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GROWTH AND UTILIZATION OF TIMOTHY – MEADOW FESCUE PASTURES

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ABSTRACT

Development of efficient grazing systems for the short northern growing season represents a challenge. Results of research in herbage growth and animal production must be combined to improve pasture utilization. For this purpose, precise knowledge on growth processes of pastures, including leaf growth and senescence, tiller formation, development of herbage mass and its digestibility in Nordic timothy (*Phleum pratense* L.) and meadow fescue (*Festuca pratensis* Huds.) swards is required. Knowledge of herbage utilization, including the effect of herbage allowance and turnout day on herbage intake is also needed.

Growth dynamics of timothy and meadow fescue were monitored under field conditions. The effect of cutting height on herbage mass production and regrowth in pure stands was studied in field trials. The influence of canopy factors on regrowth rate was also studied. The measured factors included tiller population density, concentration of water-soluble carbohydrates, concentration of high and low degree polymerization fructans and post defoliation leaf area. The accuracies of various indirect herbage mass measurement techniques were compared. Furthermore, the effect of herbage allowance and the timing of turnout day on animal performance and herbage utilization were studied in grazing experiments.

Growth processes of timothy, and to a lesser extent meadow fescue, such as leaf and tiller dynamics differed clearly from those of perennial ryegrass (*Lolium perenne* L.) in a more temperate climate. The clearest differences occurred in the generative (i.e. reproductive) phase of growth, resulting in different sward structures. Nordic timothy and meadow fescue swards are tall, develop rapidly, are of low bulk density and have a low tiller density with a high proportion of generative tillers, especially during the early part of the growing season. In addition, they have limited ability to change growth pattern in response to sward management. The differences in sward structure explained many of the results obtained.

Timothy and meadow fescue differed from each other in generative growth phase in May-June and less in vegetative growth phase in July – August. Overall timothy was characterised by higher tissue turnover rates. Meadow fescue expressed higher regrowth ability than timothy, especially when a sward was defoliated during the generative growth stage. Generally, the regrowth rate of timothy and meadow fescue was higher at higher defoliation heights up to 9 cm. The proportion of vegetative tillers was the most marked factor affecting

regrowth rate during the generative growth phase (June-July) for timothy and for timothy dominated swards. During the vegetative stage, none of the canopy factors studied was of major importance for regrowth (August). In canopies where HM correlated more strongly with the height of the canopy than with tiller population density, those methods relating better to sward surface were the more accurate. Therefore, herbage mass of Nordic timothy and meadow fescue mixtures can be measured with a disk meter or with an HFRO Sward Stick sufficiently accurately. A capacitance meter is the least accurate tool.

The effect of herbage allowance on milk production was 0.16 kg milk kg $^{-1}$ dry matter, which is similar to that for perennial ryegrass pastures despite differences in sward structure. In spring the development rate is rapid and only 5 days difference in turnout date caused major enhancements in the growth pattern of pasture in the early part on the season. Early turnout resulted in better herbage quality and HM utilization, together with easier management, but did not improve the milk yields compared with normal turnout.

The results showed that pasture utilization is largely affected by herbage allowance and timing of turnout. In order to maintain high herbage production, pastures should not be grazed much below 9 cm, although the consequences of one close grazing for herbage production is probably minor. This coincides well with the livestock need of 9 – 10 cm post grazing sward height and high quality grass feed.

LIST OF ORIGINAL PUBLICATIONS

The thesis consists of the following papers, which are referred to by their Roman numerals in the text.

I Virkajärvi, P. 1999. Comparison of three indirect methods for prediction of herbage mass on timothy-meadow fescue pastures. *Acta Agriculturae Scandinavica*. Section B, Soil and Plant Sciences 49: 75-81.

II Virkajärvi, P. & Järvenranta, K. 2001.Leaf dynamics of timothy and meadow fescue under Nordic conditions. *Grass and Forage Science* 56: 294-304.

III Virkajärvi, P., Sairanen, A., Nousiainen, J.I. & Khalili, H. 2002. Effect of herbage allowance on pasture utilization, regrowth and milk yield of dairy cows in early, mid and late season. *Animal Feed Science and Technology* 97: 23-40.

IV Virkajärvi, P., Sairanen, A., Nousiainen, J.I. & Khalili, H. 2003. Sward and milk production response to early turnout of dairy cows to pasture in Finland. *Agricultural and Food Science in Finland* 12:21-34.

V Virkajärvi, P. 2003. Effects of defoliation height on regrowth of timothy and meadow fescue in the generative and vegetative phases of growth. *Agricultural and Food Science in Finland* (in press).

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The author was fully responsible for the experiments in publications I and V. The author took full responsibility for planning and conducting the experiment and calculating the results reported in paper II. The author fully participated planning and conducting the experiment and data analysis in papers III and IV.

LIST OF ABBREVIATIONS

BD	Bulk density, kg DM m^{-3}
CMR	Capacitance meter reading (ds)
CV	Coefficient of variation, %
D	Day
DMH	Disk meter height, cm
DD	Degree days, day °C
DM	Dry matter
DW	Dry weight
ECM	Energy corrected milk
HA	Herbage allowance
HDP	High degree of polymerization
HDPF	High degree of polymerization fructans
HI	Herbage intake, kg DM cow^{-1} d^{-1}
HM	Herbage mass, kg DM ha^{-1}
INDF	Indigestible neutral detergent fibre
IVOMD	In vitro organic matter digestibility, g kg^{-1} OM
LAI	Leaf area index , m m^{-2}
LAR	Lear appearance rate, Leaf $tiller^{-1}$ d^{-1}
LDP	Low degree of polymerization
LER	Leaf elongation rate, mm $tiller^{-1}$ d^{-1}
LLS	Leaf live span, D, DD
LSR	Leaf senescence rate, mm $tiller^{-1}$ d^{-1}
LW	Live weight, kg
MF	Meadow fescue, *Festuca pratensis*, Huds.
MSW	Mean stage by weight
N	Nitrogen
NDF	Neutral detergent Fibre, g kg^{-1} DM
NEFA	Non esterified fatty acids
OM	Organic matter
OMD	Organic matter digestibility, g kg^{-1} OM
RCB	Randomized complete bloc
RHA	Relative herbage allowance (ds)
RSD	Residual standard deviation
SD	Standard deviation
SE	Standard error
SEM	Standard error of the mean
SH	Sward surface height, cm
SR	Stocking rate, cow ha^{-1}
T	Timothy, *Phleum pratense* L.
TNC	Total non-structural carbohydrates
WSC	Water soluble carbohydrates

1. INTRODUCTION

1.1. BACKGROUND

Summer milk production contributes one third to the annual milk production of Finland (Information Centre of the Ministry of Agriculture and Forestry 2003a). During 1999 - 2002 summer milk production had an annual value of €27 0 - 290 million, and consequently represented 13 % of the annual gross return of Finnish agricultural production (Finnfood 2003). Grazed grass is the cheapest good quality forage available. Since 1995 its production costs have varied from €0.15 to €0.17 per feed unit, whereas silage has ranged from €0.25 to €0.26 (Puurunen & Lampinen 2002). In addition, grazing has reduced time used for manure spreading. Grazing is important also for animal welfare (Tirkkonen 1997) and according to Finnish animal welfare legislation (396/1996) cows and heifers must have access to pasture or to alternative exercise areas. In surveys, consumer attitude to animal welfare was strongly positive (Seppälä et al. 2002). Furthermore, in a survey among farmers conducted in 1997, 90 % of milk producers were willing to continue grazing (Tiilikainen 1997).

Joining the European Union has rapidly changed Finnish agriculture. The average herd size is increasing, but more importantly, the proportion of large herds (> 50 dairy cows per herd) has increased (Information Centre of Ministry of Agriculture and Forestry 1996, 2003b). Therefore, the advantages of grazing have been challenged by modern harvesting and feeding technology used by farmers with large herds. In Finland, during the last 20 years grassland research has aimed mainly at silage production. Most of the work was done between the late 1960s and early 1980s (e.g. Rinne 1978, Rinne & Ettala 1978, Rinne & Ettala 1981, review by Ettala 1985) and only a few papers were published during the 1990s on grazing (Tesfa et al. 1995, Syrjälä-Qvist et al. 1996). Efficient grazing under a short growing season at high latitudes is a challenge. Pasture use efficiency in Finland has been commonly considered to be low due to lack of precise knowledge concerning pasture growth process and utilization of resulting herbage. As a consequence, a project aimed at improving the efficiency of grazing was launched by Agrifood Research Finland (MTT) in 1997. One of the main objectives of this project was to investigate both herbage and milk production and draw conclusions on pasture growth and utilization under Nordic conditions. This thesis represents a part of that research project.

1.2. MANAGEMENT FACTORS AFFECTING HERBAGE INTAKE AND ANIMAL PRODUCTION

The objectives of grazing management are to 1) supply herbage of high feed value over the growing season at low cost, 2) ensure efficient utilization of herbage while maintaining acceptable levels of animal performance 3) maintain sward productivity (Holmes 1989, Mayne et al. 2000). As a result of these objectives grazing processes and pasture management are complex.

At a system level, stocking rate (SR, cow ha^{-1} calculated over the grazing season) has long been recognised as the most important factor affecting per unit area pasture production (McMeekan 1956, Mott 1960, In Finland: Rinne & Ettala 1981). SR does not take account of the herbage mass (HM) per unit area and thus daily pasture allocation (herbage allowance, HA, kg dry matter (DM) animal^{-1} day^{-1}) is a more precise measure, relating the amount of feed to the number of animals. HA is recognised as one of the primary factors affecting herbage intake and thereby animal performance on grazed pastures (Le Du et al. 1979, Mayne and Peyraud 1996, Spörndly 1996). Other important management factors are the length of grazing season (Carton et al. 1989, Roche et al. 1996), supplementary feeding such as concentrates (Meijs & Hoekstra 1984, Meijs 1986, Khalili & Sairanen 2000, Delaby et al. 21001) and silage (Mayne et al. 1990, Mould 1993), and grazing system (Ernst et al. 1980, Mayne et al. 1990).

The timing of turnout is one important measure that aims at full use of the grazing season (Baker & Leaver 1986, Carton et al. 1989, Sayers & Mayne 2001). The general effect of turnout date is that with delayed turnout herbage production is faster than livestock can consume it. This accumulation of HM in spring is connected with a high proportion of generative tillers and it causes increased plant senescence and accumulation of dead material. Consequently, the feeding value of the grass decreases and the proportion of areas that is rejected by grazing animals increases. Also high pre-grazing herbage mass (HM kg DM ha^{-1}) leads to lower tiller production. Together with the death of generative tillers, this may lead to lower tiller density, which in turn will lower the productivity of the sward later in the season (Baker & Leaver 1986, Carton et al. 1989, Sayers & Mayne 2001). Due to rapid changes in environmental parameters and the grass canopy during the beginning of the short Nordic growing season (Deinum et al. 1981, Mukula and Rantanen 1987, Skjelvåg 1998, Rinne 2001) the importance and consequences of early turnout in Finland may differ from those reported from other parts of Europe.

1.3. SWARD STRUCTURE AND HERBAGE INTAKE OF CATTLE IN INTENSIVELY MANAGED PASTURE

The classical concept of intake control in ruminants suggests that both physical and metabolic factors contribute to the regulation of voluntary intake. Interaction of the animal, diet and feeding situation provides the triggers for control signals. With high quality forages, an animal's energy requirement (metabolic regulation) determines feed intake, whereas for low quality forages an animal's intake constraint (physical regulation) limits feed intake (Freer 1981, Mertens 1994). During short-term foraging strategy sward structure is a primary factor regulating herbage intake (HI) via ease of prehension (Penning et al. 1998). It has been shown in a numerous studies that bite mass has the greatest influence on HI whereas biting rate and grazing time are compensatory variables (reviewed by Forbes 1988, and Penning et al. 1998). For cattle, sward height (SH) is the major determinant of bite volume, both for bite depth and bite area (Wade et al. 1989, McGilloway et al. 1999). Moreover, other variables, such as bulk density of the sward, leaf:stem ratio and pseudostem barrier, have marked impact (Forbes 1988, Rook 2000). In general, for grazing cattle it was shown that the bite mass increases with increasing sward height (Wade et al. 1989, Laca et al. 1992), bulk density (Laca et al. 1992) and proportion of green leaves (Forbes 1988).

There are no published results concerning the effect of HA or timing of turnout on animal performance or herbage production on northern timothy - meadow fescue pastures. Rinne & Ettala (1978, 1981) studied the effect of stocking rate, concentrate feeding and grass species on the milk production of dairy cows, but they did not use a fixed herbage allowance. It is already known that timothy and meadow fescue, the two most common grass species in north-east Europe, have both lower tiller production and regrowth ability than perennial ryegrass, for example Ryle (1964). This may also lead to low bulk density. Furthermore, it is known that, for example, SH tends to be higher in Nordic swards (Tesfa et al. 1995), but there is no precise knowledge on sward structure (bulk density, leaf:stem ratio etc.) and how the structure might explain results obtained from grazing studies in a larger context.

The growing season in the northernmost parts of Europe is short, ranging from 95 days in northern Finland to 130 days in southern Finland (Pulli 1992). Typically the changes in growth rate of herbage and decrease in nutritive value are fast in the early part of the summer compared with areas of lower latitude (Deinum et al. 1981, Rinne 2001). It was assumed that due to differences in sward structure the relationship between HA and animal performance would be different compared with results for perennial ryegrass pastures in a temperate climate. Also the consequences of early turnout of cows was assumed to be different to those reported with perennial ryegrass from other parts of Europe.

1.4. SWARD STRUCTURE AND ESTIMATION OF HERBAGE MASS

As HM is a key factor in almost all grazing experiments, and direct estimation of HM is time consuming and expensive, considerable effort has been put in to developing other methods to estimate HM (Frame 1993). These methods include plate meters (Powell 1974, Castle 1976), sward sticks (Bircham 1981), capacitance meters (Vickery et al. 1980), visual appraisal (O'Donovan et al. 2002), measurements of LAI (Harmonney et al. 1997) and spectral methods (near infrared; Mitchell et al. 1990; high-resolution visible radiation, Williamson 1990). It was assumed that sward structure at high latitudes would affect the accuracy of the indirect measurement techniques to an extent that published results from other environments would not be applicable because different methods produce different results according to sward structure. Thus it was necessary to establish a suitable indirect HM measurement technique for timothy - meadow fescue pasture. The disk meter, sward stick and capacitance meter were all simple and available at a reasonable price, and were included in the study since the aim was to use the method(s) in subsequent field experiments.

1.5. GROWTH PROCESS OF GRASSES UNDER GRAZING

Relationships between pasture management factors, grazing process and sward regrowth are illustrated in Fig. 1. Efficient use of pastures requires knowledge of grass growth processes. The importance of regrowth is crucial. A fundamental feature of pasture is that it exists in a dynamic state even when the herbage mass (HM) is constant - tillers and leaves die and new tillers and leaves are formed (Jones & Lazenby 1988, Lemaire & Chapman 1996). In a grass community the basic production unit is a tiller (Langer et al. 1964, Davies 1971a, Lemaire & Chapman 1996, Höglind et al. 2001). Tiller population density and the mass of individual tillers determine the herbage mass. In closed canopies the increase in tiller mass is more important than tiller density. Leaf appearance rate (LAR; leaves tiller^{-1} day^{-1}), leaf elongation rate (LER; mm leaf tiller^{-1} day^{-1}) and leaf senescence rate (LSR; mm leaf tiller^{-1} day^{-1}) are the key components determining tiller mass in vegetative swards. In reproductive swards stem formation also plays an important role. Since each leaf carries an axillary bud at its base, LAR also determines the limits of tiller production (Davies 1988, Nelson 1996). In a dense or closed canopy tiller dynamics is related to leaf area index (LAI). During the main growing season a typical perennial ryegrass tiller in its vegetative stage produces a new leaf every 7 – 10 days (Davies 1971a). Leaf life span (LLS) of perennial ryegrass is about 330 degree days (DD; Lemaire & Chapman 1996). The entire leaf canopy can be replaced within 3 - 4 weeks at normal temperatures (Davies 1971a, Lemaire & Chapman 1996). About 30 % of leaf DM is translocated to other organs before full senescence (Robson & Deacon 1978, Woodward 1998). Knowledge of the growth process described above of e.g. perennial ryegrass has reached a stage where mechanistic process-based models can be formulated. Recently, a similar mechanistic process-based model was derived for timothy as well, but it could not yet be completely parameterised based on knowledge of timothy only (Höglind et al. 2001).

When grazing, the animals selectively remove leaf material, the photosynthetic apparatus of a plant. In addition, animals cause plant death by removing apices from reproductive tillers and by pulling out tillers. Animals change the physical environment of a tiller (light, temperature, nutrients and water) by trampling, dispersal of faeces and urine, reducing litter formation and soil porosity and removing surrounding vegetation. The amount and type of tissue removed, plant development stage when the removal occurs and the prevailing environment are important in determining the effect of defoliation on plants (Richards 1993).

When pasture starts to regrow after defoliation there are four main factors that affect regrowth rate. Firstly, the function of carbohydrate reserves has been long known (Smith 1967, Booysen & Nelson 1975). The carbohydrate reserves in grasses are mainly fructans and therefore are often referred to as water-soluble carbohydrates (WSC) or total non-structural carbohydrates (TNC). In grasses these terms can be regarded as being synonymous. A critical level of WSC (Davies 1988, Donaghy & Fulkerson 1997) or the total pool of TNC (biomass x concentration) may be of greater importance for regrowth than the concentration of WSC (or TNC; Fulkerson & Slack 1995, Duru & Calviere 1996). Also, the degree of polymerisation of fructans may be an important factor in regrowth ability, since fructans with a low degree of polymerisation (LDP; degree of polymerization < 7 – 10 units) are more rapidly available for regrowth than fructans with a high degree of polymerisation (HDP; Volaire & Gandoin 1996, Volaire & Lelievre 1997). Secondly, remaining leaf area represents another carbon pool on which the regrowth process can be based. TNC pool may be relatively small compared with potential photosynthesis (Richards & Caldwell 1985). The photosynthetic capacity of the remaining leaves may increase (compensatory photosynthesis) and senescence may be delayed following defoliation (Richards 1993). Thirdly, N reserves (vegetative storage proteins; Ourry et al. 1996, Volenec et al. 1996) or other organic compounds have been proposed to play an important role in regrowth (Richards & Caldwell 1985, Richards 1993). Fourthly, the amount and status of available meristems affect regrowth (Richards & Caldwell 1985, Richards 1993). The regrowth after defoliation is fastest from intercalary meristems, followed by newly developed leaf primodia and least rapidly from newly initiated axillary buds (Briske 1985). The relative importance of these four factors for regrowth is dependent on the plant species and environment as well as the grazing system.

A farmer has numerous management options in order to improve regrowth of a given sward. These affect the regrowth potential via four factors (as shown in Fig 1). The most important effects of the grazing system on these four factors are defoliation height and frequency (Fulkerson & Donaghy 2001). Other management factors, including fertilization, have a marked impact as well, but are beyond the scope of this summary.

A number of studies on leaf appearance and leaf elongation rate were carried out with perennial ryegrass, *Lolium perenne* L. (*e.g.* Ryle, 1964, Davies 1971a, Brereton et al. 1985, Gautier et al. 1999) and tall fescue, *Festuca arundinacea* Schreb. (Zarrough et al. 1984, Skinner and Nelson 1995) in temperate climates and in controlled environments. Moreover, numerous studies concerning regrowth ability were conducted with perennial ryegrass (Parsons et al. 1988a, Fulkerson & Donaghy 2001), tall fescue (Dougherty et al. 1992) and cocksfoot (*Dactylis glomerata* L.; Huokuna 1964, Volaire & Gandoin, 1996). The knowledge gained on plant physiology and growth dynamics has been valuable in developing theories and management guidelines for efficient grazing management, including grazing frequency and intensity, residual sward height and timing of turnout and grazing system (Parsons et al. 1988b, Mayne et al. 2000). Much less is known about the growth dynamics and regrowth ability of timothy and meadow fescue. It is known that these species differ with respect to regrowth and drought tolerance (Landström 1992), but the difference in response to defoliation height and the reasons behind this mutual difference are not well known. Most data were gathered under controlled conditions and not under long day conditions (Langer 1959, Ryle, 1964). However, Heide et al. (1985) demonstrated that the growth pattern of timothy changes markedly when grown under long days compared with short days. Therefore, information obtained under Nordic conditions is needed, from experiments undertaken in the field under conditions where species have to compete for light, water and nutrients. This knowledge could be used both in extending general theories developed for perennial ryegrass and developing management guidelines for Nordic conditions.

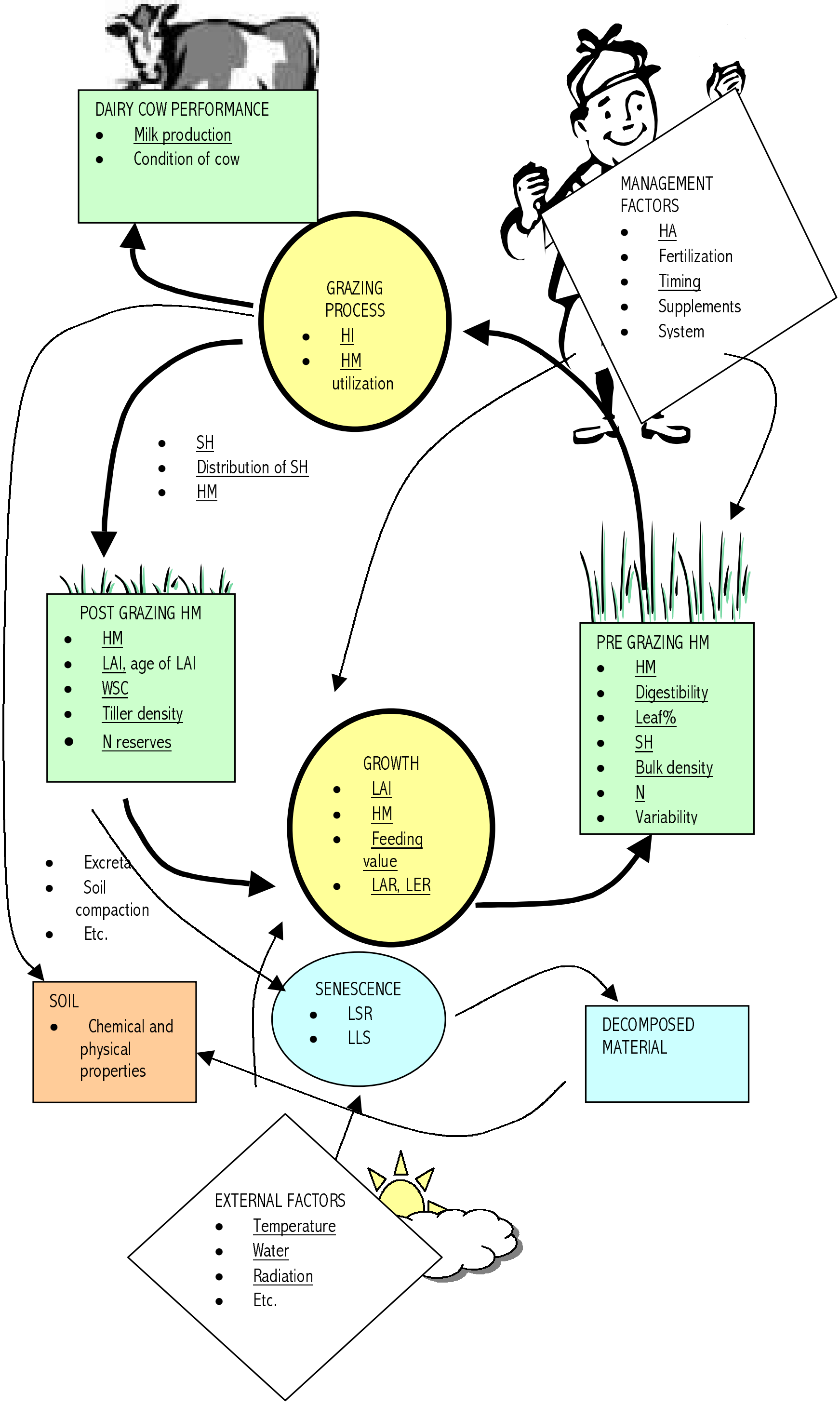

Figure 1. A schematic representation of principal relationships among management factors, grazing and sward regrowth in a rotational grazing system. Underlined parameters were measured in this study.

1.6. OBJECTIVES

The general objective of this work was to link plant and animal factors to generate knowledge that could have a significant impact at farm level as well as adding to the body of knowledge on growth and utilization of pasture.

The work was based on the hypothesis that Nordic timothy – meadow fescue pastures are taller, have lower tiller population density and have higher organic matter digestibility at the same phenological stage as perennial ryegrass swards, for which most research theories and management guidelines apply. These structural differences

1. affect the choice of the most accurate indirect HM measurement technique,

2. modify growth processes and therefore

3. change the relative importance among main factors limiting regrowth and

4. change the relationship between HA and milk production

The specific objectives were

1. To determine a suitable indirect HM measurement technique for timothy – meadow fescue pasture (Paper I)

2. To generate knowledge of the growth processes of timothy and meadow fescue and critical factors affecting their regrowth ability (Papers II, V)

3. To improve the pasture management of dairy farms through new knowledge of the effect of timing turnout and HA on milk production, pasture utilization and grass regrowth (Papers III, IV)

The results will be restricted to milk production on timothy - meadow fescue pastures under Nordic conditions and on light mineral soils with a medium coarse texture and good water holding capacity.

2.MATERIALS AND METHODS

2.1. EXPERIMENTAL DESIGN AND GENERAL MANAGEMENT

The data from the five experiments listed in Table 1 contributed to this thesis. The detailed weather conditions, soil properties seeding rates and fertilization are described in the papers.

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

Exp. No.	Subject	Experimental layout	Treatments	Location and study period	Paper
1	HM measurement technique	Field experiment (survey)	Disk meter, Sward Stick, Capacitance meter	Tohmajärvi (62°20’N, 30°15’E) 1993-1994	I
2	Timing of turnout	Animal production trial (continuous group trial) + plot trial (simulated grazing; RCB)	Early and normal turnout date	Maaninka (63°10’N, 27°18’E) 1997	IV
3	Herbage allowance	Animal production trial (3 x 3 Latin square) + pasture production (daily paddocks as RCB)	HA 19, 23 and 27 kg DM cow^{-1} d^{-1} (over 3 cm)	Maaninka 1998	III
4	Growth process	Field experiment, (survey, marked tillers)	Timothy, meadow fescue	Maaninka 1999	II
5	Defoliation height	Plot trial (2- factor Split-plot; RCB)	Main plot: timothy and meadow fescue. Sub plot: defoliation height 3, 6 and 9 cm	Maaninka 2000-2001	V

The experiments were conducted on 1 - 5 year old swards in order to have well established canopies. The experiments were performed under field conditions, which meant that the canopies were under regular environmental stresses where there was competition for light, water and nutrients.

2.2. MEASURED VARIABLES AND CHEMICAL ANALYSIS

Comparison of indirect HM measurement techniques included disk meter (rising plate type), capacitance meter and sward stick (SH measurement device; Table 2).

Growth processes of tillers were described in terms of leaf dynamics, apex development stage and pseudostem height of individual tillers. Measured factors affecting the regrowth potential of swards included population density of both vegetative and generative tillers, tiller size, and post defoliation LAI. In addition, concentration of WSC, HDP fructans and N were analysed and WSC pool calculated as post defoliation biomass x WSC concentration in biomass (Table 3).

Pasture production and growth rate was measured as HM or as LAI. (Table 2). HM was measured to different heights (from 1 to 9 cm) according to the objective of each study. Pasture HM utilization was calculated as the difference between pre- and post-grazing HM, or described as the proportion of infrequently grazed area, or as post-grazing SH (Table 2). Sward structure was described in terms of population density of tillers, SH, BD, development stage and leaf content of herbage DM. Animal production measurements included milk production, live weight (LW) change, HI, rumen DM content and diet apparent digestibility. External factors affecting production included weather parameters, soil texture, soil moisture content and soil nutrient status (Table 2).

The feeding value of HM was estimated by analysing N, OM, NDF, and Indigestible NDF (INDF) content in grass DM as well as IVOMD of grass OM (Table 3). Milk was analysed for fat, protein and urea. Non esterified fatty acid (NEFA) concentration of blood plasma was analysed in order to gauge the fat metabolism of the animals (Baldwin & Smith 1983).

2.3. STATISTICAL METHODS

The effect of treatments on measured variables were generally analysed using analysis of variance (ANOVA) according to individual experimental design (SAS MIXED and SAS GLM procedures; SAS Institute 1991, Littell et al. 1996). When more than two levels of a continuous factor were used, the significances of linear and quadratic effects were studied using contrast statements (Papers III and V; Mize & Schoultz 1985). Comparisons of treatment means were performed using Tukey’s procedure or contrast statements. Validity of assumptions of data and residual diagnostics were checked graphically using SAS UNIVARIATE procedure. Correlation and regression analysis was used to analyse the relationship between indirect and direct HM measurements (Paper I), between weather parameters and leaf dynamics (Paper II) as well as the relationship between post defoliation sward parameters and subsequent regrowth rate (Paper V; SAS Institute 1991).

Table 2. Summary of measured variables, their measurement unit and method used (general view, details in papers).

Variable	**Unit(s)**	**Method**	**Paper**
Herbage mass	kg DM ha^{-1}	Disk meter (rising plate type)	I
		Capacitance meter, Pasture Probe™ V 4.3 Mosaic Systems, Palmerston North, New Zealand.	I
		Sward surface height by HFRO-type Sward Stick; (Bircham 1981, Barthram 1986)	I
		Clipping by scissors to 1 cm	I
		Clipping by scissors to 3 cm	III
		Clipping by scissors to 5 cm	IV
		Clipping by scissors to 3, 6 and 9 cm	V
		Cutting by Haldrup 1500 plot harvester to 7 cm	II,III
Lear appearance rate	Leaf tiller^{-1} d^{-1}	Calculation based on *in situ* measurements on marked tillers	II
Leaf elongation rate	mm tiller^{-1} d^{-1}		II
Leaf senescence rate	mm tiller^{-1} d^{-1}		II
Leaf live span	D, DD		II
Leaf number		*In situ*: Fully expanded and emerging leaves of marked tillers	II
		After dissection: unemerged leaves of tillers corresponding the marked tillers	II
Apex height	Mm	Dissected tiller corresponding the marked tillers (Sweet et al. 1991)	II
Apex development stage	Scale 1- 13	Dissected tiller corresponding the marked tillers (Sweet et al. 1991)	II
Pseudostem height	Mm	*In situ*: Marked tillers In laboratory: Dissected tiller corresponding the marked tillers	II
Tiller population density	Tillers m^{-2}	*In situ*: 10 cm x 10 cm areas	IV
		In laboratory: 5 cm x 20 cm turfs	V
Growth rate	kg DM ha^{-1} d^{-1}	HM increment	III,IV, V
Growth rate	LAI d^{-1}	LAI increment	III,IV, V
Leaf area index	*Ds*	*In situ*: Li-COR 2000 Canopy Analyzer, LI-COR Inc. Lincoln, Nebraska, USA	II,III,IV,V
		In laboratory: Hayashi AAM-7 leaf area meter. Hayasi Denko co. Ltd. Tokyo, Japan	II
Sward surface height (pre and post defoliation)	Cm	HFRO-type Sward Stick; (Bircham 1981, Barthram 1986)	I,III,IV,V
Bulk density	kg DM m^{-3}	Calculated based on SH and HM	
Development stage	Scale 20-58	In laboratory according to Simon & Park 1981	III,IV, V
Leaf content	g kg^{-1}	In laboratory	III
Botanical composition	g kg^{-1}	In laboratory	I,III, IV
Proportion of infrequently grazed area	%	Line transects measurements	III

(Table 2. Cont.)			
	%	Calculated from SH measurements	III
Milk production	kg ECM cow^{-1} d^{-1}	From 2 daily milkings	
Herbage intake	kg DM cow^{-1} d^{-1}	Calculated from daily pre-grazing and post grazing HM	III
Rumen DM content	kg DM cow^{-1}	Manual evacuation	III
Diet apparent digestibility	g kg^{-1}	Fistulated cows, INDF as internal marker	III
Live weight	Kg	Gravimetric on two successive days	IV
Weather parameters	°C, mm, W m^{-2}	Temperature, daily mean, max, min at 2 m height, precipitation, pan evaporation, Global solar radiation	I,II,III, IV,V
Soil nutrient status	mg l^{-1}, pH	According to standard procedures	II,III, IV,V
Soil texture	% dw	According to standard procedures	V
Soil moisture	% plant available moisture	Gypsum resistance blocks, Model 5201, Soil moisture Equipment Corporation, Santa Barbara, CA. USA	II,III, IV,V

Table 3. Summary of analytical methods, their measurement unit and method used (general view, details in papers).

Variable	**Unit(s)**	**Method**	**Paper**
Dry matter content	g kg^{-1}	Gravimetric after force air oven drying at 100 °C 20 h	I-V
Water soluble carbohydrates	g kg^{-1} DM	Water extraction + HPLC chromatography (Aminex HPX-42A strong cation exchange column in Ag^{2+} form) with RI-detector	IV,V
High degree of polymerization fructans	g kg^{-1} DM	Water extraction + HPLC chromatography (Aminex HPX-42A strong cation exchange column in Ag^{2+} form) with RI-detector	V
OM content	g kg^{-1}	Ashing at 600 °C for 12 h	III
N		Kjehdahl-N	III
In vitro organic matter digestibility	g kg^{-1} OM	Cellulase method (Friedel & Poppe 1990)	III, IV
	g kg^{-1} OM	NIR, Boreal Plant Breeding	V
Neutral detergent Fibre	g kg^{-1} DM	Robertson & van Soest 1981	I, III
Indigestible NDF		Nylon bag technique, NDF after 288 h rumen incubation with ash correction (Robertson & van Soest 1981)	III
Milk fat	g kg^{-1}	Infra red milk analyzer (Milcoscan 605)	III, IV
Milk protein	g kg^{-1}	Infra red milk analyzer (Milcoscan 605)	III, IV
Milk urea	g kg^{-1}	Enzymatic decomposition + colorimetric method (McCullough 1967)	III, IV
Non esterified fatty acids		Enzymatic treatment + colorimetric analysis (Shimizu et al. 1980)	III

3.RESULTS AND DISCUSSION

The general objective of this work was to link plant and animal factors to generate knowledge that could have a significant impact at farm level as well as adding to the body of knowledge on the subject. Therefore, the experiments covered several areas of the production chain. Consequently, this section begins with results of growth processes of grasses. Subsequently the results cover the indirect HM measurement techniques and these are used in the following section, utilization of herbage by grazing animals. The production chain is concluded in the last section through consideration of practical implications of the knowledge gained from the experiments.

3.1. GROWTH PROCESS OF TIMOTHY AND MEADOW FESCUE

3.1.1. Leaf dynamics and tiller production

Leaf dynamics

Leaf dynamics of timothy and meadow fescue differed from each other and the differences were most marked in spring (May-June; generative growth phase) rather than in autumn (July-September, vegetative growth phase). Timothy was characterized by higher tissue turnover rates than meadow fescue, but the magnitude of differences was dependent on the growth phase (Table 4; Paper II).

The observed mean LAR for timothy was very similar to values obtained by Ryle (1964) in the glasshouse (LAR 0.14). Belanger (1998) found a wider range both in spring and autumn (LAR 0.07 – 0.25). Meadow fescue had a clearly lower LAR, which appears typical for the species (LAR 0.10; Ryle, 1964) and also for tall fescue (LAR 0.07 – 0.08; Ryle, 1964; Van Esbroeck et al., 1989). The original measurements of LER in this work included extension of both leaf lamina and internodes. However, since the following LER values refer only to extension of leaf lamina in the generative and vegetative phases of growth, they are comparable to the values given by Belanger (1996, 1998). The recorded LER_{gross} values for timothy were always higher than those for meadow fescue. The values established for timothy were comparable in spring, but lower in autumn than those of Belanger (1996, 1998), who reported LER_{gross} up to 78 mm tiller^{-1} d^{-1} with high N fertilization. There are no published results for meadow fescue. It is important to note that the difference between the generative and the vegetative growth phases would be even greater if total elongation rates (internode + lamina) were used. Estimates of LSR for timothy and meadow fescue have not been published.

LLS in degree days (DD) for timothy was clearly longer than that reported by Belanger (254-266 DD; 1996, 1998). LLS in DDs from this study were also longer than those for perennial ryegrass (330 DD; Davies 1988), especially in autumn. Meadow fescue had even longer LLS and it increased markedly from spring to autumn. In spring LLS in DD of meadow fescue was between that for perennial ryegrass (Davies 1988) and tall fescue and in autumn it was similar to that for tall fescue (570 DD; Lemaire 1988) and cocksfoot (569 DD; Calviere and Duru 1995), but in the latter study the side tillers were removed as they emerged.

Mean $\mathrm{LER}_{\mathrm{net}}$ was 44 – 60 % of mean $\mathrm{LER}_{\mathrm{gross}}$. $\mathrm{LER}_{\mathrm{net}}$ was negative at the end of both measurement periods. Thus, $\mathrm{LER}_{\mathrm{gross}}$, calculated only from growing leaves, would give an erroneous measure of the current production and leaf area development and $\mathrm{LER}_{\mathrm{net}}$ is clearly a more relevant descriptor in determining the leaf area development or growth of a tiller than $\mathrm{LER}_{\mathrm{gross}}$ (Paper II).

Table 4. Effect of species and season on leaf appearance rate (LAR), leaf elongation rate per degree day ($\mathrm{LER}_{\mathrm{gross}}\mathrm{DD}$), leaf life span in degree days (LLSDD) and leaf area. T = timothy, MF = meadow fescue. (Reproduced from Paper II)

	Spring		Autumn			P-values		
	T	MF	T	MF	SEM	Species	Season	Species x Season
LAR (leaves d^{-1})	0.130	0.083	0.126	0.070	0.0065	**<0.001**	0.118	0.43
$^{a}\mathrm{LER}_{\mathrm{gross}}\mathrm{DD}$ (mm $tiller^{-1}$ $°C^{-1}$ d^{-1})	2.24	1.30	1.39	0.94	0.124	**<0.001**	**<0.001**	**0.021**
LLSDD	389	414	465	633	20.0	**<0.001**	**<0.001**	**<0.001**
^{a}Leaf area (cm^{2} $tiller^{-1}$)	52.2	17.8	34.5	28.8	5.39	**<0.001**	0.47	**0.003**

^{a}Leaf lamina

$\mathrm{LER}_{\mathrm{gross}}$ was satisfactorily accounted for by daily mean temperature and daylength, but LSR did not correlate well with any of the measured climatic variables (Fig. 3 in Paper II). Woodward (1998) proposed that temperature and LSR are closely related. During the first observation period in this experiment high temperatures were related to high canopy LAI and long days and thus air temperature correlated positively with LSR. In autumn high temperatures were related to low LAI values and air temperature correlated negatively with LSR. The effect of temperature was therefore masked by LAI and decreasing daylength at the end of August and in September. Indeed, LAI alone explained 85 % and 73 % of the variation in LSR in timothy and meadow fescue, respectively. This response was probably related to radiation extinction at the base of the canopy with such high LAI values (Monsi and Saeki 1953) and as consequence, to the increased senescence (Bircham and Hodgson 1983). However, such a response was not so clear in autumn, where it may have been masked by low temperatures at that time, which generally decrease LSR (Vine 1983, Woodward 1998).

It is evident that timothy in particular (at high latitudes), and in to a lesser extent meadow fescue, differed from perennial ryegrass (at lower latitudes) with respect to leaf number and leaf life span. Thus, the three leaf rule for vegetative perennial ryegrass (Davies 1971a) cannot be applied as such to timothy, the discrepancy between species being largest during the generative growth phase in May - June. As Davies (1988) stated, the phenomenon established for perennial ryegrass might be similar for other grasses, although the number of leaves can differ. The present data (Paper II) suggested that in vegetative timothy the average leaf number would be near five and in meadow fescue near four (Fig. 2). The different definition of live leaf, or more precisely the definition of the moment when a leaf is classified as dead, creates some uncertainty in comparisons among experiments.

This discrepancy is also a consequence of climatic factors. Firstly, in the Nordic short summer generative growth is of major importance since it begins almost immediately after the start of the growing season and covers much of the growing season (Papers II, IV, V). On the other hand, during the vegetative growth phase in the second half of the summer, there is only a short period when climatic factors (daylength, temperature) do not change rapidly. (Paper II; Skjelvåg 1998). Thus ‘steady state growth’ seldom occurs in Finnish swards.

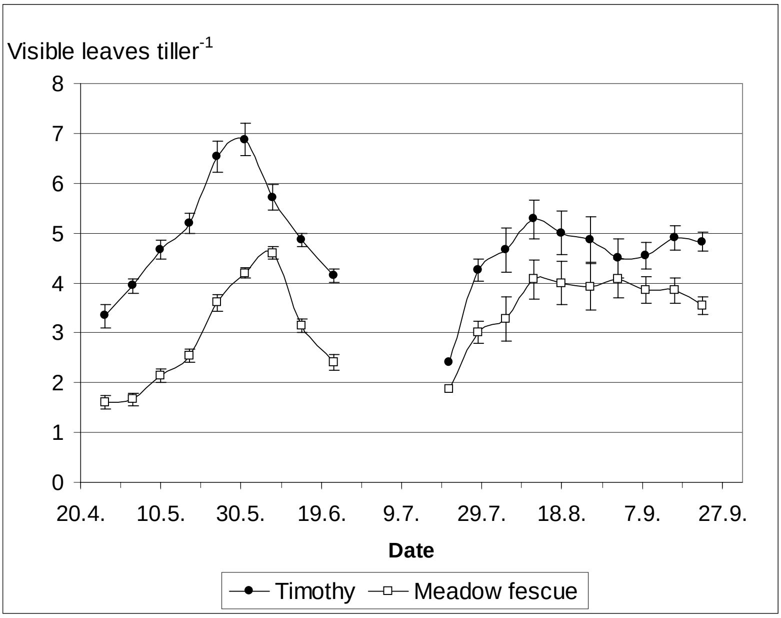

Figure 2. The mean numbers of visible live leaves of timothy and meadow fescue during generative (20.4 – 19.6) and vegetative (21.7 – 22.9) growth phase (redrawn from Paper II). Vertical bars represent ±SE.

Tiller production

The tiller population density (all tillers) in timothy - meadow fescue swards ranged from 2360 to 5280 tillers m^{-2} (Papers II, IV). When timothy and meadow fescue were grown in pure stands, the tiller population densities were slightly higher for meadow fescue (3880 – 4490 tillers m^{-2}) than for timothy (2930 – 4200 tillers m^{-2}), although the difference was not always significant (Paper V). The difference between the species in the proportion of vegetative tillers was more pronounced, since it was clearly lower in timothy in June. As the population density of all tillers was similar again in August, timothy must have produced at least approximately 180 % – 210% more new tillers between June and August in order to compensate for the higher proportion of cut generative tillers. Since each leaf carries a bud at its base, LAR determines the limits of tiller production. The ratio between the potential tiller buds and actual number of tillers produced is called site-filling ratio (Davies 1974, Davies 1988, Nelson 1996). It is not possible to determine the actual site-filling ratio without exact measurement of tiller and leaf initiation. However, from the results of Paper V it can be calculated that timothy produced 1.9 – 2.4 times more new tillers per tiller during the generative growth period than meadow fescue. Furthermore, for timothy the LAR was 1.6 times higher (see Table 4; reproduced from Paper II). Therefore, the high tiller production of timothy corresponded well with its high LAR values and it seems likely that the site-filling ratio is only slightly higher for timothy than for meadow fescue. This is in contrast to the results of Ryle (1964) who found in a glasshouse experiment of single-spaced plants that the development of a new tiller began later in timothy than in meadow fescue, i.e. after 5.4 leaf appearance intervals vs. after 3.5 leaf appearance intervals, respectively. However, timothy had a higher LAR and meadow fescue produced only slightly more tillers than timothy during a certain time period (Ryle 1964). A more detailed study under field conditions, including tiller death, is needed to establish the precise dynamics of tiller production of timothy and meadow fescue.

The higher proportion of generative tillers in timothy compared with meadow fescue was also noted at the beginning of August. In this study meadow fescue expressed a higher synchronization pattern in tiller growth stage than timothy, both early and late in the season (Paper V).

The recorded tiller densities were lower than usually reported for perennial ryegrass pastures in more temperate climates, 9000 – 19 000 tillers m^{-2} (Garwood 1969, Baker & Leaver 1986, Roche et al. 1996). Perennial ryegrass swards are able to increase tiller population density even more, up to 41 000 tillers m^{-2}, if they are for example continuously grazed to a low sward height (Penning et al. 1991), but can produce similar densities as found in this study when grazed rotationally by cattle (Brock et al. 1996) or cut infrequently (Binnie & Chestnutt 1991, Wilman & Gao 1996). According to Heide et al. (1985), this shift to larger but fewer tillers is a general adaptation of grasses to the cool, long days of the high-latitude summer.

Direct comparisons of tiller density and dynamics of tiller production between timothy and meadow fescue are rare. Ryle (1964) reported that timothy produces the same number of tillers as meadow fescue over the same period although the site-filling rate is much lower due to the greater number of leaves produced. According to Langer (1959), timothy produced slightly more tillers and it was also more responsive to frequent cutting than meadow fescue. In addition, Langer (1959) pointed out that timothy recovered well, but not necessarily rapidly, from the loss of shoot apices with a four week interval between cuts under favourable conditions. However, after removing apex-bearing shoots under dry conditions there was a clear delay in tiller and dry matter production.

The reason for expression of a high number of generative tillers even during the beginning of August is that timothy is an obligate long day species. It needs only a single long day induction for flowering whereas most temperate, perennial grass species need short days or low temperature for primary induction and then long days for secondary induction (Heide 1994). Therefore, axillary tillers that emerged later in the season may have switched to the generative growth phase due to the 19 - 20 h daylength at the experimental site. In contrast, the axillary tillers of meadow fescue need vernalization or a period with short days before they are able to switch to the generative growth phase (Heide 1994).

3.1.2. Effect of management and canopy factors affecting sward regrowth

The growth process of a sward is crucially dependent on whether tillers are in a generative stage or a vegetative stage. The relative growth rates for HM production of vernalized tillers is 30 – 50 % higher than that for unvernalized tillers (Davies 1971b, Bartholomew & Chestnutt 1978). Thus, in the following section generative and vegetative growth phases are considered separately.

Regrowth - management factors

Regrowth differed markedly according to the grass species under study. In the present study meadow fescue expressed higher regrowth (kg DM ha^{-1} d^{-1}) ability than timothy. However, the difference in regrowth was dependent on the year since in June - July 2000 the growth rates were similar, but in 2001 the growth rate of timothy was low, at only 63 % of the growth rate of meadow fescue. There was no difference between the species in the D-value for regrowth. The better regrowth of meadow fescue was more pronounced in the cumulative regrowth yields (sum of three cuts, generative and vegetative growth) as it produced 8 – 21% higher cumulative regrowth yields than timothy. In August timothy and meadow fescue were more similar with respect to regrowth factors than in June – July (Paper V).

The results suggest that in order to achieve a more constant HM production on pastures, the proportion of meadow fescue should be increased in seed mixtures over that used currently (timothy 12 – 22 kg $ha^{-1}$and meadow fescue 10 - 11 kg ha^{-1}, equivalent of 2500 – 4650 seeds m^{-2} for timothy and 500 seeds m^{-2} for meadow fescue). This is particularly the case where timothy fails to produce new tillers after cutting of stem apices (Papers IV, V). A larger proportion of meadow fescue may ensure better HM production.

However, HM production is only one step towards efficient pasture management. It is noteworthy that compared, for example, with perennial ryegrass, timothy has produced 14 % higher daily LW gains for lambs (Davies & Morgan 1982) and a high milk solids yield of dairy cows (Thom et al. 1998; timothy – perennial ryegrass mixture). This suggests that timothy has a high feeding value or high intake characteristics. However, direct comparisons in animal production per unit area between timothy and meadow fescue in Finland are still lacking. Therefore, the optimum balance between timothy and meadow fescue cannot be stated. Furthermore, it is well known that the botanical composition of a sward is dependent on several factors other than just the seed mixtures, including management factors, edaphic factors, climate during the growing season and non-growing season, and also the growth type determined by the genotype (Pulli 1980, Sheldrick 2000, Paper II).

Defoliation height had a similar effect on both species. Increasing the defoliation height from 3 to 9 cm increased the growth rate of both species by 19 % linearly by increasing the cutting height in June - July 2000. In June - July 2001 defoliation height had no effect on the growth rate. The defoliation height had no effect on the D-value of regrowth HM, although it tended to decrease with increasing defoliation height in June - July 2001 (Paper V).

In August 2000 the regrowth rates increased by 27 % after increasing the cutting height. In 2001 the defoliation height had no effect on the regrowth rates. The positive effect of increasing the defoliation height was more clearly seen in the cumulative regrowth yields, since an increase occurred in both years (29 and 10 % respectively; Paper V). Since defoliation height had no effect on the regrowth rate in June and August 2001 but did affect the cumulative yield, it can be concluded that the consequences of a single close defoliation per growing season may not be significant. On the contrary, when close defoliation is repeated throughout the growing season, it is likely to reduce the HM yields.

At first glance the magnitude of the effect of defoliation height is rather small during one regrowth cycle. For example, in June 2000 during 21 day regrowth cycle it would be equivalent to 66 kg DM ha^{-1} per one cm reduction of defoliation height and in August 51 kg DM ha^{-1} per, for example, 28 d regrowth cycle. However, the cumulative effect would be considerable. If calculated at an annual HM production level of 8000 kg DM ha^{-1} (Paper IV), the effect of +29 and +10 % would be equivalent to 133 – 387 kg DM ha^{-1} per one cm reduction in defoliation height and the difference between 3 cm and 9 cm would be equivalent to 800 – 2300 kg DM ha^{-1}.

This result contrasts with the general concept regarding the effect of defoliation height on perennial ryegrass swards, for which a stubble height of 5 cm is considered an optimum when the cutting interval is set to 3-leaf stages (Donaghy & Fulkerson 1998, Fulkerson & Donaghy 2001). It should be noted that the effect of cutting height is bound up with cutting frequency (Huokuna 1964, Fulkerson & Slack 1995, model of Parsons et al. 1988b, Parsons & Penning 1988). Even performance of perennial ryegrass is decreased if it is frequently cut to 2 cm (Fulkerson & Slack 1995, Hernandez-Garay et al. 1999). In this work the swards were defoliated at growth stages typical of current farming practice (Papers III, IV, V) and no interaction with defoliation height and interval was studied. The most probable explanation for the results contrasting with those obtained for perennial ryegrass lies in the difference in the ability of the grass species to adapt to close defoliation. While perennial ryegrass is a grazing tolerant species, it is well able to compensate for reduced tiller height caused by close defoliation through increasing tiller population density (Ryle 1964, Grant et al. 1983, Baker & Leaver 1986, Brock et al. 1996). Moreover, cocksfoot (Brock et al. 1996) and smooth meadow grass (Frankow-Lindberg 1991) tolerate grazing by increasing tiller density at least to some extent. Kunelius et al. (2003) found that there was considerable variation among timothy cultivars regarding size - density relationship when defoliated at the same height, but compensation was obvious only late in the season. Overall, based on Papers IV and V, the ability of timothy and meadow fescue to compensate for reduced tiller size by increasing tiller density is less than that of perennial ryegrass. This holds at least under long day conditions, which are known to increase tiller size and height and reduce tiller formation of timothy (Heide et al. 1985). Although size/density ratio was not directly calculated in the experiments, the lack of compensation was confirmed, since an increase in defoliation height led to an increase in both residual tiller size and density of vegetative tillers in August in both years (Paper V). Therefore, both timothy and meadow fescue react to defoliation height more like prairie grass (*Bromus willdenowii* Kunth.; Xia et al. 1994, Slack et al. 2000) rather than perennial ryegrass in a temperate climate.

In contrast with the results obtained from cut plots, for *in situ* measurements on a grazed timothy - meadow fescue sward there was no benefit from increase in sward residual height from 8.6 to 11.3 cm or from 7.3 to 9.9 cm or from 8.6 to 12.4 cm (Paper III) for the recovery rate of leaf area or HM. The within treatment variation in post-grazing SH on the grazed swards was large (large CVs) compared with small difference between the treatments. This may have masked the effect of different residual heights on the regrowth rates of large paddocks (Paper III). Furthermore, the study was conducted in a moist year, which probably favoured regrowth.

In summary, based on HM production, farmers should avoid grazing pastures much under 9 cm, although the consequences of a single close grazing are probably not significant. Furthermore, grazing with cows rather than mechanical defoliation leads to non-uniform defoliation (Fig. 1 in Paper III,) which partly masks the effect of defoliation height. Grazing naturally has many effects on the canopy other than defoliation and these can also obscure the effect of defoliation height under farm conditions. As shown later in Chapter 3.3, the suggestion for at least 9 cm defoliation height coincides well with livestock requirement for 9 – 10 cm residual SH.

Timing of the initial cut affects regrowth after the cut and annual HM production (Paper IV). Regrowth rate after the first cut was measured as an increment of LAI during the first 10 days after cutting. Regrowth was rapid and almost linear at the first two cutting dates studied (sward growth stage ~MSW 23). However, regrowth was slower at the last two cutting dates (sward growth stage MSW 32 - 41) with a clear lag period, during which the increment in LAI values after defoliation was low or zero. In this experiment the timothy and meadow fescue tillers had had enough time after winter to recover their reserves of carbohydrates, since regrowth was rapid after the two initial cutting dates, when the vegetation was still very young. Thus, early turnout did not reduce regrowth potential *per se.* On the contrary, regrowth after a late first cut was impaired due to the low number of vegetative tillers (Paper IV, see below).

Canopy factors affecting regrowth - tiller population density

The proportion of vegetative tillers is the main factor affecting regrowth rate (June-July, generative growth phase) of timothy and timothy dominated swards (Fig 3; Papers IV, V). In addition to DM production, the recovery of leaf area after 10 d regrowth correlated positively with the number of vegetative tillers per m^2 (correlation coefficient 0.77, $P = 0.003$) and not with WSC or post LAI (Paper IV).

In June the proportion of vegetative tillers in the total tiller population of the timothy meadow fescue dominated canopy decreased from 1.00 – to 0.18 in 21 days (3 June to 24 June; Paper IV). In Paper V, where only a single cut was taken in June of 2000 and 2001, timothy had only an average of 1040 and 1720 vegetative tillers m^{-2}, respectively. Vegetative tillers as a proportion of total tiller population were only 0.33 – 0.56. In contrast, meadow fescue had a reasonably high number of vegetative tillers (2710 – 3110 m^{-2}) and high proportion (0.72-0.87) of vegetative tillers. During the vegetative growth phase the tiller population density for vegetative tillers was not so important for regrowth rate (Fig. 3).

Since those generative tillers for which apices were higher up or near to defoliation height lost their apices in defoliation, a large part of the regrowth must have taken place through initiation of new tillers from axillary buds. This process is slower (Briske 1985, Davies 1988) and uses WSC pools less effectively than regrowth directly from existing meristems (Richards & Caldwell 1985). Therefore, it is logical that the growth rate and the number of vegetative tillers in June - July correlated positively (Papers IV, V). In the case of timothy, the results were similar to the early findings of Jewiss (1972). Recently Bonesmo (1999) showed that the proportion of non-elongated (vegetative) tillers was more important for the regrowth than the WSC concentration when different phenological stages were compared. The latter had an effect only on the initial regrowth rate. If a plant has no available active meristems at the beginning of regrowth, even high amounts of C-reserves cannot provide for rapid regrowth. For example regrowth of two wheatgrass species (*Agropyron desertorum* Schult, *A. spicatum* Scribn & Smith) was decreased to one fifth in situation where regrowth was forced to start from lateral meristems instead of active intercalary or apical meristems (Richards & Caldwell 1985, Richards 1993).

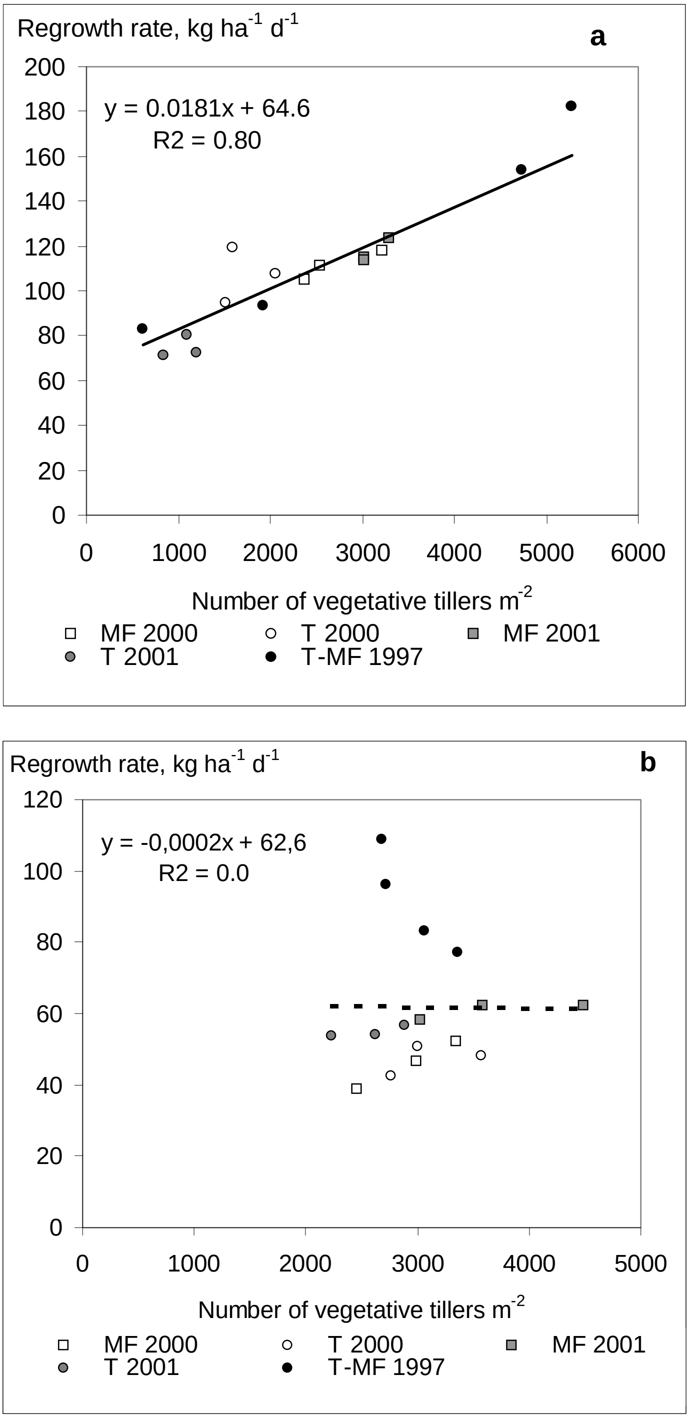

Figure 3. The relationship between the number of vegetative tillers m^{-2} and regrowth rate kg DM ha^{-1} d^{-1} after defoliation of generative sward (a) and vegetative sward (b). T = timothy, MF = meadow fescue (Papers IV, V).

Since a reduction in defoliation height did not promote a higher tiller density (Paper V), the results suggest that the tillering of a timothy–meadow fescue sward cannot be improved much by close grazing early in the season. This is in contrast to perennial ryegrass swards (Baker & Leaver 1986, Sayers & Mayne 2001). Nevertheless, close grazing (via adjustment of HA) improves the HM utilization (see Chapter 3.3.1 and Paper III). It may also lead to an improved feeding value of HM in subsequent harvests by preventing the late stages of stem formation (Paper IV) although the effect is not always apparent (Paper III; see more in Chapter 3.3.).

Effect of WSC, LDP and HDP fructans, post defoliation LAI and N reserves on regrowth

There were large year, year x species and year x defoliation height effects on post defoliation parameters under field conditions (Papers IV, V). In regrowth after defoliation during the generative phase the concentration of WSC, LDP and HDP fructans, the WSC pool per tiller or per unit area, post defoliation LAI, N reserves, and tiller size did not much affect the regrowth rate. During the vegetative growth phase no single factor essential for regrowth can be identified. The most probable reason why no single canopy factor to explain regrowth rate in a vegetative sward was detected was that increase in the defoliation height positively influenced all the most important post defoliation parameters (residual LAI, residual HM, tiller size, WSC pools per tiller and per area and N pool). Therefore, there were strong correlations between component variables measured. Furthermore, large differences in weather conditions between the years affected the growth rate of timothy. However, this could not be linked with variation in the measured explanatory variables. The results contradict those of small scale experiments on the importance of WSC concentration (Fulkerson & Slack 1995), or WSC pool (Christiansen & Svejcar 1987, Fulkerson & Slack 1995, Duru & Calviere 1996) or LAI (Booysen & Nelson 1975) on the regrowth. It is also noteworthy that in the present experiment the sward had a reasonable rest period (21 – 28 d) leading to sufficient pre-defoliation sward state. In other words, the treatments resulted in pre-defoliation LAI values of 3.2 - 5.8. These can be regarded as sufficient for sward HM production (Bircham & Hodgson 1983; Parsons et al. 1988b), i.e. the swards had enough time after the previous defoliation to replenish their carbohydrate and other storage pools (Paper V). The results could have been different with shorter cutting interval as mentioned earlier (see also negative effects of repeated defoliation at too early growth stage Mislevy et al. 1977, Pulli 1980). However, the results are in line with *in situ* results of Le Du et al. (1979) where different HA did not have any effect on regrowth. Furthermore, for *in situ* grazing with different levels of HA, Kim et al. (2001) found that the importance of N and C reserves were of the same magnitude and no dominant factor affecting regrowth could be given.

3.2. ACCURACY OF INDIRECT HM ESTIMATION TECHNIQUE

The results showed that the observation day had a significant effect ($p<0.05$) on the equation parameters for HM estimation when using the sward stick and capacitance meter, but not when using the disk meter. Therefore, the HM prediction equations were estimated separately on each occasion (Total 17 occasions). The sward stick models failed once and capacitance meter models twice to explain variation in HM. A summary of the comparisons is presented in Table 5. It can be concluded that the disk meter and sward stick were in general similar, but the capacitance meter was less accurate. None of the methods is accurate if the vegetation is lodged or trampled.

The r^2 and RSD values were comparable with those of most previous studies (Michell & Large 1983, Gonzalez et al. 1990, Harmonney et al. 1997), but lower RSDs have also been reported (Fulkerson & Slack 1993, Virkajärvi & Matilainen 1995). The accuracy varied considerably between the observation days. The highest CVs recorded were mainly related to situations when HM was low, under 1500 kg ha^{-1} DM (Paper I).

Table 5. Accuracy of linear HM prediction models for disk meter, sward stick and capacitance meter when applied to the validation data set from each set of measurements (n = 9-20 per data set, total 256; reproduced from Paper I. RSD = residual standard deviation, CV coefficient of variation).

Method	R^2		RSD, kg ha^{-1}		CV, %	
	Range	Mean	Range	Mean	Range	Mean
Disk meter	0.33 - 0.91	0.61	132 – 706	380	13 - 67	25.1
Sward stick	0.40- 0.78[1]	0.64	199 – 827	392	12 – 57	26.3
Capacitance meter	0.19 - 0.80[2]	0.44	182 – 1151	493	15 – 59	31.3

1) Sward stick models failed once to produce r^2 value, not included in range or in average r^2 values

2) Capacitance meter models failed twice to produce r^2 value, not included in range or in average r^2 values

The sward stick reacts merely to sward surface, the disk meter to sward surface and sward rigidity, while the Pasture Probe™ capacitance meter reacts most strongly to HM located in the zone near the point where the probe touches the soil (Mosaic Systems 1991). In the sparse (averages 2900 – 4520 tillers m^{-2}) and tall (SH range up to 51 cm) timothy – meadow fescue swards at high latitudes, the sward surface height appears more important for HM than the mass located near the soil surface. This was confirmed by correlation analysis where sward surface height correlated better with HM ($r = 0.85$) than canopy density ($r = 0.26$). The strong correlation of sward surface with HM was obvious also in other studies during this work (Papers IV and V). Thus it is logical that the disk meter and sward stick were more accurate on most occasions. Indeed, when the HM was very low (< 1500 kg ha^{-1} DM) CMR was the most accurate method. This phenomenon is partly supported by the literature. For example, Greathead et al. (1987) tested CMR particularly for short and dense swards with HM < 3000 kg ha^{-1} DM. They reported that most accurate and unbiased estimates were found in the middle range for the HM used. In general, indirect estimation techniques have been compared in numerous studies and the accuracy of different methods has varied according to prevailing sward properties (Michell & Large 1983, Greathead et al. 1987, Gonzalez et al. 1990, Fulkerson & Slack 1993, Gabriels & Van Den Berg 1993, Harmonney et al. 1997). It is not possible to suggest a single superior method for all types of grassland. In canopies where HM correlates more strongly with the height of the canopy than with tiller population density, those methods that react to sward surface are most probably more accurate, whereas methods that react to sward density are more suitable for those canopies where HM correlates with sward density.

3.3. INFLUENCE OF PASTURE MANAGEMENT ON ANIMAL PRODUCTION AND HERBAGE UTILIZATION

3.3.1. Effect of herbage allowance on HM and milk production

Increasing HA from 19 to 27 kg DM cow^{-1} day^{-1} increased the energy corrected (ECM) yield linearly by a mean response of 0.16 kg ECM kg^{-1} DM (Fig. 4.), but it had no effect on the milk composition. The increase in individual animal performance of 6 % led to a reduction of 25 % in animal production per unit area. Increasing HA also increased HI and decreased herbage utilization (Table 6; Paper III).

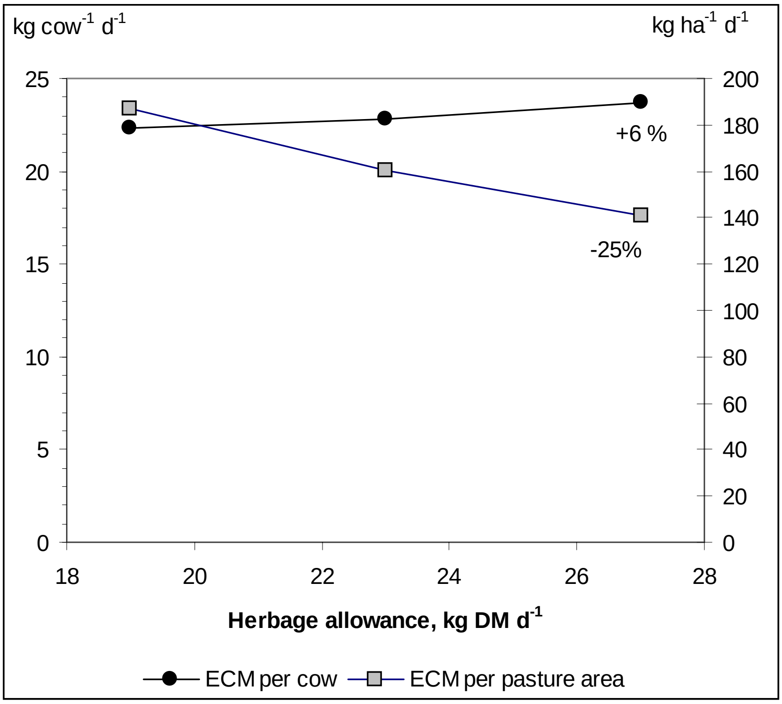

Figure 4. Effect of herbage allowance on daily energy corrected milk (ECM) yield per cow (left Y-axis) and per hectare (right Y-axis).

Table 6. Effect of herbage allowance (HA) on energy corrected milk (ECM) production per animal and per unit area, herbage intake (HI) and utilization of herbage mass (HM; Paper III).

	HA, kg DM cow^{-1} d^{-1}		
	19	23	27
ECM yield, kg cow^{-1} d^{-1}	21.9	22.3	23.2
ECM yield ha^{-1} d^{-1}	187	160	141
HI, kg DM cow^{-1} d^{-1}	15.0	16.5	16.8
HM utilization (> 3 cm)	0.77	0.71	0.62

The observed mean response of milk yield per animal (i.e., 0.16 kg kg^{-1} HA) due to increasing HA is consistent with results from earlier Scandinavian studies (Kristensen 1988) and other studies at comparable animal production levels without feed supplements (Fig. 5; Peyraud et al. 1996, Maher et al. 1997, Dalley et al. 1999). The milk response to increased HI in this study was 0.72 kg ECM kg^{-1} DM. Thus, the marginal response of the additional ME to milk yield was 0.06 kg ECM per MJ additional ME. This is low compared with the theoretical response of 0.19 kg ECM (Tuori et al. 1996), which indicates that the energy intake was fairly adequate at the lowest HA during the collection period. For reference, in a review of Finnish studies on silage plus concentrate feeding, this value was 0.093 kg ECM per MJ additional ME (Huhtanen 1998). It is also interesting to note that response of high-yielding dairy cows on pasture to concentrate supplementation was 1.04 kg ECM (Delaby et al. 2001) and 0.87 kg ECM (Sairanen et al. 2003) per kg concentrate DM. The use of concentrate supplementation on pasture is an important theme, but beyond the scope of this work.

The average milk yield level was lower in many earlier experiments (12 to18 kg day^{-1}; Le Du et al. 1979, Combellas & Hodgson 1979, Stakelum 1986) compared with this study (23 kg ECM day^{-1}). It is obvious that the effect of HA kg DM cow^{-1} day^{-1} is dependent on the animal production level. Moreover, the HM quality may vary and have different energy values on different occasions and for different circumstances. Therefore, a more consistent view is achieved when HA is calculated as a relative herbage allowance (RHA) that takes into account the energy requirement of the animals as well as energy supply as follows:

RHA = (DM allowance of kg cow^{-1} day^{-1} x energy content of DM, MJ ME kg^{-1} DM)/energy requirement, ME MJ cow^{-1} day^{-1}

Using equations given by Tuori et al. (1996) for the estimation of energy requirements and the information on animal production and herbage composition given by Le Du et al. 1979, Combellas and Hodgson 1979, Kristensen 1988, Peyraud et al. 1996, Maher et al. 1997, Dalley et al. 1999, the relationship between RHA and ECM production can be plotted together (Fig. 5). Energy for LW change was not accounted for and an increase of +15 % of the maintenance energy was accounted for grazing activity (NRC 1988). The figure shows that the effect of additional increments in RHA is stronger between RHA values from 1 to 2 and less between values from 2 to 3. It also shows that there is a clear difference in milk yield level between experiments, which is most probably due to differences in animal production potential (genetic merit, stage of lactation). In contrast, when the RHA and HM utilization from the same experiments are plotted together it can be seen from a wide range of studies that the relationship is almost uniform (utilization = 0.85 - 0.47ln(RHA); r^2 = 0.89; Fig. 6). Thus, neither the different swards and canopies, nor the production potential of animals interfere much with the RHA – HM utilization relationship.

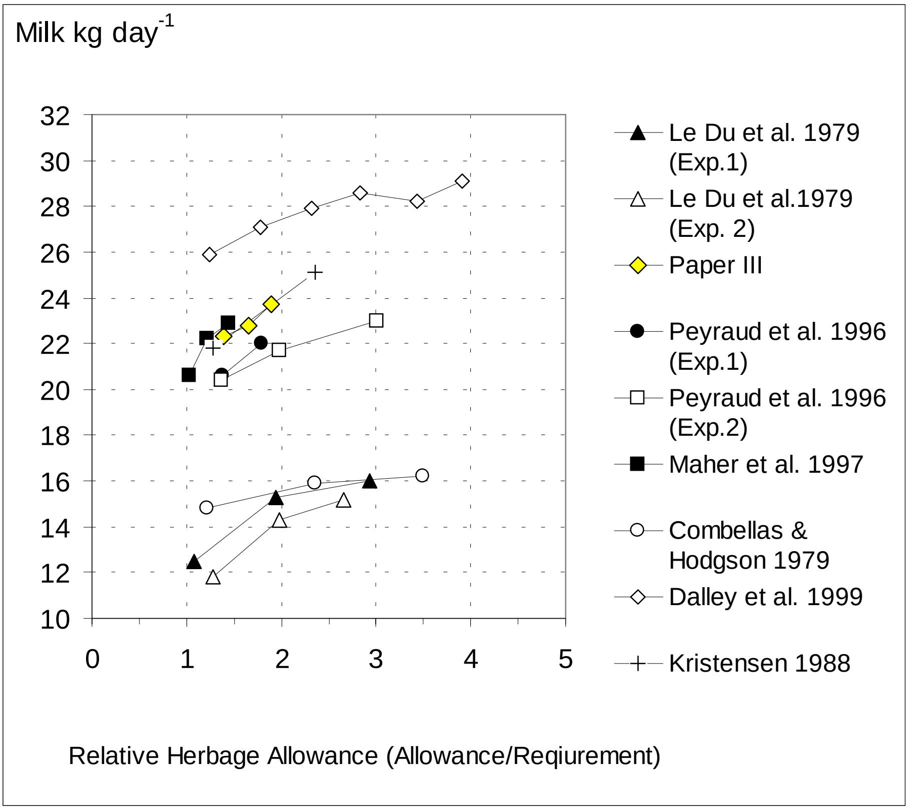

Figure 5. Relationship between RHA and milk production. HM estimated to ground level except Maher et al. 1997 (4 cm). Milk yields expressed ECM (Paper III), solid corrected milk (Le Du et al. 1979, Combellas & Hodgson 1979), fat corrected milk (Peyraud et al. 1996) or as milk; recalculated from Paper III).

It is noteworthy that the energy balance of a dairy cow does not have to be zero. In early lactation the balance may well be under zero, whereas in late lactation it should be positive (Forbes 1995). Therefore, the stage of lactation affects the relationship between RHA and milk production. This is the most likely explanation for the low utilization values of Dalley et al. (1999) relative to corresponding RHA, since in their experiment the cows were in early lactation (41 ± 9 d). Consequently, the cows with the three lowest RHA levels (1.2, 1.8 and 2.3) lost 0.44, 0.21 and 0.20 kg LW d^{-1}, respectively. Therefore, they used much of the body reserves to produce the high milk yields observed and had lower HI relative to their requirements than cows in other experiments. On the contrary, the cows on the three highest RHA levels increased their LW (Dalley et al. 1999).

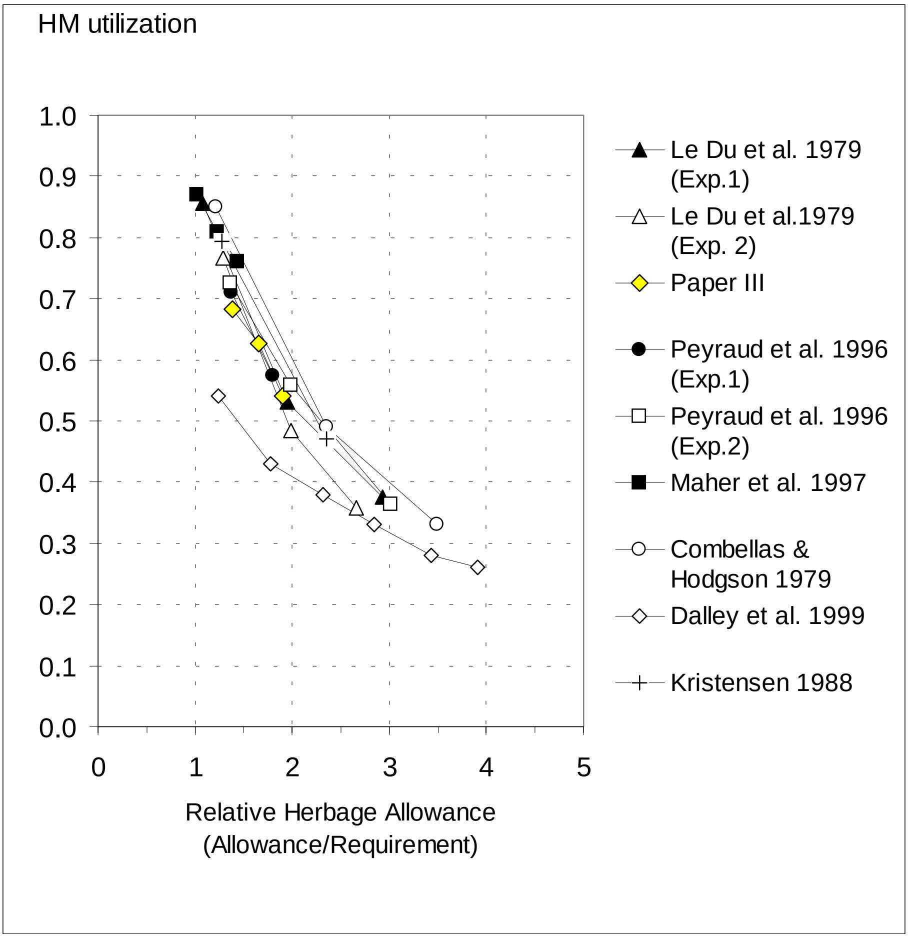

Figure 6. Relationship between RHA and HM utilization. HM estimated to ground level except Maher et al. 1997 (4 cm).

It can be concluded that the general relationship between HA and milk yield increment seems to be similar for timothy – meadow fescue swards under Nordic conditions to perennial ryegrass swards under more temperate conditions. This similarity was observed despite pre-grazing sward heights being high (period means in the range of 31 – 39 cm), bulk density being low (period means in the range of 0.80 – 0.92 kg DM m^{-3}), and leaf content being relatively low (period means in the range of 460 - 680 g kg^{-1}) compared with studies conducted with perennial ryegrass swards (Mayne and Wright 1988, McGilloway et al. 1999, Casey & Brereton 1999, Parga et al. 2000). This means that the ease by which a cow harvests the energy is similar despite the differences in sward structure between Nordic timothy – meadow fescue swards and perennial ryegrass swards in more temperate climates. This conclusion is supported by the nearly uniform relationship between RHA and HM utilization.

Based on experiments conducted mainly with perennial ryegrass, increasing SH has a positive effect on bite size and thus herbage intake rate (Wade et al. 1989, Spörndly & Bursted 1996, McGilloway et al. 1999, Casey & Brereton 1999), whereas low bulk density and low leaf content has a negative effect on the bite size (Forbes 1988, Laca et al. 1992, Casey & Brereton 1999). In tall swards the effect of SH is most important, but in shorter swards the effect of bulk density increases (McGilloway et al. 1999, Casey & Brereton 1999), therefore the effect of SH is most probably dominant in Nordic, tall and sparse timothy - meadow fescue pastures. Because the effects of these parameters were not measured it is not meaningful to discuss further the effect of sward structure on herbage intake. It is noteworthy that despite the low leaf content in June, 460 – 670 g kg^{-1} DM, the IVOMD remained high at 794 g kg^{-1} OM (SE 8.4 g kg^{-1} OM; Paper III). This is related to high nutritive value of young stems, which is also indicated in Paper IV and in silage studies (Rinne & Nykänen 2000).

The concentration of non esterified fatty acids (NEFA) in blood plasma increases when cows mobilise fat depositions because of negative energy balance (Baldwin & Smith 1983). In this experiment the observed plasma NEFA concentrations were higher (P=0.08) when grazing on HA 19, indicating higher fat mobilization and lower energy balance than for the cows on the highest HA. When energy requirements were calculated according to Tuori et al. (1996), including milk production and maintenance (+10 % grazing activity energy; NRC, 1988) before the experimental periods, the calculated ratios of ME supply to ME requirements were 0.92, 1.00 and 1.02 for allowances 19, 23 and 27, respectively. Because the cows were in mid-lactation, the energy demand should have been met. This suggests that HA 19 cannot be regarded as an adequate feeding level for the cows used in this experiment. Furthermore, it is possible that in the case of continuous treatments over a longer term, HA 19 would not have been adequate to maintain the milk yields and body reserves without supplements. Instead the results suggest that HA 23 is a reasonable compromise between production per animal and production per unit area. HA 27 leads to 11% smaller milk yield per hectare and cannot be regarded as efficient utilization of pasture. When animal energy requirements and feeding values of grass are taken into account, it can be calculated that HA 23 was equivalent to a RHA of 1.6 – 1.7 (ME allowance/ME requirements). It is obvious that concentrate supplements, either energy or protein, are needed in any case if the cows produce higher milk yields than found in this study (Mayne et al. 2000, Delaby et al. 2001, Sairanen et al. 2003). Provided supplements will lower the pasture HA requirement, but that theme is beyond the scope of this work.

For a farmer the adjustment of HA is a difficult task that includes measurement of HM and allocation of pasture area to the animals. Consequently, in several studies post grazing SH has been proposed to be a good estimate for the HA used (Le Du et al. 1979, Baker et al., 1981, Mayne et al. 1987, Wright & Russel 1987). In the present experiment, the SH values corresponding to an adequate level of HA (HA 23) were in the range of 8.9 – 10.3 cm, which are surprisingly similar to the results obtained for perennial ryegrass swards for high yielding dairy cows (8 – 10 cm; Le Du et al. 1979, Mayne et al. 1987, 2000). Therefore, the post grazing SH of 9 –10 cm is proposed to be a suitable value for timothy – meadow fescue pastures in order to meet requirements for animal production and HM utilization.

3.3.2 Effect of timing of turnout on HM and milk production

Early turnout, when SH was only 8 – 10 cm, decreased the annual HM production in the plot trial ($P = 0.005$) compared with normal turnout (5 days later). Due to a higher average OM digestibility ($P < 0.001$) the difference in digestible OM yield was not significant ($P = 0.14$). Similarly, early turnout decreased the mean pre-grazing HM in the grazing trial. The differences in HM quantity and quality between early and normal turnout occurred mainly in late June and early July and thereafter levelled out. Early turnout was associated with a briefer period of pasture shortage than normal turnout. There were no differences in yields of milk, milk fat or milk protein ($P > 0.05$; Paper IV).

High latitude pastures typically appear to reach SH values up to 40 cm without a marked drop in digestibility (Papers III, IV). On the contrary, values higher than 40 cm (especially for normal turnout) were associated with lower IVOMD (below 750 g kg^{-1} OM). This was reflected in the post-grazing SH of frequently grazed areas, which was high for both groups whenever the pre-grazing SH was higher than 40 cm, indicating lower utilization and greater need for topping (Paper IV). From Fig. 7 it can be seen that the recommended post-grazing SH of 9 – 10 cm for dairy cows (Chapter 3.3) coincides well with a relatively high herbage IVOMD in the case of early turnout (Fig. 7a,c). When the turnout, and consequently the pasture rotation, was delayed, the canopy had an IVOMD under 750 g kg^{-1} OM already in sward horizons lower than 20 cm (Fig. 7b), which indicated a low feeding value of the grass. It is also important to note in Fig. 7a that in samples taken on 18 June the correlation between the content of leaves and the IVOMD was weak. The IVOMD values remained near 800 g kg^{-}

^{1}OM in any layer sampled above 5 cm, whereas the leaf content varied from 400 to 1000 g kg^{-1} DM. This means that the digestibility of the stem fraction remained high during the early part of the generative growth phase. Later in the season the correlation between leaf content and IVOMD was clearer (Fig. 7c).

Early turnout did not impair regrowth *per se*, but it lowered the annual herbage DM yields. Early turnout had lower average HM, but nearly the same HA and pasture area as in normal turnout. Together this led to faster pasture rotation for early turnout in the grazing trial, and the paddocks were grazed twice by late June whereas the paddocks of normal turnout were grazed only once. In the simulated plot trial the regrowth intervals of early turnout were on average over the grazing season 9 days shorter than those of normal turnout. Furthermore, the average number of harvests per season increased from 3.5 to 5 (Paper IV).

High cutting frequency was shown to lower the DM and also digestible OM (DOM) yields (Mislevy et al. 1977, Frankow-Lindberg 1989). Thus, early turnout restricted the HM production in this experiment by 1280 kg DM (14.3 %) calculated over the whole season. The difference in HM production between the turnout dates was largely explained by the stem formation process, which favours HM production, but at later stages detracts from the nutritive value of the grass (Mislevy et al. 1977, Binnie et al. 1980, Mason & Lachance 1983, Carton et al. 1989). This process was better used during normal turnout, especially at the latest initial cut. Although the regrowth of the latest initial cut was slow, the first yield was very high due to stem formation and thus a high annual HM production was achieved. It is important to note that the lower HM production with early turnout was counterbalanced by a higher nutritive value of the grass. The DOM yield, a more important sward production parameter than HM, was therefore similar for both turnout dates.

The low utilization of swards higher than 40 cm was largely explained by the low IVOMD, but also by increased stem rigidity. The advanced stem formation was indicated by the high MSW of the canopy that was associated with high SH in the early part of the season (Paper IV). It causes lower intake per bite due to reduced bite area, because an animal’s ability to cut the vegetation per a bite is restricted (Laca et al. 1993, Rook 2000) and rigid stems may even escape from jaws (Laca et al. 1993) easily. In addition, increased stem rigidity may cause marked losses due to trampling of the canopy. As the stem formation itself is beneficial in annual DOM production, the process should be utilized in milk production until the digestibility or stem rigidity limits HI and the utilization of HM.

In this study the difference in turnout date was only five days, which was too short to show any effect of grazing plus indoor feeding compared with indoor feeding alone. It could be argued that the time difference between the treatments in our experiment was small. However, a short transition period is typical in Finland. Examples of longer transition periods are given by Roche et al. (1996) and Sayers and Mayne (2001), who both found a positive response in milk production for early turnout during the transition period (+1.4 kg and +3.1 kg day^{-1}, respectively). In the experiment of Roche et al. (1996) the duration was 21 d and in Sayers and Mayne (2001) 40 d.

With only a few days of delay in turnout date, the pasture growth type and hence its management, can change dramatically, while animal production remains the same. In order to achieve an easy-to-manage but efficient pasture rotation, farmers should consider early turnout. A delay in turnout will easily lead to lower HM digestibility together with lower HM utilization which will lead to increased need for supplements. It is beneficial to let pastures reach a SH of up to but not exceeding 40 cm.

In the grazing trials of this thesis, cows within a group were used as individual observations. The basic shortcoming of this approach is the social synchronization of the eating behaviour of cows. This issue was raised by Rook & Huckle (1995) who found that there was a clear synchronization pattern in eating, ruminating and idling of dairy cows on pasture. They concluded that the use of individual cows as replicates in grazing experiments should be avoided whenever possible as they cannot be regarded as independent observations (Rook & Huckle 1995). However, the data of Rook & Huckle (1995) consisted entirely of behavioural variables. As shown in chapter 1.3, bite size has the greatest influence on herbage intake, whereas biting rate and grazing time are compensatory variables (e.g. reviews by Forbes 1988, and Penning et al. 1996). The actual effect of synchronization on herbage intake or milk production is not shown. In the presented experiments, milk production and composition were the main parameters, whereas eating behaviour was not recorded. Therefore, the animals can be regarded as individuals, although grazing on the same paddock. In the case of behavioural data the conclusion of Rook and Huckle (1995) is very important.

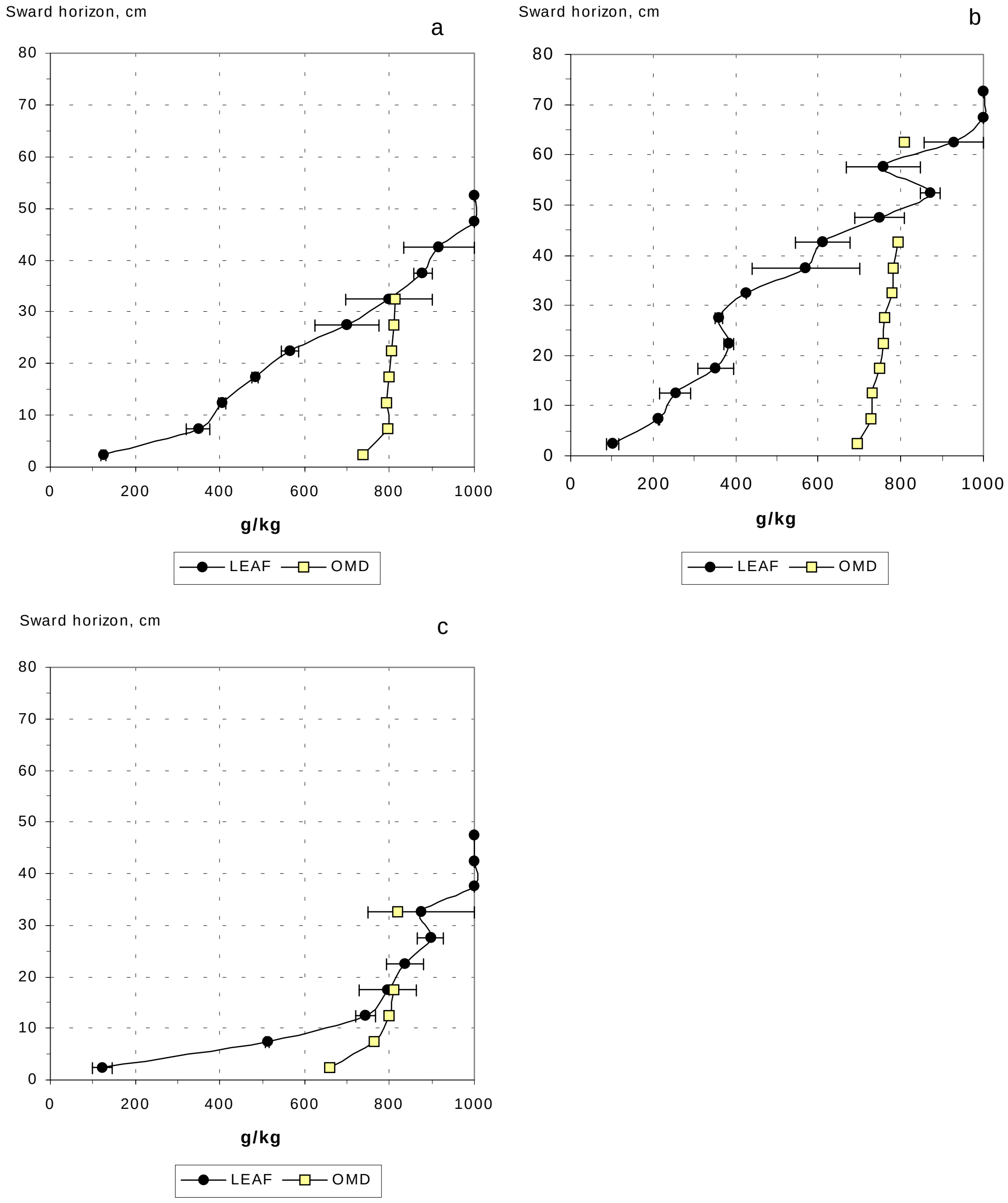

Figure 7. Examples of leaf content (g kg^{-1} DM) and IVOMD (g kg^{-1} OM) at different sward layers a) for early turnout, 2nd rotation 18 June; b normal turnout, 1st rotation 22 June and c) normal turnout in 4th rotation 8 August. For leaf content n = 2 both samples consisting of 6 – 8 subsamples. Horizontal bars represent ±SE of means. For chemical analyses the samples were bulked and SE cannot be given.

The second weakness in using animals as an individual observation is the confusion between the soil and the treatment effect. In the turn-out day experiment the three fields used were all split and randomized between the treatments and in the HA experiment the daily strips were randomized each day within a block. Therefore the soil effect was likely to be minor.

3.4. PRACTICAL IMPLICATIONS

Herbage allowance is a key factor that affects productivity per unit area and its effect on herbage utilization is not much influenced by climate or grass species under temperate conditions. Therefore, planning flexible grazing systems that allow changes to match grass growth and herbage demand is essential (e.g buffer feeding, use of concentrates etc.). Meadow fescue tolerates repeated defoliation better than timothy. Based on HM production farmers should avoid grazing pastures much under 9 cm, although the consequences of a single close grazing are most probably minor for both grass species. From the animal production perspective this coincides well with the animal need of 9 – 10 cm post grazing sward height and good feeding value of the grass (IVOMD). Leaving higher stubble does not provide any benefit for regrowth during grazing, although milk yields per cow increase slightly while milk yield per unit area decreases. The lower the defoliation height the longer should be the rest period in order to achieve similar pre-grazing sward states. Pre-grazing sward heights of up to 40 cm are acceptable, since the digestibility of the stem fraction remains high during the early part of the generative growth phase. Moreover, the stem formation is beneficial for HM and DOM production and this advantage should be used. As soon as stem rigidity increases the utilization of pasture will be low because of lowered herbage intake, lowered feeding value and increased trampling. Grazing of such paddocks should be avoided or minimized. Early turnout on 8 – 10 cm pre-grazing sward height during a transition period is recommended in order to ease pasture management and ensure higher digestibility during the early part of the summer. Because grazing represents a continuum, some paddocks must be grazed in such a way that the regrowth rate will be lowered compared with other paddocks (because of stem formation and following low proportion of vegetative tillers). Therefore, a flexible rotation system should be used.

In research work, the disk meter and sward stick are both useful tools to assess HM, but they need to be frequently re-calibrated. Relative herbage allowance is useful in assessing suitable

HA levels for research purposes, for example in exploring the effect of the amount of concentrates or the effect of fertilization levels on milk production from pastures.

4.CONCLUSIONS

1) Nordic timothy – meadow fescue pastures are tall, have low tiller population density, low HM bulk density, occasionally low leaf content and exhibit rapid development rate and herbage accumulation rate in spring. They are of similar feeding value compared with perennial ryegrass pastures despite structural differences.

2) Growth processes of timothy and meadow fescue clearly differ from each other in the generative growth phase in May-June and less in the vegetative growth phase in July-August. Overall timothy is characterized by higher tissue turnover rates than meadow fescue.

3) Timothy (at high latitudes) differs from perennial ryegrass (at lower latitudes) in having more leaves and a longer leaf life span. Meadow fescue has longer leaf life span than both timothy and perennial ryegrass.

4) Meadow fescue expresses higher regrowth capacity than timothy. Defoliation height had a similar effect on both species. Generally, the higher the defoliation the higher the cumulative yield and usually the regrowth rate.

5) The proportion of vegetative tillers is the dominant factor affecting the regrowth rate in June-July (generative growth phase) for timothy and for timothy dominated swards. During the vegetative growth phase the population density of vegetative tillers was not of such importance. In general, during the vegetative growth phase under field conditions no such single factor can be identified, if the sward has had a reasonable rest period. There were large year and year x species and year x defoliation height effects on post defoliation parameters under field conditions.

6) HM can be measured with a disk meter or with a HFRO sward stick sufficiently accurately. The disk meter needs least calibration for different pasture conditions. The capacitance meter does not suit tall, sparse canopies.

7) Despite high pre-grazing sward height, low tiller population density, low HM bulk density and occasionally high stem proportion in timothy - meadow fescue mixtures, the effect of herbage allowance on milk production was similar to that found for perennial ryegrass pastures (0.16 kg milk kg^{-1} HA). A post-grazing sward height of 9 – 10 cm is suitable for sward utilization and regrowth. This coincides well with the reasonably high feeding value of the grass. The lower the defoliation the longer the rest period should be.

8) In spring the development rate is rapid and even a five day difference in turnout date caused major changes in the growth pattern of pasture, which lasted to early July. Although better herbage quality and HM utilization were achieved together with easier management with the early turnout, the milk yields remained equal for early and normal turnout dates.

9) Although important, the initial defoliation date affected annual HM yield less than the length of the regrowth interval.

Suggested future research

1) The effect of concentrates should be studied together with HA and high yielding dairy cows. In addition to HI and substitution rate, the economic result is of primary concern. Such research has been continued after completing experiments in the context of this work.

2) The development of stem rigidity should be studied further with the aim of modelling stem development and IVOMD using weather parameters and continuing to model HI and milk production. Based on Paper II, and knowledge of IVOMD models for silage production, the development of stem rigidity should be closely related to temperate sum. The model would aim at short-term extrapolation of paddock management.

3) The mechanisms and genetical variation among timothy varieties in tiller initiation and following regrowth rate should be clarified, especially under dry conditions.

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