI) were well suited to the cold conditions.

Waste of roughages may increase in outdoor facilities due to rain and snow if the feeding place is uncovered. At the Tohmajärvi outdoor facilities, the feeding places were uncovered, but waste of feeds was marginal due to the restricted feeding regimen, except the *ad libitum* feeding in VI. The cows may have eaten some of the clean straw used for bedding in all the experiments conducted at the Tohmajärvi facilities, but the energy deriving from this source may be of minor value without effects on animal performance. The cold housing conditions may be rather demanding for machinery. In the conditions at Tohmajärvi on the coldest mornings, about -40°C, difficulties were encountered in the use of machines. This fact has to be taken into account when choosing the housing and feeding system for the cows.

Water delivery via insulated pipes into heated cups functioned without major problems, but careful checking of operation was required during the coldest periods. Adequate provision of water is necessary for growing cattle since decreased water intake results in reduced feed consumption and LWG. It is essential also for dry, pregnant and suckling beef cows (Kelly 2006). Bowden et al. (1981) reported that water intake ranges from about 6.5 l/kg feed DM consumed for calves to 3.5 l/kg feed DM consumed for mature beef cows. The water intake approximately halves as the air temperature decreases from 32°C to 4°C and is about 25% less in winter than in summer. Water consumption was evaluated at the Tohmajärvi facilities by Manninen (1998b) who found that Hf cows overwintered in the uninsulated barn had an average daily water consumption of 16 l in November and 36 l in May (2.0-4.5 l/kg feed DM). The corresponding values outdoors were 12 and 30 l/cow (1.5-3.7 l/kg feed DM). The higher water consumption measured on May was mainly due to the demands of milk production. The lower consumption of water outdoors can be explained by the opportunity to eat snow. The snow cover in the outdoor facilities grew steadily during the winters, reaching a depth of one metre in mid-March (IV, VI).

3.1.5.2. Bedding and wind breaks

Importance of bedding

Peat and straw were used as bedding materials indoors (I-III, V-VI), since peat alone did not function satisfactorily in the indoor pens. Bedding was added approximately twice a week, during the calving season more frequently, if necessary. At the beginning of the indoor feeding period the bedding area was about 90 cm lower than the passage. The indoor pens were not lowered during the winter period. Straw was used in the outdoor areas (IV, VI), additionally sawmill by-products, mainly bark (VI). The use of straw for bedding was measured (VI) and averaged daily 5.0-6.3 kg/cow outdoors and 2.4 kg/cow indoors (Kivinen et al. 2001). The availability of sufficient straw for bedding purposes should be evaluated before making a decision to keep cattle outdoors during the winter period.

Although bedding causes labour drawbacks it will have positive economic effects via increased weight gain. Bond et al. (1970) studied the effects of mud, wind and rain on beef cattle performance in California, where air temperatures in winter, however, were relatively mild. Muddy pen conditions increased the feed requirements by 20-33% and reduced the daily gains by 25-37%. If the animals in a muddy pen had a dry resting place, their production losses were considerably smaller. Probably one reason for the good animal performance in the present study was the cleanliness of the animals, both indoors and outdoors, measured in VI. In cold conditions, a wet and dirty coat considerably reduced the insulative value resulting in increased thermal demand on the animal (Young 1981).

Importance of wind breaks

The outdoor pens were equipped with L-shaped wind breaks (IV, VI), except the two outdoor pens averaging 300 m^2 (IV). The wind breaks were of minor value, mainly because hard winds are uncommon in the region (Manninen et al. 2007) and there was a forest behind the four pens. The wind conditions at Tohmajärvi Research Station were dualistic. South-West winds were usually milder than North-East winds during the winter. The wooden wind breaks were built against the North-East winds, but the wind speed exceeded 5 m/s only occasionally (VI). Manninen et al. (2007) measured the average wind speed throughout two successive winters to be 2.5 m/s with wind peaks of 5-10 m/s occurring arbitrarily at intervals between two or three weeks. The wind blew from various directions without any dominant direction, and the highest measured wind speed was 16 m/s. One method of evaluating the combined effects of wind and temperature is to use the wind-chill factor (NOAA 2004). The wind-chill factor was found to be of minor importance in the conditions at Tohmajärvi due to the mild winds (VI, Manninen et al. 2007).

The wind breaks used had a 3-cm space between boards and offered an adequate barrier to mild winds, which is in good accordance with the results of Moysey and McPherson (1966) who reported that a 20% porosity fence gave better protection against snow and wind than a solid fence. The type of wind break used is in good accordance with the model (2.5 m high slatted) Webster (1974) recommended for use in cold, dry continental western prairies. Wind breaks are common for cattle grazing winter ranges. However, Olson et al. (2000) showed that wind breaks offered minimal benefit for pregnant, mature AbHf cows grazing a foothill range. No effects on reproductive performance were observed although the cows with wind breaks tended to have better immune response and backfat thickness than the cows without wind breaks. At such circumstances cattle may alter their behaviour, as long as they are in sufficient body condition, on a day-to-day basis reflecting either an immediate response to the day's weather or possibly a compensatory response to the previous day's weather (Olson and Wallander 2002). Cattle may also respond to hard wind and cold by selecting moderate microclimates for grazing and resting which remain above their LCT (Houseal and Olson 1995). Redbo et al. (2001) concluded that dairy heifers in Swedish conditions at a latitude of 60°N can be sustained in a cold climate if they are provided with wind breaks and dry lying places.

The main influence of wind breaks for cattle is saving of feed and this increases as the temperature gets colder. Christopherson (1985) states that assuming prevailing winds of 4.2-5.0 m/s, shelter from the wind would be expected to reduce the feed requirements of cows by about 10.5 ME MJ/d/cow during winter. Bruce (1982) evaluated the benefits of housing spring- and autumn-calving suckler cows and stated that housing can save a maximum of 7 ME MJ/d/cow but assumes that in practice it is much less. On the contrary, Young et al. (1972), with mature beef cows, studied the impacts of shelter and bedding on animal LW, behaviour and changes in energy requirements and concluded that stalls and bedding had little advantage on cow performance, not sufficient to cover the costs of the stalls. The shelters were beneficial for cows in reduced BC during periods of severely cold weather. In IV and VI, the feeding was restricted, except the *ad libitum* treatments in VI, the cow BC remained good during the winter period and, therefore, the effects of wind breaks on feed consumption may have been minor.

One possible reason for the good cow performance in I-VI might have been the photoperiod at northern latitudes. Pringle and Tsukamoto (1974) overwintered pregnant beef cows satisfactorily at a latitude of 60°45' in a spruce forest area, in an open shed or a closed barn offering hay. They concluded that the wide variation in photoperiod between summer and winter in the north may enable beef animals to effectively cope with long cold winters through increased grazing activity in summer, followed by diminished activity and lower feed requirements during winter.

3.2. Effects of different feeding strategies

3.2.1. Feeding recommendations for suckler cows

The production of beef from suckler cows can never be as efficient energetically as milk production from dairy cows, since there is a two-stage conversion process first of feed into milk and then of milk into body tissue. Since the beef cow is less productive than the dairy cow, the dietary needs are lower and can be fulfilled with less energetic feeds (Allen and Kilkenny 1984). Energy is the major component of feeds and the principal nutrient required by a suckler cow (Broadbent 1984). Other components are important but, for example, protein deficiency is easy to correct. Therefore, winter feeding strategies for suckler cows should mainly consider the effects of manipulating dietary energy supplies.

According to Lowman (1997a), feed costs account for about 75% of the total variable costs for both autumn- and spring-calving herds. Furthermore, 80% of total feed costs arise from the cow herself, with feed to the suckled calf being relatively insignificant. Of the annual feed eaten by an average cow, 73% is used to maintain the cow, 7% is used to meet the demands of pregnancy and approximately 20% goes for milk production. The breed, size, BCS and expected calving date of a cow are important in arranging the winter feeding.

Calculation of feeding in Experiments I-VI

No official feeding recommendations for suckler cows are available in Finland. Therefore, the feeding in I-VI was planned on the basis of the energy recommendations for dairy cows. The cows were assumed to produce ten kilogrammes milk.

In I-III-1, the feeding was arranged according to the Finnish recommendations (Salo et al. 1982). The recommendation for maintenance was documented as $LW^{0.75}/500^{0.75} \times 4.0$ fattening feed units (FFU). The energy needed for pregnancy was calculated using the recommendation for the last two months for dairy cows, i.e. 1.4 and 2.2 FFU/d. Additionally, 0.4 FFU/kg fat-corrected milk was calculated for milk production. The feed evaluation system changed in Finland in 1995 from a net energy-based system to a ME-based system (MAFF 1975, 1981, 1984) and, thus, the results of II and III-1 were calculated according to the ME-based system (Tuori et al. 1996).

In III-2-VI, the feeding was planned and calculated according to Tuori et al. (1996, 2002). The maintenance recommendation was documented as 8.31 ME MJ $+ 0.091 \times$ LW, which corresponds to 0.49 ME MJ/kg$^{0.75}$, including a 5% safety margin. The energy needed for pregnancy was calculated using the recommendation for the last two months for dairy cows, i.e. 18.7 and 33.9 ME MJ/d. Additionally, 5.15 ME MJ $\times$ kg energy-corrected milk was calculated for milk production. The possible changes in body weight were not taken into account.

The feeding was planned so that protein, mineral and vitamin requirements were fulfilled according to the Finnish recommendations for dairy cows (Salo et al. 1982, Tuori et al. 1996, Tuori et al. 2002).

Suckler cow feeding recommendations

The feeding recommendations for beef cows vary largely and different energy and protein evaluation systems and units are used, making comparisons between the recommendations difficult. On the other hand, to present one single feeding recommendation for suckler cow might be challenging since many types of beef cows, production systems, feeds and climatic conditions exist.

The National Research Council (NRC 2000a) nutrient requirements for beef cows are used e.g. in the United States and Canada. The requirements are based on cow weight (LW classes; 1000, 1200 and 1400 lb), expected average daily gain, stage of production (gestation or lactation), level of milk production (average or superior), since 1996, also cattle type, management style and feeding environment are regarded. The diet nutrient density requirements of lactating beef cows include total digestible nutrients (TDN), net energy for maintenance (NE_m, mcal/lb), CP, metabolizable protein (lb/d), degradable intake protein that minimizes dietary CP (DIP_{opt}), Ca and P. Within each LW class, requirements are computed for three different levels of peak milk production (15, 20 and 25 lb/d) during a 29-week lactation period. Monthly milk production potential is predicted by the model from typical lactation curves which are computed from an estimate of peak milk production. In practice, the peak milk production can be estimated from mature cow weight or frame score and from average expected 205-day steer weaning weight.

In the United Kingdom, no official national standard feeding requirements for beef cows exist (Lowman 2006). However, guidelines for practical feeding are given by SAC (1978). For spring-calving cows the target BCS values are 3.0, 2.5 and 2.0 at weaning, calving and mating, respectively. It is recommended that suckler cow feeding is based on target BCS values (Lowman et al. 1976), separately expressed for spring- and autumn-calving cows.

French beef cow feeding recommendations of INRA (Petit and Agabriel 1989) are proposed for different types of cows differing in size and muscle conformation, milk production potential and feed intake capacity. They take into account both the physiological needs of the cows (maintenance, pregnancy and lactation), and the ability of the cow to be underfed during the wintertime, if over-feeding during the grazing period is possible. Under-feeding depends mainly on age, calving season, physiological stage and cow BCS at housing. Feeding recommendations are given for three types of cows, large beef cows (Ch, Maine Anjou, beef dairy crosses), beef cows with limited feed intake capacity (Li, Blonde d'Aquitaine) and beef cows of hardy breeds (e.g. Salers, Aubrac). Primiparous cows are considered separately. For each case the recommendations give daily energy allowances (UFL, feed unit for lactation), protein (PDI, protein digested in the small intestine), feed intake capacity (CFU, fill unit for cattle) and Ca, P and Mg.

The Swedish feeding recommendations for suckler cows take into account cow LW, pregnancy and milk production (SLU 2003). The maintenance requirement is expressed as ME MJ/$kg^{0.75}$. The protein requirements are expressed as digestible CP and amino acids absorbed in the small intestine (AAT). For cows in good BC at housing, the maintenance energy requirements can be 80% of the recommended level, but a reduction of protein requirement for maintenance is not recommended.

In Denmark, the feeding recommendations (Strudsholm et al. 1999) for suckler cows take into account cow LW, BCS, weight gain/loss (during dry period and lactation), pregnancy (last 4 months and last 14 days of pregnancy), milk production and foetus size and are expressed as feed units (FE) and digestible CP.

Recommendations for maintenance

Factors that influence the maintenance requirements of beef cows include e.g. mature size, breed, environment, level of nutrition, activity and physiological stage (e.g. non-pregnant, pregnant, dry, milking). These genetic and environmental interactions can have a substantial influence on maintenance requirements and affect overall production potential. Additionally, season has a substantial impact on beef cow maintenance requirements (Laurenz et al. 1991).

The maintenance energy requirement of a beef cow accounts for nearly two-thirds of the annual requirements. It increases with animal size and is generally considered to be proportional to $LW^{0.75}$ (Petit et al. 1992). According to Lemenager et al. (1980), LW alone cannot be used to accurately determine the energy requirements of the larger breeds or breeds with high milk production potential, but used with BCS and estimated milk production predicts energy needs during early lactation more accurately than LW and milk production alone. Russel and Wright (1983) studied the maintenance requirements of mature, non-pregnant, non-lactating HfFr and Blue Gray beef cows and concluded that the maintenance requirements are more closely related to body protein mass than to body weight and summarized the daily maintenance requirement as ME MJ = 0.147*LW-0.016*BCS*LW.

According to NRC (1984, 2000b) the tabulated maintenance energy ME values should be decreased (for heat) or increased (for cold) by 0.91% for each °C prior exposure above or below 20°C. For acute heat stress, maintenance energy requirements should be adjusted according to severity. For acute cold stress, maintenance energy expenditure should be increased according to exposure to temperatures below their LCT. A dry pregnant beef cow having LW of 500 kg, in middle third of the pregnancy, with a LCT value of -25.0°C in dry, low wind conditions corresponds to increased energy requirement of 1.0 ME MJ/d per °C below the LCT value (NRC 1981). Simultaneously, in wet snow, 4.5 m/s wind conditions the LCT value is expressed as -7.3°C corresponding to increased energy requirement of 1.4 ME MJ/d per °C below the LCT value, respectively. The severity of the challenge to survive is dependant both upon environmental conditions and upon animal's level of acclimatization to cold, i.e. acclimatized cattle may survive in situations where non-acclimatized cattle may die (NRC 1981). In the present study, the cold periods may have influenced the maintenance requirements. On the other hand, according to Petit et al. (1992) heat is more stressful than cold.

The feeding recommendations for beef cows are mainly based on energy metabolism studies with dairy cows. Petit et al. (1992) summarized the results of several experiments and concluded that cattle of typical beef breeds require about 15% less ME for maintenance than dairy type breeds, because of a lower physical and metabolic activity, partly attributable to less demand from internal organs and less thyroid activity. For the same reasons, maintenance requirements are approximately 10-30% higher in lactating than in dry cows (Neville and McCullough 1969, Van Es 1972). Later, Neville (1974) calculated maintenance requirements for dry and lactating Hf cows to be 0.52 and 0.73 ME MJ/kg$^{0.75}$, indicating the maintenance requirements to be 38-41% greater for lactating than for dry cows. Recently, Agnew et al. (2003) described higher maintenance energy requirements for the current high genetic merit dairy cows as a consequence of their higher lean mass proportion and their relatively higher intake, the latter consequently enlarging the internal organ sizes.

Several publications have assessed the energy requirements of different beef breeds. Brelin (1979) found that Hf and Ch breeds needed on average 83 and 91% of the Swedish requirement standards for energy for dairy cows, while Swedish red and white needed 115%, mainly a result of the high milk yield during the suckling period. At the moment in Sweden, the recommendation for a suckler cow daily maintenance is expressed as 0.507 ME MJ/kg$^{0.75}$, being the same as for dairy cows (SLU 2003). Ortigues et al. (1993) calculated the maintenance energy requirements for dry, non-pregnant Ch cows to be 0.516 and 0.536 ME MJ/d/kg$^{0.75}$ for lean and fat cows. Thompson et al. (1983) evaluated the maintenance energy requirements for pregnant, mature AbHf and Ab-Holstein cows to be 0.54 and 0.59 ME MJ/kg$^{0.75}$, respectively, suggesting that fat AbHf cows had 6.1% lower energy requirements than thin cows, the opposite being true with Ab-Holstein cows. In addition, cows with more fat had a lower maintenance energy requirement during winter.

Petit et al. (1992) summarized the results of numerous experiments and reported 0.40-0.55 ME MJ/kg$^{0.75}$ for dry beef cows and 0.50-0.65 ME MJ/kg$^{0.75}$ for lactating beef cows for maintenance. For penned animals, values of 0.50 and 0.55 ME MJ/kg$^{0.75}$ may be used respectively for dry and lactating beef cows.

Recommendations for pregnancy and lactation

In mid-gestation, cows have the lowest nutritional requirements since the cow is dry and foetal growth is slow (Corah 1995). The foetus gains 65-80% of its total BW during the last third of gestation, although in the last two to three weeks of pregnancy the growth rate may remain almost constant (e.g. Petit et al. 1992, Corah 1995). The efficiency of utilization of ME for pregnancy, above maintenance, is rather low, generally estimated to be 0.10-0.15, averaging 0.13 (Petit et al. 1992). Concurrently, the heat production of the cow increases substantially in pregnancy, especially near parturition. The additional energy required to produce a calf of 40 kg is estimated to be from 9 to 38 ME MJ/d by INRA (1978) from 12 to 0 weeks *pre partum*. According to SLU (2003), for the last eight weeks of pregnancy, 3.6 ME MJ/d/100 kg LW in addition to maintenance requirements is needed.

There is a tendency between and within beef breeds for milk yield to be positively related to body size (Petit et al. 1992). The peak daily milk yield is generally 1.0-1.3% of LW and total yield during the first 210 days 200-220 kg/100 kg LW in mature, well-fed beef cows (Petit et al. 1992). Van Es (1975) described a requirement of 5.7 ME MJ/kg milk (medium quality hay and q=0.45), the corresponding value being 5.0 ME MJ/kg 4-% milk according to SLU (2003). Petit and Agabriel (1989) state the total net energy requirements of a Ch cow of 650 kg LW at peak milk yield of eight kilogrammes per day to be 1.7 times the maintenance requirements.

According to SAC (1978), eight weeks pre-calving a 650 kg mature spring-calving cow, losing LW 0.35 kg/d, has a total ME requirement of about 75 MJ/d. The corresponding value for a spring-calving 500 kg heifer, gaining 0.3 kg/d, is 85 MJ/d. Post-calving, a 650 kg spring-calving cow, having a daily milk yield of 10 kg and losing LW 0.24 kg/d, needs 120 ME MJ daily.

3.2.2. Feeds, feed and nutrient intake, live weight and body condition

The main purpose of farming beef cows is to convert grazed forage into weaned calves (Petit et al. 1992) and thus, to utilize areas and feeds unsuitable for other animal production or farming. In Western Europe and North America, grazed grass supplies 60-80% of the annual nutrient intake (Petit et al. 1992), the corresponding value in Finland being approximately 15-30%. Moving North the importance of grazed grass as a feed resource for suckler cows decreases and the importance of winter feeding increases, thus affecting the economic output of suckler cow production when subsidy politics are disregarded. Since the winter feeding period is long in Finland, approximately 240 days, the importance of the availability of alternative feeds for winter feeding is considerable.

Alternative feeds used in the present study

Urea-treated straw (I) may be a potential feed alternative for hay, since the treatment of straw with a urea-solution is less dependent on weather conditions than hay-making. Additionally, straw is a common by-product of grain grown on the farm. The lower digestibility of straw compared to hay may not be as critical in the feeding of suckler cows as in the feeding of dairy cows or growing cattle. However, if the US is given *post partum* as a sole feed for the lactating suckler cow, the cow may not be able to eat US in the amounts required. Urea-treated straw, combined with small amounts of GS or concentrates in the *post partum* diet of a lactating suckler cow, may fulfil the energy and protein needs of the cow.

The effect of urea treatment is based on the hydrolysis of urea to ammonia, which prevents the growth of fungi and undesirable bacteria such as *Clostridia* (Block et al. 1989). Earlier studies (e.g. Aronen 1990) have shown that the treatment of straw with a urea solution is a practical method to preserve high-moisture straw against mould. The treatment and storage of straw succeeded in I, but the energy value of the urea-treated straw was lower compared to hay (6.7 vs. 9.0 ME MJ/kg DM). The CP content of the urea-treated straw should have exceeded 200 g/kg DM rather than the analysed value of 98 g/kg DM. This may be explained by evaporation of urea as gaseous ammonia during baling and storage, which Sundstøl and Coxworth (1984) reported to be the disadvantage of ammonia-based treatments. In contrast to the results of Alaspää (1986), moulding was not a problem in I. Faulkner et al. (1985) reported the NH_3 treatment of wheat straw to increase the straw digestibility, the LWG and feed intake of AbHf cows and, thus, to be a safe method for treatment of straw for beef cows. According to the Finnish feeding recommendations (MTT 2006), the estimates for digestible organic matter in dry matter (D-value) for untreated barley and oat straw, ammoniated straw and alkali-treated straw are 430, 440 and 530 g/kg DM and the corresponding energy values 6.0, 6.2 and 7.4 ME MJ/kg DM, respectively. On the other hand, Heikkilä et al. (1989) reported the average digestibility of untreated barley and oat straw to be better compared to the untreated wheat and rye straw. However, large variation was measured among varieties. Mann et al. (1988) found ammoniated wheat chaff to be a good alternative feed to hay in winter feeding of beef cows.

Whole-crop silages (III-2, IV, VI) were used as alternative feeds for GS. The energy content of WCBS averaged 10.0-11.0 ME MJ/kg DM and that of WCOS 9.5-9.9 ME MJ/kg DM. The energy contents of WCBS and WCOS measured both *in vitro* and *in vivo* are in good agreement with the average value of 9.4-10.7 ME MJ/kg DM reported by Kristensen (1992). Differences may exist in the composition and feeding value of whole-crop cereal silages due to the differences in the proportion of grain and straw between the crops, treatment application, maturity and the vegetation stage (Adesogan et al. 1998). According to the Finnish feeding recommendations (MTT 2006), the feed value of WCBS is given for three contents of neutral detergent fibre, i.e. 450, 500 and 550 g/kg DM and, thus, corresponding D-values of 690, 640 and 600 g/kg DM and energy contents of 10.7, 9.9 and 9.3 ME MJ/kg DM, are given. Taking a reliable feed sample from that type of forage, particularly in farm conditions, may be difficult. An unrepresentative feed sample may give an over- or underestimated energy value which may lead to miscalculation in the planning of the restricted feeding scheme. Therefore, the use of whole-crop silages for suckler cows requires the availability of a representative feed sample and a reliable analytical method in order to obtain the correct energy values to calculate the feeding.

If the suckler cows are fed with good quality GS, D-value more than 690 g/kg DM, as a sole feed (IV), the daily portion in the restricted diet may be quite small and, thus, the time used for eating may be rather short. This may lead to behavioural problems, e.g. oral stereotypes like tongue rolling (Lindström and Redbo 2000), although these were not observed in the present study. In practice with group feeding, one dominating cow may eat the GS portions of cautious or shy cows which may lead to over- or underfeeding of individual cows. Therefore, whole-crop silages, especially WCOS in Finnish conditions, with rather low ME content may be an appropriate roughage for winter feeding of suckler cows. The *in vivo* apparent digestibility of organic matter (OM) was significantly lower for the WCBS than for the GS in III-2 (0.68 vs. 0.76). The *in vivo* apparent digestibility of OM for the WCOS (0.65) was lower than for the WCBS (0.71) and for the early-cut GS (0.76) in IV.

It can be suggested that the energy requirements of suckler cows in cold conditions can be fulfilled by using one suitable roughage as a sole feed, except untreated straw and US. Thus, the practical feeding would be rather easy to organize. However, the feed values are required to formulate the restricted feeding regimens. In farm conditions, the feeding should be based on the feed values and condition scoring of cows, as advised in the United Kingdom.

Oat hull-based flour-mill by-product was used as a feed alternative for straw in III-1. The pelletted and crushed BP included oat hull, dried grass meal, wheat molasses and calcium lignosulfonate. The CP content of the BP was 48 g higher than that of the straw, mostly due to the proportion of dried grass meal in the mixture. The ME and AAT values were similar for straw and BP. The utilization of BP on farms mostly depend on its availability, price and energy content. In cold outdoor conditions and with a possible shortage of straw, it is advantageous to reserve the available straw for bedding purposes to assure animal welfare, and use e.g. BP instead of straw for feeding.

Feed and nutrient intake in Experiments I-VI

Restricted and fixed feeding regimens were used in the present study, excluding the *ad libitum* groups in VI. The daily intake of DM, ME and ME per metabolic LW for the experimental winter period were 6.7-10.5 kg, 54-109 MJ and 0.53-0.86 MJ/kg$^{0.75}$, respectively, disregarding the *ad libitum* groups in VI (Table 6 and Table 7).

Group feeding was used for the cows in I-VI and in all the other experiments done at Tohmajärvi Research Station. Ignoring the flat-rate (III) and *ad libitum* feeding groups (VI), the cows were offered increased *pre* and *post partum* feedings. The amount of roughages offered to cows was increased *pre partum* and during the calving period on the basis of the estimated average calving date of the group (III-2, IV, V). Based on the estimated calving dates, concentrates (I-III-1, VI) were offered to the cows individually by tieing up the cows to the feeding fence for a short period. All cows had the opportunity to eat simultaneously and the tieing up assured that each cow got her own portion of concentrate, i.e. a possible dominating cow in the group could not disturb the others. As a consequence of the experimental facilities, feed and nutrient intake have to be expressed as average group values for the entire winter period. Therefore, comparisons with other studies are difficult as numerous other studies involve exact experimental weeks pre- and/or post-calving due to possibility of feeding the cows individually (e.g. Laflamme and Connor 1992, Sinclair et al. 1994, Charmley and Duynisveld 2004a, McGee et al. 2005a).

The AbAy and ChAy heifers (II-1) received 0.75-0.80 ME MJ/kg$^{0.75}$ daily during the experimental winter period. The total DM intake was 1.3% higher for the A than IA fed heifers. Feeding occurred without major problems and only small refusals were collected on some days when the day-to-day variation was highly positive for several consecutive days. The energy intake in II-1 was slightly higher than Manninen et al. (1998) reported for HfAy and LiAy heifers (0.72-0.77 ME MJ/kg^{75}), but lower than observed with Hf heifers offered a restricted diet (0.85 ME MJ/kg$^{0.75}$, Manninen 2000). In the United Kingdom, the daily recommendation for a spring-calving 500 kg heifer, eight weeks pre-calving, gaining 0.3 kg daily, is 85 ME MJ, i.e. 0.80 ME MJ/kg$^{0.75}$ (SAC 1978). The energy offered in II-1, 73-82 ME MJ/d during the entire winter period, was slightly lower than this recommendation for the pre-calving period if the length of the entire winter period, post-calving feeding period and also cold conditions are considered. However, the LW of the heifers in II-1 was below 500 kg since the pre-grazing LW averaged 456-516 kg. According to Petit et al. (1992), in normal to good nutritional conditions in Europe, first-calving heifers achieve approximately 75-85% of their mature weight after calving at two and three years and half of the residual growth is achieved before the second calving. If the heifers do not receive extra feed for their growth, they continue to grow their own frame using body reserves and may lose BC rapidly.

The second-calf HfAy and LiAy cows received 0.53-0.73 ME MJ/kg$^{0.75}$ daily (I) and the second-calf AbAy and ChAy cows 0.80-0.86 ME MJ/kg$^{0.75}$ (II-2), respectively. In II-2, cows receiving diet IA did not consume all the straw and hay offered, which was the reason for the difference in total DM intake between the A and IA diets. In a study reported by Manninen (1998b), Hf-cross cows in their second parity received 0.62-0.65 ME MJ/kg$^{0.75}$ daily, which largely agrees with I. Sinclair et al. (1998) offered over the first two parities two annual energy intake levels, 0.705 and 0.820 ME MJ/kg$^{0.75}$ daily, for low and high milk potential, small- or large-size cows (Ab, Welsh Black, Ch, Simmental (Si)) leading to daily energy intake for approximately six months pre-calving 65-90 ME MJ, four weeks post-calving 80-110 ME MJ and pre-mating 105-130 ME MJ. Corresponding to the results observed in II, animals from each of the four breeds gained weight but lost BC during their first two parities in a manner that was dependent on their annual level of energy intake.

Mature cows in III-VI received 0.65-0.84 ME MJ/kg$^{0.75}$ daily. In other experiments in the same facilities mature cows received 0.54-0.87 ME MJ/kg$^{0.75}$ daily (Manninen 1998a, Manninen et al. 2002a, Manninen et al. 2006). Chapple (1982) offered March-calving, North Devon-Fr single-suckling cows with LW of 550 kg at housing, either 60 or 48 ME MJ/d (0.53 or 0.42 ME MJ/kg$^{0.75}$) from housing in December until turnout in May. Cows given 48 ME MJ lost more LW during the winter period than those given 60 ME MJ (116 vs. 96 kg) but had higher LWG at grass than cows given the higher ration (106 vs. 89 kg). Calf BW, performance pre-grazing and 200 day weight were unaffected by the level of cow winter feeding. The energy Chapple (1982) offered to the cows was considerably lower than offered to the cows in the present study, but the winter periods at Tohmajärvi were longer, the cows heavier and the weather conditions colder.

The experimental indoor feeding period averaged seven months in III-1. During this period the cows on diets Control and Alternative received a total of 20,400 and 16,600 ME MJ/cow, respectively. In III-2, the experimental winter feeding period was six months, leading to a total energy consumption on diets Control and Alternative of 17,600 and 15,500 ME MJ/cow, respectively. Lowman (1988) stated that an average beef cow needs 18,000 ME MJ per year, i.e. 49 ME MJ/d, for maintenance. However, this estimate may be for a smaller cow than the cows in I-VI and for milder climatic conditions. According to Broadbent (1984), a spring-calving suckler cow weighing 500 kg needs 50 MJ ME daily from late October until the beginning of January, 70 ME MJ in January and February and 80 ME MJ in March and April before turnout at the beginning of May. This step-up feeding requires a total amount of 12,500 ME MJ during the entire winter period equivalent to a daily amount of 65 ME MJ (0.61 ME MJ/kg$^{0.75}$), if offered on a flat-rate basis. This estimate was best achieved in I (54-77 ME MJ, 0.53-0.73 ME MJ/kg$^{0.75}$, initial LW 493 kg).

In VI, during the entire winter period a cow on the *ad libitum* diet consumed on average 6,360 ME MJ (30 ME MJ/d) more than a cow on the restricted diet. During the winter feeding period the cows outdoors on the restricted diet maintained their LW (-3 kg), while those outdoors on the *ad libitum* diet gained 41 kg. At pasture the LWG was 61 and 32 kg for the cows overwintered outdoors on the restricted and outdoors on the *ad libitum* diets, respectively. The pre-grazing cow BCS outdoors on the *ad libitum* diet averaged 3.1 and outdoors on the restricted diet 2.7. On the basis of the BCS and LW values measured it can be suggested that the restricted feeding was at least sufficient for mature beef breed cows. *Ad libitum* feeding with WCBS may not be a recommendable winter feeding strategy for a mature beef breed suckler cow in good BCS at housing, both environmentally and economically, although this was not calculated in VI.

Dairy cow energy recommendations were used when the diets for winter feeding were formulated for the cows (I-VI). Winter feeding was planned taking into consideration the assumed milk production, pregnancy, cow LW and energy content of the experimental feeds. The initial cow BCS was not taken into account (II-VI) because no official recommendation for regarding BC was available. In Finland, efficient suckler cow production aims to improve the cow BC during a rather short grazing period. Further, suckler cows in good BC (at least 3) post the grazing period are expected to use their body reserves and loose LW during the long winter period. In the present study, rather small losses in cow LW and particularly in cow BCS indicate that the dairy cow feeding recommendations used for suckler cows were too high, especially for the mature beef breed cows in good BC at housing (III-2-VI). Bowden et al. (1981) present that after second calving cows may lose about 10% of their fall weight during the following winter. In the present study, the unnecessarily high amount of energy offered to the cows and thus, the too high BCS (some cows almost overfat) at calving and at the onset of grazing, had no negative effects on dystocial cases or rebreeding. However, there was evidently some waste of nutrients. In practice, this may lead to impaired economic output from the herd, if the feed allocation within a herd is not optimal.

Table 6. Mean daily intake of dry matter (DM), metabolizable energy (ME), amino acids absorbed in the small intestine (AAT), crude protein (CP) and diet crude protein content (DPC) in I-VI and in other experiments during the experimental winter period at Tohmajärvi Research Station.

Exp.	Breed[1]	Calving	DM, kg	ME, MJ	AAT, g	CP, g	DPC, CP g/kg DM
I	HfAy, LiAy	2	6.7-9.1	54-77	457-661	Na[2]	Na
II-1	AbAy, ChAy	1	6.7-7.6	73-82	568-638	859-965	127-128
II-2	AbAy, ChAy	2	8.4-9.4	87-95	660-721	863-925	98-103
III-1	AbAy, ChAy	M[3]	9.2-9.6	77-97	594-736	865-910	90-97
III-2	Hf	M	8.9	87-99	696-742	1032-1296	116-145
IV	Hf	M	9.2-10.5	97-109	749-849	935-1728	91-189
V	Hf	M	9.5	93-94	757-761	1091-1099	115
VI	Hf	M	9.2-12.6	101-134	792-1052	987-1251	99-107
A	HfAy, LiAy	1	7.0-7.5	65-74	538-588	Na	Na
B	ChAy	M	10.9-13.9	87-108	720-902	Na	Na
C	Hf-cross	2	8.0-8.2	75-77	608-623	Na	Na
D	Hf	1	9.0-11.3	94-121	745-948	1310-1740	146-154
E	HfAy, Liay	M	Na	Na	Na	Na	Na
F	Hf-cross	M	8.3-10.9	73-93	592-759	836-1094	100-101
G	Hf	1,2	9.0-9.2	77-80	667-690	872-907	97-98
H	Hf	M	11.0-11.1	102-103	869-881	1160-1176	105-106

I, IV and VI, not statistically tested. II, III and V, mean values if no significant differences ($P < 0.05$) between treatments, min-max values if statistically significant differences between treatments. A-H $P < 0.10$.

A, Manninen et al. 1998; B, Manninen 1998a; C, Manninen 1998b; D, Manninen 2000; E, Manninen and Huhta 2001; F, Manninen et al. 2002a; G, Manninen et al. 2002b; H, Manninen et al. 2006.

[1] AbAy, Aberdeen Angus-Ayrshire; ChAy, Charolais-Ayrshire; Hf, Hereford; HfAy, Hereford-Ayrshire; LiAy, Limousine-Ayrshire; Hf-cross, Hf×AbAy and Hf×ChAy and Hf×HfAy.

[2] Na, Not available.

[3] M, Mature.

Table 7. Cow live weight (LW), body condition score (BCS), metabolizable energy (ME) daily intake (MJ/kg$^{0.75}$) and ratio of LW change to BCS change in I-VI and in other experiments during the experimental winter period at Tohmajärvi Research Station.

Exp.	Breed[1]	Calving	LW, kg			BCS				
			Initial	Pre-grazing	Post-grazing	Initial	Pre-grazing	Post-grazing	ME MJ/ kg$^{0.75}$	LW change/ BCS change
I	HfAy, LiAy	2	493	440-505	543	Nm[2]	Nm	Nm	0.53-0.73	Na[3]
II-1	AbAy, ChAy	1	423-451	456-516	512-562	2.8-3.1	2.5	2.7	0.75-0.80	-172- -54
II-2	AbAy, ChAy	2	504-552	480-560	532-594	3.0	2.5	2.6	0.80-0.86	-41-37
III-1	AbAy, ChAy	M[4]	567	552	608	2.6	2.3	2.5	0.67-0.84	*27-61*
III-2	Hf	M	692	682	760	3.3	3.2	3.3	0.65-0.74	*38-92*
IV	Hf	M	741	714	811	3.2	2.9-3.4	3.8	0.70-0.77	-100-140
V	Hf	M	787	724	788	3.3	3.1	3.6	0.65	235-272
VI	Hf	M	670	688	733	2.9	2.7-3.2	2.9-3.2	0.76-1.00	-340-400
A	HfAy, LiAy	1	390-449	408-438	419-449	Nm	Nm	Nm	0.72-0.77	Na
B	ChAy	M	643	600	663	2.8	1.8-1.9	2.5	0.70-0.87	*37-50*
C	Hf-cross	2	608	560-581	642	3.0	2.4	2.9	0.62-0.65	*52-86*
D	Hf	1	509-523	547-634	579-624	2.9	2.9-3.4	3.1	0.85-1.02	-1267-231
E	HfAy, LiAy	M	590	523-570	613	2.6	2.0-2.5	3.1	Na	101-200
F	Hf-cross	M	729	644-729	737-774	3.2-3.4	2.7-3.2	3.0-3.6	0.54-0.66	0-207
G	Hf	1,2	556	518	591	3.1	2.5	2.8	0.70-0.71	*60-71*
H	Hf	M	746	759	809	3.4	3.4	3.7	0.71-0.72	92-1500

Mean values if no significant differences between treatments, min-max values if statistically significant differences between treatments. I, VI and A-H $P < 0.10$, II-V $P < 0.05$.
A, Manninen et al. 1998; B, Manninen 1998a; C, Manninen 1998b; D, Manninen 2000; E, Manninen and Huhta 2001; F, Manninen et al. 2002a; G, Manninen et al. 2002b; H, Manninen et al. 2006.
[1] AbAy, Aberdeen Angus-Ayrshire; ChAy, Charolais-Ayrshire; Hf, Hereford; HfAy, Hereford-Ayrshire; LiAy, Limousine-Ayrshire; Hf-cross, Hf×AbAy and Hf×ChAy and Hf×HfAy.
[2] Nm, Not measured.
[3] Na, Not available.
[4] M, Mature.

Effects of nutrition on LW and BCS

Under most beef and dairy cow production systems, animals undergo cyclical changes in LW, BC and body composition. The changes are a consequence of the seasonal nature of fodder production or the inability of the animals to consume enough food at particular stages of production to meet their energy requirements. Hence, cows are usually dependent to some extent on their body reserves at certain times of the year and replenish the depleted reserves at a later stage (Wright and Russel 1984a). Lipids are a variable component in the adult cow and may account for about two-thirds of the empty body weight change of a beef cow (e.g. Chigaru and Topps 1981, Wright and Russel 1984b). Energy deficient animals use their reserves of fat first, but some catabolism of protein may also occur, generally leading to more serious effects than if fat tissue only is depleted, possibly adverse effects on the reproductive activity of the cow depending on the period and the severity of the undernutrition (Chigaru and Topps 1981).

The annual changes in the cow LW were the primary reason for defining a method to quantify body condition using the subjective assessment. The term condition was first described by Murray (1919) in an attempt to determine the amount of fat in animals. According to Murray (1919), condition may be defined as the ratio of the amount of fat to the amount of non-fatty matter in the body of the living animal. The body reserves of beef cows at specific stages of the production cycle are an important determinant of their performance and the level of body reserves post-grazing influences the amount of winter feed required to ensure satisfactory cow performance (Lowman et al. 1976).

Body condition scoring assesses only subcutaneous fat cover and breed differences in the distribution of fat. Most beef breeds (e.g. Hf, Ab, Ch, Li) tend to deposit excess fat externally, while dairy breeds deposit more fat internally. Wright and Russel (1984c) calculated that a one unit change in BCS was associated with a change of 2,242 MJ of body tissue energy in HfFr, Blue-Gary, Galloway and Luing cows and 3,478 MJ in Fr cows. Wright et al. (1986) calculated that each unit of BCS loss in late pregnancy contributes the equivalent of 3,200 dietary ME MJ while 6,600 dietary ME MJ are required for a one unit increase in BCS. Sometimes LW is used as a guide to BC but may be markedly affected by gut fill and the weight of the products of conception. For example, live weight may decrease about 1.6 times the BW of the calf. Gut contents can vary from 13% on grass to 20% on low-quality hay in *ad libitum* diets (Petit et al. 1992). Animals can be markedly different in LW but still have a similar level of body reserves and, on the other hand, animals of similar LW may differ markedly in BC.

The common BC scoring systems are the nine-point system (Wagner et al. 1988) and the six-point system (Lowman et al. 1976). Vizcarra et al. (1995) used HfAb cows to determine the reproducibility (the correlation between an animal's score by one technician and its score by a another technician), repeatability (the correlation between an animal's score on one occasion and its score by the same technician on another occasion) and degree of expertise required to assess the BC. Three groups of technicians were used which were 1) technicians with at least two years of expertise in BC scoring, 2) technicians familiar with cattle but no previous experience with BC scoring and 3) technicians with no experience with cattle. The results indicated that periodical training of technicians is needed to standardize the system and the nine-point scale was a precise system for evaluating cows within one unit of BCS and, thus, the method was a precise system for evaluating the energy reserves of beef cows. In II-VI, the BC scoring was done according to Lowman et al. (1976) by 2-4 independent observers on two or three successive days and, therefore, the values reported are the average values of those observations.

The cow BCS was 2.6-3.3 at the onset of the experimental winter feeding periods (II-VI). The change in the BCS and LW during the winter period in relation to the daily energy intake (ME MJ/kg$^{0.75}$) in I-VI and in the other experiments arranged at Tohmajärvi Research Station are presented in Figure 3 and Figure 4. The changes in BCS and LW during winter can be rather different at the same level of energy intake due to e.g. cow age and breed. The change in the BCS during the entire winter period was negative in most of the experiments. This is acceptable if the BCS of the cows is good at housing, at least 3.0. In the present study the initial BCS was below 3.0 in II-1, III-1 and VI. The BCS of the mature AbAy and ChAy cows was on average 2.6 at the onset of the winter feeding period

(III-1), being lower than Lowman et al. (1976) recommended (3.0) for cows at housing. During the winter period the cows in II-VI lost BCS except those on the GS and WCBS diets in IV and those on the *ad libitum* diets outdoors in VI. The increasing energy level in the experiment generally diminished the decrease in BCS during the winter period. At the onset of grazing/mating the BCS was below 2.5 only in III-1. At pasture all cows in II-VI increased their BCS.

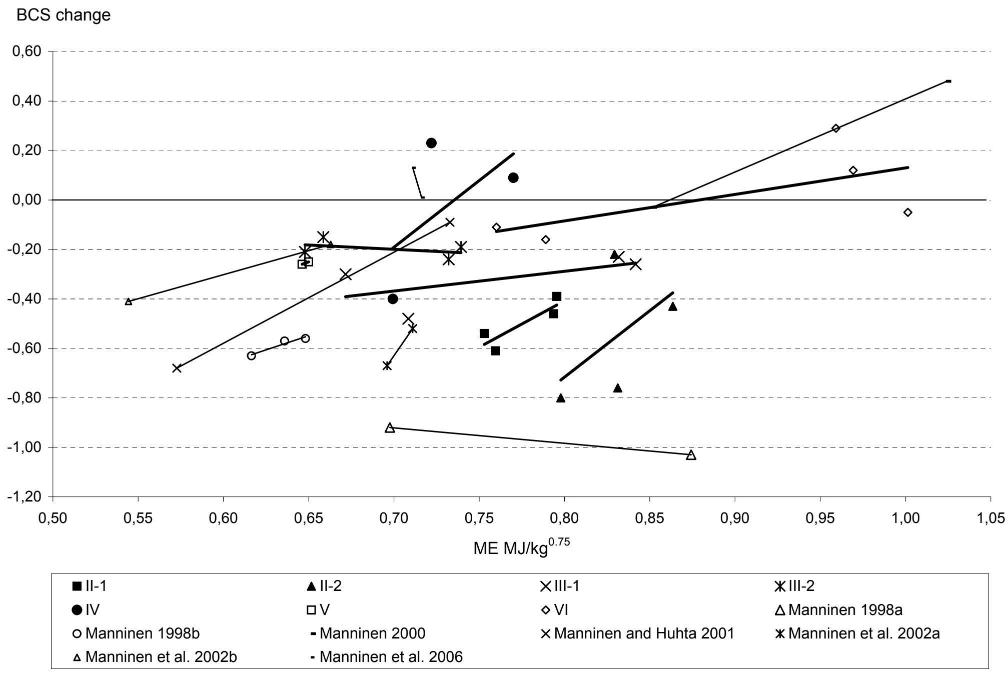

Figure 3. Changes in body condition score (BCS) in relation to daily energy intake in Experiments II-VI and in other experiments during the experimental winter period at Tohmajärvi Research Station.

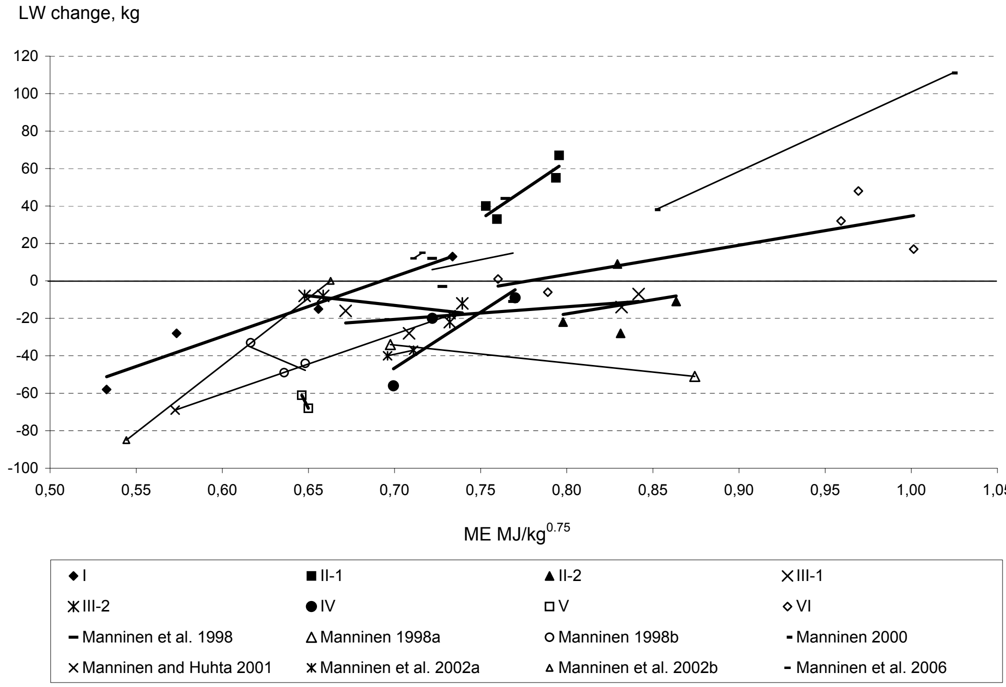

Figure 4. Changes in live weight (LW) in relation to daily energy intake in Experiments I-VI and in other experiments during the experimental winter period at Tohmajärvi Research Station.

The changes in BCS and LW during the winter period were -0.80 - +0.29 units and -68 - +67 kg, respectively (I-VI). According to Lowman et al. (1976), the BCS for spring-calving cows should be 3.0 at weaning and 2.0 at mating, i.e. one unit loss of BCS from weaning to the next mating is acceptable if the cows can replenish the BCS losses at pasture. One unit BCS loss (-1.03) was observed in a study with mature ChAy cows (Manninen 1998a), in others the losses were less. Therefore, it can be suggested that the BCS losses could have been greater, at least with mature Hf cows, without negative effects on cow and calf performance.

The ratio of LW change to the BCS change during the winter period is defined in Table 7. In II, the ratio is mostly negative, since the AbAy and ChAy cows were non-mature and still growing, leading to increased LW but decreased BCS during the winter period. Small changes in the BCS and/or LW during the winter period may give misleading values of the ratio (e.g. V, VI, Manninen 2000). However, the values in III and in studies by Manninen (1998a, 1998b) and Manninen et al. (2002b) are in good agreement with the value of 68 kg of body weight change associated with each unit of BCS change (scale 1-5) described by Buskirk et al. (1992).

Vanzant and Cochran (1993) evaluated the impacts of step-up protein supplementation on the performance of HfAb cows and their calves when grazing tallgrass prairies in winter. In accordance with the results observed in III, the cows did not benefit appreciably from staggering the rate of feeding. Increasing the amounts of protein supplement with advancing gestation failed to influence the reproductive performance or weaning weights of calves and, therefore, step-feeding did not offer any benefits over level-feeding for cows calving in moderate BC. Pregnant Hf cows in feedlots were offered cracked wheat or whole wheat with pasture hay every second or fourth day for 3-6 months pre-calving and during lactation every second day, with the result that feeding frequence had no effects on animal performance (Graham et al. 1986).

The BCS of the beef-dairy cows seemed to be slightly lower than that of the Hf cows in all experiments conducted at Tohmajärvi Research Station, leading to an assumption that the amount of energy offered to the Hf cows, on the basis of the energy recommendation for dairy cow, was too high, even in cold conditions. This agrees with the statement that typical beef breeds need about 15% less ME for maintenance than dairy-type breeds (e.g. Brelin 1979, Petit et al. 1992, SLU 2003).

On the basis of the results observed in the present study together with the other experiments conducted at Tohmajärvi Research Station, it can be suggested that a pregnant mature suckler cow with a BCS of 3.0 at housing may have a daily energy need during the entire winter period, approximately from the beginning of October till the end of May, of 0.60-0.70 ME MJ/kg$^{0.75}$ (i.e. for a 600 kg cow 73-85 ME MJ/d) in winter conditions similar to the present study. For young cows and/or beef-dairy crosses, the corresponding value should be somewhat higher, 0.70-0.80 ME MJ/kg$^{0.75}$ (i.e. for a 500 kg cow 74-85 ME MJ/d). This amount of energy can be offered to the cows in cold housing facilities using conventional or alternative feeds provided by an inaccurate feeding, flat-rate feeding, step-up feeding or feeding every third day strategy. This suggestion assumes that the cows have an opportunity to replenish the possible LW and BCS losses at pasture before the next winter period. The feeding recommendation has to be based on the cow BCS prior to the winter feeding period. Furthermore, estimated calving dates and feed values for the winter feeds give essential information for planning the feeding.

Dietary crude protein content

Since the milk production of suckler cows is lower than that of dairy cows, it can be assumed that the protein requirements for suckler cow milk production are also lower. Feeding protein above the required amount may not be harmful but, since protein is an expensive part of the diet, overfeeding is not good practice economically (Bowden et al. 1981) or environmentally.

The dietary CP content (DPC) varied 90-189 g/kg DM in II-VI (Table 6). The highest DPC content was measured with GS as a sole feed for the cows (IV). Bowden et al. (1981) states that the diet of a lactating beef heifer should contain at least 100 g/kg DM of CP which was exceeded in II-1 (127-128 g/kg DM). Lowman (1997a) suggests that the diet should contain 90-100 for dry spring-calving and about 110 g CP/kg DM for lactating beef cows. Those recommendations correspond with the Canadian guidelines (Yurchak and Okine 2004) suggesting for an average beef cow in mid-pregnancy, in late-pregnancy and post-calving 70, 90 and 110 g CP/kg DM, respectively. The SLU (2003) protein requirements are expressed as digestible CP and AAT and are for a 600 kg cow 300 and

315 g/d, respectively. The protein intakes in I-VI exceeded the Swedish recommendations. It can be assumed that all diets (I-VI) included sufficiently CP and AAT for cows for the entire winter period.

The milk urea content mainly reflects the protein content of the diet. The milk urea content was higher for the ChAy than for the AbAy cows (II-1, 19.1 vs. 17.2 mg/100 ml). In IV, the milk urea content averaged 31.3, 21.1 and 18.1 mg/100 ml for GS, WCBS and WCOS diets, respectively, reflecting the CP content of the feeds. In V, the feeding frequency had no effect on the milk urea content which averaged 24.3 mg/100 ml. The measured milk urea contents were rather low if compared to those measured with dairy cattle (Shingfield et al. 1999) reflecting the rather low intake level of suckler cows and the low dietary CP content, except in IV with GS.

3.2.3. Milk production and milk composition

Dawson et al. (1960) presented the results of the first evaluation of beef cow milk production, measured with beef Shorthorn cows during the years 1915-1918 and 1930-1935. Throughout the later period the milk production was estimated by the calf suckling (CS) method. The peak milk yield 10.3 kg/d was observed at the end of the second month and in the last month milk production averaged 6.2 kg/d. Throughout the earlier years, the cows were milked as they were dairy cows leading to a milk yield of 2,205 kg for a lactation period of 365 days.

Milk yield is a primary component of maternal performance, and milk quantity rather than quality is important in calf 205-day weight (Rutledge et al. 1971). The profitable beef cow production requires that feeding during lactation is sufficient for the cow to produce milk and to maintain or achieve the BC necessary to rebreed (Bartle et al. 1984). Jeffery et al. (1971a) stated that 40-50% of the variation in weaning weight results from the cow milk yield, and breed and age differences of the dam account for 82-87% of the variance in cow milk yield (Jeffery et al. 1971b). For example, Butson et al. (1980) reported a 1 kg increase in average daily milk yield to be associated with a 7.7 kg increase in weaning weight. On the other hand, Rutledge et al. (1971) found that a 1 kg increase in daily milk yield averaged over the first four months of lactation resulted only a 2.5 kg increase in weaning weight.

Evaluation of beef cow milk production

The machine milking (MM) and CS techniques are the two common methods of evaluating the beef cow milk yield. Somerville and Lowman (1980) compared MM to CS in beef cows and concluded that MM without the use of exogenous oxytocin may be unreliable. In the present study (II-V), oxytocin was given to the cows intramuscularly to ensure complete emptying of the udder. It can be suggested that the MM method probably describes the cow's milk production more accurately, whereas the CS technique represents the capability or vigour of an individual calf to suckle milk.

Factors affecting beef cow milk yield and milk composition

The milk yield was good in Experiments I-V (Table 8) and better than most of the values in the literature (Table 9), suggesting that the cows were in good BC at calving, received sufficient energy prior to the grazing period, entered good pastures and that the cold winter conditions had no negative effects.

According to NRC (2000a), the daily peak milk yield is variable, being 6.0, 12.0 and 15.0 kg for Chianina, Si and Holstein cows, respectively. The breeds used in the present study were described as having the daily peak milk yields of 7.0 and 8.0 kg for Hf and Ab, respectively, and 9.0 kg for both Li and Ch. The milk yields measured in I-V were higher than the NRC (2000a) values.

Due to the low milk yield, the production stress of beef cows is much lower compared to high yielding dairy cows, explaining the longevity of beef cows. According to Sirkko (2007), the average parity in 2006 in recorded Finnish beef herds was 2.6-3.1 (Hf, Ch, Li, Ab and Si). The corresponding value for dairy herds in 2005 was 2.3 (Kyntäjä 2006). The rather low value for beef cows indicates an increasing number of young animals in the herds rather than low culling age of the cows since suckler cow production is increasing rapidly in Finland.

Table 8. Average daily milk yield (kg), milk composition (g/kg) and body condition score (BCS) at calving in I-V.

Experiment	Method[1]	Breed[2]	BCS[3] at calving	Milk kg	Fat g/kg	Protein g/kg	Lactose g/kg
I	CS	HfAy, LiAy	Nm[4]	9.2	Nm	Nm	Nm
II-1	MM	AbAy, ChAy	2.7	10.8	46.0	30.6-33.0	48.8
II-2	MM	AbAy, ChAy	2.4-2.7	12.6	41.4-46.9	29.3-32.8	48.9
III-1	MM	AbAy, ChAy	2.5	11.6-13.0	40.1	29.5	49.1
IV	MM	Hf	3.1	9.5-11.4	38.7	32.2	49.7
V	MM	Hf	3.2	9.5	39.7	33.0	49.6

Lactation: I and II-2, 2nd lactation; II-1, 1st lactation; III-1, IV, V, mature.
Mean values if no significant differences between treatments, min-max values if statistically significant differences between treatments. I $P < 0.10$, II-V $P < 0.05$.
[1] CS, calf suckling; MM, machine milking.
[2] AbAy, Aberdeen Angus-Ayrshire; ChAy, Charolais-Ayrshire; Hf, Hereford; HfAy, Hereford-Ayrshire; LiAy, Limousine-Ayrshire.
[3] BCS, body condition score.
[4] Nm, not measured.

Beef cow milk production is influenced by the cow, i.e. cow breed, size, genetic milk production potential and age, and the calf, i.e. vigour, health, BW and sex. Compared to dairy cows, the daily milk yield of suckler cows increases rather slowly after calving and the maximum milk yield is reached 1-3 months *post partum*, depending on the balance between the milk potential of the dam and the suckling ability of the calf (Petit et al.

1992). Turnout to grass and double suckling increase the milk production. In the present study, except in I, the milk production was fairly steady and no major increases were seen after the end of the winter feeding period (Figure 5). Mondragon et al. (1983) reported that milk yields were similar throughout lactation in the first parity but declined over stages of lactation in parities two and three. The milk production of second-calf AbAy and ChAy cows (II-2) was higher compared to the corresponding heifers (II-1), which agrees with the results reported by Russel et al. (1979) and Butson and Berg (1984).

Total milk yield per lactation increases 20-30% from the first lactation onwards to a maximum observed between the third and the sixth lactation (Le Neindre 1974). Butson and Berg (1984) observed that the dam age affects the milk production significantly, i.e. two-year olds producing 100%, three-year olds 125%, four-year olds 136% and, finally, mature cows 139%. Rutledge et al. (1971) observed a peak milk yield of beef cows at the age of 8.4 years. According to Johnson et al. (2002) multiparous Brangus cows produced 66-84% more milk than heifers during early and late lactation.

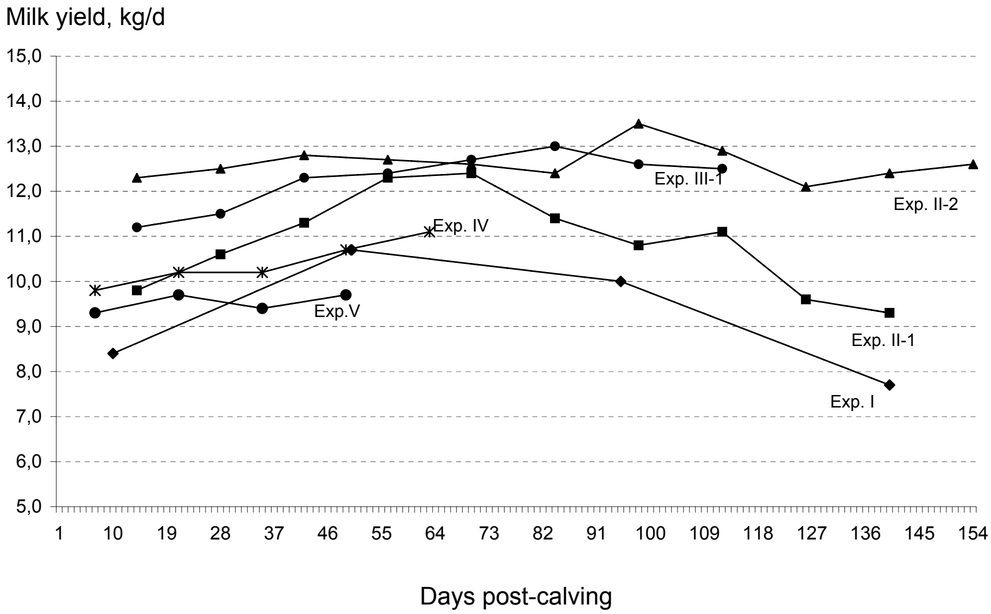

Figure 5. Milk production in Experiments I-V.

The effect of cow breed on milk production has been evaluated widely, showing that the breeds differ in their milk production capacity, partly due to the differences in cow size. (e.g. Gaskins and Anderson 1980, Franke and Martin 1983, Jenkins and Ferrell 1992, Sinclair et al. 1998, Litwińczuk and Król 2002, McGee et al. 2005b). In the present study, the effect of breed on milk production and milk composition was estimated in II. The feeding accuracy or cow breed did not affect the milk yield which averaged 10.8 and 12.6

kg/d in II-1 and II-2, respectively. In both lactations, the milk protein content of the ChAy cows was higher than that of the AbAy cows (II-1; 32.7 vs. 31.0 g/kg and II-2; 31.9 vs. 29.3 g/kg). In II-2, the milk fat content of the ChAy cows was higher than that of the AbAy cows (45.4 vs. 42.2 g/kg).

In the present study in I-III-1, the cows were beef-dairy crosses and in IV-V Hf cows. The differences between beef-dairy and Hf cows in milk yield mainly originated from the experimental treatments, the cow age and the milk evaluation method used. There was a moderate tendency to lower milk fat content in the Hf cows compared to the beef-dairy crosses while the milk protein and milk lactose contents were fairly constant (Table 8). The milk fat and protein contents measured in III-1, IV and V were unaffected by the treatments and agree with most of the values from the literature presented in Table 9.

Table 9. Milk production and milk composition measured in some other experiments.

Breed[1]	Feeding	Maturity[2]	Method[3]	Milk yield, kg/d	Milk composition Fat, g/kg	Protein, g/kg	Reference
Gelbvieh×Ab	Supplemental protein	PP	MM	7.0-9.5	40.0-41.0	37.0-39.0	Alderton et al. 2000
Hf×Dairy shorthorn	Feeding levels	PP	MM+CS	5.6-9.8	40.4-41.8	Nm	Economides et al. 1973
Ab, Ab-crosses	Feeding levels	PP	MM	5.1-6.8	33.0-38.0	29.0-34.0	Lalman et al. 2000
Ab×Hf	Protein levels and sources	PP	MM	4.7-5.9	31.9-34.3	30.7-31.2	Rusche et al. 1993
Hf×Ab	Alfalfa+concentrate energy metabolism	PP	CS+MM	2.5-7.7	40.7-42.9	35.9-39.8	Reynolds and Tyrrell 2000
Hf, Beef Shorthorn×Hf	Silage replacement with straw, with or without barley or soybean meal	PP+ MP	MM	4.9-5.8	31.1-33.8	29.3-39.1	Charmley and Duynisveld 2004b
Hf×Fr Hf×Fr Hf×Fr	3 experiments, differing feeding levels	PP+MP PP+MP PP+MP	CS CS CS	9.1-9.2 8.2-9.4 7.9-8.9	39.5-41.3 37.3-43.3 39.1-43.4	29.7-32.3 27.6-30.7 27.3-29.8	Baker et al. 1982
Ab×Gelbvieh	Fat supplementation	MP	MM	8.4-9.0	33.1-35.7	28.6-30.4	Lake et al. 2005
Blue Gray	Feeding levels	MP	MM	7.8-8.1	38.1-39.0	Nm	Lowman et al. 1979
Hf×Fr	*Pre* and *post partum* energy and protein supply, single/twin suckling	MP	CS	8.8-10.1 10.1-13.2	33.6 37.5-44.1	28.1-31.8 30.4-35.0	Sinclair et al. 1994

Breed[1]	Feeding	Maturity[2]	Method[3]	Milk yield, kg/d	Milk composition		Reference
					Fat, g/kg	Protein, g/kg	
Hf, Beef Shorthorn×Hf	Prot. supplementation post-calving	MP	MM	8.8-13.6	30.2-42.8	30.7-33.8	Charmley et al. 1999
Hf-cross	Silage replacement with straw-barley-soybean meal	MP	MM	6.8-7.7	27.4-32.7	36.5-40.2	Charmley and Duynisveld 2004a
Ab×Hf	Interval feeding of sunflower seeds	MP	CS	6.3-7.1	23.7-27.7	28.7-31.7	Banta et al. 2006
Blue Gray, Hf×Fr	Feeding levels	MP	CS	6.0-11.9	Nm	Nm	Russel et al. 1979
Hf×Ab	Feeding levels	MP	MM	1.9-9.0	21.0-27.0	23.0-27.0	Perry et al. 1991

[1] Ab, Aberdeen Angus; Fr, Friesian; Hf, Hereford.
[2] PP, primiparous; MP, multiparous.
[3] MM, machine milking method; CS, calf suckling method.

In the present study, the feeding strategies had minor effects on milk production. An interaction between the treatments in the mean milk yield was observed in III-1. Cows offered diet Alternative (BP + GS) on the S strategy produced more than those on the F strategy (13.0 vs. 11.6 kg/d), the opposite being true (11.7 vs. 12.5 kg/d) on diet Control (straw + GS). Cows offered WCOS produced less milk than those offered GS (9.5 vs. 11.4 kg/d, IV). The feeding frequency had no effects on milk production which averaged 9.5 kg/d (V).

Milk production of heifers

Heifers need energy and protein for maintenance, milk production, successful rebreeding and their own growth. According to Bowden et al. (1981), heifers may need as much as 75% more energy *post partum* than *pre partum* to meet their requirements for milk production.

In II-1, the milk production of the AbAy and ChAy heifers was on average 10.8 kg/d which is more than Economides et al. (1973), Rusche et al. (1993), Alderton et al. (2000), Lalman et al. (2000) and Reynolds and Tyrrell (2000) reported for primiparous beef cows. The main reason for the better milk production in II-1 may be the differences in breed, i.e. the heifers in II-1 were beef-dairy crosses. Manninen et al. (1998) offered LiAy and HfAy heifers either hay- or GS-based diets (65-74 ME MJ/d) and measured the milk production by the CS method. The feed had no effect on the average milk yield, but the HfAy heifers produced more milk than the LiAy heifers (7.7 vs. 5.8 kg/d). These values are lower than in II-1, probably due to the differences in the milk evaluation method, breed and feeding. Mondragon et al. (1983) observed milk yield estimates to be higher for the CS than for the MM method with intramuscular injection of oxytocin.

In II-1, the BCS of the heifers averaged 2.7 at calving, the pregnancy rate was 100% and the ICC was 61-68 days. Therefore, it can be suggested that the daily energy intake 73-82 ME MJ during the experimental winter period was sufficient for the beef-dairy heifers in cold conditions to meet their requirements for maintenance, growth, milk production and successful rebreeding in a short period. Lalman et al. (2000) offered Ab and Ab-crossbred heifers four feeding levels (1.8, 2.1=maintenance, 2.4 and 2.7 Mcal of ME/kg DM) *post partum*. Increasing dietary energy intake was associated with a curvilinear increase in milk yield and milk fat content. Greater milk yield at day 30 of lactation was associated with a longer *post partum* interval (PPI). In II-1, the PPI was unaffected by treatments. Bowden (1981) fed F_1 crossbred beef heifers a normal or normal+10% energy level during late pregnancy and first lactation, resulting in more milk (6.5 vs. 5.9 kg/d) on the higher than on the lower level. On the contrary, Corah et al. (1975) offered Hf heifers 100 or 65% of the recommended energy level 100 days *pre partum* and observed no differences in milk production (4.8 vs. 5.0 kg/d). In II-1, the milk yield was higher than Bowden (1981) and Corah et al. (1975) observed, mainly due to differences in breed and energy intake.

The milk fat content of the AbAy and ChAy heifers in II-1 averaged 46.0 g/kg and, thus, was higher than values reported by Economides et al. (1973), Rusche et al. (1993), Alderton et al. (2000), Lalman et al. (2000) and Reynolds and Tyrrell (2000). The milk protein content measured in II-1, averaging 30.6-33.0, agrees with the values reported in those studies.

Effects of plane of nutrition on milk yield

The plane of nutrition (I) did not affect the milk production which averaged 9.2 kg/d for HfAy and LiAy cows. Manninen and Huhta (2001) fed mature HfAy and LiAy cows approximately 70 days *pre partum* either 71 or 92 ME MJ/d and 46 days *post partum* from 71 to 113 ME MJ/d. Consistent with I, feeding levels had no effect on milk production which averaged 11.8 kg/d. The better milk yield in a study reported by Manninen and Huhta (2001) compared to I can partly be explained by the differences in cow age and the method used (MM). Russel et al. (1979) offered mature Blue Gray and HfFr cows in the final 12 weeks of pregnancy 34-78 and 30-58 ME MJ/d with no effects on milk production. Baker et al. (1982) fed HfFr cows 61-64 ME MJ/d for the last eight weeks of pregnancy following either low (49-56 ME MJ), medium (46-64 ME MJ/d) or high (85-100 ME MJ) energy levels for the first eight weeks of lactation. The feeding levels had only minor effects on milk production, but turnout to grazing increased milk production.

On the contrary, Jenkins et al. (2000) observed with beef-cross F_1-cows that increasing the daily ME intake linearly increased peak yield and total yield. Martinsson (1983) studied the effects of lower winter feeding levels in Swedish conditions on the performance of HfSRB beef cows and their progeny. The calves grew slowly pre-grazing when the cows were fed a restricted diet, mainly as a result of reduced milk production. With autumn-calving HfFr (Somerville et al. 1983) and Blue Gray cows (Lowman et al. 1979) the 150-day cumulative milk yield increased significantly with increasing plane of nutrition. Somerville et al. (1983) concluded that energy-deficient beef cows attempt to maintain their milk production at the expense of body reserves. According to Lowman et al. (1979), suckler calf production is a continuous process, i.e. the effect of plane of nutrition imposed in one phase of the production cycle must be considered in relation to subsequent performance.

On the basis of the results in I and by e.g. Russel et al. (1979), Baker et al. (1982), Jenkins et al. (2000) and Manninen and Huhta (2001), it can be suggested that the effects of the plane of nutrition on milk production mainly depend on the amount of energy offered and the length of the period of under- or overnutrition in relation to calving, cow BCS at parturition and breed.

Cow body condition and milk production

In the present study all cows had a good BCS at parturition averaging 2.4-3.2, and a maximum 0.2 unit decrease in BCS was observed from calving to grazing, suggesting that those minor changes did not affect the milk production and milk composition (II-V). Lents et al. (1997) determined with spring-calving Hf and HfAb cows the effects of *post partum* body condition and concluded that the BCS at calving (scale 1-9: <3.5, 4, 4.5, >5) had no effects on milk composition. Increasing BCS at calving with dairy cows lead to a higher peak milk yield and lower feed intake in early lactation (Land and Leaver 1980). With mature

HfFr cows, Sinclair et al. (1994) concluded that there is little benefit to be achieved in having cows in good body condition at calving, since cows given a standard diet at a fixed level during the *post partum* period adjust their level of performance with respect to milk yield and composition. It can be suggested that beef cows in good BC at calving, offered adequate amounts of energy, produce sufficient milk for a single calf. However, the calving season and the duration from calving to turnout during the spring must be considered.

3.2.4. Dystocia

Dystocia can be defined as difficult parturition and is an important economic issue in beef production, since it is a major cause of calf mortality and lower *post partum* conception in cows (e.g. Laster et al. 1973, Laster 1974, Odde 1989). Along with larger herds, increasing veterinary assistance and labour costs, the economic importance of easy calvings and viable calves has increased, both in beef and dairy herds (e.g. Philipsson 1976). The most important maternal factor influencing calving performance is parity and among calf factors, BW seems to be dominant (Philipsson 1976). Other factors which are connected to dystocia are the sex of the calf, the pelvic area size and the LW of the dam and, the pre-calving energy level (e.g. Laster 1974, Naazie et al. 1989, Odde 1989). Cow and sire breed affect the incidence of calving difficulty (e.g. Allen and Kilkenny 1984, McGuirk et al. 1998).

Dystocial cases in the present study

The dystocial cases observed in I-VI suggest that they were not related to feeding treatments, breed or cold housing conditions. The use of sires and sire breeds which result in a low incidence of difficult calvings, careful supervision of the calvings and knowledge of the expected calving dates after ultrasound scanning were undoubtedly the primary reasons why calf losses were avoided. Additionally, the cows were neither obese nor thin at parturition.

In other experiments conducted at Tohmajärvi Research Station, overwintering ChAy and HfAy cows in various cold housing facilities did not increase the incidence of dystocial cases (Manninen 1998a, Manninen 1998b). Faulty disposition of the calf was the reason for the calving difficulties observed in studies reported by Manninen et al. (2002a, 2002b, 2006).

Effect of feeding level

The feeding level (I) did not affect the incidence of calving difficulty and no cow was obese *pre partum*. The one calving classified as difficult probably resulted from the small size of the dam with a pre-calving LW of 366 kg although the calf BW was rather low, 34.6 kg (Table 10). Naazie et al. (1989) concluded that although calf BW is the most important variable influencing dystocia in heifers, the ratio of the calf BW to the dam's weight at calving is more critical. In VI, one calving indoors in the *ad libitum* diet was classified as difficult due to faulty disposition leading to the loss of the calf.

In many studies the *pre partum* feeding level has influenced the calf BW but not the incidence of dystocia (e.g. Bellows et al. 1972, Laster 1974, Corah et al. 1975). With HfFr and ChFr once-calved heifers, Keane et al. (1991) found no effect of *pre partum* feeding level on calf BW and calving difficulty. Manninen (2000) fed Hf heifers *ad libitum* or restricted and reported no difference in the incidence of calving difficulty, probably as a result of sufficient *pre partum* LW and BCS. Manninen and Huhta (2001) fed mature HfAy and LiAy cows 70 days *pre partum* either 71 or 92 ME MJ/d and stated that 11% of the cows needed slight assistance with no treatment effect. Fiems et al. (1987) reported that restricted feeding in late pregnancy reduced the BW of calves and calving difficulties.

Effect of breed and age

In the present study in I-III-1, the cows were beef-dairy crosses. No differences were observed between the breeds regarding dystocial cases. McGuirk et al. (1998) reported that the easiest calvings were for Hf (1.1%) and Ab (1.4%) cows, while Ch (4.3%), Blonde d'Aquitane (3.7%) and Si (3.1%) cows had the most difficult calvings. Philipsson (1976) suggested that a reduction in the incidence of dystocia and calf mortality can be achieved through selection within breeds.

Calvings of AbAy and ChAy heifers in II-1 resulted in 50.8% needing slight assistance, while 9.5% were difficult and 6.4% were very difficult. Four calvings were classified as very difficult of which one was recorded as a stillbirth and the others had no extra explanation (calf BW: 43.0, 44.0, 47.5 kg). The six calvings classified as difficult had calf BW of 37.5, 39.5, 40.0, 42.5, 43.5 and 45.0 kg without extra explanations suggesting that the calf BW was probably the main reason for the difficult or very difficult calvings observed with heifers. This suggestion agrees with the comment presented by McGuirk et al. (1998) who reported that heifers had more difficult calvings, higher calf losses and shorter gestations than mature cows.

With heifers the severe dystocia may reduce the pregnancy rates by around 15% during the following rebreeding, the second calves may be born later than the first and they may be lighter than the first calves (Nelson 1991). The results in II-1 do not support this statement, since the pregnancy rate with AbAy and ChAy heifers was 100%, the ICC was on average below 70 days and the calves born in II-2 were on average seven kilogrammes heavier than those born in II-1. The results lead to an assumption that the amount of energy offered to the heifers during the winter period, on average 0.75-0.80 ME MJ/kg$^{0.75}$, was sufficient for successful rebreeding.

Manninen et al. (1998) offered LiAy and HfAy heifers either hay- or GS-based diets (65-74 ME MJ/d) during the indoor period and reported interactions between diet and sex and between breed and sex for calving difficulty. The HfAy heifers had more calving difficulties with male than female calves (1.50 vs. 1.06), while no differences were observed between sexes born to the LiAy heifers (1.34 vs. 1.32). Heifers on the GS diet had more calving difficulties when they had male than female calves (1.78 vs. 1.21), while heifers on the hay diet producing female calves had slightly more calving difficulties than those producing male calves (1.18 vs. 1.06).

With the second-calf AbAy and ChAy cows (II-2), the incidence of assisted calvings was reduced notably compared to heifers (II-1) and only two calvings were recorded as difficult and described as twin birth and BW of 44.0 kg with faulty disposition. Eight calvings needed slight assistance. With mature AbAy and ChAy cows (III-1), the incidence of assisted calvings corresponded to II-2. One calving was classified as difficult due to stillborn twins and another without extra comment. The calf died later, however.

With mature Hf cows, the proportion of easy calvings was very high (III-2-VI). Uterine torsion (III-2), prolapses of the dam (IV) and faulty disposition of the calf (VI) were the reasons for the difficult calvings and, hence, not related to the experimental treatments.

Table 10. Dystocial cases in I-VI.

Exp.	Cow breed[1]	Sire breed[2]	Cows initial	Calvings	BCS[3] at calving	Easy		Slight assistance		Difficult		Very difficult	
						n	%	n	%	n	%	n	%
I	HfAy, LiAy	Ch	63	63	Na[4]	52	**82.5**	10	15.9	1	1.6		
II-1	AbAy, ChAy	Ab	64	63	2.7	21	**33.3**	32	50.8	6	9.5	4	6.4
II-2	AbAy, ChAy	Hf	64	64	2.4-2.7	54	**84.4**	8	12.5	2	3.1		
III-1	AbAy, ChAy	Li	56	56	2.5	46	**82.1**	8	14.3	2	3.6		
III-2	Hf	Hf	56	56	3.0	53	**94.6**	2	3.6			1	1.8
IV	Hf	Hf	48	48	3.1	46	**95.8**	1	2.1	1	2.1		
V	Hf	Hf	32	32	3.2	32	**100.0**						
VI	Hf	Hf	35	35	2.7-3.1	33	**94.2**	1	2.9	1	2.9		
1st calving			64	63		21	**33.3**	32	**50.8**	6	**9.5**	4	**6.4**
2nd calving			127	127		106	**83.4**	18	**14.2**	3	**2.4**		
Mature			227	227		210	**92.5**	12	**5.3**	4	**1.8**	1	**0.4**
Total			418	417		337	**80.8**	62	**14.9**	13	**3.1**	5	**1.2**

Calving: I and II-2, 2nd calving; II-1, 1st calving; III-VI mature.
I and VI $P < 0.10$, II-V $P < 0.05$.
[1] AbAy, Aberdeen Angus-Ayrshire; ChAy, Charolais-Ayrshire; Hf, Hereford; HfAy, Hereford-Ayrshire; LiAy, Limousine-Ayrshire.
[2] Ab, Aberdeen Angus; Ch, Charolais; Hf, Hereford; Li, Limousine.
[3] BCS, Body condition score.
[4] Na, Not available.

Assisted calvings more common with male calves

Although the total number of severe dystocial cases in I-VI was small, more calving assistance was needed with male calves than with female ones (Table 11). This finding agrees with the results reported by Bellows et al. (1971), Laster et al. (1973) and McGuirk et al. (1998). The incidence of assisted calvings was independent of the BW of females. Calving assistance was offered to males primarily of BW 40-43 kg and above 49 kg. Laster et al. (1973) stated that calving difficulty increases by 2.3 ± 0.21% for each kilogram increase in calf BW.

Table 11. Calf birth weight and assisted calvings in I-VI.

Birth weight kg	Assisted, difficult or very difficult Male	Female
< 32	2	4
32-36	7	3
36-38	4	4
38-40	4	6
40-43	10	4
43-45	3	3
45-47	6	2
47-49	4	4
>49	8	4
Total	**48**	**34**

3.2.5. Calf performance

The biological profitability of suckler cow production is dominated by the number of weaned calves and the weaning weights achieved (Allen and Kilkenny 1984). During the first weeks of life, milk is the sole feed for the calf and, therefore, milk consumption determines the calf growth rate. Factors like milk potential of the cow, reduced calf appetite, mastitis, udder form, cow maternal instincts and their interactions may affect the milk consumption of the calf and, thus, the calf daily LWG. Milk dominates calf growth during the first months (Table 12, Allen and Kilkenny 1984).

Table 12. Influence of cow milk yield on the live weight gain (LWG) of spring-born calves (Allen and Kilkenny 1984).

	Estimated daily milk yield (kg)		% of calf LWG from milk	
Month	Hereford×Friesian	Blue Gray	Hereford×Friesian	Blue Gray
1	8.6	7.5	100	100
2	10.5	9.0	100	95
3	11.0	9.2	75	70
4	9.8	8.0	61	50
5	8.8	7.0	51	41
6	7.5	5.8	45	36
7	6.0	4.5	35	25

In the present study, all calves were weighed at the age of 14 days, although reported only in I, V and VI. The LWG from birth to age 14 days was observed to be useful in evaluating the onset of milk production of the dam and the dam's maternal instincts. Generally, the calf daily LWG during the first two weeks averaged 1.0±0.2 kg. Daily LWG below

0.5 kg during the first two weeks caused extra inspection of the cow and the calf. The reasons for depressed calf LWG mainly originated from the dam's unsatisfactory nursing characteristics or weakness of the calf.

Effects of cow feeding level on calves

Studies of the impact of cow nutrition on foetal growth have mostly focussed on the last trimester of pregnancy when most of the increase in foetal size occurs. The maternal diet controls foetal growth by providing nutrients for the conceptus. However, there is evidence that changes in dam nutrition have a considerable role in foetal development at a much earlier stage of pregnancy, affecting neonatal survival and even adult performance (Robinson et al. 1999).

In I, the diet type and feeding level had no effect on calf performance but pre-weaning the males grew on average 86 g/d better than the females. In addition, the feeding level had no effect on calf performance in VI. Corresponding to I and VI, Manninen et al. (2002a) fed mature Hf cows indoors WCBS either 73 or 93 ME MJ/d with no effect on calf pre-weaning LWG which averaged 1361 g/d. Drennan and Bath (1976) fed mature suckler cows GS *ad libitum* or restricted during late pregnancy and GS *ad libitum* during 6-7 weeks of lactation and reported no effects on calf BW and subsequent LWG, but the calf LWG was affected by the milk yield of the dam, calf sex and calving date.

On the contrary, Hight (1966, 1968a, 1968b) and Tudor (1972) reported that low *pre partum* feeding reduced calf BW. Corah et al. (1975) and Hamilton et al. (1995) observed with primiparous beef cows that a low *pre partum* energy level produced lighter calves or lower calf LWG. Houghton et al. (1990), Perry et al. (1991) and Freetly et al. (2000) reported similar effects with mature beef cows. With Blue Gray and HfFr cows, Russel et al. (1979) measured the maximum calf BW at a *pre partum* intake of about 58 ME MJ/d. Feeding for 70 days *pre partum* 71 ME MJ/d for mature HfAy and LiAy cows resulted in a lower pre-grazing LWG (1226 g/d) for Li×HfAy and Li×LiAy calves compared to those born to cows fed 92 ME MJ/d (1356 g/d) *pre partum* (Manninen and Huhta 2001). Calves born to Hf heifers fed during the winter period restricted (94 ME MJ/d) tended to grow better pre-weaning (1192 vs. 1094 g/d) than those born to heifers fed *ad libitum* (121 ME MJ/d, Manninen 2000).

In Sweden, Martinsson (1983) studied during several years the effects of winter feeding levels on Hf×Swedish Red and White cows and calves. Offering 99 and 65% of the recommended energy to cows resulted in lower LWG pre-grazing but at weaning the calf LWs did not differ significantly. In another experiment, cows were fed 95 or 75% of the recommended energy and protein requirements, which resulted in reduced BWs and LWG pre-weaning. Martinsson (1983) concluded that the lower calf LWG pre-grazing mainly resulted from reduced milk production. However, the calf pre-weaning LWG was lowered significantly in only two out of the ten years of the experiments.

According to Petit (1979), only very severe underfeeding of cows at the end of pregnancy reduces the BW of calves corresponding to a weight loss in mature cows pre-calving of more than 5% of the initial LW. Jones et al. (1979) measured the average winter weight loss of cows as 60 kg (± 36.2 kg) which affected calf BW significantly but had no effect on the subsequent pre-weaning LWG or weaning weight of the calves. In the present study the winter LW losses of the cows were rather low and maximum values of 61 and 68 kg were observed with mature Hf cows in good BCS (V). This may partly explain the good calf performance results.

Finally, Petit et al. (1992) suggested that the effects of the plane of nutrition on calf growth depend on the amount of energy offered to the cow as well as the cow's own body reserves in late pregnancy, i.e. the BC. Petit (1979) outlined that reducing the feeding level before calving increases the period from calving to conception before decreasing calf BW and later LWG.

Minor effects of feeding strategies on calf performance

The different feeding strategies with traditional or alternative feeds in II-V had only minor effects on calf performance (Table 13). This may be explained by the sufficient energy offered to the cows and consequently good BC at parturition and before the grazing period.

Table 13. Calf birth weight and live weight gain (LWG) in I-VI.

Exp.	Cow breed[1]	Sire breed[2]	Calving season	Birth weight, kg	Pre-grazing LWG, g/d	Grazing LWG, g/d	Entire experiment LWG, g/d	Creep feeding, onset
I	HfAy, LiAy	Ch	2 Apr-14 Jul	40.6-43.1	1198	1407-1510	1282-1368	14 Aug
II-1	AbAy, ChAy	Ab	16 Mar-28 May	39.2	924-1116	1252-1503	1184-1418	18 Aug
II-2	AbAy, ChAy	Hf	3 Mar-28 Apr	46.2	1168-1399	1352-1620	1262-1528	10 Aug
III-1	AbAy, ChAy	Li	17 Mar-1 Jun	41.5-57.5	1203	1353	1301	No
III-2	Hf	Hf	29 Jan-28 Apr	40.7-46.7	921-1300	1250-1703	1138-1472	No
IV	Hf	Hf	22 Feb-14 Apr	44.2	1122	1519	1357	No
V	Hf	Hf	12 Feb-13 May	40.2	1131	1270-1466	1255	No
VI	Hf	Hf	11 Mar-21 Apr	43.3	908-1186	1335	1251	No

Cows' calving: I and II-2, 2nd calving; II-1, 1st calving; III-VI, mature.
Mean values if no significant differences between treatments, min-max values if statistically significant differences between treatments. I and VI $P < 0.10$, II-V $P < 0.05$.
[1] AbAy, Aberdeen Angus-Ayrshire; ChAy, Charolais-Ayrshire; Hf, Hereford; HfAy, Hereford-Ayrshire; LiAy, Limousine-Ayrshire.
[2] Ab, Aberdeen Angus; Ch, Charolais; Hf, Hereford; Li, Limousine.

In II-2, calves born on diet A were 4.2 kg heavier at the onset of the grazing period than those born on diet IA. In V, at the end of the experiment the differences between treatments varied depending on the sex. Females were 2 kg heavier than males in treatment D, the opposite being true in treatment 3D (258 vs. 229 kg). At pasture, the LWG was 49 g/d better for the 3D calves than for the D calves. Calves born to ChAy dams were heavier before the grazing period than those born to AbAy dams, but the cow feeding accuracy had no effects (II-1). The cow breed and feeding accuracy had no effects on calf LWG pre-weaning, but the males grew better than the females (II). Calf sex caused the occasional significances observed in III. Cow winter feeds had no effect on calf performance (IV).

The pre-weaning LWG of Ab×HfAy and Ab×LiAy calves, born to heifers offered either GS- or hay-based diet, was unaffected by the breed and diet (Manninen et al. 1998). Feeding mature Hf cows indoors daily or every second day did not affect calf performance (Manninen et al. 2006).

Cow BCS and calf performance

The effect of change in cow BCS from calving to grazing on the pre-grazing calf LWG in II-VI and in other experiments conducted at Tohmajärvi is presented in Figure 6. Beef-dairy and first and second calving cows lost BCS from calving to grazing more than beef or mature cows but the pre-grazing calf LWG seemed to be unaffected. It appears that the opportunities to affect the LWG of spring-born calves pre-grazing via the cow winter feeding strategy or the feed are rather marginal if the cows have a good BCS at parturition and receive enough energy to sustain good milk production since the milk is the main nutrient for the calf during the first two months (Table 12). Genetic factors and aspects of cow and calf health affect the pre-grazing calf LWG.

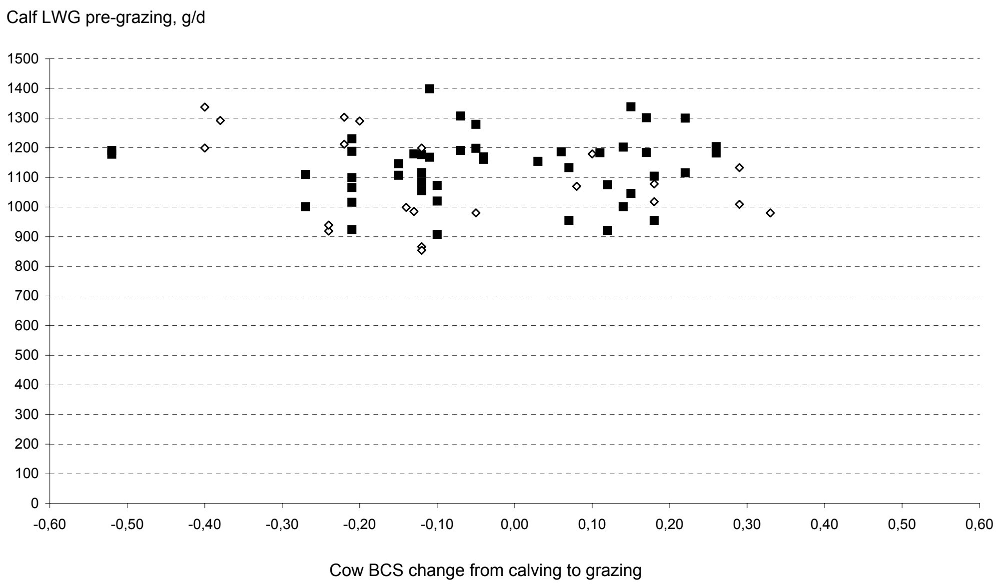

Figure 6. Change in cow body condition score (BCS) from calving to grazing in relation to pre-grazing calf live weight gain (LWG). Black dots represent calf groups from Experiments II-VI and black and white dots calf groups from other experiments conducted at Tohmajärvi Research Station.

Multiparous AbHf cows were fed different diets during mid-gestation to calve with a

BCS in the range 4-6 (scale 1-9) (White et al. 2002). Cow *pre partum* nutrition and cow BCS at calving did not influence the calf BW and calf gain during the first three months, suggesting that the foetal growth rate is rather protected from dietary changes of the dam when cows calve with a BCS between 4-6. With multiparous HfCh cows, Laflamme and Connor (1992) observed that the cow BCS at parturition had no effects on the calf performance, but an increase in BC at parturition yielded an improvement in most of the reproductive traits measured. DeRouen et al. (1994) observed with spring-calving heifers that calf growth rate was unaffected by pre-calving BCS or BCS at calving, but BCS at calving influenced pregnancy rate and days to pregnancy, indicating that BC at calving is a reliable indicator of *post partum* reproductive performance for spring-calving heifers. The results of Laflamme and Connor (1992), DeRouen et al. (1994) and White et al. (2002) largely support the findings observed in the present study and emphasize the importance of cow BCS at calving.

Creep feeding of calves

Supplementary concentrate feeding can provide additional nutrients, especially energy, for calves when adequate nutrients are not available from either the dam's milk or the grazed grass (Bowden et al. 1981). Creep feeding may be uneconomical if cows have good milk production potential and good pastures are available. Allen and Kilkenny (1984) calculated on the basis of Meat and Livestock Commission data that feeding 35 kg of concentrate will increase weaning weight by ten kilogrammes in an average suckler herd in the United Kingdom.

In I and II, calves were creep-fed with barley *ad libitum* from mid-August until weaning to facilitate adaptation to the post-weaning diet. The intake was on average 0.4 kg/d at pasture and 0.5 kg/d indoors prior to weaning in I and on average 0.6 and 0.5 kg/d at pasture during the two successive years in II. Since all the calves were creep-fed, the effects of supplementary concentrate feeding on calf LWG cannot be evaluated. However, at that time the calves were approximately five months old and, as shown in Table 12, on average 50% of calf LWG at that age originates from the milk. Thus, creep feeding may have had positive effects on calf performance as well as advantageous effects on the BCS of young beef-dairy dams. Bowden et al. (1981) stated 6-7 month old calves to consume as much as three kilogrammes of creep feed daily, which is considerably more than measured in I and II. This may indicate that the beef-dairy cows in I and II had good milk production even pre-weaning, that the pastures were of good quality in the late months of the grazing season or probably that barley alone was not a very palatable creep feed.

The impacts of feeding strategies and feeds on calf performance (I-VI) were minor and without practical importance. It can be suggested that these strategies are well suited to cold conditions. The effects of cold on calf pre-grazing performance were minimal, mainly due to the suitable housing facilities with sufficient bedding available, the careful supervision and the good cow maternal instincts with sufficient milk production.

3.2.6. *Grazing, mating and conception*

3.2.6.1. Grazing management

Grazed grass is in most beef production regions the main and the most economical feed for beef cattle and generally, a very high quality feed to support the animal nutrient demands. In Finland, the grazing season is rather short, mainly 140 days in southern parts of the country, and, therefore, an effective grazing period before the winter feeding period is significant for suckler cow performance. To evaluate the grass growth and to optimize grazing conditions, sward height (SH) has proved to be an effective and economical method to combine the needs of both the grass plant and cattle (Lowman 1997b, Marshall et al. 1998). Sward height is the dominant sward variable that influences the intake of herbage at the vegetative stage of growth (Ferrer Cazcarra et al. 1995). The post-grazing SH was measured using a sward stick (Bircham 1981) in III-2, IV and V. In addition, the quality of the grass grazed was measured by analysing the D-value and CP concentration.

The cows, calves and bull/bulls were continuously (I) and rotationally (II-VI) grazed on sown peatland pastures near the winter housing facilities. The pastures were predominately timothy (*Phleum pratense* L.) and meadow fescue (*Festuca pratensis* Huds.) with a small proportion of red clover (*Trifólium praténse* L.). Fertilization was done with a compound fertilizer (NPK) with a nitrogen level of 160-190 kg/ha/year divided into two to three applications. The amounts of phosphorus and potassium were adjusted according to soil analyses. The pastures were topped as necessary. In average grazing conditions, the grass growth was rapid during the first two to three weeks of the grazing season. Therefore, the surplus pasture areas were usually cut for silage in mid-June.

In the present study, the cows increased their BCS during a rather short grazing period and the BCS after the grazing season as well as the calf daily LWG at pasture were good (Table 7 and Table 13). However, the post-grazing BCS of AbAy and ChAy cows (II, III-1) was below 3.0, presumably due to breed and, thus, better milk production potential compared to mature Hf cows, rather than unsatisfactory grazing conditions.

In I-III, a total of 40, 57-58 and 27-37 ha were available for grazing and making GS. In IV-VI, the stocking rate was calculated more precisely, being 1.9-2.5 and 1.7-1.9 livestock units (LU)/ha in the early and in the late season, respectively. In other experiments in the same grazing conditions the stocking rate has been 2.0 LU/ha in the early season and 1.5-1.7 LU/ha in the late season (Manninen 1998a, Manninen 1998b, Manninen 2000, Manninen et al. 2002a, Manninen et al. 2002b, Manninen et al. 2006).

The post-grazing SHs in the present study were 11-12 cm. More variable values (8-12 cm) were reported by Manninen et al. (2002a, 2002b). Using mature Hf cows the post-grazing SH in August was assessed to be 7-8 cm (Manninen et al. 2002a) which might be too low for Finnish circumstances. The post-grazing SHs measured in the present study were slightly higher compared to dairy cows on timothy swards in Finland (9-10 cm, Virkajärvi et al. 2002). Lowman (1997b) presented the target grass height for continuously stocked *Lolium perenne* pastures in the United Kingdom grazing conditions to be 7-8 cm from turnout to late July and 8-9 cm for the final grazing period. At these heights, cattle are able to consume all their requirements in less than ten hours of grazing. Wright (1988) states that the SH of 8-10 cm in the United Kingdom grazing conditions best maintains maximum cow and calf LWG at pasture. In Finnish grazing conditions the post-grazing SH should be higher than those recommended in the United Kingdom, mainly due to differences in grass species and length of the grazing period.

The pre-grazing D-values were good, being 725, 720 and 722 g/kg DM in III-2, IV and V, respectively, and comparable to other Finnish values obtained from mixed timothy meadow fescue dairy pastures (Virkajärvi et al. 2002, Virkajärvi et al. 2003, Sairanen et al. 2006). Manninen et al. (2002a, 2002b) measured the D-values at Tohmajärvi to be at the lowest slightly below 700 g/kg DM. The grass CP content averaged 218 and 172 g/kg DM in III-2 and V, respectively.

The pre-grazing herbage mass (>5 cm) varied from 450 to 4700 and from 960 to 4130 kg DM/ha in III-2 and IV, respectively. The rather low pre-grazing herbage mass value of 450 kg DM/ha in III-2 refers to a measurement made early in the grazing season.

3.2.6.2. Mating and conception

In I, the cows ran with a bull in one group after the OS and double fixed-time AI procedure. Natural breeding was used in II-VI by placing the cows into two equal mating groups (II-IV, VI) or into one mating group (V). The criterion for the bulls chosen for one mating season was that they should be as much alike as possible to minimize the differences in calves originating from the sire. The mating period, pregnancy rate, ICC and BCS at parturition and before the mating period are presented in Table 14. The pregnancy rate is calculated based on the number of cows that entered the mating period, i.e. disregarding dead and those who were removed from the experiment before the mating period.

Table 14. Mating and conception in I-VI.

Exp.	Breed[1]	Cows, initial	Cows, entering mating	Pregnant	Mating period, days	BCS[2] at calving	BCS at onset of grazing	Pregnancy rate, %	Calving to conception, days
I	HfAy, LiAy	63	63	43	32	Nm[3]	Nm	69	Na[4]
II-1	AbAy, ChAy	64	63	63	97	2.7	2.5	100	61-68
II-2	AbAy, ChAy	64	62	61	85	2.4-2.7	2.5	98	89
III-1	AbAy, ChAy	56	54	53	81	2.5	2.3	98	75
III-2	Hf	56	50	49	96	3.0	3.2	98	76
IV	Hf	48	42	42	90	3.1	2.9-3.4	100	89
V	Hf	32	31	31	97	3.2	3.1	100	78
VI	Hf	35	33	30	82	2.7-3.1	2.7-3.2	91	101

Calving before mating: I and II-2, 2nd calving; II-1, 1st calving; III-VI, mature.
BCS and calving to conception: Mean values if no significant differences between treatments, min-max values if statistically significant differences between treatments. II-V $P < 0.05$, VI $P < 0.10$.
I, Oestrus synchronisation - Artificial insemination - Natural breeding.
II-VI, Natural breeding.
[1] AbAy, Aberdeen Angus-Ayrshire; ChAy, Charolais-Ayrshire; Hf, Hereford; HfAy, Hereford-Ayrshire; LiAy, Limousine-Ayrshire.
[2] BCS, Body condition score.
[3] Nm, Not measured.
[4] Na, Not available.

Good pregnancy rates except in Experiment I

Fertility, i.e. animals cycling, pregnant, calving and calves weaned, is an economically important factor influencing the profitability of suckler cow production (e.g. Lowman 1988, Mapletoft 1992). To achieve a 365-day calving interval, an ICC of 80-85 days is required. In II-VI the pregnancy rates were 91-100% and the ICC 61-101 days. The average ICC exceeded 90 days only in VI. The results indicate that the ovarian cyclicity probably resumed early *post partum*. The earlier the cyclicity begins *post partum*, the greater is the chance of successful conception during the limited mating period (Peters and Riley 1982).

On the basis of the results observed in I-VI, the different winter feeding strategies with traditional or alternative feeds had no negative effects on reproduction. However, the rather small number of cows per experiment has to be taken into consideration. Although beef breeding success is largely affected by nutrition, cow BCS is the most critical factor (e.g. Lowman 1988, Mapletoft 1992). The *post partum* BCS for the first- and second-calf AbAy and ChAy cows averaged 2.4-2.7 and for the mature AbAy and ChAy cows 2.5. The corresponding BCS values for the same cows pre-grazing averaged 2.5 and 2.3. For the mature Hf cows, the *post partum* BCS averaged 2.7-3.2 and the pre-grazing BCS 2.7-3.4. Although the BCS values were slightly lower for the beef-dairy crosses than for the Hf cows, all the cows had good BC at calving and prior to the mating period, suggesting that the energy offered during the winter and especially post-calving was sufficient for successful rebreeding in a rather short time.

Osoro and Wright (1992) concluded that the cow BC at calving and the breed were the most significant animal factors affecting reproductive performance. The importance of the BC at calving for an early return to oestrus and good pregnancy rates was also determined by e.g. Richards et al. (1986), Selk et al. (1986), DeRouen et al. (1994) and Spitzer et al. (1995). Using multiparous spring-calving beef cows, Morrison et al. (1999) concluded that the reproductive performance of cows calving in moderate BC was not influenced by great changes in body energy reserves during the last trimester of pregnancy. A BCS of 5 (scale 1-9) at parturition was critical to ensure acceptable reproduction. Also Boadi and Price (1996) concluded that cows may be allowed to lose BC during the last trimester of pregnancy, provided that they have a BCS of 2.5 (scale 1-5) or better at calving. With mature autumn-calving, hill-grazed Ab cows, Morris et al. (1978) observed that attention should be paid to the *pre partum* nutrition, but during 40 days *post partum* cows can be fed to maintain their LW without affecting their reproductive performance. On the contrary, Perry et al. (1991) concluded that beef cows must be fed adequately both *pre* and *post partum* to achieve optimal reproductive efficiency and that for commercial producers the *post partum* energy level may be even more important economically than the *pre partum* energy level because of its impact on oestrous cyclicity and the eventuality of conception. In II-VI, the BCS losses from calving to grazing were on average maximum 0.2 units, partly explaining the good pregnancy rates. The BCS at calving for the mature Hf cows was at least 2.7 in III-2-VI and, therefore, the amount of energy offered to the cows *pre partum* might have been even lower without negative effects on reproduction.

Varying energy levels during the winter period (Manninen 2000, Manninen and Huhta 2001, Manninen et al. 2002a), different cold winter housings (Manninen 1998a, Manninen 1998b, Manninen et al. 2002b) and feeding mature Hf cows every second day (Manninen et al. 2006) did not impair the pregnancy rate. The main reasons for the good pregnancy rates were obviously the sufficient amount of energy offered to the cows during the winter period (Table 6) and, thus, good BC at calving and prior to the mating period (Table 7).

The rather low pregnancy rate of 69% in I may have resulted from OS followed by double fixed-time AI and an attempt to inseminate the repeats due to the practical difficulties of adequately detecting oestrus with nearly invisible signs. A further possible explanation for the poor reproductive efficiency may be related to the LW of the cows at the beginning of the experiment. In an attempt to maintain a high milk yield the cows may have lost too much BC between calving and mating, although this was not measured. Hodgson et al. (1980) fed adult HfFr and Blue Gray spring-calving cows 12 weeks *pre partum* 75% of the estimated maternal maintenance energy requirements and *post partum* until grazing hay for maintenance together with concentrate sufficient either for 2.25 or 9.00 kg/d milk and concluded that conception from AI following OS was not affected by the plane of nutrition in early lactation. With crossbred beef heifers, Dunne et al. (1999) found that a two-week reduction in energy intake after AI severely reduced embryo survival rate.

Post partum interval in Experiment II

With dairy cows, the use of milk progesterone analysis to monitor reproductive function during the *post partum* period is common. With suckler cows, accurate assessment of reproductive function is always compromised by the difficulties connected with accurate determination of oestrus (Mann et al. 2005). An extended PPI, i.e. interval from calving to first ovulation, is one major cause of poor reproductive efficiency in suckler cows (Diskin 1997). In II, the resumption of ovarian activity and subsequent ovarian function were assessed with milk progesterone (P_4) profiles. The treatments had no significant influence on the length of the PPI. In II-1, the interval from calving to grazing was markedly shorter than in II-2 and most of the variation in PPI can be explained by the length of the interval from calving to grazing. In II-2, the average voluntary waiting period (VWP, interval from calving to grazing and bull exposure) was 74 days (minimum 59 days), and 23 of the 24 cows conceived during the first three weeks at pasture. In II-1, the average VWP was only 30 days. Despite the short VWP, in 22 of the 24 cows, ovarian activity resumed during the first three weeks at pasture.

Although suckling and nutrition are the major factors in determining the length of PPI (Short et al. 1990), grazing and especially its onset seem to have an influence on the resumption of ovarian activity (II-1). Petit and Agabriel (1989) suggested that when calving takes place in late winter, less than two months before turn-out, the high level of nutrition usually achieved on spring grass induces a rapid return to oestrus and high fertility. It is obvious, that grazing may also have some other mechanisms on the reproductive functions, because the animals in II were in good condition also during the indoor feeding period. Mann et al. (2005) used milk progesterone to monitor reproductive function in autumn-calving beef suckler cows and found a relatively low incidence of reproductive cycle problems in beef-dairy suckler cows, but animals with problems had significantly impaired reproductive function.

Lowman (1985) summarized the results of autumn-calving herds and described two matters which most affect the overall herd fertility, i.e. a compact two-month calving period and the BCS at the start of mating. These findings may also apply to spring-calving herds.

4. GENERAL CONCLUSIONS AND PRACTICAL APPLICATIONS OF THE RESULTS

The general conclusions and practical applications of the results listed below are appropriate for group-fed spring-calving suckler cows.

1. All evaluated feeds used in the present study, i.e. urea-treated straw, whole-crop silages and oat hull-based flour-mill by-product, were suitable for immature and mature suckler cows. These alternative feeds can partly replace hay and grass silage in the winter diet of suckler cows. Roughages with high or even moderate digestibility, e.g. grass silage or whole-crop barley silage, if offered *ad libitum* to suckler cows, may be uneconomical and environmentally undesirable, since the cows consume excessive quantities of such feeds leading to unnecessarily high body condition and therefore, waste of energy and nutrients. Feeds with low dry matter content, e.g. unwilted grass silage, may freeze in cold winter housing conditions if offered *ad libitum* to the cows. However, this may be a minor problem in suckler cow feeding with a restricted feeding scheme.

2. Winter feeding strategies were evaluated by changing the amount of energy offered to the cows and by changing the feeding accuracy, feeding frequency and feed allocation. The amount of energy offered to the cows during winter can be decreased, thus allowing the cows to lose live weight and body condition if the losses can be replenished at pasture. Accurate feeding daily is not needed providing that the total amount of energy offered, over a period of a few weeks, is adequate to fulfil the energy requirements of suckler cows. Feeding every third day is an acceptable winter feeding strategy for mature suckler cows during the entire indoor feeding period in marginal circumstances. However, the cows must receive enough energy determined per day for maintenance, pregnancy and milk production. The flat-rate feeding strategy can be practised as a simple way of managing the nutrition of mature suckler cows during the long indoor period since the precise date of calving is often unknown and the duration of calving period may vary largely.

3. Winter feeding strategies had only minor effects on cow milk production and milk composition. The cows received at least moderate amounts of energy and were in good body condition at parturition with no need to use their own body reserves for milk production. This explains the good milk production and, consequently, the good calf live weight gain. The winter feeding strategies applied to the cows did not increase the incidence of dystocial cases. Only a few severe calving difficulties were observed and they were mainly related to the age of the cow or to the sex, birth weight or disposition of the calf, not to the experimental treatments.

4. Calf live weight gain was good, which suggests that the cow milk production was sufficient and the pastures were of good quality. The calf live weight gain was mostly affected by calf sex, while the winter feeding strategies had only minor effects on calf performance without practical importance. It seems that the opportunities to affect the calf live weight gain prior to the grazing period via the winter feeding strategy for the cows are rather marginal if the energy requirements of the cows are satisfied.

5. Pregnancy rate was unaffected by the winter feeding strategies. This may be due to the good body condition of the cows at the onset of the mating period, the good pastures available for the cows to increase body condition simultaneously with rather high milk production and, finally, the use of fertile bulls.

6. Finnish energy recommendations for dairy cows proved to be too high for mature beef breed suckler cows in good body condition at housing. On the basis of the results, it can be suggested that a pregnant mature suckler cow with a body condition score of 3.0 (scale 0-5) at housing may need 0.60-0.70 ME MJ/kg$^{0.75}$ energy daily for the entire winter period, approximately from the beginning of October to the end of May, in weather conditions similar to those in the present study. This amount of energy can be offered to the cows either by using the step-up feeding strategy or in case of mature cows, using the flat-rate feeding strategy, either with traditional or alternative feeds. For young and/or beef-dairy crosses, the corresponding value should be moderately higher, 0.70-0.80 ME MJ/kg$^{0.75}$. These values could be utilized if official feeding recommendations are to be issued for suckler cows in the future in Finland. Special emphasis should be given to beef-dairy crosses and/or young animals who easily loose body condition from calving to mating, leading to reduced pregnancy rates. The feeding recommendation should be based on the body condition score prior to the winter feeding period. In addition, estimated calving dates and feed values for the winter feeds give useful information for planning the feeding.

7. All winter housing facilities in the present study offered adequate shelter for the suckler cows and calves. The feeding strategies introduced to the cows are well suited to conditions similar to those in the present study. Although adult ruminants are cold-hardy and have low estimates of lower critical temperature, production in cold conditions requires that shelter against rain and wind, a dry resting place, adequate amounts of feed suitable for cold conditions and water are provided for the animals. To avoid animal welfare problems, all winter housing facilities should prevent the animals from becoming wet and dirty and ensure a safe feeding place for each cow. This may also be the way for public acceptance of less expensive winter housing solutions or even for outdoor wintering of the cows leading, ultimately, to better economic output from suckler herds in Finland.

Future research topics in suckler cow production in Finland

- Economic evaluation of different winter feeding strategies
- Grazing recommendations for spring-calving suckler cows
- Evaluation of calf losses in suckler herds and possibilities to minimize them
- Calf health and its effects on output

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