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Grazing management for Nordic organic dairy farming

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Grazing dairy cows form part of a complex ecosystem involving their interaction with the pasture plants, soil micro-organisms and climatic conditions. In Nordic organic dairy farming, grazing represents a challenge with the short grazing season and limited number of winter-hardy plant species combined with restrictions on the use of fertilisers and supplementary feeding. The aims of this study were to investigate factors limiting grazing and to develop adjusted grazing management for Nordic organic dairy farming conditions. The study, including seven field or feeding experiments, was conducted on the Siikasalmi experimental farm of the University of Joensuu (62°30'N, 29°30'E) in Eastern Finland in 1994 – 2000. The focus in the study was to combine the aspects of plant, animal and organic production, as they are all involved in organic dairy pastures. This pioneer work provides a characterisation of Nordic organic pastures, suggests novel legume species for Nordic conditions, considers the use of manure compost fertilisation, proposes tools to improve grazing efficiency and assesses the benefits of supplementary feeding.

This study showed that intensively managed organic pastures can support at least moderate herbage production with good nutritive value, although organic pastures are heterogeneous mixtures of three botanical components, grasses, legumes and weeds, which are clearly divergent regarding dependence on soil nitrogen availability and herbage nutritive value. The botanical proportions and seasonal changes affect the nutritive value and growth of the herbage. The choice of legume species for grazed mixture is of key importance. White clover is the most suitable perennial pasture clover for Nordic conditions, but the additional inclusion of beneficial birdsfoot trefoil in perennial clover-grass mixtures is suggested. Hairy vetch is best suited for grazed annual legume-grass-cereal mixtures and can support extended grazing in the autumn. At the farm level, including both annual and perennial swards will help to balance the temporal variation of the herbage mass and extend the grazing season in the autumn. Application of soil-deposited manure compost increased herbage production, but decreased proportion of utilised herbage and had no effect on the amount of utilised herbage. Hence, manure compost fertilisation, if necessary to improve the soil fertility of a certain area, is recommended to be used for cereals included in pasture-crop rotation rather than for grazed swards.

It should be noted that in organic farming systems herbage production is often lower than in heavily fertilised conventional systems when normal rotation cycles are used in order to obtain herbage with adequate nutritive value. The pre-grazing herbage mass affects the stocking rate, grazing area requirement, milk yield per animal and milk yield per hectare. The milk yield per hectare was clearly increased by applying daily strip grazing instead of paddock grazing. In organic dairy farming, excessive herbage allowances are rarely useful because of the limited pre-grazing herbage mass. The herbage allowance should not go below the level which the system can tolerate. Post-grazing sward height is a good indicator for the implementation of adequate allowances and for continuous monitoring to prevent inefficient under-grazing and detrimental over-grazing. In the present study the milk-yield response to concentrate feeding was relatively high (0.68- 1.04 kg milk per 1 kg concentrates). Both energy and protein supplementation resulted in increased milk production. The organic pasture herbage did not fully satisfy the mineral requirements of grazing dairy cows. Low concentrations of Na and Mg in herbage, especially the latter associated with high K, require mineral supplementation.

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ABBREVIATIONS

ADF	acid detergent fibre
DM	dry matter
CP	crude protein
GP	grazing period, animal occupation period on grazing area within a rotational grazing system
HA	herbage allowance
HM	herbage mass
IVOMD	*in vitro* organic matter digestibility
NDF	neutral detergent fibre
PRE HM	pre-grazing herbage mass
POST HM	post-grazing herbage mass
POST SH	post-grazing sward height
S grazing	Strip grazing
P grazing	Paddock grazing

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LIST OF ORIGINAL PUBLICATIONS

This thesis is mainly based on the following publications but it also includes some previously unpublished results. In the text the publications are referred to by the Roman numerals I-V.

I Kuusela, E., Khalili, H. 2002. Effect of grazing method and herbage allowance on the grazing efficiency of milk production in organic farming. Animal Feed Science and Technology 98, 87-101.

II Khalili, H., Kuusela, E., Suvitie M., Huhtanen P. 2002. Effect of protein and energy supplements on milk production in organic farming. Animal Feed Science and Technology 98, 103-119.

III Kuusela, E., Khalili, H., Nykänen-Kurki, P. 2004. Fertilisation, seed mixtures and supplementary feeding for annual legume-grass-cereal pastures in organic milk production systems. Livestock Production Science Vol 85/2-3, 113-127.

IV Kuusela, E. Annual and seasonal changes in production and composition of grazed clover-grass mixtures in organic farming. Agricultural and Food Science 13, 309-325.

V Kuusela, E. Annual and seasonal changes in mineral contents (Ca, Mg, P, K and Na) of grazed clover-grass mixtures in organic farming (submitted manuscript, Agricultural and Food Science).

1 INTRODUCTION

1.1 What is organic farming?

The main aspects of conventional farming against which have been criticised are the increased use of chemicals: mineral fertilisers, herbicides, pesticides and fungicides in crop production and feed additives, hormones and antibiotics in animal production (Sundrum 2001). Therefore organic farming has been developed as an alternative. Organic farming aims to minimise the use of external inputs and represents a deliberate attempt to make the best use of local natural resources. According International Federation of Organic Agriculture Movements (IFOAM) organic agriculture comprises a whole system approach based upon a set of processes aiming to support a sustainable ecosystem, safe food, good nutrition, animal welfare and social justice (IFOAM 2002).

Since 1980, the IFOAM has created international standards for what may be labelled as organic. Within the European Union, Austria and the Scandinavian countries are in the forefront in the proportion of their agricultural area devoted to organic farming, and Denmark in the share of organic dairy farming in its agriculture (Sehested et al. 2003). The first Finnish standards for plant production and animal production were developed by Luomuliitto ry (the Union for Organic Farming) in 1986 and 1988, respectively (Heinonen 2002). Today in all the EU countries regulation 1804/1999, supplementing regulation 2092/91 on organic production, provides a minimum standard concerning the right to label food as organic (CEC 1999). In Finland, the state authorities carry out the inspection and certification of organic production. Ministry of Agriculture and Forestry Decrees No 346/2000 and No 127/2001 specify the authorities and the inspection and control system for organic production (KTTK 2003).

1.2 Development of organic farming in Finland

Although the first traces of the ideas of organic agriculture in Finland as Natural Agriculture and Biodynamic Farming date back to the beginning of the 20th century, the biochemist Professor A.I. Virtanen can be considered the pioneer of organic farming in Finland (Heinonen 2002). During the 1930s, Virtanen developed a nitrogen self-sufficient cultivation method, which included crop rotation with pastures, bread grains and intensive red clover leys for winter feeding preserved as silage. The AIV method was first developed for preserving the valuable clover herbage (Virtanen 1938).

The oldest existing organic farms in Finland were converted in the 1960s, but until the 1980s there were less than thirty organic farms (Heinonen 2002). These pioneers, although many of them were economically as successful as conventional farmers, had ideological motivations for converting. During the 1980s, specialised marketing channels started to function and in 1990 the state conversion aid programme was launched. In 1989 there were 373 certified organic farms, but mainly due to the conversion aid, the number of farms started to increase. Finland's entry into the European Union at the beginning of 1995 brought more farms to convert to organic farming. In Finland the number of organic farms in 2003 was 4983 (6.8% of all farms) and the area under organic cultivation or being converted was 159 987 hectares (7.2 % of total area) (KTTK 2004). Converting animal production to organic farming is not a requirement for conversion or for receipt of production aid for organic farming. About 45% of Finnish organic farms practise animal production, but in 2003 only 413 farms had certified organic animal production and 218 farms had organic milk production (KTTK 2004). The strategy of the Ministry of Agriculture and Forestry aims at reaching a 15% share of organically farmed land in Finland by 2010 (KTTK 2003). The action plan for 2002 – 2006 emphasizes the development of organic animal production. Future environmental and food trade policies within the European Union, and also worldwide, may further increase interest in local low-input systems in peripheral regions. The political environment within which livestock farming in much of Europe operates (Common Agricultural Policy) is shifting the balance of economic advantage towards legumes and away from high usage of inorganic fertilizer (Rochon et al. 2004). However, in many parts of Europe there has been a net decline in the use of forage legumes since the 1980s, despite the reputed value of legumes for low-input livestock production systems.

Organic livestock farming often makes severe demands on farm management. The preference for home-grown feed and limitations in the choice of bought-in feed is bound to result in a wider and unintended variation in the nutritional value of animal diets under organic than conventional practices (Sundrum 2001, Hovi et al. 2003). Consequently, optimising the balance between the supply and requirements of nutrients is probably more challenging under organic than in conventional systems, especially if the quality of basal forages is low. From the farmer's standpoint, conversion of animal production systems increases production costs, effort and bureaucracy due to the housing, husbandry and feeding directions for organic animals (Koikkalainen and Haataja 2000). Also the underdeveloped market for organic animal products in Finland has retarded conversion. Compared to a few years ago, the market demand for organic milk products has recently been increasing relatively slowly. However, in practice all cows on organic farms, labelled or not, are mainly fed on farm-grown feeds (silage, pasture, cereals) of organic origin. The willingness of consumers to pay premium prices for alternative practices enables farmers to reduce economic pressure on production costs and to begin practising organic animal husbandry (Sundrum 2001). For organic milk the extra price in Finland is today about 0.06 euro per litre for contract producers, but at the moment new contracts are not being made and the future price support is uncertain. Because of market-led development of the situation of organic farming, organic animal husbandry especially depends to a high degree on consumers' demand for organically produced products and for added values such as biodiversity, the preservation of species and the protection of nature, the landscape, groundwater or animals, etc., which are closely related to the production process (Sundrum 2001). In accordance with expectations, organic farming has been proven to increase the biodiversity in fields, field margins and other agricultural surroundings (Rydberg and Milberg 2000, Hopkins and Hrabe 2001, Pitkänen and Tiainen 2001) and to decrease the negative environmental impact of farming (Sundrum 2001, De Boer 2003). This is because organic farming does not use mineral fertilisers or pesticides, and its crop rotation cycle is considerably more varied than in modern conventional farming, especially compared with monoculture cultivation of cereals. Also on dairy farms uneven and selective grazing can be beneficial for biodiversity (Bailey et al. 1998). However, organic dairy farming may not be able to satisfy all the demands of consumers, where they are based on unrealistic ideas rather than on the biological facts of the production process.

It should be pointed out that in Finland the average annual milk yield of recorded cows increased from 3275 kg in 1950 to 8121 kg in 2003 and will increase further (Finnish Milk Recording). The average annual milk yield of Finnish organic farms was 7193 kg in 2003 and on some organic farms, annual milk yields already exceed 9000 kg per cow. In Denmark, 6% of organic dairy farms have more than 9000 kg milk per cow (Sehested et al. 2003). It has sometimes been suggested that there should be separate breeding programmes for organic animal production aimed at sustainability and health rather than future increases in productivity. The greater the gap between conventional and organic milk yields, the greater is the need for financial support. In any case the nutritional requirements of current dairy cows with high genetic potential must be satisfied to support their welfare (Hovi et al. 2003).

1.3 Background of Finnish grazing concept

In Finland, modernisation was initiated after the great famine years in the 1860s. More attention was paid to animal husbandry and particularly to dairy cows and, consequently, to grassland farming instead of low-yielding natural pastures. In the 1880s, two thirds of Finland's permanent agricultural lands were meadows, and only one third tilled fields (Pitkänen and Tiainen 2001). Grazing was based on meadows and forest pastures, which comprised a large diversity of species. It has been estimated that 30-40% of Finland's plants benefit from traditional forms of land use such as grazing and mowing (Alanen 1996). Today the remaining meadows and forest pastures are heritage landscapes, habitats that will not survive without specific preservation measures (Vainio et al. 2001).

Since the 1960s, the best yielding intensively managed and rotationally grazed short-term pastures have generally been used in Finland. Only 0.03 of the Finnish forage production area comprises swards older than 4 years (Information Centre of the Ministry of Agriculture 1998). Hard winter conditions limit the number of potential grass species to only few such as timothy (*Pleum pratence*) and meadow fescue (*Festuca pratensis*), and in Southern Finland, cocksfoot (*Dactylis glomerata*) (Nissinen and Hakkola 1995). Before the increased use of N fertilisers, red clover (*Trifolium pratense*) was often included in seed mixtures (Heikinheimo 1948). Timothy, meadow fescue and red clover are climatically the best suited species for Finnish swards and organic pastures, although they are less tolerant of grazing than perennial ryegrass (*Lolium perenne*) or white clover (*Trifolium repens*), which are commonly used in Central Europe (Virkajärvi and Höglind 1999). In recent dissertation it was concluded that conventional timothy-meadow fescue pastures are tall, have low tiller population density, low herbage mass bulk density, occasionally low leaf content and similar nutritional value compared with perennial ryegrass pastures despite the structural differences (Virkajärvi 2004). Also smooth meadow-grass (*Poa pratensis*), red fescue (*Festuca rubra*) or recently tall fescue (*Festuca arundinaceae*) (Niemeläinen et al. 2001) has been recommended in some instances for Finnish grazed swards.

1.4 Grazing - an essential part of organic dairy systems

Grazing dairy cows form part of a complex ecosystem involving their interaction with the plants of the pasture, the soil micro-organisms and the climatic conditions (Leaver 1985). Grazing is the most natural feeding method for cattle and also the cheapest source of nutrient for dairy cows thus contributing to the competitiveness of milk production, preserving the rural landscape and giving a beneficial image of dairy production. Grazing provides animal freedom for a wide range of species-specific behaviour and is also a natural source of vitamin D, but extreme conditions such as heat (>25°C) or wet combined with cold can stress grazing animals (O'Connell et al. 1989, Hemsworth et al. 1995). According to organic farming regulations, cattle should have daily access to pasture when conditions are adequate for grazing (CEC 1999).

In the Nordic Countries, milk production based on grazed grass is limited due to the short grazing season and in some cases as a result of low herbage yields from organic pastures. For example in Finland the length of the grazing season is 3-5 months. According to a farm study (16 farms), the yield of pasture decreased by 40% after converting to organic farming (Turkki and Viitala 1996). High yielding dairy cows are challenging grazing management in organic farming to exploit fully the potential contribution of herbage. In early-mid lactation, supplementary feeding is needed also at pasture to meet the demands of high-yielding animals. According to regulations, the proportion of forage (on a dry matter (DM) intake basis) must be at least 0.60, but during the first three months after calving the proportion of concentrates can be increased to a maximum of 0.50 (CEC 1999). According Finnish Milk Recording in 2002 the DM basis proportion of grazed herbage and hay in diet comprised about 0.13 and 0.04, respectively, both in organic and conventional milk production, but the proportion of silage in diet was higher for organic than for conventional milk production (0.44 and 0.39, respectively).

2 THE PRESENT SITUATION

2.1 Grazed species

Due to climatic constraints, the grass species suitable for Nordic perennial organic legume-grass pastures are the same as those used in conventional farming. Although species may be the same, the herbage growth and quality of organically cultivated grasses may be different from conventional fertilised swards. Red clover has been used as the primary legume within Finnish organic farming systems owing to its high yield potential and relatively good winter hardiness, although it is not well suited to multiple-cut systems or close grazing (Nissinen and Hakkola 1995, Taylor and Quesenberry 1996, Clark and Kanneganti 1998). White clover tolerates frequent close grazing better and is the most important pasture legume in several regions of Europe (Frame and Newbould 1986, Schils et al. 1999). Some white clover cultivars recently introduced to Finland, for instance the Estonian 'Jögeva4', have proved to be reasonably resistant to frost (Nykänen-Kurki and Kivijärvi 1996, Sormunen-Cristian and Nykänen-Kurki 2000). Alsike clover has been recommended instead of red clover on acid and moist soils. It could be an alternative to red clover also in short-term pastures. Applying a mixture of white and alsike clover might decrease temporal changes in the proportion of clover because of the different growth rhythms of the species.

In low-input grazing systems the beneficial effects of legumes on animal nutrition and soil fertility are well known, but so also is the risk of legume bloat, which is due to extensive ruminal fermentation which occurs following the ingestion of high quantity of legumes (Leaver 1985, Lane et al. 2000, Assefa and Ledin 2001, Beever et al. 1999). Only a few legumes such as birdsfoot trefoil (*Lotus corniculatus*) have been recorded as being non-bloating, whereas both clovers and vetches have been reported to cause bloat (Piper et al. 1923, Duke 1981, Min et al. 2003). The common recommendation not to graze on legume-predominated areas is difficult to follow in organic farming practice. According to Majak et al. (1995) legume bloat can be reduced by several ways: by advancing states of plant maturity, by moving cattle onto a new pasture in the afternoon, by grazing continuously and by applying bloat preventing feed supplements, which are not permitted in organic farming (CEC 1999). Majak et al. (1995) summarised, that grazing systems, which promote continuous and rapid ruminal clearance are most likely to reduce the occurrence of bloat. Birdsfoot trefoil contains condensed tannins which bind protein and hence prevent bloat and decrease rumen protein degradation (Tamminga and Suderkum 2000). Birdsfoot trefoil could be a useful legume for organic pasture farming.

However, a more serious problem than high clover content in feeding is often the year by year decrease in the proportion of clover in Nordic perennial swards. Perennial pastures could be partly replaced by annual legume-grass-cereal mixtures. The different growth rhythms of perennial and annual pastures could balance the amount of herbage available during the grazing season and extend the season in autumn. In Finland, annual cereal-grass mixtures have already been introduced in conventional farming (Nissinen 1992, Nissinen and Hakkola 1998) and cereal-legume mixtures for silage production in organic farming (Joki-Tokola et al. 2000). Common vetch *(Vicia sativa)*, hairy vetch *(Vicia villosa)*, Persian clover *(Trifolium resupinatum)* and some white clover varieties *(Trifolium repens)* could be suitable legumes for grazed annual mixtures under Nordic conditions (Duke 1981, Joki-Tokola et al. 2000).

Clovers, like many other grazed legumes, are not dependent on N-fertilisation and are rich in CP and minerals, especially Ca and Mg, and low in neutral detergent fibre (NDF), cellulose and hemicellulose (Leaver 1985, Buxton 1996). Grasses have high contents of NDF, cellulose and hemicellulose, but their herbage production and herbage crude protein (CP) content is clearly dependent on soil N availability. Weeds, although unsown, comprise the third herbage component after grasses and legumes. Under conventional grassland management practices weeds are undesirable. For organic farming and other low-input systems they can have a beneficial role in improving biodiversity, the nutrient cycle and animal nutrition (Lampkin 1994, Wardle and Nicholson 1996, Kallah et al. 2000). Weeds can also be used as indicators of growing conditions. Dicotyledonous weeds are sometimes called forbs or herbs.

2.2 Plant nutrition and fertilisation

In natural systems animal products can be seen as the result of a biogeochemical cycling of nutrients through soil, water, air, plants, animals and manure (Tamminga 2003). In agroecosystems human intervention, such as external inputs of energy, fertilisers and feeds from distant areas, change the balance. The sustainability of livestock grazing has to meet the criterion of being an offtake of production (forage) without disruption to the functioning of the ecosystem (Vavra 1996). In organic farming, which aims to minimise the use of external inputs, herbage production is dependent on biological N_2-fixation, soil mineralisation and nutrient recycling (Granstedt 1992, Lampkin 1994, Younie 1999). Well established pastures can maintain good soil fertility and support high herbage production since the majority of grazed nutrients are directly returned via the faeces and urinary excretion of the grazing animals (Holmes 1968, Leaver 1985). The establishment and maintenance of N_2-fixing legumes in the sward should match the N losses from the pastoral system (Ledgard and Steele 1992, Weller and Cooper 2001). A high CP content of the herbage is indicative of substantial biological N fixation, partly capitalised in current herbage production and partly invested for future needs. Legume-poor unfertilised pastures have a uniform mosaic appearance with visible green patches of legume-rich areas, urination spots and zones around faeces. This is due to herbage N being removed from the whole pasture area but returned via faeces and urine to small areas at high concentrations (Wilkins and Garwood 1986, Afzal and Adams 1992). In organic pasture farming the need for other fertilisation, in addition to the recycled manure of the grazed animals, must be considered carefully.

If urine is separated, diluted urine can be spread on the growing sward to promote grass growth similarly to mineral fertilisers. This system has been recommended also for those organic grazed swards with a decreased proportion of legumes. In 1994, the use of urine application was tested in a survey study at Siikasalmi (unpublished). One-year-old alsike, red and white clover – grass plots (10 x 10 m) were divided into two similar areas (no replicates). Urine was applied (20 t ha^{-1}) in early July. As a consequence the average pre-grazing herbage mass (PRE HM) of the treated areas was increased (15%), post-grazing herbage mass (POST HM) was increased (25%) and clover proportion was decreased (23%) compared to the untreated areas. The application of urine affected both animal preference and sward composition. In August 1995, undesirably high herbage K contents (>40 g kg^{-1} DM) were recorded from a recently established sward which had received applications of diluted silage effluent and urine during the previous summer. Because of the risk of increased herbage K content and decreased animal preference, the effect of urine application was not studied further. However, for low K soils urine application might be useful (Baars 2002).

The most commonly used fertiliser in organic dairy farming is manure. Each farm must consider individually how to make the best use of this important nutrient source. If animal production is based on farm-produced feeds, as recommended in organic farming, the amount of available manure per hectare is clearly limited because of the large area of forage needed per animal. On non-self-sufficient organic dairy farms almost all of the cultivated area is usually under perennial swards. In this case, replacing the manure accrued during the long indoor feeding period can be difficult, if it is not spread over the growing swards. On pastures, where urine and dung are directly recycled, the benefits of additional urine or manure compost fertilisation could be lower than for other crops. Nevertheless, N fertilisation has positive linear effects on the HM production and CP content of grasses (Holmes 1968). However, manure fertilisation may reduce the legume proportion in mixtures and the smell of manure may decrease herbage utilisation during grazing (Marten and Donker 1966, Leaver 1985, Wilkins and Garwood 1986, Assefa and Ledin 2001).

2.3 Implementation of grazing

Dairy cows performance is generally similar under continuous and rotational grazing systems (McMeekan 1956, Leaver 1985). The benefits of rotational grazing have usually been reported for legume-based swards at high stocking rates (Leaver 1985, Schlegel et al. 2000). Current plant species influence the choice of grazing system. For instance in Denmark continuous grazing is usually used with perennial ryegrass and white clover swards. Because winter-hardy grasses (timothy and meadow fescue) and also red clover suffer from close grazing, rotational grazing system is more suitable for Nordic organic dairy farming. Rotational grazing is also easier to manage than continuous grazing, because rotational grazing allows precise identification of grass quantity and quality (Campling 1975, Peyraud and Gonzalez-Rodrigez 2000). Strip (S) grazing is a more controlled form of rotational grazing and allows the vegetation to rest between grazings. In daily S grazing the specified quantity of grass per cow, i.e. daily herbage allowance (HA), is maintained by daily adjustment of the grazing area according to the HM. If the HA is too low, the milk yield per animal will decrease but excessive HA results in a lower milk yield per hectare.

Post grazing sward height (POST SH) is a practical management tool for grazing. In conventional rotational grazing both intake and milk production depress if the cows are forced to graze the sward down to mean height less than 8-10 cm (Le Du et al. 1979). Hence low POST SH, indicative of over-grazing, will decrease the animal performance and also retard regrowth of the sward. High POST SH due to under-grazing will decrease the utilisation of pasture and consequently have a negative impact on herbage nutritive value, if swards are not topped. Targeting POST SH depends on the species, fertilisation, sward structure and grazing system (Le Du et al. 1979¸ Parga et al. 2000). Both HA and sward structure affect the POST SH. For instance, daily HA of 12 kg DM (above 8 cm) and similar PRE HM (5589-5857 kg OM ha^{-1}) has been reported to result in lower POST SH for control sward compared to leafy sward (8.4 and 10.3 cm, respectively, Parga et al. 2000). In Finland, a POST SH of 10 cm is recommended, due to the low bulk density and relatively low tiller density of the prevalent grass species (Virkajärvi and Höglind, 1999, Virkajärvi 2004). This could be an adequate POST SH also for organic pastures in Finland, since the same grass species are used.

2.4 Animal nutrition and supplementary feeding

Milk yield, which is the ultimate harvest from pasture, determines the needs of the animals. The nutritive value of the herbage and access to herbage affect the intake and nutrient supply in grazing cows (Leaver 1985, Mayne et al. 1999). For any given grazing system the pasture species, application of fertilisers, sward growing conditions, stage of maturity and stocking rate affect the nutritive value of the herbage (Leaver 1985, Delagarde et al. 1997, Wales et al. 1998). Thus the herbage nutritive value indicates the efficiency of grazing management and the need for supplementary feeding. It is well known that high forage diets do not provide sufficient energy for milk production, especially during early lactation, and therefore energy supplements are needed.

In organic farming, legume protein-rich forages are crucial for the transfer of nitrogen to the soil/plant system. Although grasses and, particularly, legumes supply N for rumen microbes, this approach is inefficient due to the large extent of N degradation in the rumen resulting in substantial losses of ammonia and N (Beever and Siddons 1986, Shingfield et al. 2001). In conventional milk production the effects of protein supplementation on animal performance in grazing animals are variable (Delaby et al. 1996, Delagarde et al. 1997, 1999, Jones-Endsley et al. 1997). Delaby et al. (1996) showed that replacement of cereals with a slowly degradable protein improved milk production to a greater extent in cows offered low compared to heavily fertilised grass swards. High-quality protein such as rapeseed feed has been shown to be a good protein supplement for conventional grass silage based diets (Huhtanen 1998). Therefore it could also be an efficient means of improving milk production in organic farming.

The mineral content of pasture herbage is often not optimal for grazing animals and mineral imbalances can be detrimental to animal health and welfare (Leaver 1985, Hovi et al. 2003). This is because mineral requirements for pasture plants and grazing animals are not congruent. In addition the mineral content of pasture herbage depends on the plant species, the availability of minerals in the soil, the climatic and seasonal conditions and the stage of maturity (Underwood and Suttle 1999). The efficiency of nutrient uptake is found to change during the year, according to variation in the ambient conditions of light, temperature and soil water content, and the physiology of the plant itself (Scholefield and Fisher 2000). Soils contain varying total reserves of native nutrients. Fertilisation changes soil nutrient status. For instance, the native phosphorus reserves of Finnish soils are poorly available for plants, but the high rates of P fertilisation applied since the 1940s have significantly increased the P status of cultivated soils (Saarelainen 2003). Besides fertilisation, potassium availability depends on the prevalent soil mineralogy, but the rate at which potassium becomes available to plants is of primary significance and varies between soils and even between crop rotations (Clement and Hopper 1968). Also availability of micro nutrients, such as selenium availability, depends on soil mineralogy and is difficult to improved in organic farming systems (Eurola and Hietaniemi 2004). Complicated interactions between minerals affect the plant uptake in the soil, and selective grazing and differences in mineral absorption and utilisation affect the minerals actually utilised by the animals (Evans et al. 1986, Underwood and Suttle 1999). Mineral concentrations, forms, interactions with other minerals and even with vitamins affect mineral availability for animals and the current needs of animals affect the final utilisation of minerals. For instance, adequate P nutrition depends on the chemical forms in which P occurs in the diet, the vitamin D status of diet and animal, food intake, level of performance and the dietary Ca concentration (Underwood and Suttle 1999).

Clovers are richer in Ca and Mg and many trace elements compared to grasses (Leaver 1985) and several weeds for many minerals (Wilman and Riley 1993). Under extensive grazing systems, particularly, grasses, clovers and weeds have in clearly different mineral contents (Garcia-Ciudad et al. 1997). The botanical proportion of organic pastures is subject to changes between seasons and within-season, which may affect the mineral supply for grazing animals.

2.5 Actual problems on farms

In autumn 1994, I interviewed 14 organic farms in the North Karelia region concerning their grazing management practices such as fertilisation, seed mixtures and grazing system (unpublished). Most (53 %) of the farms had converted to organic farming recently (0 - 5 years ago) or the conversion period was still on-going (23 %). According to the farmers, the important problems experienced with grazing were low herbage yield (54 %) and decreasing legume proportion (31 %). Red clover was the most commonly used pasture legume (67 %), followed by white clover (20 %) and alsike clover (7 %) and vetches (6 %). Regarding sward establishment, most farms (92 %) used composted manure for fertilisation, but during the following seasons only some farms (25 %) used fertilisation (urine or composted slurry). The average length of the GP was usually more than 3 days and the average interval between GPs was 3-4 weeks. From this survey study, experience from Siikasalmi Farm and several personal contacts with farmers, advisors and researchers it was evident improved grazing management of organic pastures was urgently required. A later farm study confirmed this opinion (Turkki and Viitala 1996).

3 AIMS OF THE STUDY

The aims of this study were to investigate factors limiting grazing and to develop adjusted grazing management for Nordic organic dairy farming conditions. The perspectives of plants, animals and organic farming system were considered (Fig. 1). Pasture comprises a complex system with many interactions. The species composition and growing conditions affect the quantity and quality of herbage production. Plant nutrition depends on soil fertility and biological N_2 fixation (legumes), and can be improved by fertilisation. The implementation of grazing influences herbage utilisation but also future herbage growth. The nutrition of grazing cows depends on the intake and nutritive value of the herbage and can be improved by supplementary feeding. Milk is the ultimate output from the pasture. The manure from the grazing animals, uneaten herbage and dead roots, etc. are recycled to the soil. Some losses are inevitable. Applying organic production methods, herbage should grow well during the entire grazing season, animal feeding should correspond to the requirements of grazing cows and the whole system should maintain soil fertility in order to support future herbage production.

Special objectives in developing grazing management for Nordic organic dairy farming were to

- Characterise the quantity and quality of herbage from organic pasture in order to improve grazing management and the nutrition of the grazing animals (I, II, III, IV, V)
- Find novel legume species replacing red clover to maintain an adequate legume proportion in the pasture (III, IV)

- Introduce annual legume-grass-cereal mixtures for organic grazing management to balance the amount of available herbage during the grazing season and to extend the grazing season in the autumn (III)
- Assess the effect of composted manure fertilisation on grazed swards (III)
- Develop efficient grazing systems to improve milk yield per hectare (I, II)
- Study the effect of concentrate supplementation on nutrition and animal performance (I, II, III)

4 MATERIAL AND METHODS

4.1 Site of the experiments

The study was conducted at the Siikasalmi Experimental Farm of the University of Joensuu. Siikasalmi Farm is situated 62°30'N, 29°30'E in the commune of Liperi, province of North Karelia, within the Finnish milk production zone. Between 1992 and 1999 the University of Joensuu administered the farm, which comprised at that time 61 ha of cultivated area

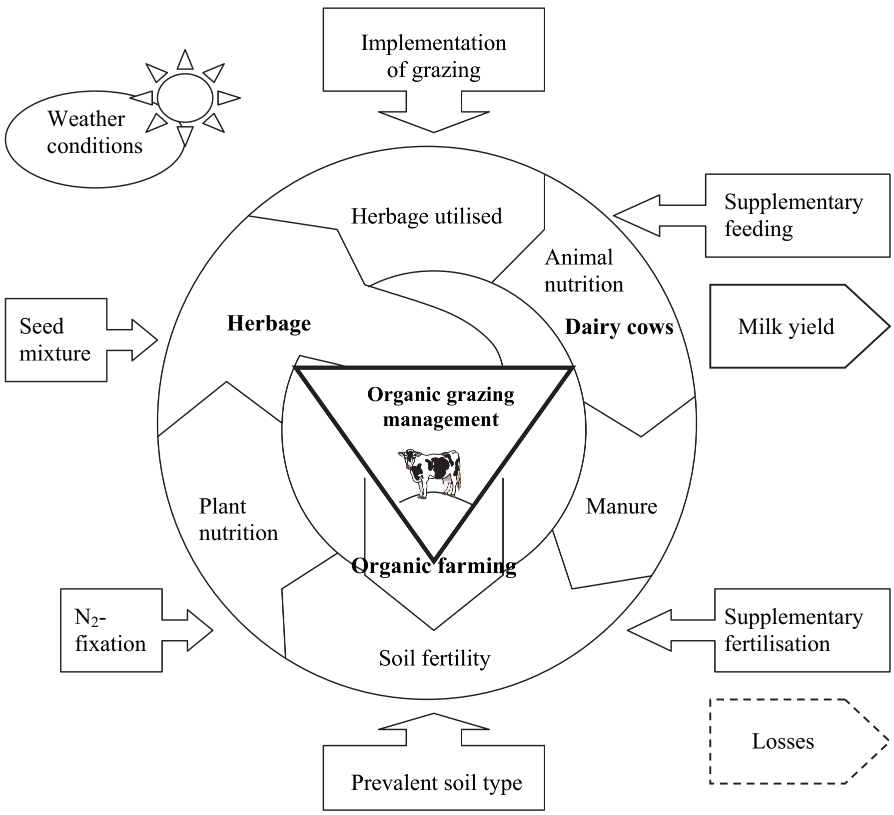

Figure 1. Elements influencing the grazing management under development for organic dairy farming.

(including 7 ha rented area). The main enterprise on the Siikasalmi farm was milk production, but cereal, beef and pigs were also produced. Conversion of the entire farm to organic production was started in 1992 and was almost complete by 1996. After converting, crop yields decreased only slightly and the milk yield improved compared to the previous conventional farming period (Granstedt 1999). The five-year crop rotation (barley/rye/rape as cover crop – ley – ley – wheat/rye – oats/oats + pea) worked well. The farm produced organic fodder for the animals (silage, pasture, hay, oats, barley, pie, rape) as well as rye and wheat for sale. According to a paired-sample t test of soil samples (54) taken from the same points in 1993 and 1998, organic farming increased the amount of available P (16.0 vs 24.3 mg l^{-1}, $P<0.001$), slightly decreased the amount of available K (111 vs 97.9 mg l^{-1}, $P<0.05$) and had no effect on Ca and Mg availability (unpublished). However, Siikasalmi, like many other organic farms, had unexpected difficulties with grazing after converting to organic farming.

4.2. Experimental design and treatments

This thesis contributed data from seven experiments (Table 1).

Experiment 1: Sward renovation, 1994-1995. (Kuusela 1995, mainly unpublished)

The renovation of a two-year-old clover-grass pasture by compost application and reseeding was assessed in a grazed field study in years (Kuusela 1995). At the beginning of conversion to organic farming the sward had been seeded with a clover (alsike and red clover)/ grass mixture, but in year 1994 after two years of grazing and tramping the sward vegetation had thinned out. The trial was of a randomised block design with three replicates and two treatments at two levels: 25 t ha^{-1} mature farmyard manure compost (CA) or no compost (NC) and 25 kg ha^{-1} seed sawn (SS) or no seed sawn (NS). The plot size was 20 x 10 m. Cattle manure originated from Siikasalmi farm was mixed with straw, processed one week in a drum compostory and matured approximately 8 months in a heap under permanent cover before application. The seed mixture contained 33% clover (1:1 alsike and white clover) and 67% grasses (timothy, and meadow fescue smooth-stalked meadow grass). During the application summer (1994) the area was grazed 5 times for 1-2 days by Ayrshire dairy cows, topped after the first and second grazing period (GP) and irrigated after the fourth and fifth GP. In summer 1995 the after effect of treatments on HM and botanical proportions was observed before and after the second GP.

Experiment 2: Clover species for perennial grazed swards, 1995-1998 (IV, V)

A grazed field trial was established in summer 1995 in order to evaluate the suitability of white, alsike and red clover as pasture legumes in Nordic conditions. The seed mixtures evaluated were alsike clover (AM), red clover (RM), white clover (WM), white and alsike (1:1) clover (WAM) and a grass (GM) mixture. The trial was initiated using a randomised complete-block design with four replicates and five plots (17.50 x 17.50 m) per replicate. Soil texture of the experimental area was defined in autumn 1993 as silty very fine sand (0.02–0.06 mm) of medium fertility (Ca 1360, P 16, K 165, Mg 196 mg l^{-1}) with an organic matter (OM) content of 30–60 g kg^{-1} DM and pH (water) of 6.1 (Soil Analysis Service Ltd, Vuorinen and Mäkitie 1955). The complementary grasses consisted of

Table 1. Description of experiments contributing data to this thesis.

Exp. No.	Subject	Treatments	Measurements	Publications
1	Sward renovation	Compost application Reseeding	Sward measurements	Kuusela 1995, mainly unpublished
2	Clover species for perennial swards	Five seed mixtures	Sward measurements	IV, V
3	Birdsfoot trefoil and white clover	Three seed mixtures	Sward measurements	Unpublished
4	Grazing method, supplementary feeding	Strip or paddock grazing Four supplementary feedings	Sward measurements Animal measurements	I, II
5	Herbage allowance, supplementary feeding	Two herbage allowances Two supplementary feedings	Sward measurements Animal measurements	I, II
6	Compost fertilisation, legumes for annual swards	Compost fertilisation Four seed mixtures	Sward measurements	III
7	Legumes for annual swards, concentrate feeding regimen	Two seed mixtures Two concentrate feeding regimens	Sward measurements Animal measurements	III

meadow fescue (0.50), timothy (0.43) and smooth-stalked meadow grass (0.07). The seed mixtures (25 kg ha $^{-1}$, including 7.5 kg ha^{-1} clover in clover mixtures) were seeded with a cover crop (oats (*Avena sativa*), 'Veli', 90 kg ha^{-1}). Winter-hardy red clover 'Bjursele', white clover 'Jögeva4' and alsike clover 'Frida' cultivars were used. No fertilisers were applied. During the summer of sward establishment Ayrshire dairy cows grazed the area three times. During summers of 1996 –1998 the replicates were rotationally (21-day cycles) grazed five times per summer and years were concerned as split-plots and periods of grazing (GP1 – GP5) within a year as split-split-plots. The mean stocking rates during the grazing seasons were 4.6, 3.5 and 2.9 cows ha^{-1} for 1996, 1997 and 1998, respectively. After GP1-GP4, replicates were topped to a mower height of 10 cm to minimise carry-over effects and to control weed growth.

Experiment 3: Birdsfoot trefoil and white clover as pasture legumes (1997-1998)

A grazed field trial was established in 1997 in order to evaluate the potential of birdsfoot trefoil and white clover for use as pasture legumes. The seed mixtures were birdsfoot trefoil (BM), white clover (WM) and a grass (GM) mixture. The trial was initiated using a randomised complete-block design with three replicates and three plots (10 x 10 m) per replicate. Before the experiment, the area had been fallow for several years. The soil texture of the experimental area was silt with moderate fertility (Ca 1570, P 13, K 101, Mg 237 mg l^{-1}), an organic matter (OM) content of 30–60 g kg^{-1} dry matter (DM) and pH (water) of 6.3 (Soil Analysis Service Ltd, Vuorinen and Mäkitie 1955). The seed mixtures were sown with a cover crop (oats, 90 kg ha^{-1}). The seeding rates for GM, WM, and BM were 24 kg ha^{-1}, 24 (clover 6 +

grass 18) kg ha^{-1} and 29.5 (trefoil 11.5 + grass 18) kg ha^{-1}, respectively. The complementary grasses consisted of meadow fescue (0.50), timothy (0.43) and smooth-stalked meadow grass (0.07). The legume cultivars were white clover 'Sonja' and birdsfoot trefoil 'Cornelia'. Ayrshire dairy cows grazed the area three times during the summer of establishment. During the summer of first full grazing year the area was grazed five times for 1-3 days, applying a rotation cycle of three weeks. Periods of grazing (GP1 – GP5) within the grazing season were concerned as split-plots. After GP1, GP2 and GP4, the area was topped.

Experiment 4: Grazing method (1996-1997) and supplementary feeding (1997) (I, II)

The effect of two rotational grazing methods, paddock (P) and strip (S) grazing, on herbage and grazing area requirement was compared. Grazing pressure was controlled achieved either by regulating the HA of the daily strips or regulating the paddock POST SH. Three pastures (1 ha) were each divided into two equal areas. The grazing method was randomly applied to areas within each pasture at the beginning of both summers. For the S grazing, cows were allocated to a fresh grazing area each day with a HA above 3 cm of 20.0 (1996) or 22.5 kg DM cow^{-1} (1997). For the P grazing, cows were grazed on the same paddock until a target POST SH of 10 cm was reached with an average grazing session of 6 days. The rotation cycle was in both grazing methods 21 days, but the rest period between grazing sessions became longer for daily strips than for 6-day paddocks. The total grazing time on each pasture per grazing session was equal and the S- and P-grazed cows were simultaneously transferred to the next pasture and the areas were topped after grazing.

The effect of two rotational grazing methods on milk production was compared in a feeding experiment. The feeding study (1997) was conducted with 8 lactating (152 ± 51 days in milk) cows, as two 4 x 4 Latin squares, each having 21-day periods comprised of 14 days for dietary adjustment and 7 days for sample collection. The cows were divided to two balanced squares and the treatments were randomly assigned to each cow within a square. The control treatment herbage (H) consisted of pasture alone. Treatment energy (E) consisted of pasture *ad libitum* supplemented with 4 kg day^{-1} of a mixture of organic oats and barley (500/500 g kg^{-1}). Treatment protein (P) consisted of pasture *ad libitum* supplemented with 1.25 kg day^{-1} of commercial rapeseed meal. Treatment energy and protein (EP) consisted of pasture *ad libitum* supplemented with 2.75 kg of a mixture of oats and barley (500/500 g kg^{-1}) and 1.25 kg day^{-1} of a commercial rapeseed meal. Supplements were formulated so that the diets E and P supplied the same amount of crude protein (CP) and diets E and EP supplied equal amounts of energy.

Experiment 5: Herbage allowance and supplementary feeding (1998) (I, II)

The effects of low (LH) and high (HH) daily HA of 18 and 24 kg DM cow^{-1}, on herbage and grazing area requirement was studied within a S grazing system. Three pastures were divided into two similar areas and allocated at random to the two HA treatments. The cows received fresh pasture each day. The length of the rotation cycle was adjusted to the grazing conditions and the pastures were grazed from 2 to 4 times, depending on the severity of tramping and length of the period which vegetation needed to recover. Also some additional areas were included in the grazing rotation. The cows were transferred simultaneously to the next pasture and the grazed areas were topped.

The feeding study was conducted with 8 lactating (148 ± 45 days in milk) cows as two 4 x 4 Latin squares with 21-day periods comprised of 14 days for dietary adjustment and 7 days for sample collection. The cows were divided into two balanced squares and the treatments were randomly assigned to each cow within a square. Four experimental treatments in a 2 x 2 factorial arrangement consisted of two levels of HA (18 or 24 kg DM day^{-1}) and two levels of concentrate supplementation (2.5 or 5.0 kg day^{-1}). The concentrate consisted of (g kg^{-1}) a mixture of organic oats (450), barley (450) and commercial rapeseed meal (100).

Experiment 6: Compost fertilisation and seed mixture for annual grazed swards (1999) (III)

The effect of soil-deposited compost was studied with annual swards in a grazed field trial. The field trial was conducted according to a randomised complete-block design. The treatments with three replicates were fertilisation (main plot), unfertilised (U) or 25 t ha^{-1} farmyard manure compost (C), seed mixture (split-plot) common vetch mixture (CV), hairy vetch mixture (HV), Persian clover mixture (PC) or Persian clover – white clover (PWC). The main plots measured 35.00 x 17.50 m with subplots of 17.50 x 8.75 m. Cattle manure originated from Siikasalmi farm was mixed with straw, processed one week in a drum compostory and matured approximately 3 months in a heap under permanent cover before application. During the grazing season the experimental area was grazed 5 times by replication lactating Ayrshire cows. Periods of grazing (GP1 – GP5) within the grazing season were concerned as split-split-plots. The cows were removed from each replicate when the targeted POST SH (10-12 cm) of the unfertilised areas was approached. The rotation cycle was 21 days, except 14 days between GPI and GP2. Immediately after grazing each replicate was topped.

Experiment 7: Vetch- and clover-based seed mixture and concentrate regimen (1999) (III)

The effect of vetch and clover based mixtures on pasture herbage was studied in 1999. Three former perennial pastures (total 3 ha) were divided into two equal areas for seeding. The seed mixtures, which consisted of a vetch- (VM) and a clover- (CM) based mixture, were allocated at random to two halves of each pasture. The herbage allowance was 21.5 kg DM (above 3 cm) per cow day^{-1}. Small paddocks were grazed for three to four days. The size of the paddocks was determined on a HM basis to meet the HA demand. The cows in both grazing treatments were transferred simultaneously to the next pasture. After grazing, the pastures were topped.

The feeding study was conducted with 8 lactating (150 ± 36 days in milk) Finnish Ayrshire cows, as two 4 x 4 Latin squares with 21-day feeding periods that consisted of a 14-day adjustment period and a 7-day recording period. The cows were divided to two balanced squares and the treatments were randomly assigned to each cow within a square. Four experimental treatments in a 2 x 2 factorial arrangement consisted of two sward mixtures (clover or vetch) and 4.0 kg day^{-1} of concentrate offered either 4 kg once or 2 kg twice daily. Concentrate was offered at morning milking in both feeding regimens, and at the afternoon milking in the twice-daily treatment. The concentrate consisted (g kg^{-1}) of oats (375), barley (375) and rapeseed meal (250).

4.3. Implementation of the experiments

Grazing and feeding practices

Strips were delimited in the S grazing in experiments 4, 5 and 7 by easily-moved electric fences and a watering point moved from strip to strip (see the cover picture). Water was provided from a point outside the experimental field in experiments 1, 2, 3 and 6. Areas were topped after grazing to a mower height of 10 cm.

All cows were given a mineral mixture during milking at 0600 and 1600 h and on pasture they had access to salt licks. Supplementary feeding was given during milking according to the experiment design for experiments 4, 5 and 7. In all other experiments cows received 0–6 kg concentrate supplementation allocated acording to milk yield and regulations (CEC 1999).

Herbage and soil measurement and analysis

Herbage samples for all the experiments were hand cut using shears and an aluminium frame (74.0 cm x 22.5 cm and a height of 3 cm). The botanical composition of PRE HM was determined by hand sorting, approximately half of each of the homogenised samples for legumes, grasses, weeds and cereals. The dry matter content and botanical proportions of herbage samples were determined by oven drying at 105 °C for 24 h. Herbage samples for analysis were dried at 60 °C and stored at room temperature. In experiment 1, botanical samples collected before the second GP in 1995 were analysed for Kjeldahl N. In the other experiments the herbage samples were analysed for OM by ashing at 600 °C for 12 h, nitrogen (Kjeldahl N) and *in vitro* organic matter digestibility (IVOMD) using a cellulase-based method (Friedel 1990) and NDF according to Van Soest et al. (1991). In experiment 2 (IV), herbage samples were also analysed for acid detergent fibre (ADF) and lignin according to Van Soest et al. (1991). The mineral (Ca, Mg, P, K, Na) content of the herbage was determined in experiment 2 (V) in composite samples for each seed mixture in 1996 and for each sample during 1997 and 1998, and in experiment 3 for each sample according to Luh Huang and Schulte (1985) by ICP emission spectrophotometry (Thermo Jarrel Ash/ Baird, Franklin, USA). Soil samples were analysed according to standard procedures (Soil Analysis Service Ltd, Vuorinen and Mäkitie 1955). In experiments 2, 3, 4, 5, 6 and 7, POST SH was measured using a sward stick and a total of 15-20 and 40-50 random measurements (including both eaten and uneaten areas) per plot and paddock were collected, respectively (Bircham 1981).

Animal measurements, milk and concentrate feed analyses

The milk yield was measured with daily in experiments 4 (I, II), 5 (I, II) and 7 (III). The average daily yield results for each cow is based on measurements of milk production collected during the last 6 days of each experimental period (collection period). The average milk composition values for each cow per period are based on samples from six consecutive milkings. Samples were analysed for fat, protein and lactose using an infrared milk analyser (Milkosan 605) and for urea according to McCullough (1967). During each collection period cows were body condition scored. Representative samples of concentrates were collected during each collection period. The concentrate feeds were analysed for OM, N and NDF using the same methods described for herbage samples.

Statistics
In experiments 1 (unpublished) and 2 (IV, in the summer of establishment), the effects of treatments were determined by analysis of variance for randomised block design. In experiment 2 (IV, main experiment), the effects of seed mixture (main plot), year (split-plot) and grazing period (split-split-plot) on herbage parameters were assessed by analysis of variance for repeated measurements over time using a spilt-plot model for longitudinal data. In experiment 3 (unpublished), the effect of seed mixture (main plot) and grazing period (split-plot) and in experiment 6 (III) the effect of fertilisation (main plot), seed mixture (split-plot) and grazing period (split-split-plot) were studied similarly. Differences between the treatments were compared using Tukey's test. Relationships between herbage parameters were determined using Spearman rank correlation coefficients. In experiments 4 (I) and 5 (I), the effects of two grazing methods or two herbage allowances were analysed using the paired-sample t test. The milk data from experiments 4 (I, II), 5 (I, II) and 7 (III) was analysed using SAS systems for linear models for Latin square design (Littell et al. 1992). Effects of diets were further separated into single degree of freedom orthogonal contrasts that allowed comparisons of the effect of treatments and their respective interaction.

5 RESULTS AND DISCUSSION

The focus in this study was to combine the aspects of plant, animal and organic production, as they are all involved in organic dairy pastures. This pioneer work provides a characterisation of Nordic organic pastures, suggests novel legume species for Nordic conditions, considers the advantages and disadvantages of manure compost fertilisation, proposes tools to improve grazing efficiency and assesses the benefits of supplementary feeding. Most of the references are from conventional studies since comparable organic data are very rare.

5.1 Characterisation of organic pastures

When starting this study a typical organic pasture had not been adequately characterised and hence the picture was unclear. This study showed that organic pasture herbage is a heterogeneous mixture of three botanical components, grasses, legumes and weeds, which are clearly divergent both from the systems approach and regarding nutritive value. Hence the botanical proportions are crucial for determination of the overall nutritive value of the pasture herbage. In the present study the largest herbage component was usually grasses (Table 2). Hence their nutritive value had the most pronounced effect on the overall nutritive value of the herbage. The botanical components differ in their response to fertilisation, especially N availability. For instance, in Experiment 1 (unpublished) the CP contents of grasses, clovers and weeds were 120, 209 and 165 g kg^{-1} DM, respectively. In conventional farming the nutritive value of grasses, herbage production, intake and milk yield per cow has been reported to decrease with decreasing levels of N application (Peyraud 1998, Valk et al. 2000). The first critical consequence of N deficiency is a sharp decrease in the HM production of grasses (Mayne and Peyraud 1996). Also the CP content of N unfertilised grass has been reported to be clearly lower compared to fertilised grass (106 and 173 g kg^{-1} DM, respectively) (Delagarde et al. 1997). However, the prevailing soil fertility is of key importance (Leaver 1985). According

Table 2. Mean values of herbage quantity and quality.

Experiments	2 (IV,V) Clovers 1996-1998	3 (unpub.) Bidsfoot/ clover 1998	4 (I, II) Grazing method 1996-1997	5 (I, II) Herbage allowance 1998	6 (III) Annual 1 1999	7 (III) Annual 2 1999
Pre-grazing herbage mass (kg DM ha^{-1})	1830	1664	1265	1945	1723	1827
Post-grazing herbage mass (kg DM ha^{-1})	1090	Not measured			1157	Not me.
Number of grazing periods Per summer	5	5	4	2-4	4	4
Length of rotation cycle (weeks)	3	3	3	Varied	2-3	Varied
Post-grazing sward height (cm)	12.7*	11.7	11.2	10.3	11.7	11.1
Proportion of species of DM (g kg^{-1} DM)						
- Barleys					201	236
- Grasses	666	594	689	448	484	280
- Weeds	143	89	163	79	96	113
- Legumes	191	317	148	473	218	371
Chemical content of DM (g kg^{-1} DM)						
- Ash	97	94	90	91	118	116
- Crude protein	184	165	177	170	206	217
- Neutral detergent fibre	510	447	521	453	433	391
- Acid detergent fibre)	264	Not measured				
- Lignin (g kg^{-1} DM)	37.8	Not measured				
In vitro digestibility of OM	0.754	0.758	0.753	0.748	0.751	0.760
Mineral content of DM (g kg^{-1} DM)						
- Calcium	7.1	8.4	Not measured			
- Magnesium	2.2	2.5	Not measured			
- Phosphorous	4.3	3.3	Not measured			
- Potassium	36.2	29.0	Not measured			
- Sodium	0.08	0.20	Not measured			

* In Experiment 2, the post-grazing sward heights were only determined during 1997 and 1998.

to Delaby and Peyraud (1998), with rich and deep soils containing high levels of OM, N fertilisation can be dramatically decreased without negative impact on the milk yield from the pasture, and the herbage CP can be maintained above 150 g kg^{-1} DM. Further, with soil having low N supply because of low soil OM content the same reduction in fertilisation resulted in a clearly lower milk yield, and the herbage CP content decreased below 120 g kg^{-1} DM.

Legumes are independent of soil N and in organic systems they should provide N for the whole system. Legumes fix N for their own use and in a healthy vigorous plant only small amount of nitrogen will be made directly available to associating species (Sprent and Sprent 1990). The beneficial role of legumes for companion grasses was shown in Experiment 2 (IV), since during the establishment summer the CP of grasses was clearly lower in the pure grass mixture than in the mixture with white clover (144 *vs* 182 g kg^{-1} DM). According to Ledgard (1991), in pasture the fixed N is transferred to grasses by two routes of nearly equal importance by an 'above ground route' via animal excreta and by 'below ground transfer' via either decomposition of legume roots and plant material in grazed pastures (major) or direct excretion of N compounds from legume (minor). Environmental stress, for instance moisture stress or grazing, increases the amount of clover turnover, decomposition and also nitrogen available for other plants (Ledgard and Steele 1992). It should be noted that if the proportion of clover in an unfertilised sward is low, the amount of fixed N available for other species also decreases. In Experiment 3 (unpublished), the CP content of the total herbage was low (136 g kg^{-1} DM) in grass mixture with a low (0.116) clover proportion and high in white clover mixture (207 g kg^{-1} DM) with a high (0.586) clover proportion (Table 5). This result is in line with Wilkins et al. (1994) who reported low CP content (83–129 g kg^{-1} DM) in N unfertilised ryegrass-white clover mixtures with a relatively low proportion of clover (0.01–0.20).

In Experiments 2 (IV, V) and 3 (unpublished), the proportion of legumes correlated with the herbage CP and NDF contents and the Ca and Mg concentrations (Table 3). In Experiment 3 (after fallow), legumes were related to the PRE HM and P and K concentrations, but not in Experiment 2 (an old pasture area). Generally grasses are reported to be better competitors for K and P than clovers (Dunlop et al. 1979, Høgh-Jensen et al. 2000). The prevalent soil type and cultivation history of the area is important for soil fertility, which impacts on the role of legumes. In Experiment 2 (IV), despite year-on-year decreases in the proportion of clover in the sward, the mean summarised PRE HM did not decrease. This probably reflected a previous long pasture period and efficient recycling of nutrients. Despite the higher legume proportion, the mean CP content of the herbage was lower in Experiment 3 than in Experiment 2, suggesting a lower N availability from soil for grasses resulting in a lower competitiveness for other nutrients compared to clovers. For grazed clover and grass the adequate shoot contents of K and P for maximum growth have been summarised to vary between 20.0 -25.0 and 3.5 - 4.0 g kg^{-1} DM, respectively (Reuter and Robison 1986). In Experiment 2 (old pasture area), the mean K and P contents of the unfertilised herbage were higher. In Experiment 3, the previous fallow period and the lower soil P and K values resulted in lower herbage mean P and K values than in Experiment 2 (Table 2). In a Danish farm study, the proportion of white clover correlated with CP, NDF, Ca, Mg, K but not with IVOMD or the P content of the herbage (Søegaard 2002).

The optimum proportion of legumes in the sward has been suggested to be in the range 0.20 - 0.50 as a compromise between the amount of biological fixed N, herbage yield, animal performance, nutrient losses and bloat risk (Alder et al. 1967, Pflimlin 1993, Kristensen et al. 1995, Lane et al. 2000). However, based on current data, under Nordic conditions it is difficult to maintain a constant medium high legume proportion, important for animal nutrition, throughout the grazing season and from year to year. Since the herbage quality is related to the legume proportion, a varying legume proportion is a challenge for animal feeding. However, the composition of the herbage offered and that grazed is not the same because of animal selection (Prache et al.1998, Dalley et al. 1999). In rotational grazing systems excess of HA increases selection and limitations in HA and grazing area decreases selection. According to Penning et al. (1995), when given a choice between grass and clover, cattle selected a diet with a majority of clover and the animals did not reduce the intake of clover in their diet even when it created a risk of bloat.

The weed content and composition of the sward depend on the previous cultivation history (seed bank) and the prevalent growing conditions and management. The number of dicot species found in pre-grazing herbage samples for Experiment 2 (Kuusela and Hytti 2001) and 3 (unpublished) was 22 and 28, respectively. In Experiment 3 (after fallow), the number of species was higher and included species that would suffer from frequent ploughing and cutting. In both experiments three of the four most common weeds were of the same species, indicative of relatively good soil fertility which was confirmed by soil analysis (Lampkin 1994). In a Norwegian study, the total number of species in an organically managed pasture was 33, including monocotyledons (Steinshamn et al. 2001). Unlike HM, the biodiversity of plant species increases when the soil nutrient status, herbage biomass or vegetation height decreases (Peeters and Janssens 1998, Jutila 1997). To meet the demands of lactating cows, good pasture productivity rather than richness of species must be the main focus.

In the present study, frequent grazing and cutting after each grazing session proved an adequate method for controlling weed growth (II). However, the proportion of weeds occasionally approached the proportion of legumes. The impact of the nutritive value of the weeds on the total nutritive value of the herbage cannot be ignored. In the present study, the mineral content of the weeds was clearly higher than that of the grasses and often higher than that of the clovers (Table 4). In Experiment 2 the proportion of weeds correlated positively with CP (r_s= 0.203, P<0.01) and lignin (r_s= 0.487, P<0.001) and negatively with NDF (r_s= -0.294, P<0.001), but was not related to IVOMD (n= 288, unpublished data). In Experiment 3 (unpublished), the low amount of weeds did not correlate with herbage quality. Several species the same as, or related to, those predominating in the current study have been suggested as potential herbage species for animal feeding (Wilman and Riley 1993, Haugland 1995). In organic pasture, a controlled proportion of certain dicotyledonous weed species can be seen as beneficial herbs in animal nutrition, important factors in the nutrient cycle and inputs for biodiversity.

Herbage availability and nutritive value of herbage are of high priority, because they affect the intake of the grazing animals. Based on the mean values of measured parameters in Experiments 2, 3, 4, 5, 6 and 7, a characteristic was a moderate PRE HM associated with a medium nutritive value (Table 2). Despite the different botanical proportions, the mean IVOMD was of a similar (0.748 - 0.760) good level in all experiments both with perennial and

Table 3. Spearman correlation between herbage legume proportion in pre-grazing herbage mass and its chemical content in Experiment 2 and 3.

Experiment	2 (IV, V) clover proportion	3 (unpublished) legume proportion
Pre-grazing herbage mass	NS	0.315*
Crude protein content in PRE HM	0.298***	0.686***
Neutral detergent fibre in PRE HM	- 0.202**	- 0.763***
Acid detergent fibre in PRE HM	NS	Not measured
Lignin in PRE HM	0.514***	Not measured
In vitro OM digestibility in PRE HM	NS	NS
Ash	0.361***	0.422**
Calcium	0.673***	0.832***
Magnesium	0.493***	0.728***
Phosphorous	- 0.331***	0.526***
Potassium	- 0.140*	0.304*

In Experiment 2, the mineral contents were determined during 1997-1998 (n=200) and the other herbage parameters during 1996-1998 (n=300). In Experiment 3, all measurements were made in 1998 (n=45).

Table 4. The seven most common weed species in pastures and their proportions and average mineral contents compared with grasses and legumes in Experiments 2 and 3 during 1998.

Experiment 2 (Kuusela and Hytti 2001)		Mineral content g kg $^{-1}$ DM			
Plant species	Proportion of weeds DM	Ca	Mg	P	K
Taraxacum officinale sp.	0.350	8.4	2.9	4.0	45.3
Plantago major	0.321	15.9	3.8	4.2	38.0
Ranunculuns repens	0.132	13.1	3.4	5.8	47.0
Rumex longifolius	0.102	8.5	4.9	5.3	39.0
Polygonum aviculare	0.040	8.1	4.2	5.3	25.6
Stellaria media	0.027	7.6	3.7	7.4	73.0
Veronica serpyllifolia	0.010	9.5	3.3	5.9	33.6
Trifolium repens		12.5	3.0	3.9	33.7
Grasses		3.3	1.4	4.0	29.8

Experiment 3 (unpublished)		Mineral content g kg $^{-1}$ DM			
Plant species	Proportion of weeds DM	Ca	Mg	P	K
Taraxacum officinale sp.	0.432	12.0	2.6	4.3	46.4
Ranunculuns repens	0.133	13.6	3.8	4.6	37.7
Tussilago farfara	0.115	16.4	3.3	3.4	55.5
Plantago major	0.111	19.9	4.7	3.7	32.6
Cirsium arvense	0.096	20.7	4.6	3.5	42.5
Achillea millefolium	0.054	11.8	2.6	5.2	41.7
Achillea ptarmica	0.020	9.1	2.6	4.5	33.5
Lotus cornicultus		9.2	2.8	2.6	26.8
Trifolium repens		12.2	3.0	3.5	28.5
Grasses		3.8	1.5	3.2	26.8

annual swards. The mean CP value in the experiments varied between 165 and 217 g kg^{-1}DM. In contrast, Finnish N fertilised grass pastures usually have a clearly higher PRE HM, slightly higher digestibility and a CP content often above 200 g kg^{-1}DM (Khalili and Sairanen 2000, Virkajärvi et al. 2002, Tuori et al. 2002). These differences are understandable, because herbage digestibility depends mainly on the state of maturity (the length of rotation cycle), and a decrease in N fertilisation has only minor effects on digestibility, while the CP content depends mainly on soil N availability and for legumes, on N fixing (Buxton 1996, Mayne and Peyraud 1996). However, Delagarde et al. (1997) reported 4 % lower digestibility of unfertilised compared to fertilised pastures, because of a lower green leaf proportion. Also decreased HM can result in a need to extend the rest period between grazing and hence affect digestibility (Valk et al. 2000). When legumes are involved, the N availability for grass growth increases. For clover mixtures, a slightly lower digestibility of herbage offered can be accepted, since cows can have higher intakes and hence produce more milk from clover-grass swards compared to grass swards with the same digestibility (Leaver 1985).

The herbage mineral content affects the mineral feeding of the grazing cows. In the present study the mean Ca and Mg contents of herbage measured in Experiments 2 and 3 were higher than in conventional Finnish pastures, but the P and K contents were similar (Table 2). It should be noted that the effects of the year and GP on the measured herbage parameters were usually greater than the effects of seed mixture or fertilisation, highlighting the importance of temporal considerations (III, IV, V). This result is in line with the findings of Weisbjerg and Søegaard (2000) that the season had considerable effects on the IVOMD and CP contents of a grazed clover-grass mixture. In the present study, heterogeneity in species, herbage production and herbage chemical content both spatially and temporally was found to be a characteristic of organic pastures.

5.2. Novel legume species for grazed mixtures in Nordic conditions

The lack of suitable legume species for grazing has depressed organic pasture productivity in Nordic countries because red clover, the basal legume for organic silage, suffers from frequent grazing. Winter hardiness and tolerance of grazing are the two most important considerations for the choice of legume species for perennial grazed legume-grass swards in Nordic conditions. Following those one the nutritive value and bloat disposition of legumes for both perennial and annual swards. A systems approach is needed when considering the available amount of herbage along the entire grazing season and for minimising potential risk of transference of clover rot *(Sclerotinia trifolium)* (Taylor and Quesenberry 1996). Occasionally tolerance of extreme weather and soil conditions is needed. Based on current data and here reviewed literature the characteristics of alternative legume species in the context of Nordic grazing are summarised in Table 5. A sufficient legume proportion is essential for the nutritive value of herbage and current and future growth. In the present study, the mean legume proportions and the CP contents of seed mixtures were strongly related in Experiments 2, 3 and 6 (Fig. 2). The mixtures which gave the highest mean legume proportions also gave the highest mean CP contents, indicative to high N_2 fixation. However, CP content of seed mixtures in different experiments

Table 5. Characterisation of potential legume species for grazed mixtures in Nordic dairy farming.

		Positive	Negative
Red clover	Perennial	Basal legume for Finnish organic farming because of good yield potential for cut grasses Can tolerate drought	Suffers from frequent grazing Short lived Can cause bloat
White clover	Perennial	Tolerates close grazing Good yield potential in pasture Can increase its proportion during summer by stoloniferous progression, long lived	Suffers from hard winters Can cause bloat Can suffer from drought
Alsike clover	Perennial	Can tolerate acid and moist soil conditions	Suffers from frequent grazing Short-lived Can cause bloat
Birdsfoot trefoil	Perennial	Non-bloating and decreased protein degradation in rumen (Condensed tannins) Can tolerate poor soil fertility and drought	Can suffer from hard winters Relatively low yield potential in Nordic conditions
Persian clover	Annual	Good yield potential in pasture Supports autumn grazing	Can cause bloat (as happened in the present study) Can transform clover diseases
Common vetch	Annual	Medium digestibility	Suffers from frequent grazing Can cause bloat
Hairy vetch	Annual	Good yield potential in pasture Tolerates frequent grazing Supports autumn grazing	Relatively low digestibility Can cause bloat

was located at different levels due to differences in growing conditions. All seed mixtures displayed wide variation in legume proportions which was partly reflected variation in herbage nutritive value between and within grazing seasons (Figs. 3, 4).

<u>The choice of clovers for perennial swards</u> was assessed in Experiment 2 (IV, V). For all the seed mixtures the proportion of clover in the sward declined from year to year and varied within each grazing season, influencing the nutritive value of the herbage (IV). The annual decline in clover were primarily due to hard winter conditions, as reflected by the low but similar proportion of clover in all the clover mixtures following overwintering (Fig. 3). In agreement with Nissinen et al. (2002), in the present study the stoloniferously progressive, white clover was able to increase its proportion during summer more than the other clovers. This resulted in a higher mean proportion of clover for the mixtures containing white clover than for the other mixtures (Table 6). Combining alsike and white clover mixtures did not decrease the temporal changes in the proportion of clover in the sward (Fig. 3). The amounts of estimated grazed herbage were similar between the seed mixtures (Table 6). The different seed mixtures resulted in different CP, NDF, ADF, cellulose, hemicellulose, Ca and Na contents, but similar IVOMD and contents of lignin, Mg, P and K (Table 6). Both the white clover-based mixtures had higher CP and lower ADF concentrations than the other mixtures. The white clover mixture was distinctive in containing low amounts of NDF, cellulose and

hemicellulose and high amounts of Ca compared with the other seed mixtures (IV, V). Winter-hardy white clover cultivars are the most suitable perennial pasture clovers for Nordic conditions.

The survival and suitability of birdsfoot trefoil compared with white clover in Nordic organic grazing conditions was studied in Experiment 3 (unpublished). White clover is known to suffer from summer drought which birdsfoot trefoil should tolerate better (Ramírez-Restrepo et al. 2004), but during the moist summer of 1998 the differences in drought tolerance could not be determined. The different seed mixtures resulted in similar ($P > 0.05$) PRE HM and POST SH (Table 6). During the summer, the proportion of birdsfoot trefoil remained relatively low in the birdsfoot trefoil mixture, varying between 0.128 - 0.165. Some white clover also appeared in the birdsfoot trefoil and grass mixture plots and increased the legume proportion. Despite the lower seeding rate, the proportion of white clover in the white clover mixture was in Experiment 3 clearly higher than in Experiment 2 (Fig. 3). The experimental area had been long term grass fallow, which probably encouraged clover growth during the first summer. Despite the relatively high proportion of clover in the white clover mixture, no cases of bloat occurred when dairy cows grazed the experimental area. Birdsfoot trefoil contains condensed tannins which bind proteins to complexes that are insoluble in the rumen, thereby decreasing protein degradation and also the occurrence of bloat (Julier et al. 2002, Min et al. 2003). Hence low concentrations of condensed tannins (20-45 g kg^{-1} DM) are beneficial, but high levels of condensed tannins decrease animal performance (Min et al. 2003). The minimum concentration of condensed tannins to prevent bloat has been defined to be 5 g kg^{-1} DM (Tamminga and Suderkum 2000). In the present study, the amount of condensed tannins was not measured, but typically their content in birdsfoot trefoil varies between 5 and 36 g kg^{-1} DM, depending on the variety and growing conditions (Hedqvist et al. 2002, Tamminga and Suderkum 2000). In the present study, all the seed mixtures resulted in similar IVOMD, but different ($P<0.05$) contents of CP, NDF, Ca and Mg (Table 6). The use of birdsfoot trefoil instead of white clover did not improve the herbage yield or quality, because the amount of birdsfoot trefoil remained low. In New Zealand, a pure stand of birdsfoot trefoil has resulted in higher HM yields with better IVOMD than white clover – perennial ryegrass pastures (Ramírez-Restrepo et al. 2004). However, according to the LEGSIL study, the growth potential of birdsfoot trefoil in Finland was clearly lower compared to red and white clover (Nissinen et al. 2002). In Nordic conditions the inclusion of beneficial birdsfoot trefoil in clover-grass mixtures might be considered in order to reduce protein degradation of the herbage and decrease bloat risk, especially in young clover-rich pastures. In Sweden, birdsfoot trefoil has persisted over several years with timothy, meadow fescue, perennial ryegrass and white clover (Nilsdotter-Linde et al. 2002). If winter-hardy cultivars of birdsfoot trefoil are available, they are recommended for inclusion in Nordic organic clover-grass mixtures for grazing.

The choice of legume species for annual grazed legume-grass-cereal mixtures was assessed in two experiments (III). Of the vetches, hairy vetch was more suitable for grazing than common vetch as concluded in the experiment from the higher legume proportion and PRE HM for the hairy vetch mixture than for the common vetch mixture, the difference being distinct in the late grazing season

Table 6. Effect of seed mixture (SM) on pre- and post-grazing herbage mass, post-grazing sward height and botanical and chemical composition of pre-grazing herbage mass in experements 2, 3 and 6. Reproduced from papers III and IV, unpublished data from Experiment 3.

	Herbage mass Kg DM ha^{-1}			Post-grazing	Proportion of legumes	Chemical content in DM g kg^{-1} DM							*In vitro* organic
	Pre-grazing	Post-grazing	Pre- min. post-Grazing	Sward height [2] cm		Organic matter	Crude protein	Neutral det. fibre	Acid det. fibre	Lignin	Calcium	Magne-sium	matter digesti-bility
Seed mixtures in Experiment 2													
- Alsike clover	1910 b	1202 c	708 a	13.5 b	0.148 ab	905 a	178 a	518 c	269 b	38.8 a	5.74 a	1.92 a	0.749 a
- Red clover	1903 b	1202 c	702 a	13.7 b	0.182 b	903 a	186 b	519 c	267 b	39.9 a	6.11 ab	2.13 a	0.750 a
- White clover	1684 a	876 a	808 a	11.3 a	0.264 c	901 a	195 c	482 a	253 a	37.5 a	7.16 c	2.22 a	0.762 a
- White and alsike clover	1830 ab	1033 ab	797 a	11.8 a	0.235 c	904 a	189 bc	499 b	258 a	35.6 a	6.24 b	2.10 a	0.758 a
- Grass	1844 ab	1141 bc	703 a	13.5 b	0.126 a	905 a	172 a	533 d	274 b	37.3 a	5.76 a	2.00 a	0.750 a
Seed mixtures in Experiment 3													
- Birdsfoot trefoil	1598 a	Not measured		12.1 a	0.248 b	910 a	153 b	457 b	Not measured		7.51 b	2.41 b	0.750 a
- White clover	1800 a			11.4 a	0.586 a	900 b	207 a	392 a			11.2 a	2.86 a	0.758 a
- Grass	1592 a			11.8 a	0.116 c	909 a	136 c	493 c			6.46 c	2.11 c	0.765 a
Seed mixtures in Experiment 6													
- Common vetch	1645 a	1109 a	519 a	11.1 a	0.153 a	885 a	193 a	444 a	Not measured				0.756 a
- Hairy vetch	1821 b	1221 a	593 a	12.1 a	0.300 c	878 b	229 b	434 ab					0.727 b
- Persian clover	1758 ab	1105 a	611 a	11.7 a	0.255 b	881 ab	204 a	424 b					0.764 a
- Persian and white clover	1670 ab	1142 a	512 a	11.7 a	0.165 a	881 ab	195 a	430 ab					0.759 a

[2] Post-grazing sward height was only determined for 1997 and 1998.

[a-e] Means within the same column, the same variable and the same experiment not sharing a common letter differ significantly (Tukey, $P < 0.05$).

[*] $P < 0.05$; [**] $P < 0.01$; [***] $P < 0.001$

(Table 6, Figs. 3 and 4). The mean PRE HMs of the two clover mixtures were between the vetch mixtures. The amount of PRE minus POST HM was not affected by the seed mixture. In Experiment 7 (III), the clover-based mixture had a higher PRE HM than the vetch-based mixture, which contained both the low yielding common vetch and the more productive hairy vetch. In this experiment the high proportion of clover at the end of the grazing season was associated with an increased incidence of bloat, which was probably linked to the higher digestibility (0.785 *vs* 0.739) and legume proportion (0.675 *vs* 0.534) of the clover-based mixture compared to the vetch mixture. This result is in agreement with Hall et al. (1994) reporting that the incidence of legume bloat was connected to herbage digestibility. In both experiments, mixtures containing hairy vetch had a higher CP content and lower digestibility than the other mixtures, these results being in agreement with Asefa and Ledin (2001).

Within a grazing season the proportions of barley, grasses, legumes and weeds in the sward varied from one GP to another, with barley predominating early in the summer but being rapidly displaced by other species, whilst grasses (in Experiment 6) or legumes (in Experiment 7) became increasingly dominant during late summer (III). It is likely that differences in the starting time and implementation of grazing and variations in the legume species contributed to the differences between experiments. On average, the content of CP and NDF and IVOMD of annual pastures were satisfactory. Their seasonal changes were related to changes in the botanical proportions, but large changes in the herbage botanical composition had only minor effects on the nutritive values in Experiment 6 (Figs. 3 and 4). No consistent differences

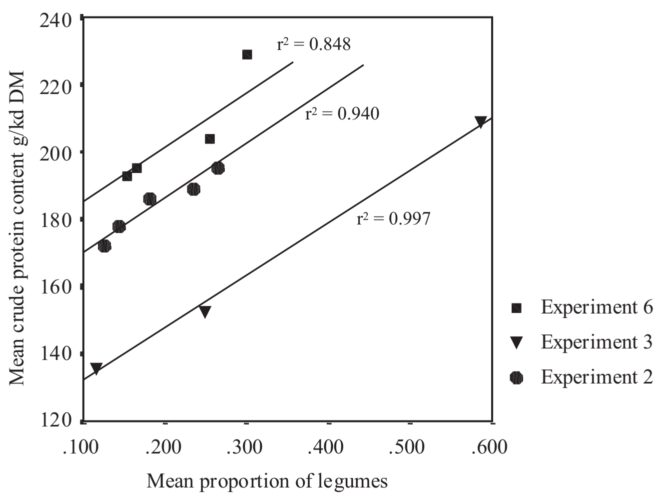

Figure 2. Scatter plots between experiment means of legume proportions and crude protein contents according to seed mixture in Experiments 2 (1996-1998) n = 5 x 60 (IV), Experiment 3 (1998) n = 3 x 15 (unpublished), Experiment 6 (1999) n = 4 x 30, III).

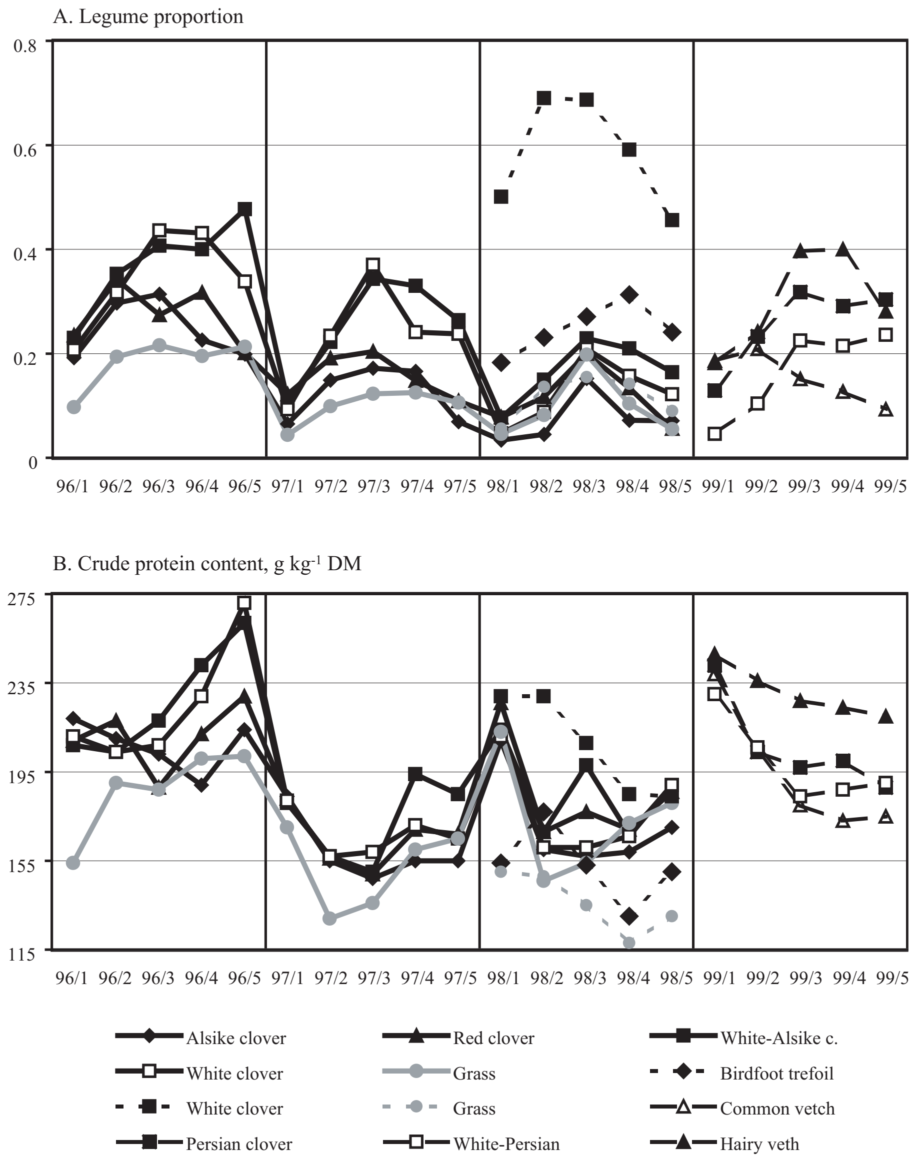

Figure 3. Temporal variation of legume proportion and crude protein content between seed mixtures in Experiments 2 (1996-1998, IV), 3 1998, (unpublished) and 6 (1999, III).

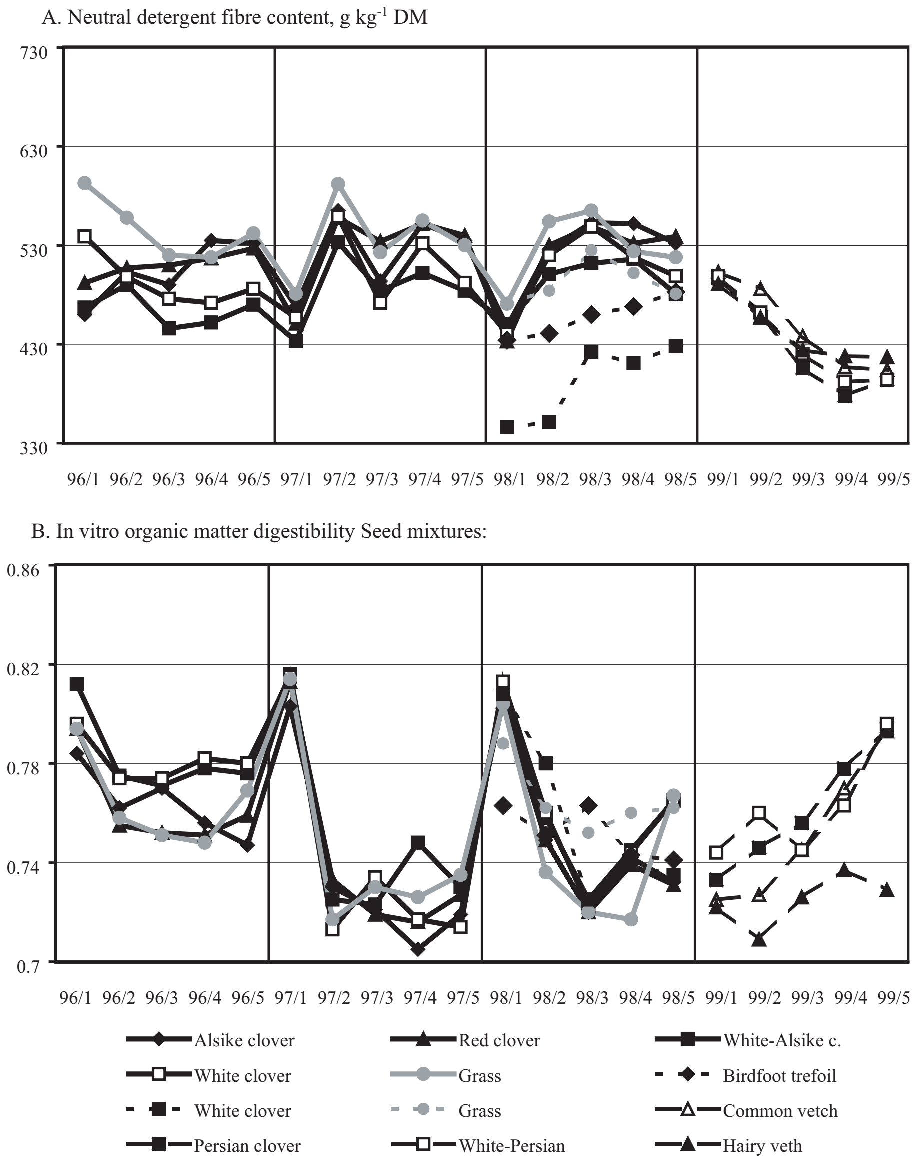

Figure 4. Temporal variation of organic matter in vitro digestibility and neutral detergent fibre content between seed mixtures in Experiments 2 (1996-1998, IV), 3 (1998, unpublished) and 6 (1999, III).

in CP and IVOMD were found between the experimental periods of the seed mixtures in Experiment 7 (III). Milk production and composition were similar for cows grazing clover and vetch seed mixtures (21.9 and 21.3 kg d^{-1} per cow, respectively), with the exception that urea concentrations were higher in milk produced from the vetch mixture compared to the clover mixture (393 and 319 mg kg^{-1}, respectively). Annual clover mixtures grow relatively well, but because of increased risk of bloat and potential transference of Crown rot they are not recommended for organic grazing systems. Based on current data and considerations, hairy vetch is the most suitable legume for Nordic grazed annual mixtures. It was able to maintain the highest legume proportion during the grazing season, without bloat, and best supported autumn grazing.

5.3 Use of manure compost fertilisation

In grassland farming, high inputs are known to result in high herbage yields but also in high nutrient losses and environmental hazards (Tamminga 2003). Recent literature has suggest that legume-based grazing systems may have the ability to reduce environmental problems by increasing the efficiency of N use and by avoiding a high transient surplus of soil mineral N (Hutchings and Kristensen 1995, Loiseau et al. 2001, Rochon et al. 2004). All grazing systems support soil fertility because most of the grazed nutrients are recycled back to pasture. Nutrient output in milk per cow is relatively low, often on the same level as the input from supplementary feeding (Fig. 5). However, the supply of nitrogen is the major factor affecting the yield of pasture plants. This supply can be derived from soil organic matter, from the excreta of the animals, from leguminous plants and from external fertiliser inputs (Leaver 1985). In organic farming systems, the proportion of legumes and their ability to accumulate N determine the potential productivity of the whole system and farmyard manure is a practical management tool to circulate nutrients and improve the fertility of low-fertility areas. The use of farmyard manure has to be carefully planned at the farm level because the amount of manure is limited.

Manure compost fertilisation increased the PRE HM by 18%, but not the amount of utilised herbage in Experiment 6 (Fig. 6). In agreement with Laws et al. (1996), in the present study the fertilised areas had clearly higher (27%) POST HM and higher (13%) POST SH compared with unfertilised areas (III). Post-grazing HM was influenced by an interaction between fertilisation and GP, such that when the POST SH decreased with advances in the grazing season the effect of fertilisation was similarly diminished (Fig. 7). The reduction in intake was attributed to smell even though the soil was harrowed after compost spreading, since the differences in the chemical

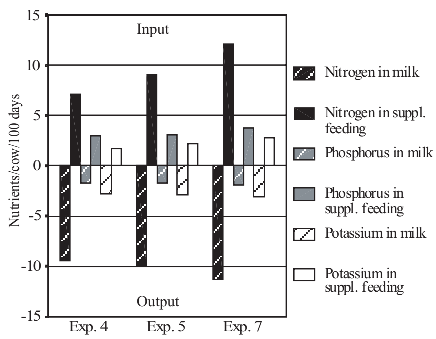

Figure 5. Average nutrient output kg in milk and input kg in supplementary feeding per cow calculated for grazing season of 100 days based on mean values from Experiments 4 (II), 5 (II) and 7 (III).

composition of the herbage were minor (III). It appears that the current reduction in POST HM between the fertilised and unfertilised treatments with advances in the grazing season can be explained as a gradual reduction in the smell of the compost and also due to adaptation by the cattle (Laws et al. 1996). In the present study, fertilisation by compost application had no effect on botanical composition, indicating that the slow release of nitrogen from the compost had only minor effects on inter-species competition (III). The mean CP content of the PRE HM was slightly higher for unfertilised compared with fertilised areas (209 and 202 g kg^{-1}DM, respectively, III). In agreement with the present study, mineral fertiliser application has been shown to reduce the CP content of oat-vetch mixtures, but unlike the present study was associated with a decrease in the proportion of legumes (Assefa and Ledin 2001). In the present study, fertilisation had no effect on the IVOMD (III), but mineral fertilisation decreased the IVOMD of oats-vetch mixtures (Assefa and Ledin 2001).

The renovation of a weak sward was studied in Experiment 1 (unpublished). During the summer of reseeding and manure compost application treatments had no effect on PRE or POST HM or clover proportion (fresh matter), reflecting the maturity of the compost resulting in only minor fertilisation or rejection effect. The average PRE and POST HM per GP were low (1090 and 787 kg ha^{-1}, respectively). When the after-effect of treatments was assessed in the beginning of summer 1995, the treatments had no effect on the mean PRE or POST HM, which were 1477 kg ha^{-1} and 808 kg ha^{-1}, respectively.

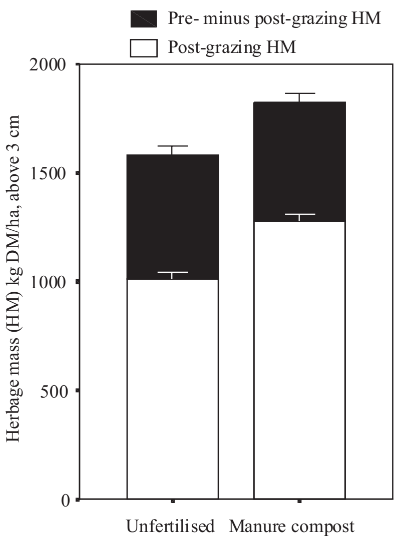

Figure 6. Effect of manure compost fertilisation on pre- and post-grazing herbage mass in Experiment 6 (III).

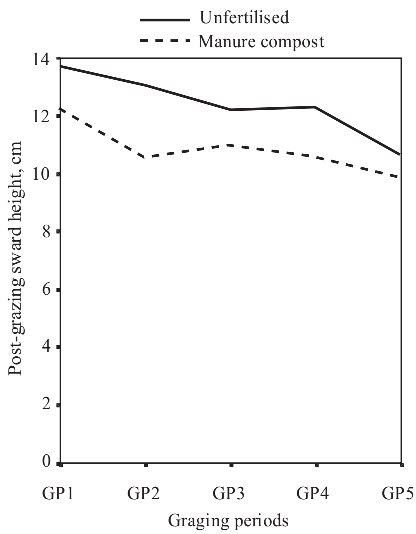

Figure 7. Effect of advances in the grazing season on post-grazing sward height of unfertilised and manure compost fertilised areas in Experiment 6 (III).

Seed application increased ($P<0.05$) the clover yield from 375 to 630 DM kg ha^{-1}, while compost application or treatment interaction had no effect on the clover yield (Kuusela 1995). The treatments had no effect on the average CP content of clovers, grasses and weeds (209, 120 and 165 g kg^{-1} DM, respectively). The application of compost or seed on growing pasture was not proven to be an efficient way to improve herbage production. In agreement with the present study, manure compost fertilisation of the sward had no effect on the herbage yield from a cut clover-grass sward in a Norwegian study, but unlike in the present study the clover proportion was decreased (Hansen et al. 1996). According to Baars (2002), the use of manure often conflicts with the growth of clover and it should only be used strategically. In some cases clover application/split seeding might be used to balance the clover proportion in the long term, but the success of the method depends on the weather conditions. According Nissinen and Hakkola (1995), the best way to improve a weak sward in Finland is to establish a new sward. Based on the current result, this recommendation also applies to organic pastures.

In agreement with the urine pilot study, the benefits of manure compost fertilisation in the form of a capitalised increase in grazed HM were not obtained in the present study. For areas which have been grazed for several years, the benefits of additional manure fertilisation seem to be minor. In case of very low herbage productivity, manure fertilisation increases the amounts of herbage offered and the animals might became accustomed to the fertilised herbage if they have no choice. For low fertility soils the long-term effects of fertilisation are most important. Organic pastures can sometimes require extra nutrient supplementation (manuring, liming, biotite, apatite or other permitted nutrients) to achieve and maintain soil fertility that can support long-term herbage production (Younie 1999). If other crops, such as harvested cereals, are included in the pasture crop rotation, it is recommended that they receive the manure compost so that the direct effect of fertilisation can be utilised in improved grain yields and so avoid the adverse effects on grazing and improve soil nutrient status.

5.4 Improvement of grazing efficiency

According to the present study, herbage production is often lower in organic grazing systems than in heavily fertilised conventional systems. Decreased PRE HM will affect the stocking rate, grazing area requirement, milk yield per animal and milk yield per hectare. It should be noted that grazed HM is the only DM harvested from the pasture and generally pasture productivity is limited due to failure in grazing management. In organic dairy farming the implementation of grazing should be optimised to avoid detrimental over-grazing and under-grazing situations. The stocking rate is one of the most important factors influencing both animal output per hectare and individual animal performance. In the present study, the impact of the stocking rate on grazing efficiency was clearly demonstrated in Experiment 2 (Fig. 8). According Finnish feeding norms (Tuori et al. 2002) applying the mean nutritional value of the herbage and estimates of the intake from pasture suggest these estimated benefits corresponded to increases of 1490 and 2960 kg ha^{-1} in energy-corrected milk (ECM) during the summer of 1997 compared with 1996 and 1998.

The pre-grazing herbage mass and the structural characteristics of the sward influence the daily herbage intake in rotational grazing systems even when a similar HA is maintained (McGilloway et al. 1999). In the present study, the mean PRE HM varied between 1265 - 1945 kg DM ha^{-1}, being generally lower than the recommendation of 2000 - 3000 kg DM ha^{-1} in conventional farming. Notable reductions in herbage intake have been observed when animals grazed swards supplying less than 2.5 t OM ha^{-1} and the HA was maintained by adjusting the stocking rate (Peyraud et al. 1996). In comparison, Finnish grazed or ungrazed natural meadows often provide HMs below 500 kg DM ha^{-1} (Jutila 1997), which is much too low for dairy cows. Limitations on the sward HM and structure, typical of unfertilised pastures, decrease the herbage intake and milk yield and increase the daily grazing area requirement compared with fertilised pastures (Delagarde et al. 1997, Peyraud and Astigarraga 1998). Within organic farming systems, N deficiency of grasses can sometimes substantially reduce herbage intake through reductions in the PRE HM and sward canopy structure. The positive correlation between PRE minus POST HM and PRE HM recorded in Experiment 6 (III) suggests the importance of sufficient PRE HM also for annual mixtures. This relationship was stronger for unfertilised areas (lower PRE HM) compared to fertilised areas (higher PRE HM), where the preference seems to be more influenced by other factors.

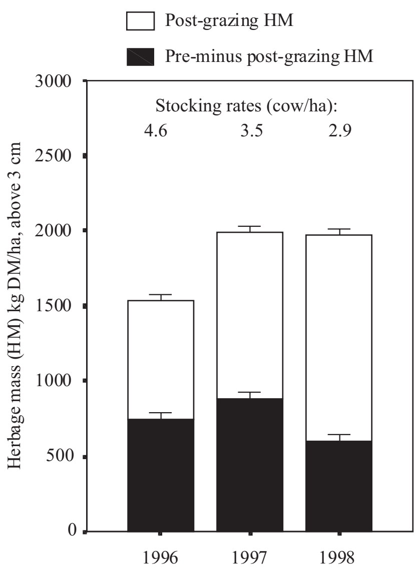

Figure 8. The effect of year on pre- and post-grazing herbage mass in 1996 – 1998 and associating estimated stocking rates in Experiment 2 (IV).

Extended rest periods between grazing episodes have been suggested as a means of increasing the HM of N deficient pasture, even if this occurs at the expense of large reduction in the herbage nutritive value and increase in the grazing area requirement (Delagarde et al. 1997). In Experiment 5 (I), by applying a flexible grazing system a higher PRE HM was obtained compared to Experiment 4 (I) and also the milk yield per hectare was higher in spite of slightly lower digestibility. However, the growing conditions and sward composition were also different. In organic farming systems, the optimum length of the rotation cycle is often a compromise between herbage quality and regrowth as measured by PRE HM. On the whole, management of organic pasture should aim to maintain good nutritive value of the basic herbage by applying an approximately normal length of rotation, but allow it slightly flexible by adjusting rotation length according to circumstances, and giving some buffer feed to meet animal requirements. Herbage of low nutritive value is much more difficult to complement in organic animal feeding.

The grazing area requirement per cow is an important consideration of grazing efficiency. In conventional farming the grazing area requirement per cow was 48% larger for unfertilised grass swards compared for fertilised grass swards (114 and 77 m^2 cow^{-1} day^{-1}, respectively) when a similar HA (above 5 cm) was maintained (Delagarde et al. 1997). In Experiment 4 (I), S grazing was more efficient than P grazing, since S grazing decreased the pasture area requirement by 26% per cow (Fig. 9) and increased the milk yield by 36% per hectare, but had no effect on animal performance. According to Dobbelaar (1988) a long exposure to a paddock extended the duration of disturbed sward growth. In the present study, in spite of the same rotation cycle daily S grazing provided longer rest periods between grazing than P grazing. Consequently PRE HM was estimated to be lower for P compared to S grazing, which contributed to the current observations as the same area was grazed repeatedly. Unlike in this experiment, Peyraud et al. (1989) found no difference between daily S or P grazing, but in their study primary growths on conventional perennial ryegrass swards were grazed. Based on the present study, rotationally grazed Nordic unfertilised organic clover-grass swards benefit from shorter animal residence.

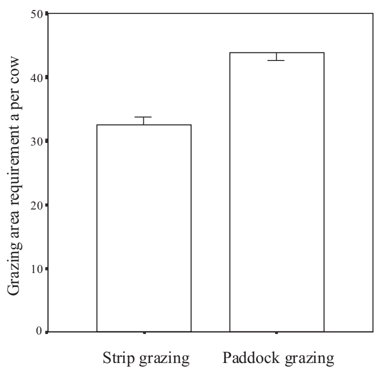

Figure 9. The average grazing area requirement per cow estimated for the summer in daily Strip grazing and Paddock grazing applying 21-day rotation cycle system.

Herbage allowance affect on milk yield per cow and hectare, pasture utilisation, POST HM and POST SH. Large incremental increases in HA have often had only minor effects on the milk production of individual animals per day (Table 7). In Experiment 5 (I), in agreement with Peyraud et al. (1989), when the HA was changed moderately, it had no effect on the daily milk yields. In contrast, according to Le Du et al. (1979), Peyraud et al. (1996) and Virkajärvi et al. (2002), larger increases in HA increased milk production per cow, but by clearly less than the increase in HA. According to Combellas and Hodgson (1979), the HA should be more than twice the intake measured on the soil surface to obtain individual maximum intakes. Consequently, the nutritive value of the herbage should be maintained by topping the swards after each grazing. The approach of maximised herbage intake per cow is not advantageous for organic dairy farming, since the intake is often limited either by low HM or, if adequate HM is obtained by extended rotation cycles, by decreased nutritive value.

In Experiment 5 (I), the milk yield per hectare was not significantly affected despite a 25% decrease in HA. In contrast, Le Du et al. (1979) and Virkajärvi et al. (2002) reported that the milk yield per hectare increased substantially when the HA was decreased, but in their studies the progressive effects of grazing treatments on the sward were minimised. In Experiment 4 (I), the HA of repeatedly grazed areas was maintained at 18 kg and 24 kg DM cow^{-1} and, consequently, negative cumulative effects of low HA on sward growth for organic swards were observed. Higher grazing pressure for the lower HA coupled with prevailing growing conditions (no fertiliser, heavy precipitation, silt soil and tramping) depressed the HM supply to a greater extent with low compared to higher herbage allowance. Hence the benefits of the lower HA were minor. The herbage allowance should not go under the level which the system can tolerate. In the present study, the sward tolerance limit was met before the animal tolerance limit, because with the lower HA the animal performance was not affected, but sward growth was depressed (I). Broadly it can be estimated that in Nordic organic dairy farming systems an adequate HA for mid-lactating cows might be somewhere in the range 20 - 26 kg DM cow^{-1}, depending on the milk yield, supplementary feeding and growing conditions.

The post-grazing sward height is a reliable indicator of adequate allowances and for continuous monitoring to prevent inefficient under-grazing and detrimental over-grazing (Le Du et al. 1979, Dalley et al.1999). Based on the current data, a target POST SH of 10-12 cm for grass-legume-based swards grown under the conditions of Nordic organic farming appears to be near optimal (I). In Experiment 5 (I), when cows compensated for the lower HA by eating closer to ground level, the decrease in mean POST SH (2 cm) compared with higher HA was associated with a reduction in herbage production. The suggested POST SH target seemed to be adequate also for annual legume-grass-cereal mixtures (III). Despite a similar HA and milk yield, the POST SH was lower for the vetch mixture compared to the clover mixture (10.3 and 11.8 cm, respectively),

Table 7. Effect of herbage allowance on milk yield from rotationally grazed fertilised and unfertilised swards.

	N-Fert	Grazing System	Herbage allowance d^{-1} (cutting height)	Supplementary feeding d^{-1}	Milk yield d^{-1} per cow
Experiment 4 (I)	no	Strip	21.5 kg DM (3 cm)	0 – 4 kg	19.3 kg
		Paddock		0 – 4 kg	19.2 kg
Experiment 5 (I)	no	Strip	18.0 kg DM (3 cm)	2.5 – 5 kg	19.5 kg
		Strip	24.0 kg DM (3 cm)	2.5 – 5 kg	20.4 kg
Le Du et al. 1979	yes	Strip	14.0 kg DM (0 cm)	No	13.2 kg
		Strip	25.0 kg DM (0 cm)	No	16.0 kg
		Strip	36.0 kg DM (0 cm)	No	17.2 kg
Peyraud et al. 1989	yes	Strip	19.0 kg OM (0 cm)	No	21.0 kg FCM
		Strip	26.0 kg OM (0 cm)	No	21.1 kg FCM
		Paddock	26.4 kg OM (0 cm)	No	21.6 kg FCM
Peyraud et al. 1996	yes	Strip	18.8 kg OM (0 cm)	No	18.3 kg [1)]
		Strip	29.2 kg OM (0 cm)	No	19.2 kg [1)]
		Strip	45.9 kg OM (0 cm)	No	20.1 kg [1)]
		Strip	18.8 kg OM (0 cm)	No	24.2 kg
		Strip	29.2 kg OM (0 cm)	No	26.2 kg
		Strip	45.9 kg OM (0 cm)	No	27.8 kg
Virkajärvi et al.	yes	Strip	19.0 kg DM (3 cm)	No	22.1 kg
2002		Strip	23.0 kg DM (3 cm)	No	22.5 kg
		Strip	27.0 kg DM (3 cm)	No	23.4 kg

[1)] Primiparous dairy cow.

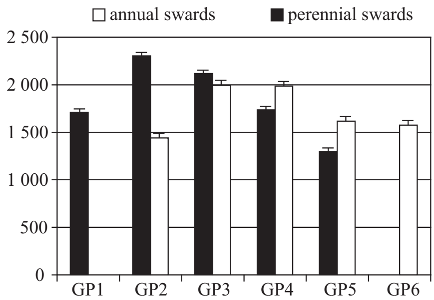

Figure 10. The effect of grazing period (GP) on the amount of mean pre-grazing HM in Experiment 2 (1996-1998, IV) and Experiment 6 (1999, III). Grazing of annuals started approximately at the same time as the second grazing period for perennials.

when the HA was maintained on an HM-adjusted grazing area basis. This result suggests that mid-lactating cows could compensate for the slightly reduced digestibility of the vetch through an increase in intake and demonstrates the sensitivity of POST SH to nutritional changes in the herbage offered (III). On farms, grazing management cannot be based on frequent HM measurements, but POST SH measurements or practised-eye estimations are manageable.

Seasonal variation in the amount of herbage offered complicates grazing management, but applying both annual and perennial swards would probably help to balance the growth rhythm of pastures and would support grazing in the autumn. Experiments 6 and 7 showed that annual legume-grass-cereal pastures have potential in organic farming systems (III). Although the annuals missed the favourable growing conditions during early summer, they compensated for this by growing well from the beginning of July to mid-September, when the herbage growth of perennial swards starts to decline (Fig. 10). In autumn, young perennial swards can be protected from sward damage and allowed to prepare for winter, when annual swards and those perennial swards, which will be ploughed up later in autumn or next spring, are mainly grazed. A combination of perennial and annual pastures adjusted according to circumstances would probably best serve the diverse requirements of different organic milk production farms.

Efficient grazing management, although laborious, is necessary to obtain sufficient HM with high nutritive value. According to Experiment 7 (III), moderate levels of concentrate can be offered just once daily to simplify the work of feeding, since the concentrate feeding regimen had no effect on milk production. This result is in agreement with previous studies (Johnson 1979, Dhiman et al. 2002). Based on current data, reducing the frequency of feeding moderate levels of concentrate could afford decreases in labour costs and simplify management practices.

5.5 Need for supplementary feeding

Summer feeding of dairy cows is mainly based on grazing. On organic dairy farms the amount and type of supplementary feeding depends on animal-specific factors, such as the milk yield and genetic potential, on farm-specific circumstances, such as the amount and type of home-grown concentrates, and on the market conditions for feeds and milk. The intake of herbage and the nutrient supply from the herbage for grazing cows is determined by the nutritive value of the herbage and HA but, as discussed earlier, the low PRE HM associated with an unfavourable sward structure can restrict the intake even when the HA is relatively high. For instance in Experiment 4 the relatively low mean PRE HM (Table 2.) of legume-poor sward probably affected the milk yield. In agreement with the present findings, Sehested et al. (2003) reported that in a Danish organic feeding study the grazing system used did not support the maximum herbage intake of dairy cows because of the low herbage mass from organic pastures despite relatively high IVOMD (0.741). In the present study, the average nutritive value of the organic herbage was quite high, although variable (Figs 3 and 4). Hence, occasionally deficiencies in the nutritive value of the herbage have affected the milk yield from the pasture. On the other hand, high K contents and occasionally high CP concentrations of organic herbage, similar to levels in conventional farming, are undesirable in cattle feeding (Tamminga 1992, Underwood and Suttle 1999).

On grass-based diets, a maximum milk yield of 20 kg d^{-1} has often been assumed to be the highest level of production that can be achieved at pasture. In Experiment 4 (II), a grass-only diet resulted in a daily milk yield of 16.8 kg per mid-lactation cow. In Experiment 2 (IV), based on the mean value of the herbage composition, it was estimated that a 15 kg DM intake would, without supplementation, have supported 20.4 kg of energy-corrected milk per day according Finnish feeding norms (Tuori et al. 2002). However, recent studies with cows of high genetic merit have shown that a milk yield of 30 kg d^{-1} can be achieved on grass (DM intake of 17 kg) under good grazing conditions in conventional farming (Kennedy et al. 2003). Also Wilkins et al. (1994) and Peyraud et al. (1996) reported a peak milk yield between 25-30 kg d^{-1} on pasture alone under good grazing conditions (Table 8).

In the present study, the herbage intakes were not measured, but in Experiment 2 (IV) the mean intake, based on PRE minus POST HM and stocking rate calculations, was estimated to be 12.3 kg DM d^{-1}, being highest in 1997, and on average, cows were then estimated to consume 15 kg herbage DM d^{-1}. This amount of herbage represents a level of intake, which could be easily attained if HA, PRE HM or herbage nutritive value is not a limiting factor. In Experiment 2 (IV), based on the mean value of the herbage composition, a 15 kg DM intake would, without supplementation, have supported 20.4 kg of energy-corrected milk per day. However, applying the values of the individual herbage samples, the daily milk yield would have varied between 14.5 - 24.6 kg. In 9% of all the measurements, the energy content of the herbage was at least 5% lower (corresponding to 0.7 kg of barley, Tuori et al. 2002) than the requirements for the estimated mean milk production. On the basis of the IVOMD and CP measurements, the mean adsorbed amino acid content (AAT) would account for almost all (97%) of the amino acid requirements for the estimated mean milk production (Tuori et al. 2002). However, for 38% of all the measurements, the protein supply was at least 5% below requirements, corresponding to a daily supplement of 0.5 kg of rapeseed meal (Tuori et al. 2002). These calculations indicate requirement for feeding supplementary energy and protein. Because a large amount of the supplementary protein is excreted in urine, moderate amounts of high-quality protein, such as rapeseed meal, are recommended in the diet for mid-lactating grazing cows (Tamminga 1992, Kebreab et al. 2002, II).

In Experiment 4, both energy (barley + oats) and protein (rapeseed meal) supplementation increased the yields of milk and milk constituents, indicating a deficiency of energy and protein for the cows grazing on organically cultivated clover-grass sward (Table 8). In Experiment 5, increasing the amount of concentrate supplementation increased the milk yield when the concentrate supplementation consisted of the same proportions of barley, oats and rapeseed meal at both levels of supplementation (Table 8). In the present study, the influence of concentrate feeding on milk yield was relatively high compared with studies reviewed by Leaver (1985), but was within the range of more recent reports in the literature (Table 8). Responses depend on the composition of the concentrate and decline with increased levels of concentrates (Hoden et al. 1991, Meijs and Hoekstra 1984, Syrjälä-Qvist et al. 1996, Sayers et al. 2000, Khalili and Sairanen 2000). However, responses increase with restricted intake when HA, HM or nutritive value are low (Hoden et

Table 8. The response of concentrate supplementation on milk yield in divergent grazing conditions.

		Concentrate kg d^{-1}	Milk yield cow^{-1} d^{-1}	Concentrate increment kg d^{-1}	Milk response kg milk kg^{-1} concentrate
Experiment 4 (I)					
Organic pasture, HA 22.5 kg DM		0	16.8		
		2.75 ^{E}	19.1	0 – 2.75	0.84
		1.25 ^{P}	18.1	0 – 1.25	1.04
		4 ^{EP}	20.4	0 – 4.0	0.90
Experiment 5 (I)					
Organic pasture, HA 18 – 24 kg DM		2.5 ^{EP}	19.1		
		5 ^{EP}	20.8	2.5 – 5.0	0.68
Wilkins et al. (1994)					
Clover-grass mixture:	Clover proportion 0.01	0	20.6		
		4 ^{EP}	25.5	0 – 4	1.23
	Clover proportion 0.10	0	22.8		
		4 ^{EP}	26.2	0 – 4	0.85
	Clover proportion 0.20	0	25.4		
		4 ^{EP}	26.3	0 – 4	0.23
Delagarde et al. (1997)					
Grass pasture:	No N fertilisation	0	22.7		
		2 ^{P}	25.3	0 – 2	1.30
	N-fertilised	0	25.0		
		2 ^{P}	27.1	0 – 2	1.05
O'Brien et al. (1999)					
Fertilised grass:	increased stocking rate	0	16.4		
	normal stocking rate	0	17.5		
	normal stocking rate	3 ^{EP}	18.7	0 – 3	0.40
Khalili and Sairanen (2000)					
Fertilised grass pastures, HA 40 kg DM		0	18.4		
		4 ^{E}	19.7	0 – 4	0.33
		4 ^{E}	21.0	0 – 4	0.65

^{E} energy supplementation (grain feeds), ^{P} protein supplementation (rape or soyabean feeds),
^{EP} energy and protein supplementation

al. 1991, Dillon et al. 1997, Patterson et al. 1998). In conclusion, a concentrate supplement including additional protein adjusted according to the state of lactation is recommended for early-mid-lactating cows grazing clover-grass swards grown under the conditions of Nordic organic farming.

Mineral nutrition is important for the welfare of grazing animals (Clement and Hopper 1968, Underwood and Suttle 1999). According feeding norms (Underwood and Suttle 1999, Tuori et al. 2002) the organic pasture herbage did not fully correspond to the mineral requirements of grazing dairy cows (V). On average, Mg content of the herbage were close to the animal requirements, but a high K content, as in conventional farming, influenced the mineral balance and increased the need for supplementation. In the present study the main differences between the seed mixtures were associated with the proportion of legume in the sward, which in turn influenced the Ca content of the herbage (Table 3). The temporal changes in mineral contents and mineral ratios were significant (V). In early summer the risk of grass tetany was present (K/(Ca+Mg) equivalent ratio > 2.2, Kemp and Hart 1957, Grunes and Welch 1989) in Experiment 2, but not in Experiment 3 (Fig. 11). Legumes, but to some extent also weeds, increased the Ca and Mg contents of the herbage and decreased the risk of grass tetany (V). In Experiment 3, the different botanical proportions and cultivation history of the field resulted in a somewhat different mineral composition of the herbage (Table 2). Except before calving, the relatively high Ca contents recorded in the present study should not be a problem, since ruminants can tolerate high Ca and a wide range of Ca/P when their vitamin D status and dietary supply of P is adequate (Underwood and Suttle 1999). Calcium-free or low-Ca mineral feeds containing Na, Mg probably best complement the mineral feeding of dairy cows grazing on organic clover-grass swards. Supplementary feeding also changes the dietary mineral content, since rapeseed meal is rich in P and Mg and cereals are low in Ca and K (Tuori et al. 2002). Mineral supplementation must always be adjusted on the basis of the current animal requirement (milk yield, body condition, age) and the dietary mineral content.

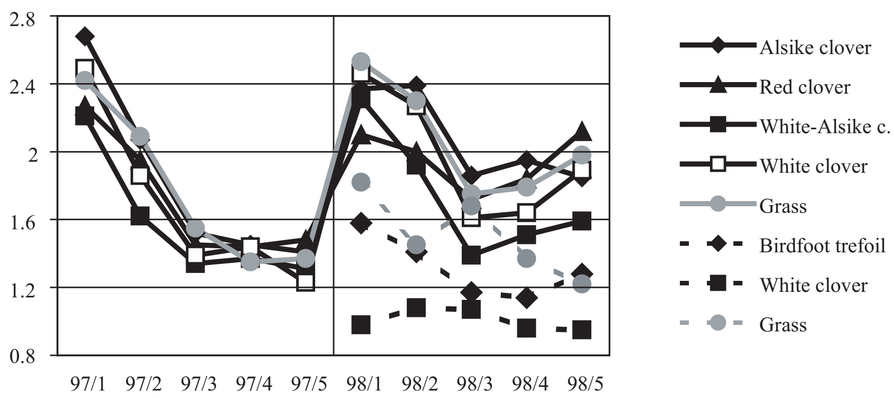

Figure 11. Temporal variation of K/(Ca+Mg) equivalent ratios between seed mixtures in Experiments 2 (1996-1998, V) and 3 (1998, unpublished).

5.6 Evaluation of methods used

This pioneer study was conducted under farm conditions, which restricted the experimental design, but the methods applied are those commonly used and approved. The focus was on systems approach.

In grazed field experiments the amount of grazed HM was estimated using the difference between PRE and POST HM. This method gives a rough estimate of harvested herbage, but the presence of animals provides a better basis for the evaluation of pasture species than the small-plot cutting method (Hopkins 1999).

A cutting height of 3 cm above soil surface commonly used for HM determination of grazing was chosen for herbage sampling (Frame 1981). However, sampling heights of 0-5 cm above soil surface have also been used (Le Du et al. 1979, O'Brien et al. 1997, Delagarde et al. 1997, Virkajärvi 2004). The sampling height must be below the height to which a sward is grazed. On the other hand, the degree of soil contamination increases as the sampling height decreases below 2 cm (Frame 1981). As the grasses used for pasture in Finland, timothy and meadow fescue, are erect-growing types (Virkajärvi 2004), a slightly higher sampling height could possibly be used in Finland. At the beginning of this study the depressed canopy structure of unfertilised swards (Delagarde et al. 1997) was not known. The height of 3 cm seemed to be a satisfactory compromise.

Due to animal selection, the quality of offered herbage was not the same as that of the grazed herbage. A sampling height below the grazing height also influenced the evaluation of the nutritive value of herbage. However, recommendations for farmers are based on results from cut samples.

Since limited resources switch-back system was used in the feeding experiments and the paired-sample t test for comparison of herbage. Although the 14-day adapting period was relatively long, switching may have affected the adapting of cows to different sward conditions.

6 CONCLUSIONS

1. Grazing management based on conventional farming practice does not fit into the Nordic organic farming system, where mineral fertilisers are not permitted. Neither natural pastures, nor extensive grazing systems can supply adequate herbage (quantity and quality) for lactating dairy cows. Hence, grazing management needs to be specially adjusted for organic dairy farming.

2. This study showed that organic pasture herbage is a heterogeneous mixture of three botanical components, grasses, legumes and weeds, which are clearly divergent both from the systems approach and regarding nutritive value. The botanical proportions affect both the nutritive value and growth of the herbage. Heterogeneity in herbage production, species and herbage chemical content both spatially and temporally was characteristic for organic pastures.

3. Intensively managed organic pastures could support at least moderate herbage production with medium nutritive value. In organic farming systems the length of the rotation cycle is a compromise between digestibility and the

amount of herbage mass, where nitrogen deficiency often depresses the production of herbage mass from grasses. For animal nutrition, the crude protein content of the clover- grass mixtures was on average sufficient, but depending on the proportions was occasionally unnecessarily high or too low.

4. The choice of legume species for the grazed mixture is of key importance, since red clover does not tolerate frequent grazing. The mixtures which provided the highest mean legume proportions also gave the highest mean CP contents, indicative for high N_2 fixation. White clover was the most suitable perennial pasture clover for Nordic conditions. However, including beneficial birdsfoot trefoil in perennial clover-grass mixtures is recommended if winter-hardy cultivars are available. Hairy vetch was the most suitable for grazed annual legume-grass-cereal mixtures and best supported extended grazing in autumn.

5. On organic dairy farms manure is the most appropriate management tool to circulate nutrients and improve the fertility of low-fertility areas, but the use of farmyard manure has to be planned carefully since at farm level the amount of manure is limited. In the present study, manure compost fertilisation had no effect on the amount of herbage utilised from the pasture. Soil-deposited manure compost increased herbage production, but decreased proportion of utilised herbage. Hence, manure compost fertilisation, if necessary to improve the soil fertility of a given area, is recommended to be used for harvested cereals included in pasture crop rotation rather than for grazed swards.

6. In organic farming systems, herbage production is often lower than in heavily fertilised conventional systems if normal rotation cycles are used in order to obtain adequate herbage nutritive value. A low pre-grazing herbage mass will decrease the stocking rate, increase grazing area requirement and decrease milk yield per animal and milk yield per hectare. Because grazed herbage is the only yield harvested from pasture, the grazing efficiency should be improved. In the present study the milk yield per hectare was clearly increased by applying daily strip grazing instead of paddock grazing, because of the benefits of short animal occupation.

7. In organic dairy farming, an excessive herbage allowance in connection with a low herbage mass is an inefficient combination, because they both increase the grazing area requirement while high herbage allowances result in only a minor response in animal performance. In the present study, moderate decreases in the herbage allowance increased the milk yield per hectare. However, higher stocking rate resulted in depressed sward growth. The herbage allowance should not go below the level which the system can tolerate. In Nordic organic dairy farming, an adequate herbage allowance for mid-lactating cows might be 20 - 26 kg DM cow^{-1}, depending on the milk yield, supplementary feeding and growing conditions. The post-grazing sward height is a good indicator for the implementation of adequate allowances and for continuous monitoring to prevent inefficient under-grazing and detrimental over-

grazing. Based on the current data a target post-grazing, a sward height of 10 - 12 cm is suggested for Nordic organic legume-grass pastures.

8. In the present study, the milk yield response to concentrate feeding was relatively high for mid-lactating cows grazing on organic cultivated swards. This was mainly because the herbage intake was limited on a herbage mass basis. Both energy and protein supplementation resulted in increases in milk production. A concentrate supplement including additional protein adjusted according to the state of lactation is recommended for early-mid lactating cows grazing clover-grass swards grown under the conditions of Nordic organic farming. Base on current study, a moderate level of concentrate (4 kg d^{-1}) can be offered once instead of twice daily to simplify feeding.

9. According feeding recommendations organic pasture herbage did not fully satisfy the mineral requirements of grazing dairy cows. Low concentrations of Na and Mg in the herbage, the latter especially in connection with high K, require mineral supplementation. The main differences between seed mixtures were connected to the proportion of legume in the sward, which affected the Ca content of the herbage. Because of temporal variation, measured values of herbage mineral content are needed to control the risk of disorders in grazing animals and for planning adequate mineral feeding.

Future challenges

- How to improve HM production from organic pastures without major negative effects on the nutritive value of the herbage?
- How to balance the legume proportion or, if this is not possible, how to cope with a varying legume proportion in animal feeding?
- How to combine the suggested legumes and grasses into optimal seed mixtures for different growing conditions and how to capitalise potential benefits of birdsfoot trefoil at organic farms?

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When you draw my picture
do it right.
Draw a small questioner in a windy field
old slacks
felted pullover
just hair down.
You know, draw barefooted
toes against healthy soil.

A poem by Eeva Heilala

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