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Legume silages for animal production : LEGSIL

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edited by
Roger J. Wilkins and Christian Paul

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Preface

This special issue of Landbauforschung Voelkenrode comprises the Proceedings of a Workshop held at FAL Braunschweig-Voelkenrode on 8-9 July 2001. The purpose of the Workshop was to present results from the project ‘Low-input animal production based on forage legumes for silage''(LEGSIL) and to discuss their practical implications for northern Europe.

This project had been carried out from February 1997 to March 2001 with funding from the EU Fair Programme (Project Fair CT96-1832). The research partners were the Institute of Grassland and Environmental Research (UK), the Scottish Agricultural College (UK), the Swedish University of Agricultural Sciences (Sweden), the University of Helsinki (Finland), Valio Ltd (Finland) and the Institute of Crop and Grassland Science, FAL (Germany).

The Workshop was attended by 86 invited delegates from 19 European countries, with wider perspectives provided by the participation of Glen Broderick (USDA Dairy-Forage Center, USA) and Alan Kaiser (New South Wales Agriculture, Australia).

The Workshop and the publication of these Proceedings was supported by the EU through Accompanying Measures within the project ‘Legumes for silage in low input systems of animal production: appraisal and dissemination of results and technologies’ (LEGSILIMPACTS) (Project QLK5-2000-30052). The Workshop structure was formulated by the complete LEGSIL team and the Workshop was organised by a group comprising Joerg Greef, Christian Paul, Sigrid Ehlers, Ulrike Soelter (all FAL) and Roger Wilkins (Institute of Grassland and Environmental Research, UK).

These Proceedings include the papers presented at the Workshop, summaries of the discussions of the papers and reports of Working Groups which discussed the relevance of the findings for different parts of northern Europe.

Roger J. Wilkins

Introduction to the LEGSIL project

Roger J. Wilkins[1], Jan Bertilsson[2], Chris J. Doyle[3], Juha Nousiainen[4], Christian Paul[5] and Liisa Syrjala-Qvist[6]

Forage legumes

Background

Forage legumes provide the basis for grassland farming through much of the world. Their importance has arisen principally because of atmospheric nitrogen (N) fixation by rhizobial bacteria growing symbiotically with the legumes. This enables legumes to grow well even in the absence of other sources of nitrogen. Moreover, the fixed N can contribute directly or indirectly to the nutrition of grasses growing in mixture with the legume and to crops following the legume. Thus forage legumes, particularly red clover, played a major role in supplying N in rotational systems which provided the basis for food production in much of Europe from the 16th to the middle of the 20th Century. In addition to this contribution of legumes to plant productivity, it has long been realised that forage legumes may have high nutritive value, associated with high contents of crude protein (CP) and minerals.

However, despite these positive attributes, the use of forage legumes in northern Europe has much declined over the last 50 years. This reduction has taken place during a period of ready availability of cheap N fertiliser and realisation that grasses give very large yield responses to N fertiliser application. From 1950 to 1990 the application of N fertiliser to grassland increased throughout Europe. In the UK, for example, the average rate of N application per ha increased over that period from 5 to 135 kg, with many fields receiving over 300 kg N ha^{-1}. Systems involving high rates of N fertiliser application, increased stocking rates and grass conservation as silage were successfully developed and much advocated by extension services throughout northern Europe. The availability of these systems made farmers and their advisors more critical of problems associated with the alternative of legume-based systems. These included difficulties in sustaining production from forage legumes, problems in achieving effective conservation as silage and risks to animal health through bloat.

Recent developments

Developments in the last two decades of the 20th Century, however, indicated that the potential role of forage legumes should be re-evaluated. These developments were in the socio-economic, environmental and technical areas.

Socio-economic

The imposition of output constraints in EU countries (e.g. milk quotas in 1984), meant that the generally lower productivity of forage legumes than grass with high N fertiliser inputs became less of a problem than previously, because output constraints were in any case limiting the required overall stocking rate or output per ha, at least at the regional and national levels. With reduction in the real prices for animal products, and the prospects of further future reductions with moves towards more liberalised world trade, it became more important to seek ways of reducing the unit cost of producing milk and meat. Forage legumes have much potential for reducing costs with the opportunity to reduce inputs of fertilisers, because of N fixation, and concentrate feeds, because of high nutritive value.

Environmental

There has been much increase in concern to protect and enhance the environment and to increase the quality of food. Research carried out in the last 20 years has highlighted the risk of large losses of N compounds to the environment with intensive grassland systems based on high rates of N fertiliser application. There were indications that losses may be lower in legume-based systems, with, for example, Ryden *et al.* (1984) reporting losses through leaching of only 30 kg N ha^{-1} with grazed grass-white clover swards compared with over 160 kg N ha^{-1} for grazed grass swards receiving 420 kg N fertiliser ha^{-1}. Jarvis *et al.* (1996) calculated lower losses of N per livestock unit through nitrate leaching, ammonia volatilisation and denitrification with grass-white clover than with grass receiving high rates of N fertiliser. There are,

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however, few direct data on N losses from legume-based production. The report by Macduff *et al.* (1990) of high leaching losses from grazed pure white clover swards indicated a need for more information on the environmental effects of increasing the use of forage legumes.

The lower requirement of legume-based systems than grass-based systems for fossil fuel and support energy is well established (White *et al.*, 1983; Jarvis *et al.,* 1996) and has substantial environmental benefit.

Concerns for both protection of the environment and for achieving high quality food production have encouraged increase in organic farming. The area of agricultural land in the EU either registered for organic production or in conversion increased dramatically from 0.3m ha in 1990 to 3.5m ha in 1999, with over 5% of the agricultural area being organic or in conversion in Austria, Denmark, Finland, Italy and Sweden. With encouragement from the EU and from national governments to increase organic production, it is important to establish methods for increasing the efficiency of such systems. The role of legumes is of paramount importance in organic production, because the use of inorganic N fertilisers is prohibited.

Technical

The major technical developments which encouraged the re-evaluation of forage legumes related to the availability of new species and varieties of forage legumes and progress in ensiling technology.

It appeared that new species and varieties may overcome some of the deficiencies of the traditional varieties in relation to pest and disease susceptibility, poor persistence and poor tolerance of stress conditions. *Galega orientalis* (referred to here as galega) has given good results in Estonia, with high yields, extreme persistency and high rates of N fixation (Raig, 1994). *Lotus corniculatus* (referred to here as lotus) is a legume reported to give good performance in dry conditions and in low-fertility situations and to survive harsh winter conditions . There is, however, little information on the performance of these two species in the northern countries of the EU. Despite reduction in the size of programmes, progress has been made in breeding improved varieties of the traditional forage legume species. Improved varieties of red clover and lucerne have been bred in Sweden for northern European conditions and white clover breeding programmes in the UK have produced varieties that appear to be widely adapted for northern European conditions, with increased competitive ability and persistence (Rhodes and Ortega, 1997).

Forage legumes have a reputation for being particularly difficult crops to ensile. This is associated with low contents of water-soluble carbohydrates and high buffering capacity, making it difficult to achieve sufficient reduction in pH to prevent clostridial fermentation. However, there has been much progress in ensiling technology over the last 30 years with the development of methods to achieve rapid field wilting, the availability of effective chemical and biological additives and improved methods for filling and sealing silos, including big-bale silage. Successful preservation of legume silages in experiments (*e.g.* Barry *et al.*, 1978; Seale *et al.*, 1986) give encouragement for the more widespread ensiling of legumes, but more comprehensive information is required.

Research requirement

Although there was a strong case for re-evaluating the role for legumes in animal production in northern Europe, there was uncertainty at several positions in the production process. Further evidence was required to help the choice of species and variety of legume and to identify appropriate management in particular circumstances. Reliable methods for grazing and ensiling were required and animal production responses needed to be quantified in different feeding regimes. The effects of growing and using legumes on the environment, particularly in relation to losses of N compounds, needed to be determined. There was also a requirement to make integrated assessments of the overall economic and environmental impacts of legume-based production.

The LEGSIL project

An application to the EU to support an integrated multi-disciplinary programme to resolve these uncertainties was successful and a 50-month project commenced in February 1997. The project (FAIR CT 96-1832) was entitled ‘Low-input animal production based on forage legumes for silage’.

The scope of the study was defined by decisions to focus (a) on northern Europe, (b) on utilisation of legumes for silage and (c) on use in dairy production systems. The restricted geographical focus made it possible to undertake common experiments across the study area using the same plant genetic materials. The decision to concentrate on silage was in line with the long winters and importance of silage in the study area, whilst the decision to concentrate on dairy cow systems corresponded with the importance of dairying throughout the study area and particularly within each of the four participant countries – Finland, Germany, Sweden and UK. The four countries provided contrasts within the study area in both latitude and continentality. The project concentrated on five forage legumes – red and white clover, lucerne, galega and lotus – and involved research on agronomy, ensiling, animal production, economics and environmental impact.

The project was coordinated by the Institute of Grassland and Environmental Research (IGER), UK, and was carried out with five partners – the University of Helsinki (HY), Finland, Valio Ltd (VAL), Finland, the Swedish University of Agricultural Sciences (SLU), the Institute of Crop and Grassland Science, Federal Agricultural Research Centre Braunschweig-Voelkenrode (FAL), Germany, and the Scottish Agricultural College (SAC), UK. An important contribution was also made by the Agricultural Research Centre of Finland.

The project concluded at the end of March 2001 and largely fulfilled its objective of providing a basis for efficient and reliable animal production from forage legumes. The use of forage legumes rather than grass for silage was calculated to increase profitability throughout the study area with advantages from the best legume-based systems calculated at 150-300 euros per ha, mainly through reduction in costs of animal production. If half of the grass silage made in northern Europe (excluding Russia) were replaced by legume silage, this would give a saving of some 700 to 1400m euros annually.

The workshop

In view of the success of the project and the significance of the results, the EU agreed to support under the Accompanying Measures scheme an application for a project to ensure the full discussion and rapid dissemination of the results. This project (QLK5 –2000-30052) is entitled ‘Legumes for silage in low input systems of animal production: appraisal and dissemination of results and technologies’ and has the acronym LEGSILIMPACTS. The Workshop, with attendance of invited research scientists, extension workers and agribusiness staff from throughout northern Europe and experts from southern Europe, Australia and USA, is one of the main activities of LEGSILIMPACTS. A series of booklets customised to different areas in northern Europe and targeted to farmers and extension workers will also be produced as part of the project.

The objective of the Workshop was to achieve the timely presentation of project results and to facilitate discussion on their implications and potential application. Consequently these Proceedings include not only the presented papers, but also summaries of points raised in discussion and, in particular, the conclusions of Working Groups considering relevance to different parts of northern Europe.

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Forage legumes – productivity and composition

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Abstract

In twelve field experiments, three in each of Finland, Sweden, Germany and UK, the production and nutritional quality of red clover (*Trifolium pratense*), lucerne (*Medicago sativa*), white clover (*Trifolium repens*), galega (*Galega orientalis*) and lotus (*Lotus corniculatus*) were investigated in a three-cut silage system over two years. Red clover was a good performer with average yield stability in different environmental situations, but with the stability decreasing with age. Red clover had a high percentage in mixture with grass and high yield of nitrogen (N), cellulase digestible organic matter (CDOM) and metabolisable energy (ME). Lucerne gave variable yields and was very productive in good conditions, but a low stability which, however, increased with age and in grass mixture. It had low persistence in northern Finland and low nutritional value. White clover was low in production, especially as a pure crop, but it had a high stability which increased with age and high nutritional value. Lotus was not outstanding at any sites, showing a low yield and persistence. It had a low content in grass mixture and a nutritional quality close to red clover. Galega was rather variable with a low stability of the legume yield. It had good persistence in north Finland but failed in establishment at the UK sites and the nutritional quality was close to lucerne and red clover. The highest yielding legume-grass mixtures gave yields that were at least as high as those from grass with 200 kg N ha^{-1} except for the Finnish sites. Pure grass was generally of lower nutritive value than the legumes, having lower concentrations of N, CDOM and ME, but a higher content of water soluble carbohydrate (WSC).

Introduction

By growing forage legumes, there is a potential, within forage conservation systems, to substitute existing N-fertilised forage or concentrate feeds with legume-based forage produced with no N fertiliser. Red clover (*Trifolium pratense*), white clover (*Trifolium repens*) and lucerne (*Medicago sativa*) are the three most widely grown species of forage legumes in northern Europe, but there is also potential for increased use of *Lotus* species, particularly *Lotus corniculatus*, and galega (*Galega orientalis*), as discussed by Wilkins *et al.* (1998). For galega and lotus, there is only limited information for northern Europe. Galega is little used in agriculture, but has been developed and improved in Estonia where it is highly productive and persistent (Nömmsalu, 1994). Lotus (birdsfoot trefoil) may be productive under conditions of low fertility and nutrient stress, and has nutritional advantages associated with condensed tannins. There is a need to compare these new species with the established species.

This work reports on the agronomy part of an EU-funded international research project (Low input animal production based on forage legumes for silage - LEGSIL). The aim of this part of the project was to assess the productivity, persistence and quality of novel and conventional forage legume species at contrasting sites in northern Europe. This paper gives an overview of the results.

Materials and methods

Sites

Twelve small-plot field experiments were established in spring 1997 at three sites in each of Finland (F), Sweden (S), Germany (D) and Great Britain (U). One site in each country was on land registered for organic production (OP). The sites were chosen from latitude 66°N in northern Finland to latitude 50°N in south-west England, to represent a range of growth conditions. A description of the sites is given in Table 1 and their locations are shown in Figure 1. At Ruukki and Viikki in Finland and at Wehnen in Germany, the establishment failed in 1997 and the trials were resown in 1998.

Treatments

At all sites, ten treatments of standard varieties of each of red clover (cv. Vivi), lucerne (cv. Vertus), white clover (cv. Aberherald), galega (cv. Gale) and lotus (cv. Leo) were established, alone or in mixture

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with a standard grass (meadow fescue - *Festuca pratensis* cv. Kasper). For comparison, two treatments were established with pure standard grass (same variety as in the legume-grass mixtures) – either not N-fertilised or fertilised with 200 kg N ha^{-1}, applied as 80, 60 and 60 kg N ha^{-1} for the three cuts. In Germany, the standard grass species was perennial ryegrass (*Lolium perenne*, cv. Limes). Six additional treatments (red and white clover and lucerne, each pure and grass mixed stands) were sown with varieties considered to be best adapted for the particular country. In red clover the adapted varieties are: Björn (F), Vivi (S), Maro (D) and Milvus (U), in lucerne: Lesina (F), Vertus (S), Planet (G), Europe (U) and in white clover: Jögeva (F), Sonja (S), Lirepa (G) and Aran (U).

Trial management

The P and K were applied according to the plant available nutrient levels in the soil. At the OP sites, organic manure or urine was used as fertilisers. A common protocol for managing the trials was used. Three cuts were taken, except for Apukka and Ruukki in northern Finland where there were only two cuts, by using plot mowers. The date of first cut was based upon growth stage of the adapted red clover (bud stage: inflorescence of main stem just visible). All sites were cut for two harvest years and some were maintained for a third year. Detailed results for the third harvest years are not given here.

Table 1:
Description of sites for the agronomy field trials

Site	Country	No. of cuts year 1	No. of cuts year 2	Establish-ment year	Soil type	pH	Latitude	Long-itude	Altitude (m)
Apukka	Finland	2	2	1997	Sand moraine	6.2	66º35’N	26º01’E	105
Ruukki	Finland	2	2	1998	Organic sand	5.3	64º41’N	25º04’E	47
Viikki	Finland	2	3	1998	Fine sand	5.4	60º13’N	25º01’E	2
Uppsala	Sweden	3	3	1997	Loam	6.1	59º49’N	17º39’E	5
Rådde	Sweden	3	3	1997	Loamy sand	6.3	57º36’N	13º16’E	185
Lilla Böslid	Sweden	3	3	1997	Silt loam	6.5	56º36’N	12º55’E	10
Wehnen	Germany	3	3	1998	Sand	4.8	53º10’N	8º08’E	9
Völkenrode	Germany	3	3	1997	Silty sand	7.2	52º18’N	10º27’E	80
Adolphshof	Germany	3	3	1997	Sand, loam and silt	8.1	52º21’N	10º00’E	74
North Wyke	United Kingdom	3	3	1997	Gravelly light loam	6.2	50º47’N	3º54’W	155
Trawsgoed	United Kingdom	3	3	1997	Silty clay loam	6.0	52º20’N	3º55’W	100
Bronydd Mawr	United Kingdom	3	3	1997	Fine loam	6.1	51º58’N	3º38’W	330

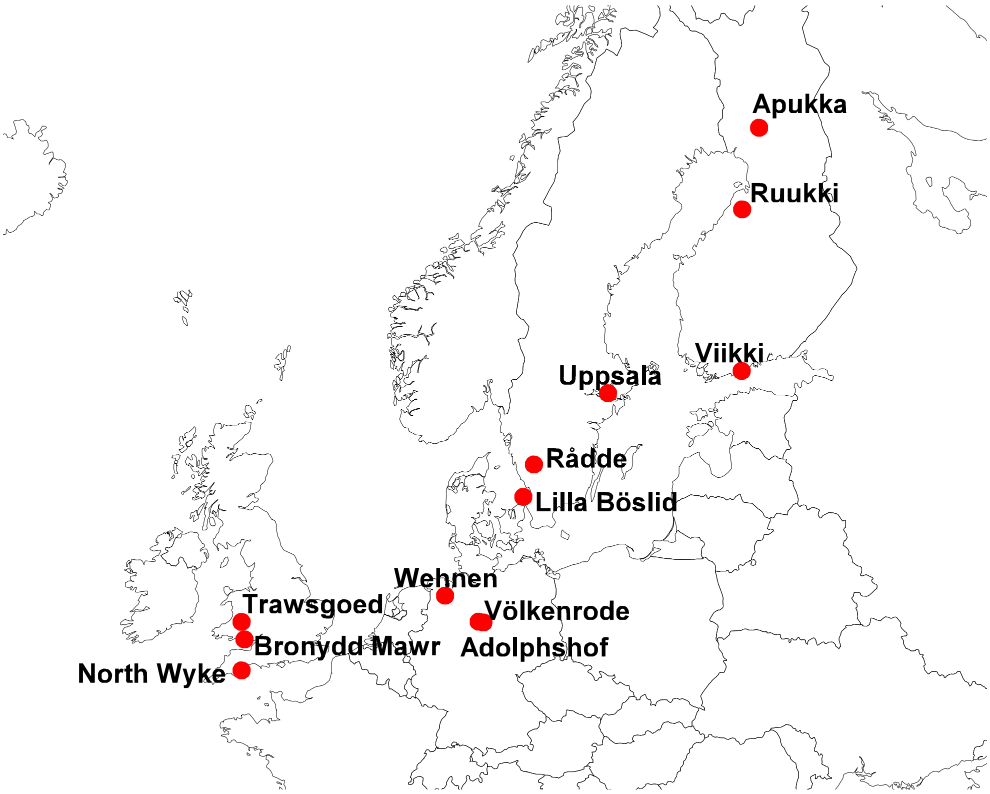

Figure 1:
Map of the trial sites in the four countries

Observations and analysis

Additional samples from each plot were hand sorted to determine the proportions of sown legume, grass and unsown species at each harvest. Ground cover was visually assessed at onset of growth in spring and at the cessation of growth in autumn for legumes, grass, unsown species and bare ground. The percentage of dry matter (DM) in the fresh harvested material was calculated from oven-dried samples. Stage of morphological development was scored with a seven-point scale (see Table 8). Sward height was measured for legumes and grasses at the first cut. The forage quality values are from NIRS determinations using calibration equations derived within the project (Paul *et al.*, 2002). The same equations have been used across all sites in all countries. The content of metabolisable energy (ME) was calculated by modifying (bias adjustment) the equation according to Weissbach *et al.* (1999) and was used for pure legume stands. Mixed stands were adjusted according to the legume content (%) in four intervals between 0 and 100 % (see Paul, 2001). All variables that have been observed or calculated are shown in Table 2 and stored in a common database. The dimension, abbreviations and time of measurement are shown. The data will be available to the public on the web when the publications are finished. All data will not be reported in this paper.

Weather at the sites

The weather at the sites was variable during the two years of the ley. The lag of one year for three sites contributed to this. In Finland the first year had a dry season compared to normal, except for Apukka, with a cold May and warm June. Year two had a dry and warm May and a wet June, except for Apukka. In Sweden year one had a wet and cold season. Year two had a cold and dry start, wet June in the south and a dry and warm July at all sites. In Germany, the start of season (May) was warm both years. At Wehnen, July was warm and dry the first year and wet and cold the second year. At the other sites, July was dry and warm in year two. In UK, the early season was wet (April), there was then a warm and dry May followed by a wet and cold June in both years, but especially in year one. As in Germany and Sweden, July was warm and dry in year two.

Table 2:
Variables in the database

Variable	Abbreviations	Dimension	Times	Comment
Green matter yield	Y.RD	g $(m^2)^{-1}$	3 cuts and sum	Tot. and fractions
Dry matter yield	Y	g $(m^2)^{-1}$	3 cuts and sum	Tot. and fractions
Botanical composition (legume, grass and weeds)	LE.PW, GR.PW, WE.PW	% of kg DM	3 cuts and sum	Sample and visual inspection
Ground cover of legumes, grass, unsown species and bare ground	CV.LE, CV.GR, CV.WE, CV.BG	% of ground area	Spring and autumn	Visual inspection
Stage of development	G.LE, G.GR	1-7 scale	3 cuts and sum	Legume and grass
Damage	DA	% of ground area	When appropriate	
Sward height	H.LE, H.GR	cm	First cut	Legume and grass
Dry matter content	DM	% of kg green matter	3 cuts	
Ash	ASH	% of kg DM	3 cuts	NIRS
Crude protein	PRO.CF, PRO.HA	% of kg DM, kg ha-1	3 cuts	NIRS
Nitrogen in crop	N.HA	kg N ha-1		
Cellulase digestible organic matter	CDOM, CDOM.HA	g $(100\ g)^{-1}$, kg ha^{-1}	3 cuts	NIRS
Cellulase undigestible organic matter	CUDOM	g $(100\ g)^{-1}$	3 cuts	NIRS
Crude fibre	CF, CF.HA	% of kg DM, kg ha^{-1}	3 cuts	NIRS
Water soluble carbohydrates	WSH, WSH.HA	% of kg DM, kg ha^{-1}	3 cuts	NIRS
Metabolisable energy	ME, ME.HA	MJ kg^{-1} DM, MJ ha^{-1}	3 cuts	Calculated
Buffering capacity	BC	g LA $(100\ g)^{-1}$ DM	3 cuts	NIRS
Fermentation coefficient	FC		3 cuts	Calculated
Soil mineral N	N, NH4, NO3	kg N ha^{-1}	Spr. and autumn	
Leakage of soil mineral N	N, NH4, NO3	kg N ha^{-1}	Between autumn and spring	

Statistical analysis

The experiment had a one-factor randomised alpha-lattice design with 18 treatments and three replications, in total 54 plots. The most important treatments for comparison were allocated to sub-replications of six plots to gain precision. In the statistical analyses, the SAS procedure Mixed was used (SAS, 1997). In the model, treatment, ley year, harvest and country were set as fixed factors and the effects of main-replications and sub-replications within main-blocks and site within country were set as random factors. Since only one trial-year in Finland has three harvests, the third harvest was excluded in this analysis. When analysing summary values over harvests, the factor harvests was excluded. Least square means (LSM) were calculated. The LSM-values can differ from the arithmetic mean values because the Mixed model has taken into account the variation between sub-blocks, main-blocks and sites. The quality data relate to the treatments with the adapted legumes as they are considered to relate more closely to the practical situation, particularly as at the southern sites the standard varieties were often at a less advanced stage of growth at harvest (especially red clover).

The genotype x environment (GE) interaction for each species was analysed by regressing (linear) the treatment mean (t) (genotype) on the trial mean (e) (environment) for all sites: $t = a + be$. The phenotypic regression coefficient is expressed as b, which is the slope of the line. Values of b are a relative measure of the sensitivity to changes in environmental stress. Values of b equal to 1.00, greater than 1.00 and less than 1.00 represent average, greater than average and less than average sensitivity, respectively. Pure grass plots in Germany were removed because a different species had been used.

Results and discussion

Total dry matter yield

Annual yields, including unsown species are presented in Table 3. Data are presented as least square means (LSM) for years of ley and countries as an average over sites. Yield levels were higher in Germany and UK in the first year and in UK the second year, compared to the other countries. There was a significant interaction ($p<0.0001$) between species, ley year and countries, demonstrating substantial differences in the performance of the legume species between countries and years. Between years, yield generally decreased in Germany and UK and increased in Finland and Sweden. Legume persistency and growing conditions could have affected these changes. In mixture with grass, red clover showed the highest yield in the first year in Germany and UK, but was outyielded by lucerne in grass mixture in the second year. In Sweden, the grass mixtures of red clover, lucerne and white clover were similar in yield in both years. In Finland red clover had the highest yield in both years.

Lucerne showed the highest production potential with yields at Trawsgoed of 17.1 and 14.1 t ha^{-1} in pure stands; these were the highest recorded yields in the first and second years respectively in all trials. At Apukka, lucerne was severely damaged by fungus during the second winter, and yielded only 3.6 t ha^{-1} in pure stand (lowest among the legumes). Galega showed a high persistency in the third year at the most northern site (Apukka), and yielded highest among the legumes in pure stand (7.9 t ha^{-1}).

In Table 4, a statistical comparison is made between pure red clover and other legumes in pure stand and relative values against red clover are shown. Significant differences are marked with asterisks showing the significance level. Differences that are mentioned below are not always significant. Among legumes, yield was largest for red clover in the first year, except for lucerne in UK. White clover and lotus had the lowest yield in both years. White clover had a better performance compared to red clover in Sweden and UK than in the other countries. In the second year, yield of lucerne and galega had increased relative to red clover. N-fertilised grass had the highest yield, except for Germany.

In Table 5 relative differences between red clover and other legumes in mixture with grass are shown. Mixture with grass reduced the yield differences between the species. Among the legumes, red clover yield was higher or similar to that of other legumes in the first year. In second year, red clover was outyielded by lucerne in Germany and England. The fertilised grass showed a larger yield than the best legume-grass mixture only in Finland.

In Table 6 the yield of the pure legume is compared with the yield when it is mixed with grass. Yield was generally increased with the inclusion of a grass, especially with white clover.

Table 3:
Total DM yield (t ha-1) as least square means

	First year ley				Second year ley			
Species	D	F	S	U	D	F	S	U
Red cl.	11.0	7.1	7.6	9.8	8.1	8.2	6.9	8.6
Red cl.+gr	11.4	8.3	7.8	11.2	8.2	8.6	8.9	8.5
Lucerne	10.1	4.8	6.8	10.5	10.1	6.4	6.5	9.9
Lucerne+gr	11.2	6.0	8.0	10.7	10.7	7.4	8.7	9.7
White cl.	4.2	3.2	6.0	7.7	2.8	5.4	5.5	7.7
White cl.+gr	8.5	5.9	7.6	9.9	5.1	7.2	8.6	8.4
Galega	9.5	4.7	5.0	7.8	7.8	7.3	4.9	7.7
Galega+gr	9.5	5.7	6.5	9.0	7.2	7.5	7.3	7.7
Lotus	6.5	4.3	5.4	8.4	4.9	5.7	4.9	6.9
Lotus+gr	9.0	5.5	6.8	9.8	5.4	6.7	7.3	8.3
Grass 0 N	2.8	4.8	4.7	6.6	1.8	4.7	5.9	5.3
Grass 200 N	7.9	8.9	7.9	11.8	6.7	10.4	8.9	9.5
sem	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2

D = Germany, F = Finland, S = Sweden, U = United Kingdom, sem = standard error of mean
Significant interaction between species, ley year and country at $p<0.0001$

Table 4:
Relative value of total DM yield, comparison between red clover pure stand (=100) and other pure legumes

	First year ley				Second year ley			
Species	D	F	S	U	D	F	S	U
Red cl.	100	100	100	100	100	100	100	100
Lucerne	92	67*	89	107	124	78	95	116
White cl.	38***	44***	78	79	34***	67*	80	90
Galega	86	66*	65*	79	96	89	72	90
Lotus	59***	60*	71	85	60**	70*	71	80
Grass 0 N	25***	67*	61*	67**	22***	58**	85	62**
Grass 200 N	71**	125	104	120	83	127	130	111

*p<0.05; **p<0.01; ***p<0.001, sem (standard error of mean) = 1.14 t DM per ha

Table 5:
Relative value of total DM yield, comparison between red clover-grass mixture (=100) and other legume-grass mixtures

	First year ley				Second year ley			
Species	D	F	S	U	D	F	S	U
Red cl.+gr	100	100	100	100	100	100	100	100
Lucerne+gr	98	71*	103	95	131*	86	97	113
White cl.+gr	74*	71*	98	89	63**	84	96	98
Galega+gr	83	69*	83	81	87	87	82	90
Lotus+gr	79*	66*	88	88	65*	78	82	97
Grass 0 N	24***	58**	60**	59***	22***	55***	66**	62**
Grass 200 N	69**	107	102	105	82	121	100	111

*p<0.05; **p<0.01; ***p<0.001, sem (standard error of mean) = 1.14 t DM per ha

Table 6:
Relative value of total DM yield, comparison between pure legume (=100) and grass mixture of each standard legume

	First year ley				Second year ley			
Species	D	F	S	U	D	F	S	U
Red cl.+gr	104	117	102	114	101	105	130	100
Lucerne+gr	111	124	118	101	106	116	133	98
White cl.+gr	204***	187*	128	128	187*	133	156**	109
Galega+gr	100	121	130	116	91	103	149*	100
Lotus+gr	139*	129	126	117	110	118	151*	120

*p<0.05; **p<0.01; ***p<0.001, sem (standard error of mean) = 1.14 t DM per ha

Percentage of legumes

The percentage of legumes in the DM in mixtures with grass varied a lot between species, harvests, ley years and countries (Figure 2), as confirmed by a significant interaction ($p<0.0001$) between these factors. In most situations red clover had the highest percentage, followed by lucerne although in Germany and Finland, galega was the second ranking in the first harvest. White clover had a higher percentage relative to the other legumes in Sweden and UK compared to the other countries. Between first and second cut the content of legumes generally increased, especially with lucerne and white clover. Lotus decreased in third cut, possibly due to stress in a three-cut system. The performance of galega varied greatly between the countries.

Forage quality

Extensive analysis of forage quality was carried out as listed in Table 2. The concentration in DM of the different quality properties were reported to the EU by Halling (2001). The general conclusions for the different legume species are given below. The most substantial differences in quality were between white clover and lucerne. White clover had the highest content of crude protein, digestible organic matter, water soluble carbohydrates and metabolisable energy but had the lowest content of crude fibre. For lucerne, the opposite applied with red clover, galega and lotus giving intermediate values. The legumes had higher quality properties than grass (except for water soluble carbohydrates), with mixtures giving intermediate values. Here we report the total seasonal yield of nitrogen (N) (Table 8) and digestible organic matter (DOM) (Table 9) for the legumes in mixture with grass. The quality characteristics of the pure legume stands are summarised in Table 10. Adapted varieties were chosen instead of standard since they relate more closely to the practical situation, particularly at the southern sites where the standard varieties were often at a less advanced stage of growth at harvest (especially red clover) (Table 7). Generally in the first year, yields of N, DOM and ME were largest for red clover. In second year, lucerne gave the highest yields in Germany and UK, white clover in Sweden and red clover in Finland. Fertilised grass competed with the legume-grass mixtures only in Finland. The yield of N in the fertilised grass treatment never exceeded that in the highest yielding legume-grass mixture.

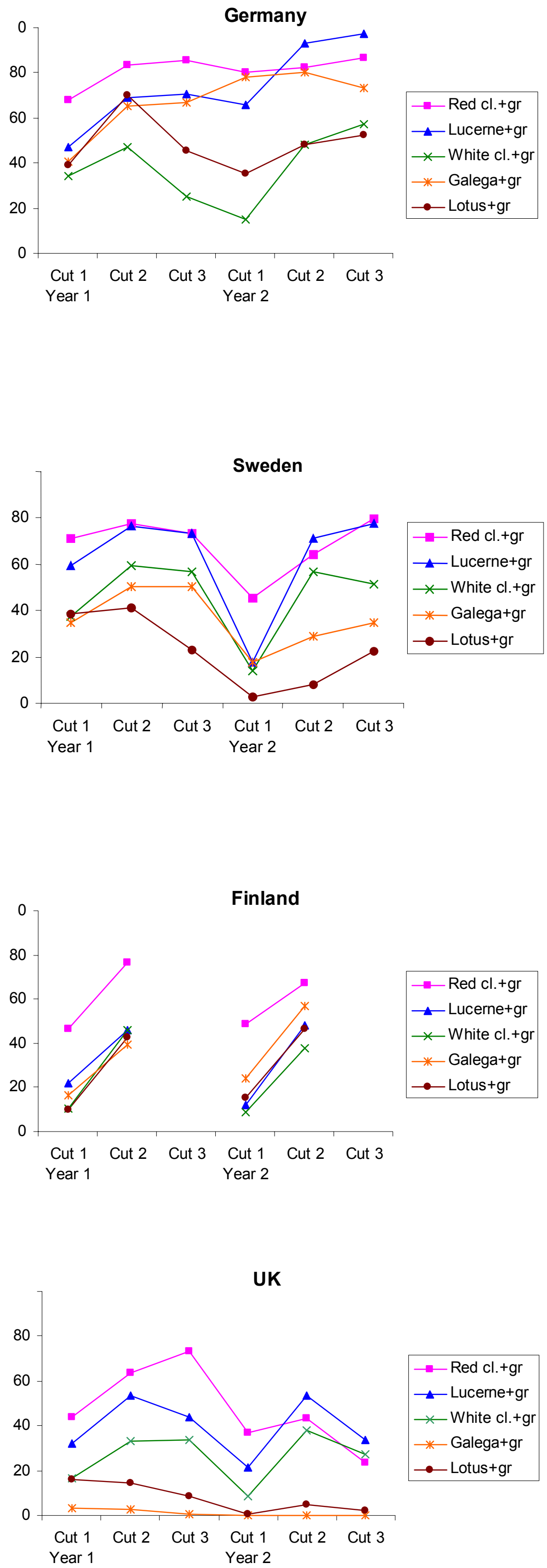

Figure 2:
Percent legumes in the DM yield of the sub-harvests during ley year 1 and 2 in the four countries

Table 7:
Development stages* of the legume species, average the two ley years

	Cut 1				Cut 2				Cut 3		
Species	D	F	S	U	D	F	S	U	D	S	U
Red cl.	2	4	3	2	2	5	5	3	6	5	3
Lucerne	3	4	4	2	5	5	4	4	5	4	6
White cl.	4	5	6	2	7	6	6	5	5	5	2
Galega	5	5	5	2	2	3	3	1	2	3	
Lotus	4	6	5	2	5	6	5	2	5	4	1
Red cl.*	4	4	4	3	4	5	5	4	6	5	3
Lucerne*	4	4	4	2	5	5	5	4	6	4	6
White cl.*	5	5	6	2	7	6	6	5	6	5	5

*Development stages scored are: 1 = Leaf stage, 2 = Steam elongation, 3 = Inflorescence of main stem just visible on some plants, 4 = Single buds on inflorescence of main stem visible on a majority of the plants, 5 = At least one open flower on inflorescence of main stem at some plants, 6 = Open flowers also on inflorescence of auxiliary stems on a majority of plants, D = Germany, F = Finland, S = Sweden, U = United Kingdom

Table 8:
Total yield of nitrogen (kg per ha) in legume-grass mixtures as least square means

	First year ley				Second year ley			
Species	D	F	S	U	D	F	S	U
Red cl.+gr*	343	185	259	259	240	218	196	170
Lucerne+gr*	261	116	248	203	264	151	173	163
White cl.+gr*	228	152	249	207	91	182	220	143
Galega+gr	260	94	162	211	218	163	126	158
Lotus+gr	239	84	176	229	104	129	96	162
Grass 0 N	46	52	73	150	29	63	66	93
Grass 200 N	153	163	143	226	131	183	146	181
sem	34	34	34	38	37	34	34	34

D = Germany, F = Finland, S = Sweden, U = United Kingdom, sem = standard error of mean
*Adapted varieties, significant interaction between species, ley year and country at p<0.0001

Table 9:
Total yield of digestible organic matter (kg per ha) as least square means

	First year ley				Second year ley			
Species	D	F	S	U	D	F	S	U
Red cl.+gr*	8 353	5 367	6 405	7 698	6 301	6 330	5 631	6 042
Lucerne+gr*	6 407	3 698	5 528	6 473	6 611	4 773	4 882	6 267
White cl.+gr*	5 615	4 831	6 129	7 083	3 330	5 578	5 961	5 592
Galega+gr	5 958	3 288	4 266	5 908	4 701	4 561	3 931	5 011
Lotus+gr	5 773	3 221	4 663	6 248	3 273	4 173	3 840	5 334
Grass 0 N	2 090	2 677	3 096	4 217	1 485	2 819	3 041	3 306
Grass 200 N	5 869	5 565	5 264	7 274	4 654	6 346	5 167	5 885
sem	737	737	737	749	803	737	737	737

D = Germany, F = Finland, S = Sweden, U = United Kingdom, sem = standard error of mean
*Adapted varieties, significant interaction between species, ley year and country at p<0.000

Table 10:
Quality characteristics for the pure legume stands (average over harvests, years and sites)

Species	Ash, g kg^{-1} DM	Buffering capacity, g LA $(100\ g)^{-1}$ DM	Digestible organic matter, g $(100\ g)^{-1}$ DM	Crude fibre, g kg^{-1} DM	Metabo-lisable energy, MJ kg^{-1} DM	Crude protein, g kg^{-1} DM	Water soluble carbohydrates, g kg^{-1} DM
Red cl.*	93	71	75	229	10.1	194	92
Lucerne*	91	68	70	278	9.5	181	72
White cl.*	102	67	80	200	10.6	225	84
Galega	87	61	71	260	9.8	203	65
Lotus	89	68	72	254	9.9	198	74
Grass 0 N	88	43	69	284	9.7	113	124
Grass 200 N	89	52	70	285	9.7	133	112

*Adapted varieties

Table 11:
Estimated phenotypic stability (regression coefficient) of the total yield, yield of sown species, legume yield and nitrogen yield of the pure legumes and legume-grass mixtures (standard varieties)

	First year ley				Second year ley			
Species	Sum Y	S sp Y	Leg. Y	N Y	Sum Y	S sp Y	Leg. Y	N Y
Red cl.	0.70	0.73	0.94	1.42	1.25	1.23	1.47	1.47
Red cl.+gr	0.84	0.89	0.79	1.04	1.09	1.03	1.33	1.56
Lucerne	1.68	1.92	1.60	1.85	1.74	1.96	1.69	1.72
Lucerne+gr	1.49	1.70	1.32	1.33	0.97	1.42	1.25	1.56
White cl.	0.61	0.22	0.41	0.86	0.72	0.08	0.02	0.61
White cl.+gr	0.79	0.78	0.38	0.61	1.03	0.62	0.04	0.99
Galega	1.04	0.91	1.45	1.12	0.91	1.48	1.66	1.09
Galega+gr	0.93	1.09	0.78	1.08	0.77	1.08	1.25	1.04
Lotus	0.89	0.51	0.90	1.02	0.90	1.01	1.04	0.92
Lotus+gr	1.06	1.06	0.76	1.27	0.90	0.62	0.57	0.93
Grass 0 N	1.08	1.55		0.28	0.85	0.94		0.12
Grass 200 N	0.93	1.43		0.12	0.79	0.75		-0.01

Value above one is more sensitive than the average, value below one is less sensitive than average
Sum Y = total DM yield ($p<0.004$ year 1, $p<0.5$ year 2), S sp Y = yield of sown species ($p<0.0003$ year 1, $p<0.08$ year 2), Leg. Y = yield of legumes ($p<0.03$ year 1, $p<0.0007$ year 2), N Y = yield of nitrogen in the total DM harvest ($p<0.002$ year 1, $p<0.004$ year 2)

Sensitivity analysis - genotype x environmental interactions

In trying to estimate the variation of different legume species and mixtures across sites or environmental situations, a sensitivity analysis was used. A linear regression was fitted between genotype (species) and environmental effect (site average) for different variables. In Table 11 the regression coefficient (slope) is given for some of the variables.

Values equal to 1.00 represent average sensitivity, greater than 1.00 represent more sensitivity than average and less than 1.00 represent less sensitivity than average. Significant differences between the slopes of the species and mixtures were found for all variables in the first year. In second year, only yield of legumes and nitrogen had significant differences in slopes. Among the significant variables in the first year, only the slope of lucerne was significantly different from the other legume species. In year two, the differences were between white clover and the other legume species. In the sub-harvests, the largest differences in sensitivity were found in the third harvest (data not shown).

It was clearly shown that lucerne had a greater sensitivity to the environment compared to the other legume species, especially in the first year and the yield of the pure crop (Leg. Y, Table 11). In the lucerne-grass mixture, the sensitivity decreased with age of the ley. Galega and lotus were generally close to average sensitivity. The pure crop of galega had a larger sensitivity than the total yield in a grass mixture, reflecting the large variation in the content of the legume. White clover was the most stable legume in the yield properties and this generally increased with age of ley. The yield of legumes (Leg. Y), were generally more stable in a grass mixture than when grown alone. Red clover had the largest increase in sensitivity in the older ley.

Conclusions

1) The following more general conclusions can be drawn for the different legume species:
   a) Red clover was a good performer in practically all countries with average yield stability between sites, which decreased with age of ley. It was the best performer in Finland except for the very north. There was a high content of red clover when it was grown in mixture with grass.
   b) Lucerne was rather variable with the lowest stability between sites (but this increased in grass mixture and with age), but where it maintained high legume content, lucerne gave the highest yields (some sites in Germany and UK). In the very north the persistence was low. At sites with low pH and high competition from unsown species, establishment was a problem.
   c) White clover, in mixture with grass, tended to improve in yield with time (especially in Finland and Sweden) and expressed a large stability in yield across the sites which increased with age of the ley. It had, relative to red clover, better performance in Sweden and UK than in Finland or Germany.
   d) Lotus was not outstanding at any site, with a low yield and low persistence. There was only a low content in grass mixtures, especially in Sweden and UK, possibly associated with the three harvest system).
   e) Galega was rather variable but showed good persistence, especially in the third year sites in Sweden and Finland. The best performance of galega was in Germany and Finland. Establishment can be a problem; in UK it failed probably because of high competition from unsown species.
2) There were substantial differences in DM yield and legume content for the different legume species, expressed by strong statistical correlations between species, ley year and countries. DM varied in first year between 3.2 and 11.4 t ha^{-1} and in the second between 4.9 and 10.7 t ha^{-1}.
3) Legume-grass mixtures gave generally higher yields than pure swards and also they surpassed the 200 N fertilised pure grass in DM yield in most countries, without receiving any N fertiliser.
4) Establishment of the legumes was critical, especially for new species where there was a lack of management experience, like galega in UK.
5) Persistency can be a problem for the legumes. This was illustrated for red clover and lotus in the experiments, with these species showing a decline in yield and legume percentage.
6) In a mixture with grass, red clover and lucerne showed the highest percentage of legume in the DM yield. White clover, lotus and galega had much lower percentages.
7) In nutrient quality, the most substantial differences were between white clover and lucerne. White clover had the highest content of crude protein, digestible organic matter, water soluble carbohydrates and metabolisable energy but had the lowest content of crude fibre. For lucerne it was the opposite case for these qualities. Red clover, galega and lotus were in between this range. The legumes had higher quality than grass (except for water soluble carbohydrates), with mixtures giving intermediate values.

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Summary of plenary discussion

1 Site • environment interaction on dry matter yields

*The performance of the five legume species varied between sites due to strong site * environment interactions. Part of the observed differences may have been due to the effect of management. Nevertheless, the periods of dry and wet conditions varied between years and this impacted on the legume crops. The yields at the organic sites also tended to be slightly higher than at the non-organic sites. However, it was be difficult to establish if the higher yields were a function of the sites being organic or whether it could be attributed to other site / management factors.*

2 Adapted varieties and seed availability for organic production

With the exception of red clover, there was little evidence of the adapted varieties performing better than the standard varieties. This raises the issue of the validity of breeding for specific localities, if the difference between standard and adapted varieties is insignificant. In relation to seed for organic legume production, there is a requirement that in 2003 that the seed used in producing grass-legume swards is of organic origin. Although the EU is producing organic seed, it is also being produced in New Zealand for the EU market. In many cases, the organic seed is produced for standard varieties as opposed to local adapted varieties. Currently, it is not known how some of the varieties will perform.

3 Galega

The galega was poor to establish. This was because it was slow to establish during the early stages of growth compared to the other legumes and did not compete well with the undersown species. In addition, there were problems with the hardness of the galega seed and dormancy. The high persistency of galega at the most northerly site (Apukka) was noted, with plots now being assessed in their third harvest year.

4 N Fixation

The galega, lucerne and lotus were inoculated with the appropriate specific rhizobium, while it was assumed that the appropriate rhizobia for the red clover and the white clover would be contained within the soil. The resultant rate of N fixation was not measured, although N fixation could be estimated from the data using the difference method. Nor was it feasible to measure the N fixed that was available to subsequent crops. Nevertheless, it was estimated that on average 200 and 180 kg N ha^{-1} was fixed in the first and second years respectively. This compares with estimated carry-over effects of 70-100 kg N ha^{-1} to subsequent wheat and rape crops from annual legumes in Australia.

5 Crude protein content

The results of the trial indicated that the red clover crude protein content was 1-2.5% units higher than that of lucerne. In contrast, there is evidence from analysis performed in the UK and the US that the crude protein content of lucerne is 2-3% higher than that of red clover. However, in the LEGSIL trials, the crude protein content of the lucerne was particularly low at some sites, mostly at sites where the crop did not perform well. This may have been due to the soil type at the site not being appropriate for lucerne. In addition, in the LEGSIL trials the most suitable harvesting date for the red clover swards, rather than the appropriate time for each of the five legume species, determined the cutting date for all swards. Although lucerne would suffer with this regime, as there is a very narrow window for harvesting it to maximise yield and quality, it is unlikely that the results would have been affected. In particular, in the case of Sweden, the lucerne was also harvested at the most appropriate time, and the results indicated that the red clover had a higher crude protein content

The efficiency of utilisation by the animal is likely to be more important than crude protein content per se, as discussed in the Workshop paper by Dewhurst et al.

Reporter: C.F.E. Topp

Assessment of nitrate leaching from beneath forage legumes

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Abstract

A cut plot experiment was conducted at twelve sites in four northern European countries to assess the production potential and impact on nitrate leaching of a range of forage legume species, grown alone and in combination with a companion grass. This paper reports the leaching data for the 1999-2000 winter drainage period. Nitrate leaching was assessed indirectly by the Nmin method (N leached is given by soil mineral N in late autumn prior to onset of drainage minus soil mineral N in spring prior to plant growth) at all sites and directly, using ceramic cup samplers at one site each in Sweden, Finland and the UK. It was not technically feasible to operate the suction cup method at frozen sites. At these sites, the application of the Nmin method also posed problems due to the apparent rapid rates of N mineralisation just prior to the spring sampling, which resulted in negative values for N leached. Good correlation between soil mineral N in autumn and actual nitrate leaching determined using ceramic cups was obtained at North Wyke (UK) and this suggested that autumn mineral N is a better indicator of potential N leaching than the autumn minus spring value for northernmost sites. Nitrate leaching varied considerably with site, legume species and with the proportion of legume in the sward. Greatest leaching potential was from beneath red and white clover, with lucerne, lotus and galega giving lower values. The lowest values were for grass without fertiliser N, whilst grass with 200kg N ha^{-1} had a leaching potential slightly below white and red clover. Pure legumes accumulated about 10 kg N ha^{-1} more potentially leachable N than did legume-grass mixtures on average. Concentrations of nitrate-N measured in suction cups at the UK site were generally <5 mg l^{-1}, but this was a reduction on the previous two years. Leaching assessed with the ceramic cups was particularly low for lucerne. While nitrate leaching from these leguminous swards was less than is commonly measured from beneath highly fertilised grass, it must remembered, when considering the relative sustainability of the two sward types, that the present data exclude any impacts of excretal returns to the soil from livestock and the legume system may produce less dry matter. The use of lucerne for reduced nitrate loss deserves further study.

Introduction

It has been known for over a decade that intensive systems of animal production reliant on large inputs of inorganic fertiliser nitrogen (N) are inefficient in N use and can give rise to large emissions to the environment (Garwood and Ryden, 1986; Scholefield and Oenema, 1997). Of particular concern is the potential for large N losses due to nitrate leaching from such systems under grazing management (Ryden et al., 1984; Scholefield et al., 1993). There is therefore an urgent need for the development and take up of more environmentally sustainable systems of livestock production in northern Europe. These systems should enable compliance with the Nitrate Directive, that limits the concentration of nitrate in surface and ground waters to 50 mg l^{-1}, yet be sufficiently productive to support farmers' incomes at economically attractive levels in each member state.

Forage legumes have been suggested as important components of low input, sustainable systems for livestock production (Thomas, 1992; Jarvis et al., 1996) and are the basis of organic agriculture (Cuttle and Jarvis, 1992). Studies of nitrate leaching from beneath forage legumes have been restricted largely to those involving white clover in combination with grasses under grazing management. Results show that N loss by nitrate leaching from grass-white clover is generally much smaller than from highly fertilised grass (e. g. Parsons et al., 1991) and this has suggested that legume-based systems are environmentally benign. However, it is now generally believed that the smaller N loss is due to the lower level of production with grass-clover and that the two systems (grass-clover receiving no N fertiliser and fertilised grass) would release similar amounts of nitrate at equal levels of production per ha (see Cuttle and Jarvis, 1992; Tyson et al., 1997; Houda et al., 1998). If this is so, we might expect nitrate leaching from beneath white clover-based swards to increase with increase in clover content and the level of N fixation per ha. There is some recent evidence for this (Loiseau et al., 2001). On the other hand, if clover-rich swards were cut for silage rather than grazed, nitrate leaching might be kept within the allowable limit. But little is known of the nitrate leaching

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potential of cut, clover-rich swards and furthermore, there is only limited information on leaching from beneath alternative forage legumes. More information must be obtained before legume-rich forages can be advocated as the basis of sustainable systems of livestock production.

The study reported in this paper (LEGSIL , EU Programme FAIR3 CT 96-1832) was undertaken to evaluate the use of five forage legumes grown in pure stands and in combination with a companion grass as the basis for economically and environmentally sustainable systems of livestock production in northern Europe. The legumes studied were white clover, red clover, lucerne, galega and lotus. The companion grass was meadow fescue with the main treatments at each site. The study was conducted at twelve sites in four countries (three sites per country), over three growing seasons during the period 1997-2000. The study comprised several elements. These included the growth and management of cut swards in a replicated plot experiments at each site; the assessment of nitrate leaching from beneath each treatment; ensiling and the subsequent assessment of feed quality; animal production from each feed and a model-based systems comparison of the economics and environmental impacts of the production of each legume relative to grass. In this paper we report and discuss data on the assessment of nitrate leaching during the winter drainage period following the 1999 growing season and compare these briefly with results from the previous two years for the North Wyke (UK) site only.

Materials and methods

Sites and soils

Plots (each 7 m x 3 m) were established during 1997 at nine sites and during 1998 at the remaining three sites, as described by Halling *et al.* (2002). Some site details are given in Table 1. There were 3 replicates of 18 treatments with all treatments randomised across each of 3 blocks. The treatments common across all sites comprised the five legumes listed above, with and without their companion grass plus two ‘grass only’ treatments with and without 200 kg N ha^{-1} fertiliser (ammonium nitrate). There were 6 additional treatments comprising white clover, red clover and lucerne, each with and without a companion grass. Whereas with the 12 common treatments the variety of each herbage species sown was the same across all sites, with these additional treatments the varieties used were those acknowledged to be the best adapted for use in each country. Plots were cut to 25 mm height 2 or 3 times per year (according to latitude of site) using a Haldrup plot harvester at times appropriate for taking silage cuts in each country. One site in each country was on land registered for organic production and on this site the 200 kg N ha^{-1} fertiliser treatment was applied as urine or slurry. Herbage samples were used for determination of dry matter and N yield, proportion of sown species and for subsequent ensilage and feeding experimentation described elsewhere.

Assessment of nitrate leaching

Two methods to assess nitrate leaching were followed. These were (i) difference in soil mineral N measured before and after the winter drainage period; and (ii) measurement of nitrate concentrations in ceramic cup samplers coupled with drainage volumes assessed with a suitable water balance model. Method (i) was applied at all sites to all treatments, while method (ii) was applied in Finland, Sweden and UK at one site per country.

Assessment of nitrate leaching by method (i) was made following the procedure used by Scholefield and Titchen (1995). Six spatially representative samples per plot were taken to 1 m depth (or to rooting depth in shallow soils), dividing each sample either into 3 by depth (0-30 cm, 30-60 cm, 60-100 cm) for 1 m cores, or into two for shallower soils. Cores from each soil layer in a given plot were combined and thoroughly mixed to give three (or two) depth samples per plot. Extra samples were taken at each depth from each plot for the determination of bulk density and water content. These values were required in the calculation of Nmin ha^{-1} from values of Nmin kg^{-1} dry soil. The latter values were determined by extracting 100 gm of field-moist soil with 200 ml of 1.0M KCl solution in an orbital shaker for 2 hours, filtering the extract through pre-washed Whatman No. 1 filters and analysing the filtrate for nitrate and ammonium using standard automated colourimetric procedures (Skalar, Breda, The Netherlands). Nitrate was determined by the hydrazine reduction method (Kamphake *et al*., 1967) and ammonium was determined by the modified Berthelot reaction (Krom, 1980).

The ceramic cup samplers for method (ii) were fabricated by fixing 25 mm 1 Bar ceramic thimbles (Soil Moisture Equipment Corp., Santa Barbara, California) to the ends of 25 mm diameter plastic tubes with waterproof epoxy-based glue. The open end of each tube was sealed with a rubber bung, bored out to take two sampling tubes of 2 mm bore.

Table 1:
Locations of sites and soil conditions

Country	Site	Location			Year est.	Soil type	pH
		Lat.	Long.	Elev. (m)			
Finland	Apukka	66º35'N	26º01'E	105	1997	Sand moraine	6.2
	Ruukki*	64º41'N	25º01E	47	1998	Organic sand	5.3
	Viikki	60º13'N	25º01E	2	1998	Fine sand	5.4
Sweden	Uppsala	59º49'N	17º39'E	5	1997	Loam	6.1
	Raadde	57º36'N	13º16'E	185	1997	Loamy sand	6.3
	Lilla Boeslid*	56º36'N	12º55'E	10	1997	Silt loam	6.5
Germany	Wehnen	53º10'N	08º08'E	0	1998	Sand	4.8
	Voelkenrode	52º18'N	10º27'E	80	1997	Silty sand	7.2
	Adolphshof*	52º21'N	10º00'E	74	1997	Sand/loam/silt	8.1
United Kingdom	North Wyke	50º47'N	03º54'W	155	1997	Loam/gravel	6.2
	Trawsgoed*	52º20'N	03º55'W	100	1997	Silty clay loam	6.0
	Bronydd Mawr	51º58'N	03º38'W	330	1997	Fine loam	6.1

* organic registered site

One tube extended to the ceramic cup for sampling extracted soil solution, while the other extended only a few cm inside the tube for the application of vacuum. The samplers were installed at 30º to the vertical using a jig to guide the auger, to minimise the effects of preferential flow from the soil surface to the ceramic cup. Good contact between the cup and the soil was ensured by pouring a slurry of fine silica flour down the hole. Six samplers per plot were installed in a square grid design. Samples were extracted every two weeks or after 25 mm of drainage (whichever was the sooner) by application of 70 mb suction for 24 hours prior to each sampling. Samples were analysed for nitrate immediately or after storage for <48 hours at 3ºC, using standard automated colourimetric procedures as described above. Total dissolved N was determined using a recently developed autoanalyser procedure in which the organic fraction is first oxidised to nitrate in-line by added persulphate and strong UV light. Amounts of nitrate leached (kg N ha^{-1}) were calculated by determination of the average nitrate concentration per plot and associating each of these with a volume of drainage. The distribution about the mean of each set of 18 values per treatment was examined to ascertain the best method of determination of the unbiased mean. The Sichel estimator (Sichel, 1952) was used to transform highly skewed distributions. Drainage was calculated from the water balance at each site assuming a simplified Penman-Monteith model.

Results

Soil mineral N

Tables 2 and 3 show the mineral N present in soil profiles during autumn 1999 and spring 2000 at all 12 sites. Apart for the sites established in 1998 (Ruukki, Viikki and Wehnen), these data indicate the levels of leachable mineral N and net winter loss of N from the profile following the second harvest year. As in previous years (Scholefield, 2000; Scholefield, 2001), the highest levels were present at Trawsgoed, Wehnen, Bronydd Mawr and Viikki, whereas the lowest were present at Apukka, Ruukki and Lilla Boeslid. Net losses of mineral N over winter were positive at Wehnen, Voelkenrode, North Wyke and Bronydd Mawr. Elsewhere, at the northernmost sites they were negative, suggesting enhanced mineralisation with the spring thaw and indicating that at such sites, the value for autumn soil mineral N is probably a better indicator of treatment effects than net change over winter.

The values of autumn soil mineral N from beneath pure legume swards were consistently greater than those from beneath corresponding legume plus companion grass, at almost all sites and with all legume types (Table 2). These differences ranged between 3 kg N ha^{-1} (North Wyke) and 17 kg N ha^{-1} (Bronydd Mawr) with mean difference of 10 kg N ha^{-1}. The largest values of soil mineral N were associated with the pure white and red clover treatments, whereas the smallest were present beneath unfertilised grass swards. Average values for the pure legumes were 36, 32, 27, 25 and 23 kg N ha^{-1} for white clover, red clover, lucerne, lotus and galega respectively. Values for grass were 17 and 29 kg ha^{-1} without and with N fertiliser respectively.

Table 2:
Soil mineral N (kg ha^{-1}) in autumn 1999

Treatment	Apukka	Ruukki	Viikki	Uppsala	Rådde	Lilla Böslid	Völkenrode	Adolphshof	Wehnen	North Wyke	Trawsgoed	Bronydd Mawr	Mean
CLR*	8.8	22.0	46.6	22.9	16.0	20.2	33.6	18.5	115	17.6	26.8	44.1	25.2
CLR+GR*	2.4	10.2	26.3	12.9	18.3	14.4	32.7	8.6	25	16.0	15.6	46.5	18.5
LUC*	13.3	13.2	28.7	21.3	17.1	24.9	23.6	14.5	16	22.1	40.7	72.9	26.6
LUC+GR*	1.7	10.9	19.1	14.4	11.1	19.1	17.7	11.7	72	20.5	36.2	37.8	18.2
CLW*	12.1	15.9	42.4	41.6	27.6	32.1	69.8	39.2	35	13.8	20.7	89.2	36.8
CLW+GR*	2.2	10.1	23.1	10.4	14.4	22.9	54.2	29.1	68	18.7	18.7	57.4	23.7
GAL*	18.2	12.9	31.9	14.5	18.0	15.3	23.4	20.3	37	25.6	17.8	44.7	22.1
GAL+GR*	5.0	11.1	35.7	11.3	13.3	10.8	18.7	14.5	19	15.0	23.1	57.1	19.6
LOT*	6.6	13.4	37.6	20.2	17.4	14.4	35.4	27.0	30	15.6	23.2	54.4	24.1
LOT+GR*	2.9	5.1	15.8	10.7	9.4	12.2	15.0	8.8	23	15.2	22.4	47.5	15.0
CLR	9.7	22.2	42.6	23.1	16.8	22.7	30.1	12.6	25	19.4	59.6	94.8	32.1
CLR+GR	3.7	10.9	29.6	17.8	12.7	12.1	30.9	13.8	48	13.3	29.3	48.4	20.2
LUC	8.0	16.0	26.6	15.2	20.0	15.1	19.1	16.6	22	34.5	44.2	92.8	32.2
LUC+GR	2.0	8.6	23.5	14.2	10.0	10.2	24.2	12.9	32	23.3	39.5	60.2	24.3
CLW	16.2	18.7	52.5	33.0	23.21	33.2	75.6	31.9	61	17.4	26.0	47.1	34.1
CLW+GR	2.4	12.5	31.3	13.3	16.5	25.6	15.6	7.7	15	17.8	28.2	48.6	20.0
GR 0N	1.6	7.6	18.8	12.3	9.9	9.9	14.0	9.8	28	15.6	20.1	64.1	16.7
GR 200N	4.9	17.2	13.9	22.4	14.2	12.9	76.7	10.7	99	15.6	18.0	38.3	22.3
Mean	6.6	13.2	30.3	18.9	16.0	18.9	33.9	17.1	35.5	18.7	28.3	58.1	23.6
CV%	35.9	26.9	26.0	20.7	15.9	22.9	32.3	45.6	41.2	44.2	53.8	47.9	
Probability	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	NS	NS	NS	NS	
LSD	3.9	5.9	13.1	4.5	2.9	5.0	18.2	12.9	22.2	13.7	25.3	46.2	

CLR = red clover, LUC = lucerne, CLW = white clover, GAL = galega, LOT = lotus, GR = grass
CV% = coefficient of variation, LSD = least significant differences of means at $p < 0.05$, NS = no significant difference ($p > 0.05$)
* Standard varieties

Table 3:
Soil mineral N (kg ha^{-1}) in spring 2000

Treatment	Apukka	Ruukki	Viikki	Uppsala	Rådde	Lilla Böslid	Völkenrode	Adolphshof	Wehnen	North Wyke	Trawsgoed	Bronydd Mawr	Mean
CLR*	23.9	28.1	48.6	49.3	87.4	25.3	8.9	22.1	11.1	9.6	34.6	26.4	31.9
CLR+GR*	13.6	23.3	52.4	19.6	68.6	28.0	12.9	13.5	10.3	10.4	29.6	50.6	27.4
LUC*	16.2	24.4	61.1	35.0	85.5	17.9	84.1	17.7	13.4	8.2	28.4	29.1	35.8
LUC+GR*	13.4	19.0	55.8	22.5	71.5	29.3	15.4	15.4	16.0	8.3	32.0	27.9	26.2
CLW*	33.5	28.1	65.1	54.8	106.3	41.8	19.4	30.5	12.3	9.9	26.4	45.5	40.9
CLW+GR*	22.1	48.7	54.1	19.5	92.6	28.4	12.1	11.0	16.7	9.4	24.5	69.5	32.1
GAL*	22.4	32.7	48.0	19.0	113.4	23.2	13.1	19.7	12.2	8.8	20.7	38.7	31.0
GAL+GR*	17.3	28.4	51.6	15.8	72.2	16.6	11.0	11.9	19.0	6.3	13.8	53.0	24.2
LOT*	27.5	24.7	53.1	30.8	87.3	25.9	14.9	20.7	18.6	6.7	19.4	42.8	30.7
LOT+GR*	16.6	26.2	47.4	14.1	109.4	22.1	13.1	11.3	18.1	8.6	27.5	53.8	30.7
CLR	26.4	28.1	66.3	31.6	85.3	30.4	14.1	19.8	11.4	5.0	25.7	25.0	29.3
CLR+GR	16.8	27.8	51.2	23.7	110.7	18.7	10.5	20.2	10.1	8.0	19.5	37.7	29.5
LUC	23.6	25.0	91.1	20.0	84.8	24.1	10.6	21.2	11.0	10.0	23.1	24.4	18.8
LUC+GR	12.6	25.0	90.1	16.3	95.6	18.2	14.4	16.2	10.6	9.8	14.5	32.2	16.6
CLW	37.1	27.4	49.0	40.3	119.5	29.2	14.9	25.0	10.3	9.6	29.1	21.6	36.3
CLW+GR	19.9	21.2	50.8	21.5	115.5	27.3	8.8	13.9	11.1	8.1	37.8	21.8	30.5
GR 0N	13.2	37.5	51.9	14.5	77.8	19.6	10.4	10.1	13.7	7.2	25.2	37.9	24.0
GR 200N	19.0	40.5	51.3	24.3	59.6	23.5	20.0	10.5	11.1	9.1	25.1	21.4	23.6
Mean	20.8	28.6	57.7	27.5	91.4	25.46	17.2	17.3	13.2	8.5	25.4	36.6	30.0
CV%	24.7	34.1	40.4	36.1	35.6	23.9	168.4	34.8	22.2	33.1	42.9	70.5	
Probability	<0.001	<0.01	<0.01	<0.001	NS	<0.005	NS	<0.01	<0.01	NS	NS	NS	
LSD	8.5	12.1	31.5	20.2	54.3	10.1	48.0	10.0	7.8	4.7	18.1	42.9	

CLR = red clover, LUC = lucerne, CLW = white clover, GAL = galega, LOT = lotus, GR = grass
CV% = coefficient of variation, LSD = least significant differences of means at p< 0.05, NS = no significant difference (p> 0.05)
*Standard varieties

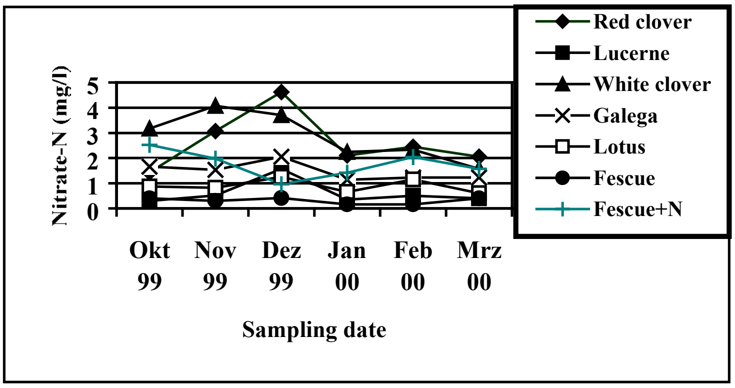

Figure1:
Concentrations of nitrate-N in soil solution extracted by suction cups beneath pure legume swards at North Wyke during 1999-2000

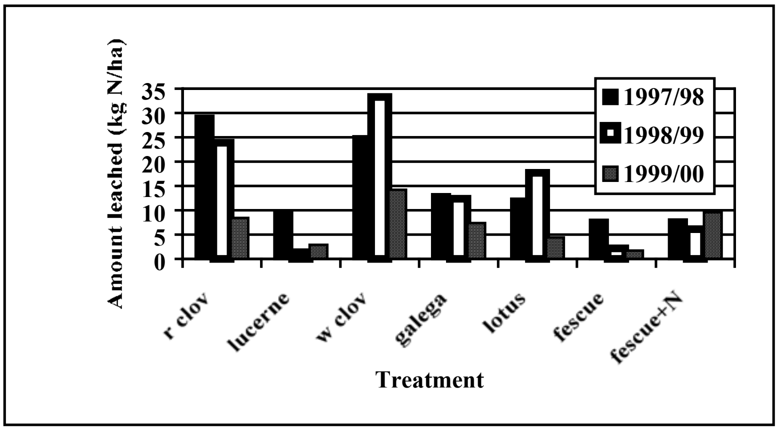

Figure 2:
Amounts of nitrate-N lost at North Wyke over 3 years estimated from suction cup data

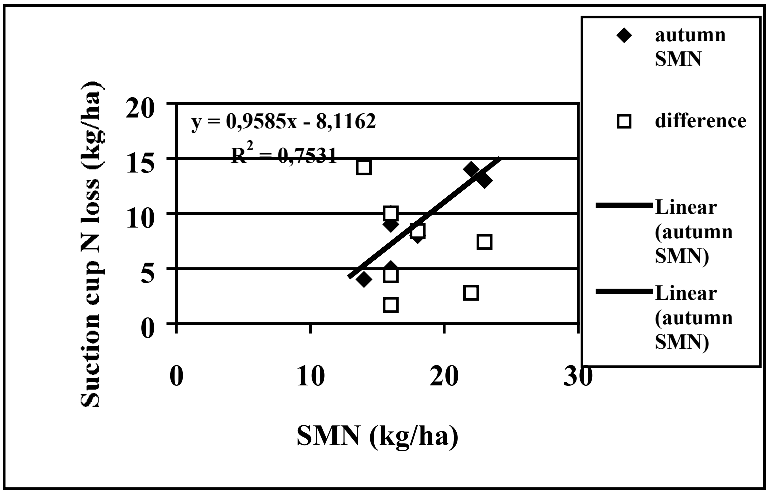

Figure 3:
Regression of N loss estimated using suction cups on autumn soil mineral N (SMN) values for the 1999-2000 drainage season at North Wyke

Ceramic suction cups

Samples of soil solution could be taken successfully during winter only from North Wyke, due to the frozen conditions in Finland and Sweden. Fig. 1 shows that the strongest concentrations of soil nitrate were beneath red and white clover, while the weakest concentrations were beneath unfertilised fescue and lucerne. This agrees reasonably well with the autumn soil mineral N data for North Wyke and generally for all sites (Table 2). The peak concentrations of nitrate-N were generally < 5 mg l^{-1}, during this winter and much weaker than during the previous two drainage periods (Scholefield, 2000; Scholefield, 2001). The amounts of N lost were also smaller than in previous years (Fig. 2), with the greatest amount (14 kg N ha^{-1}) lost from beneath white clover. Average losses of nitrate-N from the treatments during the 3 drainage periods 1997-2000 are ranked in the order white clover (24 kg N ha^{-1}), red clover (20 kg N ha^{-1}), galega (11 kg N ha^{-1}), lotus (11 kg N ha^{-1}), fescue + fertiliser N (8 kg N ha^{-1}), lucerne (5 kg N ha^{-1}) and fescue alone (4 kg N ha^{-1}). Total N losses would have included some soluble organic compounds. For the 1999-2000 drainage period these losses of soluble organic compounds were about 4 kg N ha^{-1} for all treatments except pure red clover, which gave rise to 8 kg organic N ha^{-1} loss.

A linear regression plot of estimate of loss of nitrate-N using suction cups on that using the soil mineral N method (Fig. 3) shows reasonable agreement when using autumn values alone, but poor agreement using the difference between autumn and spring values. This relationship shows a slope close to 1, but a positive intercept on the soil mineral N axis with zero suction cup loss of between 8 and 16 kg N ha^{-1}. This indicates that a proportion of the autumn soil mineral N is immobile.

Discussion

It is assumed that the source of mobile N species, susceptible to leaching from beneath cut swards, was the microbiological breakdown of senescing plant residues and 'native' soil organic matter, with any treatment differences therefore due to differences in amounts and rates of mobile N released from these organic sources. Direct leaching of residual mineral fertiliser applied to the grass would have been unlikely.

This work has demonstrated the limitations of the applicability of 'method 1' for determination of nitrate leaching under conditions where it is not technically possible to use 'method 2'. While method 1 has been used successfully in previous studies under UK conditions (e. g. Kirkham and Wilkins, 1993) and elsewhere, it is evidently not suitable for use in soils that are frozen during the winter and thaw rapidly during spring. This is due to the very rapid rates of spring mineralisation that occur at these sites and the difficulty of timing the sampling date to coincide closely with the thaw. At the UK site actual leaching, as determined by method 2, was highly correlated with values determined by method 1, with only a small proportion of autumn mineral N deemed 'immobile'. At the northernmost, frozen sites however, where any leaching would have taken place directly after the spring thaw, we might also have expected a good correlation between amounts actually leached and autumn soil mineral N, if the only difference in circumstances was the timing of the main period of N mineralisation. However, another factor complicating the determination of leaching in such circumstances is the enhanced soil structuring observed with the growth of certain legume roots (notable those of white clover) compared with those of grass (Mytton et al., 1991). Highly differentiated soil structure beneath clover-rich swards could give rise to strong concentrations of nitrate in ground water due to preferential flow of even a small amount of drainage water. On the other hand, such enhanced structuring might be expected to give relative protection from leaching to nitrate held in soil micro-pores. The important consideration in relation to this phenomenon is thus the site of the nitrate prior to leaching: either held mainly in micro-pore water within aggregates, or mainly on the surfaces of aggregates. We might expect that nitrate produced and accumulated during late summer and autumn would be more or less homogeneously distributed through soil aggregates before the onset of any drainage due to autumn rains, whereas that produced rapidly during and after the spring thaw at frozen sites would reside mainly close to aggregate surfaces. It is therefore difficult to determine the absolute amounts of N leached from beneath clover swards at sites where the soil is frozen during winter, except for those with sandy soils for which the effects of preferential flow will be minimal.

The amounts of N leached from beneath unfertilised and fertilised grass at North Wyke (UK) were within the ranges previously recorded for cut swards at that site, but the data for the legume treatments are novel and cannot be compared with any previously determined values. The values for the white clover treatment are compatible with those obtained by Loiseau *et al.* (2001) for similar swards under simulated grazing management. These workers recorded leaching losses from lysimeters sown with pure white clover within the range 28-140 kg N ha^{-1}

over a 6 year period, whereas the range for grass-white clover during the same period was 1-19 kg N ha^{-1}.

It is reasonable to assume that the amount of N rendered susceptible to leaching beneath legume-based swards would be determined by (i) the proportion of legume in the sward (and hence the amount of N fixed); (ii) the C/N ratio of the plant residues; (iii) the degree of recalcitrance of the residues to microbiological degradation, and (iv) the ability of the legume root to sequester mobile N. There is some evidence to support (i), provided by the good correlation between the yield of legume in the mixed swards and the level of mineral N accumulated in autumn for two of the Swedish sites (Halling and Scholefield, 2001). It is well known that clover-rich residues are readily degradable and N-rich, relative to grass, and so it is not surprising that the clover treatments all result in relatively high accumulated mineral N and leaching losses. What is surprising is the relatively small leaching potential of the lucerne-based swards, despite giving dry matter yields as great as those from red clover at many sites. Recent US studies (Toth and Fox, 1998; Russelle et al., 2001,) also demonstrate reduced leaching from beneath lucerne and the ability of this legume to actively sequester N from N-rich soil, indicating that both assumptions (iii) and (iv) may be true.

Conclusions

1 The direct determination of N leaching from beneath swards in regions where soils freeze during the winter is technically difficult and is probably valid only for sandy soils. Values of mineral N accumulated in the soil in autumn give good indication of relative leaching potential between treatments and, for unfrozen soils with high winter drainage, are highly correlated with actual leaching.
2 This study has demonstrated that levels of nitrate leaching from beneath legume-rich, cut swards can be as great as those from beneath grass receiving 200 kg N ha^{-1} mineral fertiliser. There can be large differences in potential for N leaching, dependent upon site factors, type of legume, proportion of legume in the sward and its dry matter yield.
3 It is unlikely that concentrations of nitrate in water draining from cut, legume-rich swards established in northern Europe would be consistently greater than that allowable under the EU Nitrate Directive. However, such systems are not environmentally benign and we should be cautious when considering the use of legumes as the basis of sustainable systems of livestock production. The species of legume, the impact of the N-rich excretal returns from feeding the ensiled forage and the generation of potentially leachable organic N should all be considered.
4 More experimental research is required to (i) establish better methods of determination of nutrient leaching to ground and surface waters from soils in frozen regions; and (ii) evaluate the potential of lucerne for reduced N leaching through active N sequestration from N-rich soils.

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Summary of plenary discussion

1 Characteristic of the N leached

The leachate measured from the suction cups had a C:N ratio of between 3:1 and 12:1, with the source of the material ranging from protein to humus.

2 Soil structure effects

Although legume swards tend to result in improved soil structure, it is expected that other management or climatic factors would be more important in determining the N leaching than soil structure factors. Nevertheless, as the structure improved the organic matter in the soil increased, and N leaching increases. However, after three-four years, it is expected that the soil structure would have little impact on N leaching.

3 Soil mineral nitrogen

N leaching would have been high at sites that had high soil mineral nitrogen status. However, there is not enough ancillary data from the LEGSIL experiments to predict which soils have high soil mineral nitrogen. In addition, the previous summer rainfall influenced N leaching, as hot dry summers tended to result in a twofold increase in N leaching compared to the losses occurring after a cool wet summer. However, there are models available that can be used to predict which soils are likely to suffer from high leaching losses.

4 Lower leaching losses from lucerne

If nitrate is available, lucerne tends to take-up nitrogen opposed to fixing nitrogen, whereas the Trifolium species still tend to fix a proportion of their N requirements. The relative quantities of the soil nitrate taken-up and the N fixed by the legume will influence the N leaching. Hence, this may explain why the leaching losses from the lucerne were lower than the other leguminous species.

5 Organic versus conventional systems

At similar levels of production, the N leaching from organic and conventional systems was similar. However, currently, production levels in organic systems are lower than that of conventional systems with high fertiliser-N inputs, and so the losses tend to be lower. Within the project there were no consistent differences between the organic sites and the conventional sites in mineral-N levels in autumn. The accumulation of N within the soil was not monitored, as the change in total N would have been extremely small compared to the total soil N.

6 Applying fertiliser in the spring

Farmers tend to get frustrated with the slow growth of the grass-legume swards in the spring, and hence they tend to apply modest levels of fertiliser during the spring to promote grass growth. The expectation is that this practise would result in increased N leaching, due to the increased total N going through the system.

Reporter: C.F.E. Topp

Ensiling of legumes

Günter Pahlow[1], Chri Rammer[2], David Slottner and Mikko Tuori

Abstract

The objective of the task was to provide reliable techniques for the conservation of forage legumes, which are difficult crops to ensile due to low contents of sugars and high buffering capacity. In Germany, Sweden and Finland the same four species, lucerne (*Medicago sativa),* red clover *(Trifolium pratense),* lotus *(Lotus corniculatus)* and galega *(Galega orientalis)* were established, harvested and ensiled at two stages of maturity, slightly and heavily wilted, with addition of formic acid (FA) or the silage inoculant Ecosyl® (ECO) and compared to an untreated control (C). At harvesting all fresh crops had very poor ensilability- indicating the need to take technological measures to reliably prevent undesirable fermentations. However, slight wilting to a target DM of approx. 250 g kg^{-1} was not sufficient to prevent butyric acid production, particularly with lucerne and galega. This could be achieved by wilting to about 400 g DM kg^{-1}, but silage quality was still significantly improved by use of the additives. FA was more effective than the inoculant in reducing ammonia content, but, especially in the high DM silages, the inoculant enhanced lactic acid production and the rate of pH decline. Aerobic deterioration was generally no problem in the resulting silages.

Methodology

The investigation was carried out on a laboratory scale, using 3 replicate silos of 1.5 to 30 l capacity. The target DM contents (*c*. 250 g kg^{-1} and *c*.400 g kg^{-1}) were achieved within maximum wilting times of 1 and 2 days for the two DM levels. Each crop received the ensiling treatments of no additive (C) vs. formic acid (FA), with amounts of 6.0 or 3.5 l t^{-1} for the low and high level of wilting, vs. the bacterial additive, Ecosyl (ECO) at an inoculation rate of 10^6 colony forming units (cfu) g^{-1} fresh matter of the crops at ensiling.

The analyses carried out on the forage crops and the silages are shown in Table 1.

Results and discussion

Ensilability of the legumes was characterised by their fermentability coefficient (FC), which summarises in one figure the effects of DM content, the quantity of fermentable substrate and buffering capacity of the crop according to the equation (Pahlow and Weissbach, 1999):

$$FC = DM\ [\%] + 8\ WSC\ BC^{-1}$$

A value above 45 indicates good fermentability. This FC did not differ significantly between the three countries and the four species. However, the clear effect on the FC of differences in DM content, achieved by wilting, is shown in Table 2 for the freshly harvested legumes and the crops wilted to the two target DM levels.

Table 1:
Assessments of the crops at ensiling and of silages after 90 days storage time

Crop composition at ensiling	
Crop parameter	Dimension
Epiphytic LAB	log cfu g^{-1} FM
DM content	g DM kg^{-1}
Water soluble carbohydrates	g kg^{-1} DM
Buffering capacity	g LA $100g^{-1}$ DM
NO_3 nitrogen	g kg^{-1} TM
Silage composition after 90 days storage	
Silage parameter	Dimension
pH value	
DM content	g DM kg^{-1}
Fermentation products	g kg^{-1} DM
NH_3- nitrogen	NH_3 N in % of TN
Aerobic stability	Days at 20°C

Table 2:
Fermentability coefficients of legume species as influenced by DM content

Legume	Direct cut	250 g DM kg^{-1}	400 g DM kg^{-1}
Lucerne	27	35	48
Red clover	27	38	50
Lotus	24	34	47
Galega	29	35	47
Mean	27	36	48
SD	1.8	1.5	1.2

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The low FC for all direct-cut legumes shows that they would be very difficult to ensile, indicating the need to take measures to prevent butyric acid fermentation, which is unavoidable at a FC around 27. The FC of 36, corresponding with the slightly wilted forage, is still not sufficient to guarantee good fermentation quality. Only the higher wilt to *c*. 400 g DM kg^{-1} resulted in FC values above the critical threshold of 45.

An alternative approach was investigated at FAL. The legumes were mixed at the point of ensiling with grass of higher FC. The grass component, used in the mixtures was *Lolium perenne* with a content of WSC varying from 100 to 200 g DM kg^{-1}. This resulted in increase in the FC of the mixture to *c*. 40, when at 250 g DM kg^{-1} (Table 3). However, at this low DM content, the grass component alone was not sufficient to achieve a fermentation quality as good as with the additives. The FC of the mixtures remained below the target value of 45, indicating the risk of undesirable fermentation.

Table 3:
Fermentability coefficients of legumes, grass and legume-grass-mixtures at 250 g DM kg-1

Legume species	Legume 250 g DM kg^{-1}	Grass 250 g DM kg^{-1}	Legume-Grass Mixture
Lucerne	35	50	40
Red clover	38	52	43
Lotus	34	47	39
Galega	35	45	40
Mean	36	48	40
SD	1.5	2.8	1.5

Silage quality was classified by a single figure by using the DLG point scoring system. This method considers concentrations of butyric acid, acetic acid and ammonia nitrogen, together with pH in relation to DM content. The maximum value is 100 points for the highest fermentation quality.

The effect of additive treatments on indicators of silage quality is shown in Table 4.

All additives had significant effects on quality parameters. Ecosyl enhanced the lactic acid content. Both additives reduced protein decomposition to ammonia, with formic acid being the most effective treatment. For silage quality, characterized by the DLG scoring system, there were clear differences in ranking, with values being higher with Ecosyl than with formic acid; the untreated control gave the lowest values. However, it has to be stated that this scoring system has limitations where fermentation is severely restricted, such as the silages with high rates of formic acid. This relationship is emphasised by the content of Table 5, which gives the effect of additive treatment on all relevant fermentation products.

Table 4:
Silage quality and protein decomposition as influenced by type of additive

Additive treatment	Lactic acid g kg^{-1} DM	NH_3 % of TN at ensiling	DLG score (max. 100 points)
Control	66 b	12 a	71 c
Ecosyl®	88 a	8 b	85 a
Formic acid	22 c	5 c	77 b
HSD	4.8	0.8	3.6

Table 5:
Effect of biological and chemical additives on main fermentation products

Additive treatment	Lactic acid	Acetic acid	Butyric acid	Ethanol
	g kg^{-1} DM			
Control	66 b	23 a	4.6 a	6.9 a
Ecosyl®	88 a	21 b	0.9 b	4.5 b
Formic acid	22 c	8 c	0.6 b	1.8 c
HSD	4.8	1.6	1.3	1.5

The homofermentative bacterial additive Ecosyl significantly reduced the volatile fatty acids as well as ethanol. The inoculant was as effective as FA in reducing butyric acid production. FA dramatically restricted the silage fermentation.

The effect of legume species on silage quality is shown in Table 6. There were statistical differences between species for all three indicators of silage quality. These followed the same pattern, clearly indicating that lucerne and galega were particularly difficult to ensile, whilst better fermentation quality was generally achieved for red clover and lotus. This occurred despite very close similarity between all four species in FC, shown in the last column.

Table 6:
pH value, NH_3 fraction and DLG score in silages from different legumes

Legume species	pH value	NH_3-N in % of TN	DLG score	FC
Lucerne	4.8 a	10.7 a	71 a	41 a
Red clover	4.5 b	7.2 b	81 b	43 a
Lotus	4.5 b	6.6 b	82 b	41 a
Galega	4.6 a	8.4 a	75 a	41 a
Mean	4.6	8.3	77	41.5
SD	0.09	0.99	4.6	3.5

The preservation of forage protein is considered more deeply in Table 7, in view of its importance for the entire LEGSIL project.

Only the low DM control silages contained NH_3 N in concentrations >10 %, a value which brings about a negative effect on silage quality. Wilting to 400 g DM kg^{-1} *per se* reduced the concentration of ammonia nitrogen from 14 to 8 %. As stated above, FA was most effective in restricting protein decomposition.

In addition to the routine determination of ammonia nitrogen, all FAL lab silages from 1998 were analysed for their content of free amino acids (FAA) by IGER. In Figure 1 the regression between the (calculated) bound protein nitrogen and the respective NH_3 nitrogen content is shown. The R^2 of 0.871 indicates the good relationship between these parameters.

Lowest concentrations of NH_3 N from protein decomposition during ensiling correspond with highest contents of intact protein which has survived the fermentation process.

The protein protection can be attributed primarily to the effect of the additives. However, as shown already in Table 6, there is also a plant-species effect with significantly less protein decomposition in red clover and lotus than in lucerne and galega.

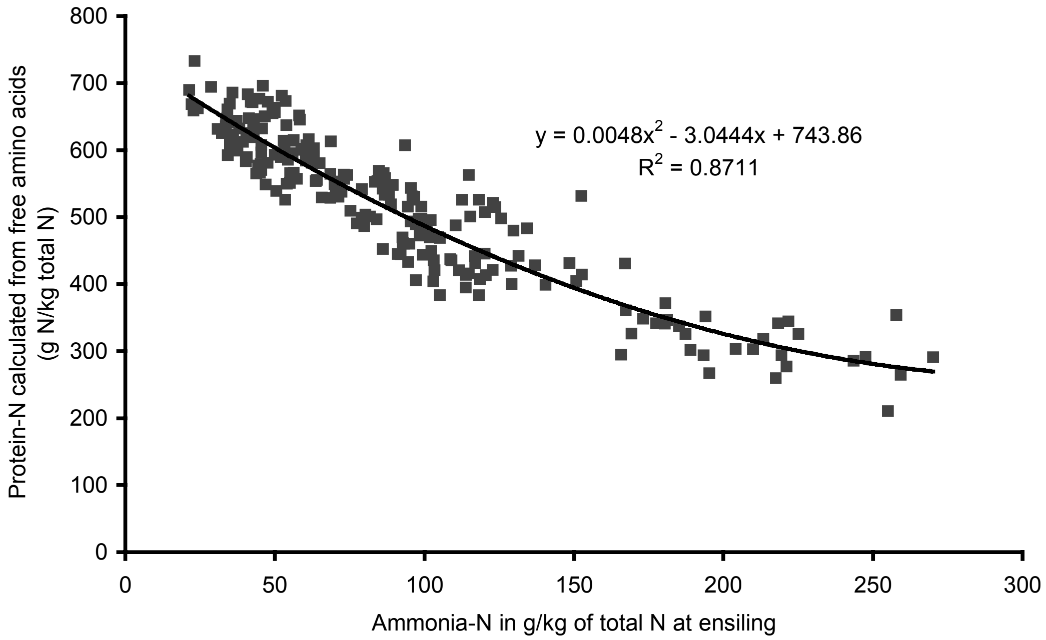

Figure 1:
Regression between bound protein N and ammonia N in legume silages

Table 7:
Protein protection by silage additives at different DM levels of legume silages (means and standard deviations)

	DM content	Control	Ecosyl ®	Formic acid
NH_3 N % of TN	250	14 ± 4	9 ± 4	4 ± 1
NH_3 N % of TN	400	8 ± 2	7 ± 3	5 ± 2

In all silages from the first experimental year, the aerobic stability was determined by measuring the temperature rise above ambient over a period of seven days according to Honig (1990). There was generally high stability, with none of the silages showing an increase in temperature within the first four days (Table 8).

Table 8:
Minimum duration of aerobic stability of legume silages measured upon exposure to air at 20 °C (n = 264)

Percentage of silages, aerobically stable for at least:			
4 days	5 days	6 days	7 days
100	99	97	89

Of the 30 unstable silages, the vast majority were from either red clover (15) or galega (13). A preliminary report of this research is given in Pahlow *et al.* (2000).

Conclusions

The results from both experimental years in all countries indicated that a DM content of 250 g DM kg^{-1} alone is not sufficient to avoid poor fermentation reliably and, particularly for lucerne and galega, a chemical additive such as formic acid at a rather high rate is required to achieve good fermentation at that low DM content. In general the recorded differences in the ensiling potential of the four legume species could be overcome by adopting appropriate ensiling technology. Wilting to a higher DM concentration is preferred and with that treatment the use of an inoculant resulted in further improvements of silage quality. A similar conclusion applies to the question of growth stage at harvest (budding or flowering), with crop yield and nutritive value being more important than ensilability of the respective plant species. The DLG score system for the classification of silage quality is less suitable if fermentation was severely restricted, as in the silages prepared with addition of large amounts of formic acid. For the range of treatments studied in this task, the best single index of successful preservation was the ammonia – nitrogen fraction, expressed as percent of the total nitrogen content of the crop at the time of ensiling.

Recommendations

- Harvest at flowering rather than at budding stage, provided the digestibility of the silage crop is not unacceptably reduced.
- Use a mower conditioner to reduce the wilting time. Dry to at least 300 g DM kg^{-1} with a field period of maximum 48 hours.
- Additive use is generally advisable for forage legumes in order to enhance protein protection and to improve fermentation quality of the resulting silage.

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Summary of plenary discussion

1 Assessment of silage fermentation quality

The author confirmed that the DLG scores for silages treated with high rates of formic acid had been penalised, sometimes by 5-6 points, because contents of acetic acid were below 20g kg DM^{-1}, which tends to reduce aerobic stability. There was also some penalty because final pH values were higher than when inocula were used. It is doubtful whether these factors did really reduce silage quality for this type of silage with its high indigenous stability upon exposure to air. For that reason ammonia-N had been considered to be a better single index of silage quality. There had been shown within LEGSIL to be a close relationship between ammonia-N and the extent *of protein breakdown calculated from assessments of ammonia and free amino acids.*

It was suggested that the content of WSC in the silage (high when high rates of formic acid or other chemical inhibitors of fermentation are used) should be considered in the silage evaluation scheme.

2 Larger-scale ensiling

Experience in LEGSIL with pilot-scale and farm-scale ensiling supported the results obtained on the laboratory scale. Silages with good fermentation quality had been made from all the legume species in situations in which DM targets were reached and additives used. This applied with 200 l barrels, big bales and with bunker silos.

At the larger scale it is important to take steps to reduce field losses. Good results had been obtained in Braunschweig and Aberystwyth with the use of a mower-conditioner with rubber rollers. This tended to even out the drying rates of leaf and stem and enable rapid achievement of target DM contents with minimum loss of leaf. It appeared to be very important to avoid re-wetting by rain of the conditioned crops.

3 Recommendations

The recommendation to harvest at flowering rather than an earlier stage of growth was challenged. The author indicated that this was a narrow conclusion relating only to ease of ensiling and picked out the statistically better preservation of silages made from material cut at flowering, reflecting mainly higher DM contents at harvest. He had pointed out that changes in digestibility with maturity could lead to a different conclusion in an overall analysis.

The recommendations made were not species specific, but the results had shown that lucerne and galega were similar in ensiling characteristics and offered a greater challenge than red clover and lotus. This was in line with differences between the species in WSC and buffering capacity. It is thus of even greater importance to achieve DM targets with the lucerne and galega.

R.J. Wilkins

Intake of legume silages by sheep

Christian Paul [1], Horst Auerbach[2] and Gerd-Joachim Schild[1]

Abstract

A feed evaluation study on prewilted silages prepared from lucerne (*Medicago sativa L.),* red clover (*Trifolium pratense L.),* goats rue (*Galega orientalis Lam.)*, birds foot trefoil (*Lotus corniculatus L.)* with perennial ryegrass (*Lolium perenne L.)* as a control involved the assessment of intake and organic matter digestibility by sheep. In order to permit general conclusions to be drawn each of these species was represented in the experiment by five to seven independent forages harvested in different physiological stages over two years.

Silage intake increased with increasing organic matter digestibility but the relationships differed between forage species. Silage intake was higher for lotus than for any other legume, i.e. red clover, lucerne and galega. Intake of grass silage was inferior to all of the legume silages. Calculated for a level of 65% digestibility of the organic matter, dairy cows are predicted to ingest silages prepared from a) lotus, b) red clover, lucerne and galega and c) grass at rates of 122, 116 and 100 g dry matter per kg metabolic weight respectively. Based on the laboratory assessment of these silage samples it was confirmed that the intake of silages was most closely associated with their content of total cell wall and enzymatically insoluble organic matter.

Introduction

Forage quality as defined by both forage intake and digestibility is of primary importance in the accurate economic evaluation of forage legumes and their consideration in diet formulation for ruminants. Lack of sufficient reliable *in vivo* data is a limiting factor and often results in the necessity to estimate these characteristics by indirect means. In particular, comparison of different forage species tends to be hampered by the interaction between effects of species and physiological growth stage. The picture gets even more complicated when additional factors introduced by the ensiling process have to be considered, so that precise comparative assessments of forage species and varieties independent of the effects of cutting and ensiling treatments can not be obtained from the available literature.

The work presented here has attempted to resolve these problems by a special feed evaluation experiment which combined the standard assessment of *in vivo* digestibility at restricted feeding levels with consecutive assessment of dry matter intake at *ad libitum* feeding levels. The decision to carry out this experiment with sheep permitted the evaluation of a relatively large number of samples at reasonable costs. It is an integral part of the series of feed evaluation studies in LEGSIL.

Materials and methods

Choice, cultivation, harvesting and ensiling of forages

In 1997 and 1998 forage plots of more than 0.5ha size each were established at the FAL experimental station of Braunschweig-Voelkenrode. The forage legume species chosen (cultivars in brackets) were lucerne *Medicago sativa L.* (Planet), red clover *Trifolium pratense L.* (Maro), goats rue *Galega orientalis Lam.* (Gale), birds foot trefoil *Lotus corniculatus L.* (Leo). Perennial ryegrass *Lolium perenne L.* was used as a standard. For each individual forage species several samples spanning a range of physiological growth stages were cut in the first or second harvest years of 1998 and 1999. Thus the following number of samples became available (numbers of samples in brackets): lucerne (n=5), red clover (n=5), galega (n=6), lotus (n=7), grass (n=6). The crops were cut at heights of 8 cm (legumes) or 5 cm (grass) by a rotary mower. For speeding up prewilting, the forages were conditioned by means of a crusher employing rubber rollers (Krone Company, Germany). When dry matter contents in the field had reached above 28 %, the pre-wilted forages were picked up, chopped to a theoretical chop length of 15mm and transported to the barn. During the subsequent mechanical mixing of 1.5 t quantities of fresh herbage by means of a feeding wagon, the chemical additive Kofasil liquid was admixed at a rate of 3 l per t herbage. The forage thus treated was filled into plastic bins of 200 l volume, compacted and closed air tight for ensiling.

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Feeding trials

After the end of the fermentation process, i.e. 5 - 6 months after filling, the silages were unloaded and single feeds from all silos holding one particular type of forage produced by mixing through a feeding wagon. The feeds were then subdivided so that each representative subsample formed a daily ration. These were then stored in a large freezer below - 18°C until required for feeding.

For the feeding trials a total of 24 sheep wethers of the Leine Valley breed of 4 – 5 years of age and 80 to 100kg liveweight were available. The trials were conducted so that for each animal and forage a digestibility trial (18 days) was followed by an intake trial (10 days). In the standard digestibility trial the forages were provided at maintenance level (13 ± 2 g silage-DM per kg liveweight per day). During the 10 days adaptation period the animals were kept tied and only confined in metabolism cages for faeces collection for the subsequent 8 days trial. In the following intake trial, the feeding level was raised to twice the maintenance level and provided *ad libitum*. In this case, the average dry matter intake was calculated from refused feed collection over 8 days, following an adaptation period of 2 days.

The experiment was designed as a Latin square with the forages being tested in each of 2 years in 2 randomly stocked pools of animals consisting of 10 animals each. In each year and pool 5 silages were given simultaneously to 5 animal groups (consisting of two animals each) over 5 consecutive feeding periods. In addition to the 20 forages tested according to this design, a further 9 forages were tested in the final year using a reduced number of animals. In this case the animals were randomly grouped to form pools of 6 animals each. In each pool 3 silages were given to 3 animal groups (consisting of two animals each) over 3 consecutive feeding periods.

Silage analysis

The silage samples were analysed according to the catalogue of routine analytical methods established at the former Institute of Grassland and Forage Research and maintained by the present Institute of Crop and Grassland Science (FAL) for a number of characteristics relating to nutrient content and nutrient availability as well as silage quality. These included:

- Dry matter content corrected for volatiles lost during drying (DMc)
- Crude protein and crude fibre according to the Weende fractionation scheme
- Cell wall content assessed according to van Soest as neutral detergent fibre (NDF)
- Digestibility of organic matter *in vitro* according to Tilley and Terry (OMD T and T)
- Content of enzyme insoluble organic matter (EULOS) assessed according to a modification of the procedure developed by de Boever
- pH – value assessed by electrode (pH)
- Fermentation products all separated by gas chromatography but expressed as lactic acid (LA); summed acetic acid and propionic acid (AA); summed butyric acid, valeric acid and caproic acid (BA)
- Ammonia nitrogen (assessed by electrode) as a proportion of total nitrogen at the time of ensiling (NH_3-N)
- Silage quality index (DLG index points) evaluated according to the current scheme approved by the DLG (Deutsche Landwirtschafts Gesellschaft / German Agricultural Society).

Results and discussion

Characterisation of silages

A minimum number of five different forage samples of different physiological age were produced to represent each particular legume species (and perennial ryegrass, constituting the control). Technological measures to ensure minimal ensiling losses and good preservation included prewilting of the forage in the field and use of a chemical additive to speed up acidification in the ensiling process. With the possible exception of one galega sample which exhibited a DM content of only 20.7%, the average DM contents of the silages achieved across species of between 31% to 35% indicated that prewilting had proceeded to a sufficient degree and given silages in the target DM range (Table 1).

Table 1:
Dry matter content (DMc) of silage samples

Species	N	Silage DMc %		
		Mean	Min	Max
Lucerne	5	33.7	25.7	43.6
Red clover	5	33.5	27.9	41.7
Galega	6	31.5	20.7	36.2
Lotus	7	31.8	28.1	35.3
Grass	6	34.8	29.2	37.2

As judged by the final pH of the silages, acidification in the different forages during ensiling had progressed to a variable extent. Lotus and red clover had reached low mean pH-values of pH 4.2 to 4.3 and as such similar values to grass. Lucerne, however, remained considerably above this level with a pH of 4.9 (Table 2) and galega was intermediate with a pH-value of 4.6.

Table 2:
Acidity and fermentation products of silage samples

Species	pH	LA *	AA *	BA *	NH_3-N**
Lucerne	4.9	7.6	5.3	.01	15.4
Red clover	4.3	12.1	4.0	.01	8.0
Galega	4.6	6.6	3.7	.02	10.2
Lotus	4.2	9.6	2.5	.01	7.2
Grass	4.2	9.3	2.6	.02	10.6

* % of DMc
** % of total N at ensiling

This pattern was associated with lucerne having a low content of lactic acid (LA) and the highest content of acetic acid (AA) compared to all other silages. Butyric acid (BA) did not cause any concern in either legume or grass silages. Protein decomposition as indicated by the proportion of the total forage nitrogen converted to ammonia nitrogen (NH_3-N) was highest for lucerne which appeared to be causally linked to the lower degree of acidification during the ensiling of this species. Despite higher absolute protein contents in red clover, lotus and galega (data not shown) as compared to grass, the silage prepared from these legume species exhibited lower or equal proportions of nitrogen converted to ammonia.

The silages prepared from lotus and red clover forage were excellent as assessed according to the current silage quality evaluation scheme of the German Agricultural Society (DLG index points). In approaching the top score of 100 they were on average equal or better than silages prepared from grass. Galega silage had a slightly reduced average quality index which was, however, due to one particular sample achieving only a score of 42. Obvious problems were notable for lucerne silage with an average score of 60 and even the best lucerne silage had a score of only 81 points.

Table 3:
Silage quality expressed according to DLG index points

Species	Mean	Min	Max
Lucerne	60	35	81
Red clover	93	88	98
Galega	85	42	97
Lotus	98	94	100
Grass	93	89	100

Feed evaluation of silages

The experimental procedure for measuring digestibility *in vivo* followed the standard procedure. However, the experiment design was intended to minimise the experimental error by more than customary replication and randomisation, i.e. feeding of each silage sample over several consecutive feeding periods to a minimum of 6 animals (9 feeds) and to 10 animals for most feeds (20 feeds).

As shown in Table 4 these measurements resulted in organic matter digestibility (OMD) values of more than 70% only for red clover (and for grass silage as a control). Lotus silage reached almost 66% and lucerne and galega silage both had mean OMD values of about 64%.

Table 4:
Organic matter digestibility *in vivo* (%) in silage samples

Species	Mean	Min	Max
Lucerne	64.1	57.5	74.3
Red clover	70.7	61.3	77.8
Galega	63.5	56.4	72.0
Lotus	65.9	58.4	70.2
Grass	71.7	62.8	81.1

Turning to the dry matter intake (DMI) of the silages under study it is notable that the grass silage samples, despite having the highest OMD values in the experiment, were clearly inferior to the silages prepared from legumes (Table 5). On average the daily DMI of grass silage by an individual sheep was only 1.7 kg whereas that of the silage from any of the legume species was above or equal to 2.0 kg. There appeared to be an ascending order in terms of legume silage DMI starting with galega, continuing with lucerne and red clover and with lotus reaching the highest level.

Table 5:
Dry matter intake of silage samples (kg dry matter per day per animal)

Species	Mean	Min	Max
Lucerne	2.1	1.7	2.4
Red clover	2.2	1.7	2.6
Galega	2.0	1.7	2.2
Lotus	2.3	2.2	2.5
Grass	1.7	1.2	2.0

In order to be able to assess whether these seemingly small differences between legume species in DMI are caused by factors relating to the characteristics of a particular species or to its particular physiological growth stage at the time of harvest, DMI was studied as a function of OMD by means of simple linear regression analysis. The result is shown in Figure 1. A picture emerges which shows that at any given OMD, sheep ingest higher quantities of lotus silage than of silage prepared from either red clover, lucerne or galega. And – as stated before – grass silage, irrespective of its particular OMD level, results in the lowest levels of ingestion by sheep. Employing the simplest possible regression model y = a + bx each of these relationships is characterised mathematically by the regression coefficients given in Table 6. The coefficients of determination (RSQ) for the two legume groups indicate that 71% of the observed variation in intake for lotus and 86% of the observed variation in intake for red clover, lucerne and galega are explained by OMD alone. With regard to grass less than 50% of the observed variation in intake is explained by OMD.

Table 6:
Results of simple linear regression of organic matter digestibility *in vivo* (x) on kg dry matter intake per day and animal (y) in three groups of silage samples

Silage group	Samples within group (n)	Regression coefficients a	b	RSQ
Lotus	7	0.04	-0.29	0.71
Red clover, Lucerne, Galega	16	0.03	-0.23	0.86
Grass	6	0.03	-0.57	0.48

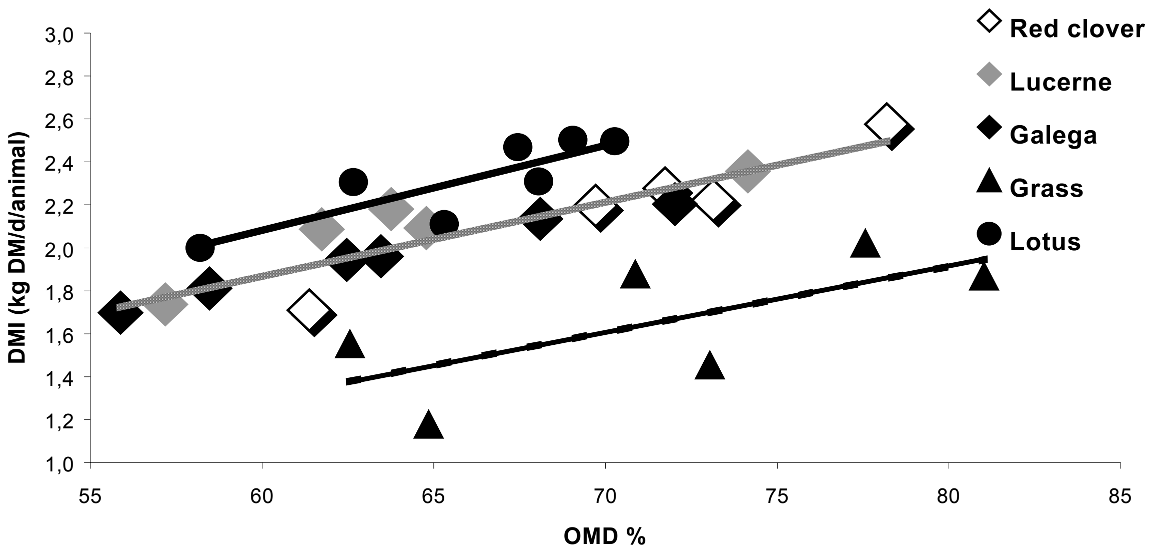

Figure 1:
Dry matter intake (DMI; kg DM per day per animal) as a function of organic matter digestibility *in vivo* (OMD) in three groups of silage samples prepared from a) lotus, b) red clover, lucerne and galega and c) grass

Utilizing these intake data an effort was undertaken to predict dairy cattle intake from them. Research at the Centre de Recherches Zootechniques et Vétérinaires at INRA Theix in France permits prediction of g dry matter ingested per kg of metabolic weight by dairy cows from data with sheep (Chenost and Demarquilly, 1982). The corresponding equation is assumed to be valid for the relationship between "standard" sheep (castrated Texel rams of 1.5 to 3 years of age at about 60 kg liveweight) and dairy cows of 600kg liveweight producing 17 kg of milk. Even if these conditions were not quite in agreement with those of the sheep trials conducted here, the resulting predicted dairy cattle intake values can certainly be assumed to provide a fair illustration of the relative intakes by dairy cows. Calculated for a level of 65% digestibility of the organic matter, dairy cows are thus predicted to ingest silages prepared from a) lotus, b) red clover, lucerne and galega and c) grass at rates of 122, 116 and 100 g DM per kg metabolic weight respectively.

Feed factors influencing organic matter digestibility and dry matter intake

In any feed evaluation experiment, aside from the obvious factors under study such as the effect of species and physiological growth stage, typical constraints such as methods of harvesting and conditioning, ensiling and feeding may also influence the results obtained. In the experiment reported here a large number of quality characteristics were assessed in the laboratory. From among them only those which have been noted in previous studies to be linked with either OMD or DMI or both have been selected for discussion here. Furthermore, as cell wall content and cell wall composition are known to differ between forage legumes and grass, an attempt has been made to establish the relationships between either OMD or DMI and the results of laboratory analyses separately for legumes only and for the total set of forages under study here, i.e. legumes and grasses.

Table 7:
Simple linear correlation coefficients (r) for the relationships between OMD (y) and diverse quality characteristics in silage samples

	Legumes +Grass	Legumes only
DMc	- .43	- .55
Crude protein	+.18	+.62
Crude fibre	- .83	- .93
NDF	- .59	- .92
OMD T and T	+.89	+.95
EULOS	- .93	- .98

According to the data shown in Table 7, OMD appears to be influenced only by the forage cell wall fraction, i.e. either as indicators of cell wall content or of cell wall digestibility. A much lower, in this case negative, influence is exerted by DM content. This finding would be surprising in grazed fresh forage but not so much in prewilted silage. Obviously, the final DM content after prewilting in this study still tended to be higher in silage from late cuts with lower OMD than in silage from early cuts with higher OMD. The content of crude protein is positively associated with OMD, but the relationship is less close in the mixed grass/legume sample set as compared to legumes only. The intensity of the negative association between OMD and either crude fibre or neutral detergent fibre content is similar in the legume samples. However, when grass is included in the sample set, the correlation coefficient for this relationship is much lower for NDF than for crude fibre. As to be expected, parameters such as *in vitro* digestibility correlate most strongly with OMD *in vivo* irrespective of whether the mixed grass/legume sample set or the legume only sample set is considered or whether the procedure is based on rumen fluid (Tilley and Terry) or the enzymatic EULOS assay (a modification of the cellulase procedure according to de Boever). The fact that the signs of the correlation coefficients are reversed between the two *in vitro* methods is due to the fact that the results in one case are expressed as digestibility percentage (Tilley and Terry) and in the other case as content of enzymatically insoluble organic matter (EULOS).

Table 8:
Simple linear correlation coefficients (r) for the relationships between DMI (y) and diverse quality characteristics in silage samples

	Legumes +Grass	Legumes only
DMc	-.49	-.53
Crude protein	+.79	+.51
Crude fibre	-.67	-.82
NDF	-.85	-.83
OMD T and T	-.05	+.68
EULOS	-.63	-.84

When these types of relationships are assessed for DMI a different picture emerges (Table 8). Surprisingly, a negative influence is exerted by DM content. When adding grass samples to the set of legumes, crude protein content appears to be the only parameter which reacts to this by a marked increase in the correlation coefficient. Strong negative influences with DMI exist in the sample set containing legumes only for parameters which are indicative of the content of (indigestible) cell wall, i.e. crude fibre, NDF and EULOS. When the mixed grass/legume sample set is considered instead, the magnitude of the correlation coefficients is clearly reduced except for NDF. Strikingly, OMD T and T does not exhibit any relationship with DMI in the mixed grass/legume sample set, whereas in the pure legume set such an association does exist.

Taken together the results obtained in this study confirm the view that silage intake is clearly most influenced by the content of total cell wall (NDF) and by the content of indigestible organic matter (EULOS) in the forage.

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Summary of plenary discussion

1 Effects of fermentation quality

The possible effects on intake of silage fermentation quality, as reflected by high ammonia-N concentrations in the lucerne silages and concentrations of acetic acid were queried. It was pointed out that the ammonia figures would include some N from the additive, which contained both hexamine and sodium nitrate. Although this would have increased ammonia for all silages, it would not give a differential effect between the crop species.

The author considered that differences in silage fermentation characteristics were not having a major impact on intake with this population of silages. Some 85% of the variation in intake could be accounted for by digestibility.

2 Intake of lotus

In relation to the reason for the high intake of lotus silages, the author referred to rumen degradability studies carried out on these silages. These had shown that DM degradability was more rapid with lotus than the other legume silages and this was probably responsible for the high intakes.

Possible effects of tannins on N digestion were queried. Tannins had not been determined in these experiments. G. Broderick indicated that tannin concentrations were generally lower in Lotus corniculatus than in other tannin-containing legumes and did not think that major effects were likely. N. Nilsdotter-Linde referred to work in Sweden. She had shown large differences between varieties in tannins, but that values for Leo, the variety used in LEGSIL, was generally low. There was, however a negative relationship between tannin content and rate of protein degradation in the rumen, despite tannin concentrations being generally low.

Reporter: R.J. Wilkins

Effects of legume silages on feed intake, milk production and nitrogen efficiency

Jan Bertilsson[1], Richard J. Dewhurst[2] and Mikko Tuori[3]

Abstract

Dairy cow experiments with a similar experimental design were carried out in Finland, Sweden and the UK over two years. The experiments involved both rumen fistulated and intact cows. Silages were prepared from pure stands of either grass or legumes (red clover, white clover, galega, lucerne) and fed to dairy cows. The cows had a fixed amount of concentrate and silage ad libitum either fed pure or in grass-legume mixtures (50:50 on DM basis). The main measurements in the trials were feed intake, milk production (including milk composition and milk quality) and nitrogen partitioning. On average feed intake was higher when legumes were fed. Milk production was higher for cows fed clover (especially white clover) than for grass. Organoleptic properties of milk (taste) were less favourable when legumes (especially red clover) were included in the rations. Nitrogen efficiency was inversely related to nitrogen intake. This meant that more nitrogen was partitioned to faeces and especially urine when legumes were fed. Grass-clover mixtures were intermediate between the pure diets in this respect.

Abbreviations

The following abbreviations are used: FIN=Finland; SE=Sweden; UK=United Kingdom; G=Grass; GRC=Grass-Red clover mix; RC=Red clover; GWC=Grass-White clover mix; WC=White clover; L= Lucerne; Ggal= Grass-Galega mix; Gal=Galega; Mixtures of crops were on a 50:50 DM-basis. G=perennial ryegrass in SE, meadow fescue in FIN and a mixture of perennial ryegrass, hybrid ryegrass and Italian ryegrass in UK.

Introduction

It is well recognised that there are major differences between grasses and legumes that relate to differences in physical and chemical composition. In particular, levels of feed intake by legumes are often higher than those of grasses when compared at similar levels of digestibility (Thomson, 1984; Thomas *et al.*, 1985; Wu *et al.*, 2001). This may give the opportunity for either increased level of production or for sustaining a particular level of production with reduced input of supplementary feeds. In organic farming the use of legumes is of course fundamental, but otherwise the implementation into farming practices of legume silage feeding has been limited. Legumes have a reputation to be difficult to ensile, but developments in ensiling technique (e.g. bales) and new additives have overcome these problems. Problems with nitrates in drinking water and stricter environmental regulations within the EU have increased the interest in replacing mineral fertilisers with more natural and sustainable systems. In recent years new varieties of legumes have also been developed. There are few, if any, reports on the ranking between new species such as galega and established legumes. It is especially important to have such figures today with the rapid development in milk production and nutrient requirements for modern high producing dairy cows and increased interest in feeding protein-rich legumes to reduce reliance on supplementary concentrates.

This paper provides an overview of results for feed intake, milk production and nitrogen efficiency from a series of linked experiments in Finland, Sweden and the UK in which legume silages were compared with grass silages. More detailed results from the different trials have been presented at conferences (e.g. Dewhurst *et al.*, 2000; Tuori *et al.*, 2000) and will also be presented in the near future. Studies of digestion and metabolism with the same silages are reported by Dewhurst *et al.* (2002).

Material and methods

Feeds and feeding

Pure swards of white clover (*Trifolium repens*), red clover (*Trifolium pratense*), galega (*Galega orientalis*), lucerne (*Medicago sativa*) ryegrass (*Lolium perenne* or *L. perenne/L. x boucheanum/L. multiflorum*) and meadow fescue (*Festuca pratensis*) were especially established for these experiments. Grass fields received moderate levels of N fertiliser (<200 kg N/year), whilst legumes received only P and K.

The crops were cut with a mower conditioner and wilted for up to 24 hours (48 hours in UK), aiming at dry matter (DM) contents in the silage of around 35%. The material was mainly ensiled in bales, but bunker

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silos or stacks were also used in Finland and Sweden (only WC year 1). Silage additives were used for all silages. In UK Ecosyl, a LAB-type additive was used. In Finland the additive was formic acid based (AIV 10 plus) and in Sweden Kofasil Ultra™ .

Silages were either fed in pure form (grass or legume) or as a mix of grass and legume. The proportion of each silage in the mixes was according to DM contents in the silages. Silage was fed three times per day in Finland and two times per day in Sweden. In the UK fresh silage was offered once daily and replenished if necessary. Refusals were weighed back once a day in Sweden and Finland. In the UK the roughage intake control feeders gave daily intakes and refusals were removed without weighing. Additionally, the cows were fed a fixed amount of concentrate and commercial mineral mixtures. The standard concentrate had the following average values for crude protein (CP), neutral detergent fibre (NDF), starch (g) and calculated MJ ME content (all per kg DM):

SE : 207 ; 309 ; 155 ; 12.7
UK : 220 ; 247 ; 229 ; 13.2
FIN : Year 1 : 180 ; 273 ; 265; 12.0
FIN : Year 2 (Stand/High) :
157/180 ; 275/273 ; 332/299 12.4/12.3

During the feeding period samples from the silages were taken every weekday (5 days per week) during the 3 periods of the experiment and pooled into samples for analyses. Feed samples were dried at 60ºC in a forced-air oven overnight. In Sweden DM in silage was corrected for loss of volatiles according to Rammer (1996) and in Finland according to Huida *et al.* (1986). Dried materials were ashed at 550º for 5 hours to determine ash and organic matter (OM) content of feeds. Feeds were analysed for CP using a fully-automated Kjeldahl procedure. Silages were analysed for fibre (NDF, ADF) according to Goering and van Soest (1970) and concentrates according to van Soest *et al.* (1991). Sugars and starch were analysed enzymatically in Sweden (Larsson and Bengtsson, 1983). In UK water-soluble carbohydrates were measured using an automated anthrone method (Method 9a; Technicon Industrial Systems, Tarrytown, NY). Starch was solubilized by boiling in water (1 h) and incubated with buffered amyloglucosidase (Sigma-Aldrich Co. Ltd., Dorset, UK; Catalogue No. A7255) to liberate sugars which were determined by the automated anthrone procedure).

In Sweden values for pH, ammonia nitrogen and volatile fatty acids (VFA) were determined on silage juice. Lactic acid was determined by HPLC. In UK volatile components of silage were determined in an aqueous extract (20 g silage in 100 ml water). Test kits were used with a discrete analyzer (FP-901M Chemistry Analyzer, Labsystems Oy, Helsinki, Finland) for lactic acid (Test kit No.139 084 using L- and D-lactate dehydrogenase sequentially; Boehringer Mannheim Ltd., East Sussex, UK). In Finland volatile components of silage were determined in aqueous extract (32 g silage in 268 ml water). Sugars were measured colorimetrically from the water extract by the method of Somogyi (1945) as modified by Salo (1965). VFA's were measured by gas cromatography, ammonia-N (McCullough, 1967) and lactic acid (Barker and Summerson, 1941) colorimetrically. Starch from the concentrates was measured enzymatically (Salo, 1965).

Animals and housing

In the UK the cows were of the Holstein Friesian breed, in Finland of the Ayrshire breed, while the Swedish cows were of the Swedish Red and White Breed (SRB). Housing of non-fistulated cows was in tie stalls and with individual access to feeds (FIN + SE) or in a free-stall barn with individual access to forages through roughage intake control feeders (UK). Detailed measurements (fistulated cows and balance studies) were all performed with cows in individual tie stalls. The cows were weighed on two consecutive days before start of the experimental period and at the end of each of the experimental periods within experiment (FIN + SE) or weekly (UK).

Sampling and analyses of milk

The cows were milked twice per day. Milk yield was recorded on consecutive days during the last week of each period. Milk composition (fat, protein, lactose) was determined by automated infrared analysis. Samples for organoleptic testing of milk in Finland and Sweden were taken at a morning milking and sent to a commercial dairy lab for evaluation.

Treatments, experimental design and statistical analyses

The following treatments were evaluated:

UK year 1:
G; GRC; RC; GWC; WC; L; all fed with a fixed amount concentrate (8 kg/d.)
UK year 2:
G; GRC; RC; WC; fed with 4 or 8 kg concentrate/d.
FIN year 1:
G; GRC; RC; Ggal; Gal; all fed with mean of 10 kg/d. of a standard concentrate
(fixed amount of 8-12 kg/d depending on block)
FIN year 2:

G; RC; Gal; Fed with 2 protein levels in the fixed amount concentrate (10 kg/d.)
SE year 1:
G; GRC; RC; GWC; WC; all fed with 8 kg/d. of concentrate
SE year 2:
G; GRC; RC; RC2; WC; RC from 2 cuts. All fed with 8 kg/d. of concentrate

The experiments were carried out as incomplete change-over trials with 15 cows, 3 blocks of 5 cows each, 5 treatments and 3 periods. The best model was found to be a modified version of design no. 8 by Patterson and Lucas (1962). Each block was balanced within itself. One of the blocks was with fistulated cows. UK experiments had more treatments (6 in year 1 and 7 in year 2), but adopted the same basic design (with 18 or 21 cows).

Statistical analyses were performed on treatment means from all experiments. Only treatments where the standard concentrate allotment was fed (8 kg for SE and UK, 10 kg for FIN) were included in this analysis. This was performed using the MIXED procedure in SAS with year*country*silage was as the random term (Littell *et al.*, 1996). Statistical differences are denoted by LSD-values (LSD= Least Significant Difference, $p<0.05$).

The statistical analyses of the organoleptic test in Sweden were performed with conventional Chi-square analysis as applied within the SAS-package.

Results

Silages

As shown in Table 1 the average DM contents of silages (except galega) were fairly similar and near the target. The range was, however, large. Legume silages had higher ash and crude protein content compared to grass. White clover was the extreme here with up to 28% CP content. Fibre contents (NDF, ADF) were lowest for white and red clover, while lucerne and galega came closer to the grasses. Contents of WSC, lactic acid, ammonia N and pH indicated that the silages in general were of good hygienic quality and had normal fermentation patterns.

Feed consumption and milk production

The results from the UK experiments were consistent between years. At the standard concentrate allotment, the silage intake was lowest for grass in both years. Intakes of pure red clover silage and pure lucerne were markedly higher than for WC in year 1 while intakes of red and white clover were similar in year 2. Milk production followed the same pattern as feed intake (WC>RC>G). When compared at the same concentrate level, the milk composition was similar for the different treatments. Increasing concentrate rate resulted in increases in milk production and reductions in silage intake, but there was no interaction between silage type and concentrate feeding level.

In the Finnish experiments the order between grass and red clover for silage intake was the same as for the UK experiments. The differences were, however, of a smaller magnitude. One reason for this might be the higher concentrate feeding than in the other countries. Galega had the highest intake in year 1 while it gave a much lower intake in year 2. This can be explained by the significantly lower DM content and lower cellulase digestibility in comparison with grass and red clover silage in the second year. Milk production followed to a large extent the intakes. The low intake of galega and consequent low milk production was particularly marked in year 2. In year 1 red clover led to increased milk yield, compared with grass, while the differences were small in year 2. The influence of protein level in the concentrates was not significant for either feed intake or milk production.

The Swedish experiments showed a marked difference between years. In year 1 grass-fed cows consumed markedly less silage then those fed red clover pure or mixtures of grass and clover (red and white). Pure white clover had the lowest intake. In year 2 the cows fed pure grass or pure white clover had much higher feed intake relative to the other silages. In year 1 the grass fed cows gave significantly lower milk production than all other treatments. In year 2 the most pronounced difference was the high milk production by the white clover-fed cows. The fat content in milk was however significantly lower than any of the other treatments

From the over-all analysis in Table 2 it can be observed that feed intake for the legumes, with the exception of galega, was higher than for grass. The ranking for feed intake was as follows:
Lucerne>Red clover>White clover>Grass>Galega

The legume-grass mixtures were intermediate between the pure crops.

Milk production was significantly higher for white clover silage than for grass. Red clover also showed high milk production figures. The ranking of silages for milk production was as follows:
White clover>Red clover>Lucerne>Galega>Grass

Milk protein production followed the same pattern as milk production, while milk fat production did not differ markedly between silages.

Table 1:
Chemical composition of the silages as fed to dairy cows. Means and range (within brackets). Calculations based on treatment means within country and year

Chemical analysis	Grass (n=6)	Red clover (n=7)	White clover (n=4)	Galega (n=2)	Lucerne (n=1)
Dry matter, g/kg	330 (191-474)	317 (208-423)	287 (202-408)	231 (191-271)	358 (358-358)
Per kg DM					
Ash, g	88 (79-113)	103 (93-119)	106 (103-110)	92 (86-98)	80 (80-80)
Crude protein, g	147 (122-164)	191 (167-205)	252 (229-278)	216 (201-230)	244 (244-244)
NDF, g (Neutral Detergent Fibre)	530 (437-575)	381 (329-439)	287 (248-323)	496 (479-513)	458 (458-458)
ADF, g (Acid Detergent Fibre)	319 (263-344)	291 (209-348)	280 (228-326)	317 (304-330)	369 (369-369)
WSC, g (Water Soluble Carbohydrates)	81 (45-118)	50 (8-93)	29 (1-55)	42 (19-64)	10 (10-10)
Lactic acid, g	42 (16-66)	61 (24-79)	79 (53-99)	26 (14-38)	60 (60-60)
pH	4.6 (3.9-5.4)	4.6 (3.9-5.2)	4.2 (3.9-4.6)	4.3 (4.2-4.4)	4.7 (4.7-4.7)
NH_3-N, % tot N	6.2 (4.0-8.7)	6.6 (3.7-11.3)	7.2 (5.2-9.7)	8.0 (6.5-9.5)	13.4 (13.4-13.4)

Table 2:
Overall means for animal performance based on treatment means from the different experiments and years. Only treatments with the standard allotment of concentrate are included

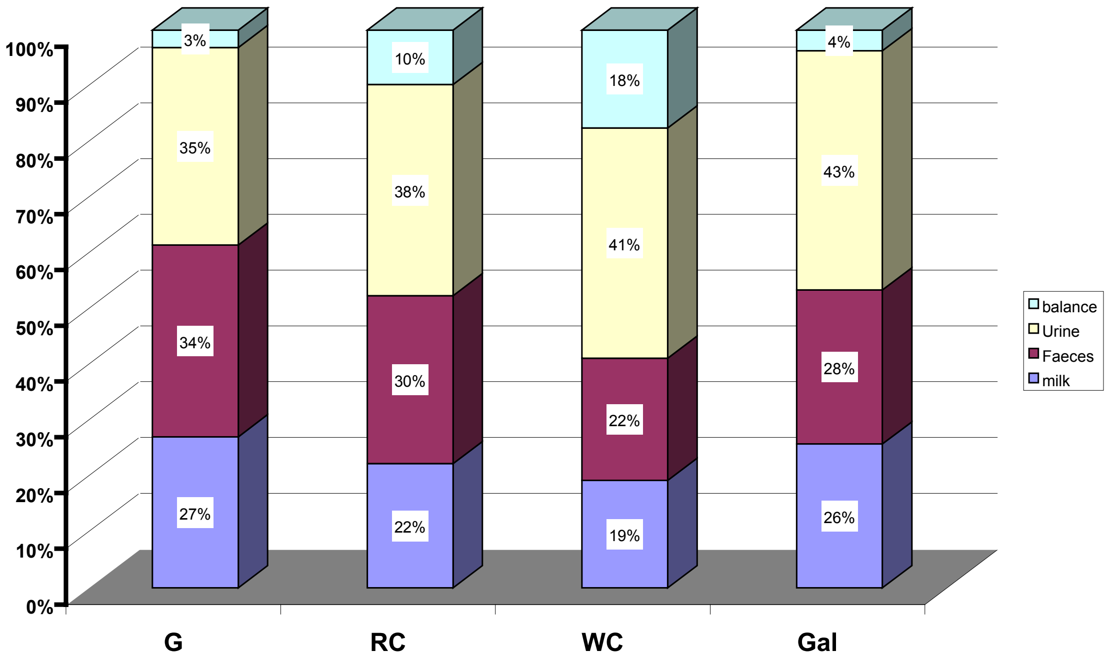
	G (n=7)	GRC (n=5)	RC (n=8)	GWC (n=2)	WC (n=4)	Ggal (n=1)	Gal (n=2)	L (n=1)	sem[1]	LSD[2]
Feed intake										
Silage, kg DM	12.6	13.4	13.6	13.6	13.2	13.2	12.5	15.0	1.0	3.2
Total, kg DM	20.3	21.9	21.2	21.3	20.8	20.9	20.1	22.6	1.0	3.4
Silage, rel. G	100	106	108	109	105	106	99	118	-	-
% LW*										
silage	2.1	2.2	2.3	2.3	2.2	2.2	2.1	2.3	0.2	0.5
total	3.4	3.5	3.5	3.6	3.5	3.5	3.4	3.7	0.2	0.5
Milk prod.										
Milk, kg	28.1	29.8	29.7	30.2	32.1	28.7	28.4	29.5	1.2	2.8
Milk, rel. G	100	105	105	107	114	102	100	104	-	-
Fat, kg	1.26	1.28	1.27	1.33	1.29	1.28	1.23	1.23	0.10	0.22
Protein, kg	0.90	0.95	0.93	0.96	1.02	0.92	0.91	0.95	0.04	0.12
Fat, g/kg	44.7	43.3	43.3	44.5	40.5	44.7	43.4	41.2	1.9	4.5
Protein, g/kg	32.1	31.8	31.3	31.9	31.9	31.9	31.9	32.6	0.6	1.1
Lactose, g/kg	46.8	47.0	47.0	47.1	47.0	46.7	46.6	46.5	0.3	0.8
N efficiency (milk N/feed N)	0.254	0.237	0.209	0.229	0.205	0.204	0.187	0.181	0.02	0.05

[1]standard error of mean; [2]Least Significant Difference, $p<0.05$; *per 100 kg live weight

Table 3
Organoleptic testing of milk in Sweden (both years). Deviation from "good milk quality" (n=90)

Silage	No. of milk samples		% of milk samples		Probability
	No*	Yes**	No	Yes	(p<)
Comparison between species[1]					
Ryegrass	17	3	85	15	
Red clover	26	19	58	42	
White clover	16	9	64	36	0.10
Comparison grass vs. Clover[2]					
Grass	17	3	85	15	
Clover	42	28	60	40	0.04

*No = no deviation from good taste; **Yes = deviation from good taste
[1]clover (red and white) include treatment groups with 50 % clover
[2]grass is only pure grass silage while clover (red and white) includes treatment groups with 50% clover



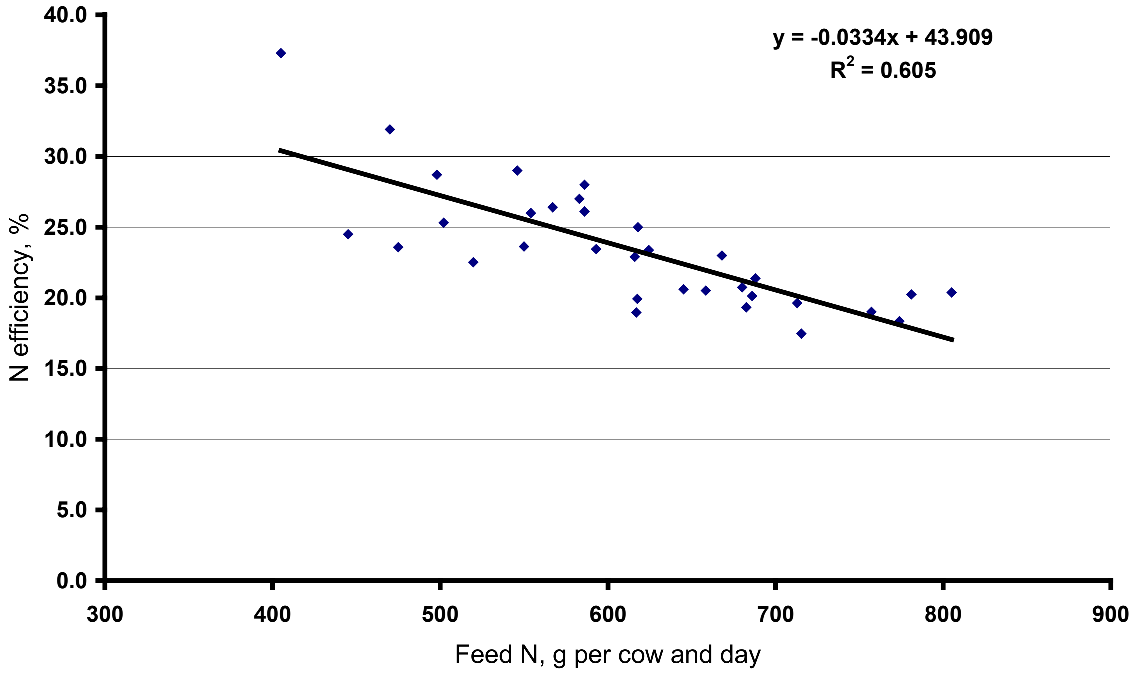


Figure 2**:**
Correlation between feed nitrogen efficiency and intake of feed nitrogen. Each dot represents a treatment mean from one country and one year

Nitrogen efficiency

The nitrogen efficiencies (nitrogen in milk as percentage of nitrogen in feeds) were in general low, with 17.8 % as the lowest value (WC in SE, year 1) and 37.3% as the highest value (G in FIN, year 2). In general the N efficiencies for grass were highest and the pure legume silages showed lower efficiencies with higher N proportions partitioned to urine and faces. The mixes between grass and legume gave intermediate values between the two (Table 2, Figures 1, 2).

Milk quality

There were several indications that feeding of legumes and especially red clover had a negative effect on the organoleptic quality of milk. As shown in Table 3 the effect was most marked for red clover. This might be associated with oxidation of milk. Al-Mabruk *et al.* (2000) showed that more antioxidative properties (tocopherol) were used and also more oxidation products (malonic dialdehyde) were formed during the storage of milk from cows fed the red clover silage.

Conclusions

The following overall conclusions can be drawn:

- Higher intake for clover and clover-grass mixtures compared to pure grass silage
- Higher milk production for clover (especially white clover) in comparison with grass
- Lower milk fat content for the white clover ration
- Reduced efficiency of conversion of feed N to milk N for legume silages (associated with higher total intake of N)
- Detection of different organoleptic characteristics of milk produced from cows fed legume rather than grass silages.
- The experiments did not show any major interactions between type of silage and concentrate feeding

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Summary of plenary discussion

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Effects of legume silages on diet digestibility and rumen function

Richard J. Dewhurst[1], Roger J. Merry[1], Jan Bertilsson[2] and Mikko Tuori[3]

Abstract

Diet digestibility and rumen function were recorded alongside a series of six experiments (two each in Finland, Sweden and the UK) conducted to evaluate feed intake and milk production from legume silages in comparison with grass silage. There were marked differences between countries in the relative ranking of the legume silages for digestibility, though these did not explain differences in production responses. There was little difference between legume silages and grass silage in their effects on rumen pH, volatile fatty acids or apparent rumen digestibilities. There was no evidence of enhanced microbial efficiency or yields, other than would be expected for higher intakes, with legume silages. Increases in Metabolisable Protein supply resulted from the increased supply of undegraded N from legume silages. Increased feed intake is a major driver behind the effects of legume silages on milk production and effects can be explained by the rumen degradation characteristics of the silages. The very high intakes of white clover silage are explained by both high rates of fermentation and passage and were achieved despite the lowest rumen fill. The high intakes of lucerne silage were probably a result of more rapid particle breakdown with this less digestible silage, resulting in high intakes but relatively low milk yields. The low intakes of grass silage, particularly in the UK, reflect low rates of fermentation and passage from the rumen.

Abbreviations

FIN = Finland; SE = Sweden; UK = United Kingdom; G = Grass; GRC = Grass-Red clover mix; RC = Red clover; GWC = Grass-White clover mix; WC = White clover; L = Lucerne; Ggal = Grass-Galega mix; Gal = Galega. Mixtures of crops were on a 50:50 DM basis. G = perennial ryegrass in SE, meadow fescue in FIN, and a mixture of perennial ryegrass, hybrid ryegrass and Italian ryegrass in the UK.

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Introduction

The previous paper (Bertilsson *et al.*, 2002) provides much of the background to this paper, including a detailed description of the forage treatments that were evaluated. A series of six feeding experiments were conducted over two years and in three countries (FIN, SE, UK) to compare a range of legume silages with grass silage. The main observations from these experiments were that legume silages had higher intake characteristics than grass silages, whilst N-use efficiency was reduced with the higher N intakes associated with legume silages.

A series of measurements of rumen function was made using fistulated cows that were offered the same diets in order to investigate the mechanisms of effects on intake and N-use efficiency. Measurements included estimates of apparent rumen digestion and microbial protein synthesis in a duodenal flow experiment conducted in the UK as well as nylon bag evaluations of the degradability of all forages. Most of the experiments included measurements of total-tract digestibility and a range of rumen parameters including pH and concentrations of volatile fatty acids. Rumen emptying studies were also conducted in all countries in order to investigate the effects of legume silages on rumen fill and particle breakdown in the rumen.

Diet digestibility

Diet (DM) digestibilities were measured using total collections of faeces (UK year 1) or an internal marker method (acid insoluble ash; FIN; SE). The *in vivo* results in Table 1 are taken from treatments where the legume silages were offered with the standard level of concentrates. *In vitro* D-values for the legume silages alone are reported for the second UK experiment.

There were marked differences between countries in the relative ranking of the legume silages for diet digestibility, which may relate to varieties, agronomy or latitude. Red clover silage in FI was more digestible than meadow fescue silage, whilst there were large differences in the digestibility of galega silages, reflecting substantial differences in harvesting dates, between the years.

Table 1:
Total-tract diet digestibilities (g g^{-1} DM)

	G	GRC	RC	GWC	WC	Ggal	Gal	L	s.e.d.	Sig.
UK Year 1	0.714	0.674	0.639	0.707	0.673			0.636	0.0096	***
FI Year 1	0.684	0.685	0.718			0.699	0.719			
SE Year 1	0.654	0.684	0.650	0.733	0.772					
UK Year 2*	0.650	0.636	0.599		0.705				0.0116	***
FI Year 2	0.669		0.721				0.629			
SE Year 2	0.700	0.721	0701		0.756					

[*] *in vitro* D-value of the legume silages

Red clover and perennial ryegrass silages were of similar digestibility in the studies in SE, whilst WC was more digestible. In the UK work, WC was, on average, of similar digestibility to the ryegrass silage, whilst lucerne silage and red clover silage were of lower digestibility.

These differences do not explain differences in production responses between experiments because the experiments (UK) with the largest and most consistent production responses to feeding legume silages (Bertilsson *et al*., 2002) also recorded the lowest digestibilities for legume silages. The UK results support earlier work, with higher intakes and higher milk production for the legumes and silage mixtures, despite lower digestibilities (Thomas *et al*., 1985) and suggest that effects on voluntary intake are dominant in explaining production responses to legume silages.

Rumen digestion

Nylon bag studies

The results of nylon bag studies conducted in the UK using year 2 legume silages are presented to illustrate effects (results with year 1 forages were similar; see Figure 1 below). Three non-lactating rumen fistulated Holstein-Friesian cows were used and were given a basal diet of 6 kg/day of grass hay and 2 kg/day of dry cow concentrates, in equal meals at 0900 and 1700 hrs. The silages were oven-dried at 45°C and chopped to pass through a 4mm aperture. Bulked samples were prepared by taking equal quantities of dried material from each of the experimental periods. Approximately 5g samples were weighed into nylon bags, with duplicate bags incubated in each cow (6 samples per time period per cow) for 2, 4, 8, 16, 24 and 48 hours. Duplicate bags were also used for the zero-time values (which were just washed using the washing machine cycle described below).

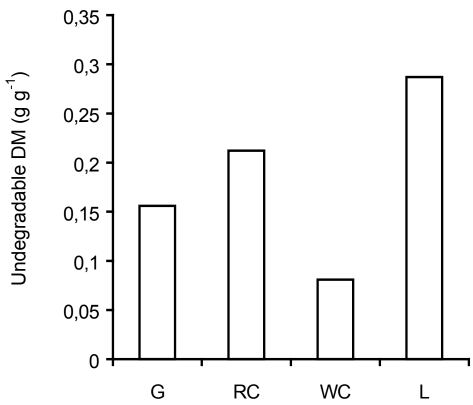

Figure 1:
Unfermentable DM fractions (g g^{-1} DM) of UK legume silages in year 1

Bags were removed from cows and immediately immersed in cold water. Bags were then washed using the cold rinse cycle of a washing machine, dried at 60°C for 16 hours and weighed. Samples of feeds and bag residues were analysed for N content, though N degradabilities are not reported here. Dry matter degradabilities were calculated for each bag and data were used to fit degradation curves for each feed. The model of Dhanoa (1988), which fits a lag and parameters a, b and c simultaneously, was adopted. Parameter estimates are shown in Table 2.

There were consistent patterns in the fitted parameters, with larger ‘a’ fractions in white clover silage and larger ‘b’ fractions in grass silage. The rate of fermentation of the b fraction (c) was highest with white clover silages and lowest with grass silages. UK material was generally less fermentable than Swedish material, perhaps reflecting the fact that it was a mixture of all cuts made during 1999. The limitation of intake and milk production with the UK grass silage seems to relate to the slow rate of fermentation of dry matter in the rumen. This was despite the relatively high total-tract digestibility of this silage. Other workers have suggested that physical limitations and not the inherent nutritional qualities of grass silages limit performance (Waghorn *et al*., 1989; Hoffman *et al*., 1998).

Year 1 forages were evaluated in a similar study in Sweden and results for the completely unfermentable DM fraction of UK legume silages are shown in Figure 1.

Duodenal flow study

Six of the animals used in the first UK study had both rumen and duodenal cannulae and were used to estimate apparent rumen digestibilities of nutrients. Estimated flows of DM to the rumen are shown in Table 3 along with estimates of the rate of passage of undegraded DM from the rumen, using estimates of rumen DM pool size from rumen emptying studies (see Table 8).

The higher passage rates for legume silages, particularly WC, are in agreement with the other results. The apparent rumen digestibility of DM for the WC diet was not higher than for other forages, despite the higher ‘a’ fraction and fermentation rate (c) (Table 3), suggesting a higher passage rate.

Rumen parameters

Mean values for rumen pH, total VFA and the molar % of VFA as acetic acid are presented in Tables 4, 5 and 6 respectively.

Table 2:
DM degradation parameters (year 2 forages)

	Lag (h)	a (g g^{-1})	b (g g^{-1})	c (h^{-1})
G (FI)	3.1	0.323	0.487	0.055
Ga (FI)	0.9	0.253	0.524	0.054
RC (FI)	2.7	0.428	0.423	0.072
G (SE)	3.6	0.415	0.451	0.058
RC (SE)	3.3	0.465	0.354	0.090
GRC (SE)	3.7	0.463	0.377	0.079
WC (SE)	3.3	0.510	0.398	0.126
G (UK)	4.5	0.404	0.525	0.033
GRC (UK)	4.6	0.410	0.412	0.047
RC (UK)	3.3	0.392	0.439	0.065
WC (UK)	4.6	0.483	0.356	0.106

Table 3:
Flow of DM to the duodenum

	G	GRC	RC	GWC	WC	L	s.e.d.	Sig.
DM flow to the duodenum (kg d^{-1})	8.9	9.4	10.5	10.5	12.8	10.7	0.97	***
Rate of passage of DM from the rumen (h^{-1})	0.039	0.039	0.040	0.040	0.058	0.051	0.0061	*

Table 4:
Rumen pH

	G	GRC	RC	GWC	WC	Ggal	Gal	L	s.e.d.	Sig.
UK Year 1	6.55	6.58	6.36	6.46	6.32			6.43	0.157	NS
FI Year 1	6.41	6.39	6.38			6.48	6.40			
SE Year 1	6.27	6.16	6.23	6.25	6.26					
FI Year 2	6.06		6.00				6.30			
SE Year 2	5.89		5.97		5.72					

Table 5:
Rumen total VFA concentration (mMol L^{-1})

	G	GRC	RC	GWC	WC	Ggal	Gal	L	s.e.d.	Sig.
UK Year 1	71	80	69	60	92			79	10.8	**
FI Year 1	122	128	124			113	119			
SE Year 1	121	139	140	133	137					
FI Year 2	137		147				128			
SE Year 2	146		153		170					

Table 6
Rumen acetate molar %

	G	GRC	RC	GWC	WC	Ggal	Gal	L	s.e.d.	Sig.
UK Year 1	61.9	63.5	63.5	62.9	61.9			63.7	0.70	***
FI Year 1	66.0	65.8	65.4			66.3	65.5			
SE Year 1	65.6	65.8	65.6	65.7	64.8					
FI Year 2	66.8		66.0		67.7					
SE Year 2	63.6		62.4		60.4					

There were only small effects of legume silages on rumen parameters measured within each of the experiments. More interesting are the differences between experiments: rumen pH was high and VFA concentrations were low with UK year 1 forages in comparison with the low rumen pHs and high VFA concentrations recorded with SE forages in year 2, which had much higher rates of fermentation (Table 3).

Microbial protein synthesis

Samples of duodenal digesta from the six fistulated cows in the first UK experiment were used to assess nitrogen flow to the duodenum, microbial N synthesis and microbial energetic efficiency. There were highly significant increases in the flow of non-ammonia nitrogen to the duodenum when legume silages were fed (particularly white clover silage; Table 7). The estimates of microbial synthesis appear low (Table 7) and we are currently looking again at some of the analyses involved. There was no evidence of increased microbial efficiency when feeding legume silages, though it may be that efficiency is higher in WC when expressed on a basis that takes account of the high level of fermentation acids in this silage.

Increases in Metabolisable Protein (duodenal non-ammonia N) supply result from the increased supply of undegraded N from legume silages. Further studies are required in order to investigate the use of low-protein concentrates to optimise rumen function and reduce the problem of low N-use efficiency encountered with our diets (Bertilsson *et al.*, 2002).

Table 7:
Microbial protein synthesis

	G	GRC	RC	GWC	WC	L	s.e.d.	Sig.
Duodenal non-ammonia N (g d^{-1})	317	370	434	424	571	389	49.4	***
Microbial N (g d^{-1})	190	165	182	181	257	171	38.8	*
Microbial N (g kg^{-1} ADOMR)	22.8	19.1	23.0	17.3	24.1	18.6	4.99	P<0.1

Table 8:
Rumen contents (kg DM) of animals offered different diets

	G	GRC	RC	GWC	WC	Ggal	Gal	L	s.e.d.	Sig.
UK Year 1	11.0	10.6	11.2	10.8	8.5			9.3	0.68	***
FI Year 1	10.9	10.7	10.8			10.3	10.5			
SE Year 1	11.9	13.6	11.9	11.7	9.8					
FI Year 2	12.3		12.9				11.8			
SE Year 2	13.8		12.2		11.9					

Table 9:
Particle size distribution of rumen contents (UK year 1)

	G	GRC	RC	GWC	WC	L	s.e.d.	Sig.
Proportion of rumen DM >2mm	0.43	0.37	0.40	0.42	0.44	0.33	0.024	***
Proportion of rumen DM 0.1-2mm	0.23	0.24	0.24	0.19	0.17	0.30	0.015	***

Breakdown of particles in the rumen

It is already clear that the usual relationships between diet digestibility and intake of grass silages do not apply with legume silages, since the least digestible forage (L) had very high intakes. Measurements of rumen fill were made to investigate further the mechanisms involved in the effects on feed intake. A rumen emptying technique was adopted and values are given in Table 8. Interestingly the rumen contents tended to be lowest for cows offered the diets that led to highest intakes: L and, particularly, WC. It seems that the high rate of fermentation of WC means that intake is not constrained by fill so that very high intakes can be attained without cows becoming full. Other studies have shown the very high intake characteristics and milk production from white clover, even as sole feed (Castle *et al*., 1984; Auldist *et al*., 1999), which probably reflects its low rumen fill effect. Mixing WC with grass silage led to reduced intakes and milk yields in our studies. The rumen emptying studies suggest that the beneficial effects of WC on passage rates may be neutralised by grass silage. It is possible that particles of other forages become trapped in the recalcitrant mat formed from grass silage. Auldist *et al*. (1999), in contrast, found that mixing 30% maize silage with WC did not reduce intakes or milk production, perhaps because maize silage is also a low-fill forage. The combination of WC and maize silage is also attractive in optimising the N content of diets in high-forage systems.

The situation with L is more surprising, given the low total-tract digestibility (Table 1) and the large unfermentable fraction (1-a-b; Figure 1) in this feed. This situation was investigated further in the UK experiment by wet sieving of rumen contents in order to measure the particle size distribution. Results expressed as proportions (g g^{-1}) of total DM are summarised in Table 9.

From these results it is clear that the high intake potential of L is made possible by a more-rapid rate of particle breakdown in the rumen (as proposed by Waghorn *et al*., 1989), so that material can leave the rumen even though it is not fermented. This high rate of passage will contribute to an even lower effective degradability of L. Cows had an exceptionally high DM intake of L and correspondingly disappointing milk yields. Of course, the low proportion of small particles with WC may be a consequence of the higher passage rate (Table 3) and future studies should investigate the kinetics of both physical and chemical breakdown in the rumen given their important effects on feed intake.

Conclusions

There was little difference between legume silages and grass silage in their effects on rumen parameters (pH and VFA) and apparent rumen digestibilities. There was no evidence of enhanced microbial efficiency or higher microbial yields, other than would be expected to arise from the higher intakes with legume silages. Increases in Metabolisable Protein supply result from the increased supply of undegraded N from legume silages.

Increased feed intake appears to be a major driver behind the effects of legume silages on milk production and effects can be explained by the degradation characteristics of silages. The very high intakes of WC are explained by both high rates of fermentation and passage and were achieved despite the lowest rumen fill. The high intake of L was probably a result of more rapid particle breakdown with this silage, resulting in high intakes but relatively low milk yields.

The low intakes of grass silage, particularly in the UK, reflect low rates of fermentation and passage from the rumen. The low fermentation rate means that similar levels of rumen digestion can only be achieved with longer retention times in the rumen. Longer retention times in the rumen lead to lower intakes, the chief cause of reduced performance with grass silage. This observation suggests that forage breeders need to give more consideration to the way in which a particular digestibility is achieved (i.e. low versus high rates of fermentation and passage) in order to ensure high digestibility, high intakes and consequent maximum production from forage.

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Summary of plenary discussions

1 *American research on N use with legume silages*

G. Broderick outlined the results from some of his research and made the following points. (a) Using formic acid for lucerne silage reduced NPN content by 35% compared with control silage made without additive. DM intakes of the silages were similar, but formic acid treatment reduced rumen ammonia content and increased yields of milk and milk protein by 3.3kg and 120g per day respectively. This response arose from improved protein utilisation associated with the reduced NPN in the silage. (b) Wilting reduced the NPN content of the silage which was 87%, 70% and 50% of the total N in silages with 17%, 35% and 64% DM respectively. (c) Red clover and lotus silages contained 30% less NPN than lucerne silage and this tended to increase N utilisation efficiency. The reduction in NPN was ascribed to polyphenol oxidase in red clover and condensed tannins in lotus. (d) In a series of five experiments with silages of 40% DM which comprised 60% of the diet DM, the intake of lucerne silages was 1 kg DM more than that of red clover silage. The forages had been harvested at the same NDF content, but in red clover the CP content was 2-3 percentage units lower and the NPN content was 33% lower.

2 *Strategies to improve N use*

Whilst 60 % of the variation in N use efficiency could be attributed to differences in N intake, it was not yet known what factors accounted for the remaining 40% of variation.

It was suggested that in different countries of northern Europe, good results would be obtained by feeding legume silages together with forages of low N content. Maize, whole-crop cereals, roots, potatoes and beets were all considered to have potential. M. Tuori reported that increasing the proportion of rapeseed meal fed with red clover silage from 10% to 20% did not affect milk yield, but had increased milk protein content and milk yield.

M. Mo reported that in experiments in Norway, the inclusion of only 20% of red clover silage together with grass silage had large effects, increasing feed intake by 2kg DM and milk yield by 0.5 kg daily. This *suggested that relationships of animal response with legume percent were not linear.*

3 *Legumes in rotations*

It was suggested that the N in excreta may be particularly important in stimulating yields of subsequent crops in rotational systems. The overall productivity of mixed organic systems is likely to be limited by the quantity of N fixed in the rotation. Thus apparent inefficiency of use of N by the ruminant on high-legume silages, may confer advantages to the overall system, provided that the N in faeces and urine is not lost during storage and field application. This consideration may be important regionally as well as within a farm. In the Netherlands, there is considerable manure movement from dairy farms to crop farms.

4 *Objectives for plant breeders*

The different relationships for different forage species between intake and digestibility produce some challenges for plant breeders. It must, however, be remembered that the relationships were all positive within species, so that breeding for digestibility was still likely to lead to increases in intake. However, additional objectives were suggested by the data presented. High digestion rate appeared to be important in facilitating high intake by red clover, white clover and lotus, whilst rapid breakdown in particle size (and rapid movement out of the rumen) is important in lucerne. C. Paul queried whether plant breeders could breed these desirable characteristics into grasses.

Reporter: M. Tuori

Laboratory evaluation of legume quality

Christian Paul[1], Merle Alex[1], Ulrike Soelter[1], Mikko Tuori[2], Maria Hellämäki[3], Juha Nousiainen[3] and Sue Lister[4]

Abstract

In the EU supported LEGSIL project, the efficient assessment of a wide range of nutritive characteristics in grass and legume forages was achieved by the utilisation of near infrared spectroscopy (NIRS) integrated with conventional chemical laboratory methods and feeding trials. In the agronomic experiments of the project more than 20.000 data concerning nutrient and metabolizable energy content as well as ensilability were ascribed to 3094 samples according to a standard analytical protocol irrespective of whether the forages were grown, harvested and prepared for later analysis in Finland, Sweden, the United Kingdom or Germany.

Furthermore, in an attempt to elucidate the possibilities for intake prediction in legume silage, two alternative methodological concepts previously developed for grass silage were investigated. These concern the silage intake ranking developed in Finland and the approach of intake prediction based on scanning wet silages by near infrared spectroscopy as proposed in Northern Ireland. It was found that neutral detergent fibre as an additional variable improved intake prediction in legume silages by means of the Finnish silage intake index (SII). An even better predictability of intake was achievable through wet silage scanning by NIRS. It is noteworthy that despite the severe limitations for NIRS calibration imposed by the small sample set in our study, 85% of the total variation in intake of legume and grass silage by sheep could be explained by NIRS. This corresponds to the success of the NIRS wet silage intake calibration set up in Northern Ireland on a much larger sample set of only grass silages.

Finally, the view is expressed that advances in dedicated NIRS hardware and software will extend the range of applications into fully automated quality monitoring processes during forage harvesting in the field and silage utilization in dairy operations.

Introduction

It is generally recognized that forage quality is a function of the digestibility and intake of the diet with animal products such as milk, meat or wool providing the most conclusive proof of the value of a given forage. However, the opportunity to test forage quality by means of feeding trials can be considered a rare exception under most practical circumstances. Therefore rational "non animal" forage testing schemes are needed which meet the requirements both of forage breeding stations as well as of dairy farms. While in the first case numerous strains and cultivars need to be assessed for nutritive value as cheaply and efficiently as possible, agricultural enterprises require a reliable integrated scheme from sampling via analysis right up to the use of the analytical data in least cost ration formulation programmes to meet the desired levels of production.

The conventional way of forage testing relies on relating the results of wet chemical analysis via feed tables or empirical equations to the response of the animal . For the practical farming situation even this approach has often proved to be too expensive and time consuming and has been replaced by more or less primitive sensory expert systems based on the visual appearance, physical constitution (grip) or smell which again were related to animal output via feed tables or equations. Such an approach had the benefit of being close "at hand" for the farmer. In the last two decades an unconventional methodological alternative has steadily gained ground which substitutes the human sensory perception of forage quality by opto-electronic sensor measurements in the near infrared part of the electromagnetic spectrum. The first experimental proof of this revolutionary new method was provided by Norris *et al.* (1976) whose publication - viewed from today - represents a true milestone in advancing feed analytical methods into the 21st century. With this method spectral data are usually obtained through reflectance measurements on unfractionated forages. These lend themselves to multivariate statistical prediction of diverse forage quality characteristics and animal performance parameters.

Forage analysis in the LEGSIL agronomy trial: Making rational use of NIRS

Near Infrared Reflectance Spectroscopy (NIRS) is based on molecular absorptions of the OH-, NH- and CH- bonds omnipresent in the organic constituents of forages and other feedstuffs. Due to the enormous complexity of these highly overlapping, partially

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repetitive absorptions and due to their interactions with the particular physical status of each sample at the time of measurement, the implicit use of Beer's Law in applying NIRS for quantitative purposes depends on statistical modelling (cf. Shenk and Westerhaus, 1994). This requires special sets of samples typical of a given product to serve for calibrating NIRS instruments. An example of such a calibration set may be provided by a set of forages dried and ground according to a specified protocol with known contents of chemical constituents, chemical fractions or quality characteristics such as water soluble carbohydrates, crude fibre or *in vitro* digestibility of the organic matter. NIRS equations developed as prediction models for any given product and constituent on a particular instrument perform adequately as long as applied to samples which are essentially comparable to those utilized in the calibration (modelling) process. Based on such a rationale, forage quality analysis in large sets of samples can be performed efficiently by calibration in a small subset of a large total set of samples. Once the characteristics of the subset are known and the NIRS prediction equation is established, the latter can legitimately be applied to the total sample set. By allowing the complete analytical characterisation of large trials without the need for a complete coverage of all samples by conventional analytical means, this procedure permits enormous savings in laboratory costs without loss of analytical information.

A case in point is provided by the agronomy trial of the LEGSIL project which aimed at evaluating the agronomic and nutritive characteristics of five different legume species grown in monoculture and in mixture with grass ranging from the south-west of the British Isles to the East into Northern Germany and up to the North East via South Sweden to locations near the Northern, Central and Southern Baltic coast of Finland (Halling *et al.* 2002). This trial was conducted over 12 locations and included from two to three cuts in two main harvest years with three field replicates at each location. The information to be gained from the trial included not only the content of nutrients and metabolisable energy, but also the ensilability of the forage samples. Thus a considerable amount of analytical effort was expected to be required for a complete characterisation of the samples. The usual practice of analysing the samples in national laboratories according to sample origin would still have resulted in a given laboratory having to process between 432 and 973 samples (Table 1) for a considerable number of parameters.

Table 1:
Number of samples analysed for diverse quality characteristics in LEGSIL agronomy trial

	Country origin of samples				
Harvest Year	UK	D	S	Fin	Total
1998	488	324	431	108	1351
1999	485	507	427	324	1743
Total	973	832	858	432	3094

Moreover, such an approach would have posed the risk of systematic deviations between laboratory methods inflating site effects, despite confirmation of previous satisfactory harmonisation of wet chemical procedures for silage analysis among laboratories participating in the LEGSIL project (Paul et al. 1999). In contrast , within a well coordinated investigation quality assessments by NIRS do not pose a problem either in terms of analytical turnover or with regard to interlaboratory errors. Due recognition of these advantages led to the decision to make use of NIRS for multiple forage analysis within the 3094 samples of the LEGSIL agronomy trial by establishing NIRS prediction equations for each required quality characteristic in a representative subset of samples and by applying these to the total sample set.

The procedure by which the subset of samples for NIRS calibration were chosen made use of an algorithm introduced by Shenk and Westerhaus (1994) for selecting spectra of representative samples from a data file containing the spectra of the total set of samples. This centers on the ranking of all spectra according to the Mahalanobis distance from the average spectrum of the file. In this way 394 samples (i.e. 12.9% of the total set) were selected. This selection was achieved by choosing in stepwise fashion a NIRS calibration set across samples of the 1998 harvest from the four participating countries and by updating this set with suitable samples from the 1999 harvest. Judged by the Mahalanobis distance between spectral data it was shown that the resulting broad based European calibration set included more suitable information for making a general NIRS model adapted to all the various sample sets from the four participating countries than a relatively narrow one based on samples from one country alone. The respective “wet chemical” laboratory methods were performed at the former FAL Institute of Forage and Grassland Research on the selected calibration samples and used as straightforward calibration inputs. For uniform quality assessment of the samples from both harvest years across countries, the European NIRS equations were then employed.

For a complete evaluation of the trial, analytical information was required a) on the content of metabolisable energy, b) on the content of crude nutrients according to the Weende method and c) on ensilability.

Considering the crucial relevance of metabolisable energy (ME) in forage quality evaluation and the relative paucity of such data for forage legumes in Northern Europe a major effort was undertaken to set up a satisfactory and promising strategy using a novel approach. Hence, its details are outlined in the following. The regression equation for ME content of grass and grass products proposed by Weissbach et al. (1999) was utilized in this strategy. It possesses the inherent advantage of being universally applicable to grass, grass silage and hay, even if produced from extremely late cuts, but it has not yet been extended to forage legumes. Its general format is based on the content of enzymatically insoluble organic matter (EIOM; in German EULOS), crude protein and crude ash. For these parameters the above mentioned European NIRS equations had been developed.

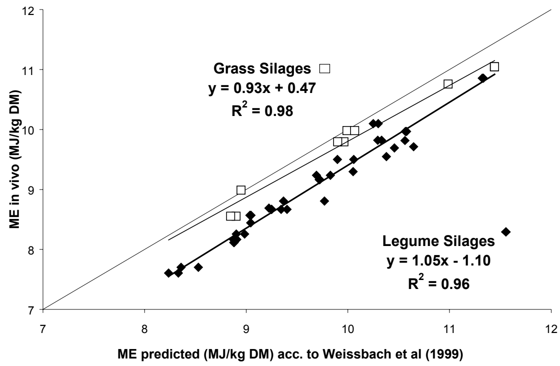

Figure 1:
Performance of prediction equation for content of metabolisable energy (ME) developed by Weissbach et al. (1999) with silages prepared from grass and legumes

The validity of this regression equation for grass silage was confirmed in the LEGSIL feed evaluation experiments of FAL on grass and legume silages performed on sheep (Paul *et al.* 2002) (Figure 1). As was expected, the prediction of ME content of silages from forage legumes by means of this equation resulted in a systematic error, the extent of which provided an opportunity to calculate ME correction equations not only for pure legumes but through interpolation also for mixtures with varying composition of grasses and legumes. As a consequence a series of four regressions intended for use with a) pure and dominantly grass (> 75% grass), b) mixtures with 50% - 75% grass, c) mixtures with 25% - 50% grass and e) pure and dominantly legume (< 25% grass) were computed (Figure 2).

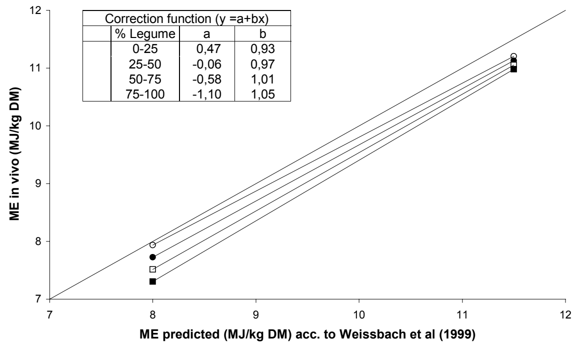

Figure 2:
Content of metabolisable energy according to Weissbach et al. (1999): Derivation of correction functions according to legume content of samples

As the calibration and cross-validation statistics appeared satisfactory (Table 2), the NIRS equations were accepted for use on all 3094 samples of the LEGSIL agronomy project. ME contents were computed by means of the NIRS predictions of the three variables and corrected according to the legume proportion of each particular sample. This finally resulted in ME contents of grasses, legumes and their mixtures in line with the results of the LEGSIL feed evaluation experiment with sheep (Paul et al. 2002)

Table 2:
NIRS calibration and cross validation statistics for variables determining content of metabolisable energy (according to Weissbach et al. (1999)

	EIOM g /kg OM	Crude Protein % of DM	Crude Ash %of DM
N	384	363	381
RSQ	0.96	0.99	0.88
SEC	15.04	0.58	0.53
SECV	16.81	0.65	0.64

In order to make use of the Weissbach model for the evaluation of the 3094 samples of the LEGSIL agronomy experiment, NIRS equations were developed for the prediction of the content of enzymatically insoluble organic matter (EIOM), crude protein and crude ash as determinants of ME content based on the samples in the calibration set.

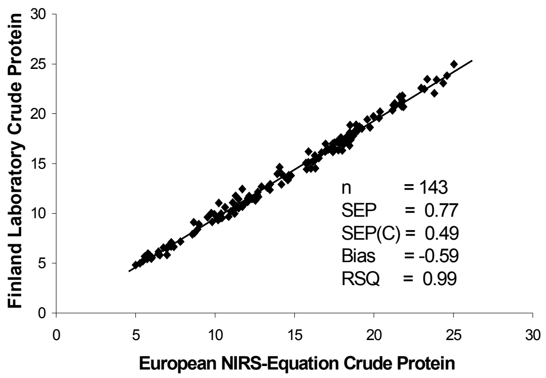

Figure 3:
Analytical performance of crude protein assessment by European NIRS equation in forage samples from Finland

The assessment of crude protein may serve as an example of how NIRS equations developed across the calibration samples from the four countries performed in comparison to conventional analytical chemistry. There was generally a high degree of correspondence between the crude protein data predicted by the European NIRS equation for given samples and the equivalent values obtained by the conventional procedure. This was typified through a comparison of the crude protein predictions by NIRS (based on the European NIRS equation established on crude protein determination at the FAL laboratory) and crude protein determined conventionally at the laboratory of Helsinki University on the samples from Finland (Figure 3). The small systematic error (bias) and the small random error (SEP(C) observed under these conditions are equivalent to the usual level of interlaboratory (bias) and intralaboratory (random) errors in the reference method. This provides proof of the excellent correspondence achieved between the European NIRS calibration and the wet chemical assessment of crude protein according to Kjeldahl. In contrast to this, the methods for the assessment of OMD in vitro as practised in the different LEGSIL partner laboratories followed different protocols and did not show the same degree of interlaboratory correspondence as the Kjeldahl method (results not shown). In this case, the utilization of the European NIRS calibration as based on one single reference lab contributed considerably to the harmonisation of the OMD data across the four different LEGSIL partner countries.

Silage intake prediction in the LEGSIL sheep feeding trial: Tapping the potential of NIRS

The assessment of feed quality remains incomplete when attention is not paid to the voluntary intake of that feed by ruminant animals. However, as pointed out by Mertens (1994), "The number and complexity of factors affecting intake make the measurement of intake potential of a forage difficult to accomplish and interpret." He also points out that the animal and feed factors regulating intake are to some extent inseparable and that therefore "the interaction of the forage, animal, and feeding situation precludes the prediction of actual intake based solely on feed characterisation". These considerations must serve as a warning to experimenters who risk severe errors when attempting to extrapolate or draw sweeping conclusions from limited feed evaluation experiments. Yet the search for feed factors regulating intake within a well defined experiment on different species of forage legumes and grass like the LEGSIL feed evaluation study by Paul et al. (2002) seems legitimate. In this case the range from low to high quality forages fed to mature sheep wethers with constant, moderate energy demand resulted in large differences in voluntary intake between roughages. It may be assumed that in this experiment – typical for any comparison between grass and legume species with sufficient variation in energy content - effects of energy availability, physical structure and palatability on voluntary intake played an important role so that on the one hand a reliable relative ranking of these species in terms of intake potential, similar to the French fill values (INRA 1989) was possible. On the other hand, the factors responsible for intake variation in these forages under the conditions of the experiment could be investigated and laboratory methods for their assessment tested . The latter appeared legitimate, particularly because the potential of two alternative methods was tested against the background of the same set of samples. In our case recently proposed approaches for the prediction of intake in grass silages as developed in Finland and in Northern Ireland were compared for their suitability for intake prediction.

The Finnish system of ranking grass silages for intake published by Huhtanen *et al.* (2002) is based on three factors, i.e. D-value (D), content of total fermentation acids (FA) and the proportion of ammonia nitrogen of total forage nitrogen (NH_3-N). The Silage Intake Index (SII) is computed in the following way:

$$SII = 100 + 0.151\,(D - 690) - 0.000531\,(FA^2 - 6400) - 4.7650\,[Ln(NH_3\text{-}N) - Ln(50)]$$

The correlation coefficients characterising the relationships between these variables and dry matter intake for the samples studied by Paul *et al.* (2002) are given in Table 3. The independent variables D-value and NH_3-N were more closely related to intake in the silages prepared from grass than in those from grass and legumes. The opposite was true for the total fermentation acids. As was to be expected, the Finnish Silage Intake Index had a closer relationship to intake when grass silages alone rather than grass and legume silages were included in the sample set (Table 3). Among the variables known to influence intake, neutral detergent fibre (NDF) is often regarded as one of the routinely measured essential feed factors for estimating the filling effect of a forage. So it appeared appropriate to also consider NDF in this investigation. The addition of NDF did indeed improve markedly the relationship of SII with intake in the mixed sample set of grass and legume silages. In contrast the addition of NDF did nothing to improve the relationship of SII with intake in the grass silage sample set.

Table 3:
Variables for rank prediction of grass silages in voluntary intake (according to Finnish Silage Intake Index (S I I)): correlation coefficients with intake observed in LEGSIL sheep feeding trial

Variable	Silage from: Grass only	Legumes + Grass
D value (g DOM / kg DM)	+ 0.69	+ 0.47
FA (g / kg DM)	+ 0.39	+ 0.55
NH_3-N (g / kg N)	- 0.70	- 0.15
S I I	+ 0.87	+ 0.36
S I I + NDF	+ 0.88	+ 0.88

The above results should not be misinterpreted as the outcome of an unfair test of the Finnish silage intake ranking scheme for grass silages. But faced with a situation where an increased utilization of forage legume silage in dairy rations might take place at the farm level, the limited applicability of the SII to pure legume silages as well as silages prepared from mixtures of grass and legumes is important. Additionally, it is worth noting that NDF can improve the performance of the Finnish SII in samples containing significant proportions of legumes without impairing its performance with pure grass silages.

Taking account of all the variables, and possibly also NDF, to be assessed in the laboratory for the prediction of voluntary intake according to SII , it is understandable that less laborious and potentially more accurate methods are still sought. Since the first report of a correlation study on NIR spectra of forages and voluntary intake by Norris *et al.* (1976) the potential of NIRS has been confirmed in several reports. . But most studies have been directed towards the goal of predicting intake based on NIRS measurements in dried silage samples. In NIRS studies - as with conventional analytical techniques - some method of dehydration is usually practised, because the bulk of energy and nitrogen containing nutrients is either part of or associated with the cell wall fraction rather than with the cellular contents. Furthermore water dominates the NIR spectrum of undried, fresh silage as a consequence of both its high content in fresh forage and its very high absorbance in the near infrared. This is exemplified by the spectra of undried and dried lotus silage (see Figure 4). But NIRS protocols for the analysis of dried silage suffer from the disadvantage of a lengthy drying process during which volatile constituents of the silages, such as fermentation acids, alcohols and ammonia (compounds which may have functional relationships with intake), are liberated and lost. Therefore the approach used by Gordon *et al.* (1998) in the very systematic investigation on the largest set of silage samples yet studied in a NIRS calibration experiment on wet silages appeared attractive. It was used as a basis of comparison with the much smaller study reported here.

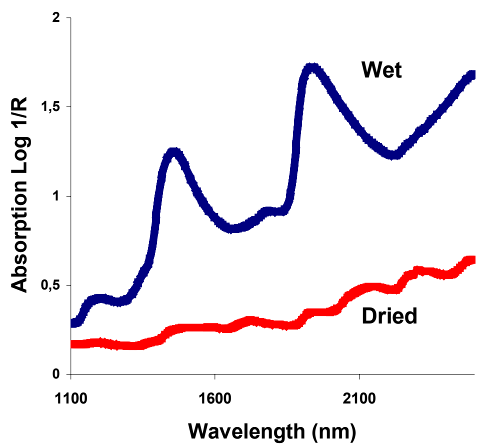

Figure 4:
NIR diffuse reflectance spectra of dried and wet silage prepared from *Lotus corniculatus* forage

The significance of whether silage in NIRS analysis is scanned as wet or dry may be appraised from the results of a principal component analysis (PCA) of the spectra obtained on the set of legume and grass silages of the LEGSIL sheep feeding trial. PCA was used to define absorbers (factors) which were underlying the NIR spectral variation of this set of samples when scanned either dried or wet. For each forage quality parameter, the three best suited absorbers were identified by correlation analysis. As far as wet silage was concerned, the multiple correlation between OMD *in vivo* and the three best NIR absorbers for OMD explained only 52% (RSQ x 100) of its variation in this sample set (Table 4). However, in the same sample set scanned in the dried state, the multiple correlation between the same data for OMD *in vivo* and the three best NIR absorbers for OMD rose considerably so that 74% of its variation was explained. An even more dramatic improvement in the same direction took place for crude protein content. In contrast to this, dry matter intake (DMI) by sheep (and NDF content) was almost equally well explained in wet and dried silage by three PCA factors. These results indicate that NIRS scanning of wet silages lends itself more to the prediction of intake than to the prediction of OMD. But it is well known that complex feed characteristics require complex NIRS regression models, so that OMD and intake are expected to be explained more satisfactorily by more than just three absorbers. Taking the results of Gordon *et al.* (1998) as an example, up to 16 PCA factors were selected for use in predicting OMD and intake.

Table 4:
Principal component analysis (PCA) of LEGSIL silage NIR spectra: proportion of explained variation of diverse forage quality parameters by optimal 3 PCA factors

	Silage scanned:			
Quality Parameter	Wet		Dried	
	RSQ	Rank	RSQ	Rank
DMc	.93	1	-	
DMI	.70	3	.74	3
OMD in vivo	.52	4	.74	3
NDF	.87	2	.88	2
Crude Protein	.53	4	.95	1

Also, in the same experiment it was shown that a) transformation of spectral data, such as derivatisation, allied to scatter correction procedures generally improved prediction accuracy and b) modified partial least square (MPLS) factors were superior to PCA factors as variables in NIRS regression analysis for predicting both intake and OMD. When calibrations were developed both for wet and dried silages according to the above mentioned findings, the lesser number of samples of the LEGSIL sheep feeding trial enforced regression models with reduced complexity than developed by Gordon *et al.* (*l.c.*), i.e. with only 6 rather than up to 11 MPLS factors. Nevertheless, in cross validation of the 6-factor models for DMI and OMD in wet silage, standard errors (SECV) of 0.12 DMI (kg / animal / day) and 2.32 OMD (%) were observed with 85% and 88% of the variation in DMI and OMD explained ((1-VR) x 100) (Table 5). The corresponding evaluation for dried silage resulted in a significantly better fit of predicted vs. observed data for OMD and a similar tendency for DMI.

Table 5:
Performance statistics of NIRS regressions* for prediction of dry matter intake and organic matter digestibility in silages scanned wet and dried

	Wet silage		Dried silage	
	SECV	1-VR	SECV	1-VR
DMI**	0.12	.85	0.11	.88
OMD***	2.32	.88	1.63	.94

* Data transformation: 1,4,4,1; MPLS regression analysis without outlier removal
** Dry matter intake: kg / animal / day
*** Organic matter digestibility: %

Considering the smaller data base, the fewer factors in the regression equation and the increase in population heterogeneity in our sample set of grass and legume silages compared to the NIRS calibration experiment solely on grass silages by Gordon *et al.* (*l.c.*), inferior results in terms of the degree of fit achieved were expected for our calibrations. However, similar performance statistics were found for the wet silage calibrations in both experiments.

Outlook

The present paper has demonstrated the potential of near infrared spectroscopy as an efficient opto-electronic tool which allows the assessment of multiple forage quality parameters through one single measurement with great ease of sample preparation, non-consumption of sample and high speed of operation. Its utilization is of paramount importance for rational feed and forage testing laboratories. Recent advances in dedicated NIRS hardware and software will extend the range of applications even further. These are due to spectrometers which allow parallel rather than sequential scanning and to regression analytical techniques for dealing with non-linearity in the opto-electronic expression of compositional variation of feedstuffs. Consequently, we will be able to fully realise the inherent capacity of the NIRS technique with its integration in a fully automated process from harvesting, sampling, minimal preparation to the analysis of forages in real time on forage harvesters (Paul *et al*. 2000). Similarly the introduction of NIRS elements into precision agriculture in dairy operations will prepare the ground for a better monitoring of feed ration optimisation than was possible before.

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Summary of plenary discussion

1 Effects of fermentation quality

The possible effects on intake of silage fermentation quality, as reflected by high ammonia-N concentrations in the lucerne silages and concentrations of acetic acid were queried. It was pointed out that the ammonia figures would include some N from the additive, which contained both hexamine and sodium nitrate. Although this would have increased ammonia for all silages, it would not give a differential effect between the crop species.

The author considered that differences in silage fermentation characteristics were not having a major impact on intake with this population of silages. Some 85% of the variation in intake could be accounted for by digestibility.

2 Intake of lotus

In relation to the reason for the high intake of lotus silages, the author referred to rumen degradability studies carried out on these silages. These had shown that DM degradability was more rapid with lotus than the other legume silages and this was probably responsible for the high intakes.

Possible effects of tannins on N digestion were queried. Tannins had not been determined in these experiments. G. Broderick indicated that tannin concentrations were generally lower in Lotus corniculatus than in other tannin-containing legumes and did not think that major effects were likely. N. Nilsdotter-Linde referred to work in Sweden. She had shown large differences between varieties in tannins, but that values for Leo, the variety used in LEGSIL, was generally low. There was, however a negative relationship between tannin content and rate of protein degradation in the rumen, despite tannin concentrations being generally low.

Reporter: R.J. Wilkins

Production of legumes in agro-climatic zones : models and predictions

Cairistiona F.E. Topp and Chris J. Doyle [1]

Abstract

A process-driven model of grass-legume swards has been developed to assess the suitability of growing and utilising forage across northern Europe. The model has been validated against fifteen sites in an FAO trial covering northern Europe in respect of pure grass swards, and against the twelve LEGSIL experimental sites in four countries in respect of five legumes and grass-legume mixtures swards. The degree of agreement between the predicted and observed growth rates and yields was good for the FAO dataset. For the LEGSIL trials, the model's predictions accorded with the observed rankings. However, they were better for total yields than individual cuts, better for country averages than for individual sites and better for monocultures than for grass-legume mixtures. To forecast expected yields across northern Europe, the region was divided into eight agro-climatic zones based on accumulated temperatures and rates of evapotranspiration. The yields projected for red clover and galega grown as monocultures were potentially similar to a grass-based system receiving 200 kg N ha^{-1}. In addition, lucerne grown as a monoculture or as a mixture, and red clover grown as a mixture performed relatively well. However, the results suggested that the yield of lotus was probably too low for this legume to be worthy of consideration under the environmental conditions experienced in northern Europe.

Introduction

Forage legumes potentially have a role to play in grassland systems throughout northern Europe (Wilkins *et al*., 2002). As part of the LEGSIL EU funded project, five leguminous species were evaluated at twelve sites across four countries within northern Europe (Halling *et al*., 2002). However, it is difficult to extrapolate confidently from the trial results to other areas in northern Europe. Accordingly, a process-driven mathematical model of grass-legume swards has been developed, validated against the trial results and used to explore the sensitivity of the results to environmental and changing economic circumstances (Doyle and Topp, 2002). This has involved dividing northern Europe into eight agro-climatic zones and forecasting the yield potential of the five forage legumes examined in the trials for each zone, using representative sites. This paper describes the development and the validation of the model, the definition of the agro-climatic zones, and the yield predictions for each of these zones across northern Europe. The economic assessment is outlined in Doyle and Topp (2002).

Development of a grass legume simulation model

The development of a mathematical model, capable of simulating the economic impacts of using legume silages in livestock systems and applicable to a wide range of sites has required the simulation of the dry matter (DM) yields of cut legume and grass-legume swards under different climatic and site conditions. One approach would have been to create simple empirical models, in which yield (Y) is estimated as a function of nutrient inputs (N), water availability (W) and other site (S) and climatic factors (C):

$$Y = f(N, W, S, C) \tag{1}$$

However, a previous attempt to develop empirical models of grass growth using statistically estimated relationships, which could be generalised to a range of European sites, has shown how difficult this can be (Corrall, 1988). There is a real danger that the resultant models are only valid for one site. Given this, there appeared to be a risk that the objective of developing a tool for predicting forage dry-matter yields throughout Europe could not be realised with this approach.

In contrast, physiological models of grass-legume growth have been developed and have been shown to be able to embrace a range of sites, although the yield predictions may be less accurate than for empirical ('statistically estimated') models. Furthermore, physiological models appear capable of providing information on the impacts of future climatic change, such as enhanced CO_2 levels, which empirical models generally cannot. For this reason, a decision was taken to develop a physiological model of legume and grass-legume swards. Such a model for grass and grass-white clover swards has been developed (Topp and Doyle, 1996a; 1996b), and this model has formed the basis of the simulation model used in this study.

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Outline of the mathematical structure of the model

The model of the sward developed allows both legume and grass-legume mixtures to be explored. Forage production is calculated on a daily basis, and is presumed to be dependent on herbage mass, temperature, radiation, atmospheric carbon dioxide (CO_2) concentration, available water and nutrients. There are five state variables, leaf dry matter, stem dry matter, root dry matter, dead material and the leaf area index of the crop. For a mixed sward, comprising both grass and a forage legume, there are separate state variables for each component. In addition, both the vegetative and reproductive phases of development are described within the model.

There are also five driving variables, namely the mean daily temperature, the level of photosynthetically active radiation, the atmospheric concentration of CO_2, the available moisture and the available nitrogen. It is assumed that photosynthetically active radiation and temperature do not vary throughout the day. Essentially temperature, photosynthetically active radiation and atmospheric CO_2 concentration are presumed to modify the rates of gross photosynthesis. In the case of a grass-legume mixture, the irradiance incident on the leaves for either component depends upon the leaf area of both the grass and the legume. Hence, the rate of canopy photosynthesis for a mixture can be derived by summing the rate for the individual components (Johnson *et al.*, 1989). Net photosynthesis is then derived by deducting respiration losses. The available moisture and nitrogen modify the net photosynthate, either by reducing the efficiency of photosynthesis or by reducing the length of the growing period. The amount of nitrogen that is available to the sward is dependent on the available pool of nitrogen in the soil, the fertiliser nitrogen applied, and the quantity of nitrogen that is biologically "fixed" by the legume. With regard to the availability of water, the soil is assumed to be saturated on 1 January. The change in available water on subsequent days is assumed to equal the difference between rainfall and actual evapotranspiration. The net assimilate is then partitioned between leaf, stem and root. The resultant leaf, stem and root materials are then either harvested or pass into the dead pool through decomposition.

Within the model, time is measured in days from 1 January. The grass and legume components within the model are separately distinguished and are divided into leaf, stem, root and dead material. In the case of grass, "stem" comprises tillers and latent developing leaves as well as true stem. For a legume, such as white clover, stolons and petioles are included in the "stem" component. To run the model, it is necessary to define values for all of the parameters. The values assumed for grass and for the five forage legumes, namely white clover, red clover, lucerne, lotus (*Lotus corniculatus* L.) and galega (*Galega orientalis* Lam) were sourced from the existing literature.

Validation of the model

The validation of the resultant model was undertaken in two distinct phases. The first phase was concerned with assessing its ability to cope with the range of environmental conditions found in northern Europe and to give reasonably accurate predictions of yield. The second phase focussed on the ability of the model to predict the comparative yields of the different forage legumes at a range of sites.

Quality of predictions at a range of sites experiencing different environmental conditions

To assess the model's ability to give satisfactory predictions under a range of environmental conditions data was taken from the FAO project "Predicting production from grassland", collected at 34 sites across Europe during the period 1982-1986 (Corrall, 1988; Peeters and Kopec, 1996). In every case yields were recorded for the grass species *Phleum pratense* and *Lolium perenne*. From this dataset, fifteen sites in northern Europe were chosen; the sites and the periods of measurement are shown in Table 1. For each site, the data for irrigated and non-irrigated conditions were studied. Using meteorological data for the sites, daily herbage accumulation rates were predicted for each of them.

Tables 2 and 3 summarise the findings for irrigated and non-irrigated swards respectively. These tables give the results for Theil's inequality coefficient (Theil, 1970), where a value of 0 indicates a perfect fit, while a value of 1 indicates a total absence of any fit between the model's simulated growth rates and the measured growth rates. The tables also give the estimated bias and variance proportions. The former is an indication of the systematic error, while the variance proportion measures the ability of the model to replicate the degree of variability in the data. The remaining error, after accounting for the bias and variance effects, is called the covariance proportion. The ideal distribution of inequality over the three sources is bias and variance proportions equal to zero, and the covariance proportion equal to one (Pindyck and Rubenfield (1981).

Table 1:
The sites and the periods of measurements used to validate the forage model

	Non-irrigated	Irrigated
Braunschweig, Germany	1982—1986	
Plas Gogerddan, UK	1982—1986	
Crossnacreevy, UK	1982—1984	1982—1984
Johnstown Castle, Eire	1984—1986	
Grange, Eire	1982—1986	
Moorpark, Eire	1982—1983	
Hurley, UK	1982—1985	1982—1985
Uppsala, Sweden	1985—1986	1985—1986
South Savo, Finland	1982, 1984—1986	1982, 1984—1986
North Pohjannaa, Finland	1982—1986	1982—1986
MacRobert, UK	1982—1986	
Auchincruive, UK	1982—1986	
Kiel, Germany	1984—1985	
North Wyke, UK	1983—1988	1983—1986
Bronydd Mawr, UK	1986	

Table 2:
Theil's inequality coefficient and the bias, variance and covariance proportions for the FAO sites which were irrigated

Site	Theil's coefficient	Bias	Variance	Covariance
Crossnacreevy, UK	0.19	0.13	0.19	0.69
Hurley, UK	0.35	0.39	0.19	0.43
Uppsala, Sweden	0.42	0.31	0.27	0.42
South Savo, Finland	0.31	0.23	0.19	0.58
North Pohjannaa, Finland	0.29	0.13	0.16	0.71
North Wyke, UK	0.34	0.39	0.23	0.39

Table 3:
Theil's inequality coefficient and the bias, variance and covariance proportions for the FAO sites which were non-irrigated

Site	Theil's coefficient	Bias	Variance	Covariance
Braunschweig, Germany	0.31	0.19	0.07	0.74
Plas Gogerddan, UK	0.39	0.41	0.25	0.34
Crossnacreevy, UK	0.20	0.04	0.08	0.88
Johnstown Castle, Eire	0.29	0.12	0.07	0.82
Grange, Eire	0.27	0.15	0.22	0.63
Moorpark, Eire	0.24	0.01	0.02	0.98
Hurley, UK	0.35	0.34	0.13	0.54
Uppsala, Sweden	0.51	0.32	0.28	0.41
South Savo, Finland	0.31	0.18	0.11	0.72
North Pohjannaa, Finland	0.27	0.03	0.02	0.96
MacRobert, UK	0.25	0.19	0.01	0.80
Auchincruive, UK	0.23	0.18	0.12	0.71
Kiel, Germany	0.24	0.00	0.00	1.01
North Wyke, UK	0.33	0.37	0.20	0.43
Bronydd Mawr, UK	0.37	0.32	0.22	0.48

On the whole the degree of agreement between the predicted and observed growth rates and yields is good. It appears that there is a tendency for the model to over-predict yield, but not seriously. There is also a tendency at some sites for the bias and variance proportions of Theil's inequality coefficient to be relatively high, being greater than 0.2. Nevertheless, the bias proportions were notably high for only the irrigated and non-irrigated sites at Hurley and North Wyke and for the non-irrigated site at Plas Gogerddan. Overall, perhaps only at Uppsala in Sweden do the results indicate that the model does not adequately predict the yield harvested at the site. Even then, the poor prediction may be a reflection of management problems at the site rather than errors in the model. If the actual yield harvested at Uppsala is compared to the observed yields at North Pohjannaa and South Savo in Finland, it appears to be low, particularly in 1985. These sites are at similar latitudes and have similar average temperatures and sunshine hours to Uppsala and so comparable yields would have been expected. Thus, the results of this validation exercise confirmed that the model predicted the general trends in seasonal production and should be reasonably valid for the predicting yield across countries in northern Europe.

Quality of predictions for a range of forage legumes

The first validation exercise was concerned solely with grass. However, as the study is concerned with examining the potential of forage legumes, it is vitally important that it is capable of predicting the relative yields of each of the forage legumes at a given site. Accordingly, data on both annual and individual cut yields for two harvest years (1998 and 1999) at all sites and for all treatments in the LEGSIL project was extracted (Halling *et al*., 2002) and the model's predictions compared to the measured results.

The results of this analysis revealed three main findings:

1. The model did produce simulated differences in yields between forage crops, which accorded with the observed rankings.
2. However, the predictions were better for total yields rather than individual cuts, better for a country than for an individual site and better for monocultures than for grass-legume mixtures.
3. The results were sufficiently robust to be used to prepare informative forecasts of yield productivity in different agro-climatic zones in northern Europe.

Figures 1 to 6 show the comparison between the predicted and observed annual total yields for the 'pure' swards of grass, red clover, lucerne, white clover, galega and lotus at all the sites recorded in the LEGSIL trials in 1999. For each graph, three figures are given, namely i) the observed 'total' yield, ii) the observed 'legume' or 'grass' yield and iii) the predicted 'total yield'. The difference between the observed total yield and the observed grass-legume yield represents invading 'weed' species. Looking at the graphs, two things are evident:

1. Although there are significant differences between observed and predicted yields, the model captures the general differences between sites.
2. At a given site, the predicted relative ranking of the different forage crops is similar to the observed ranking.

However, while the simulated ranking of the different legume and grass-legume mixtures in terms of yield was reasonably consistent with the observed rankings, the predictions were better for total yield than for individual cuts, better for country averages than individual sites and better for monocultures than for mixtures. This is demonstrated in Tables 4 and 5, which show the value of Theil's inequality coefficient, along with the bias, variance and covariance proportions. Specifically, Table 4 presents the results in respect of total yields for all sites and years by crop, including grass-legume mixtures. From this it can be seen that the value of Theil's inequality coefficient is fairly low for all the forage combinations explored in the LEGSIL trials, suggesting that the model predicted the change in variability of total yields across sites and across crop species reasonably well. Also the coefficients tended to be better (closer to zero) for the pure swards compared to the grass-legume mixtures. In particular, in the case of the grass-legume mixtures there was evidence of systematic bias in the predicted yields, reflected in the fairly high values for the bias proportion.

On the other hand, with the exception of unfertilised grass swards (Grass, 0 kg N ha^{-1}), the variance proportions were uniformly low, indicating that the model was able to replicate the variability in the observed yield data. In terms of yield predictions for all sites and for all treatments by individual countries in the LEGSIL trials, the statistical tests also confirm that, on a country basis, the predicted yields were a reasonably good fit, though there is some evidence of systematic bias, reflected in the moderately high bias proportions (Table 5).

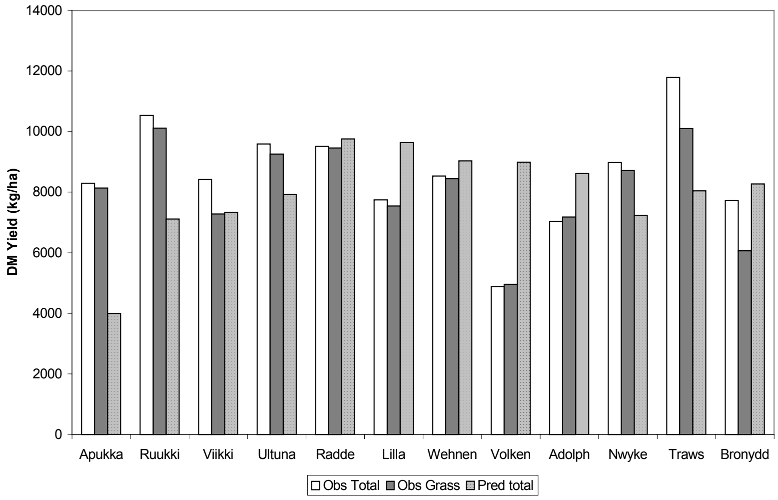

Fig. 1
Comparative predicted and observed grass annual yields in 1999

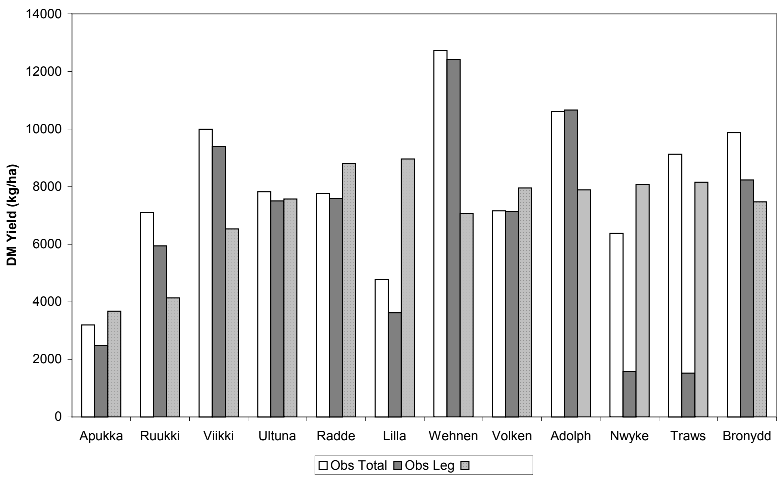

Fig. 2
Comparative predicted and observed red clover annual yields in 1999

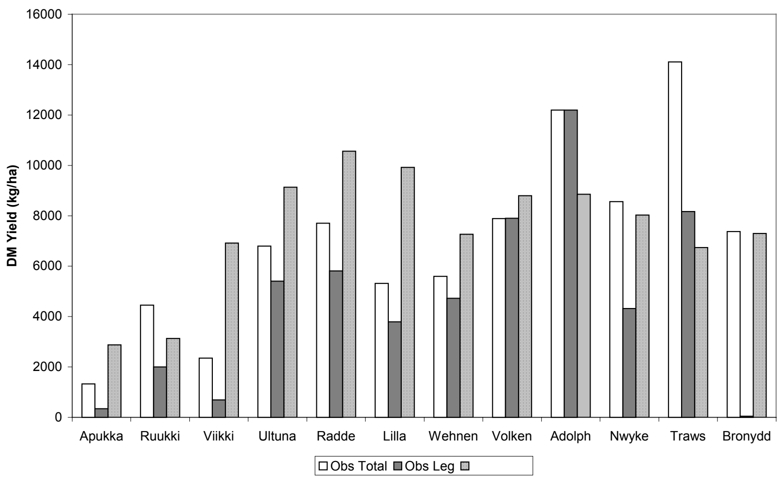

Fig. 3:
Comparative predicted and observed annual yields for lucerne in 1999

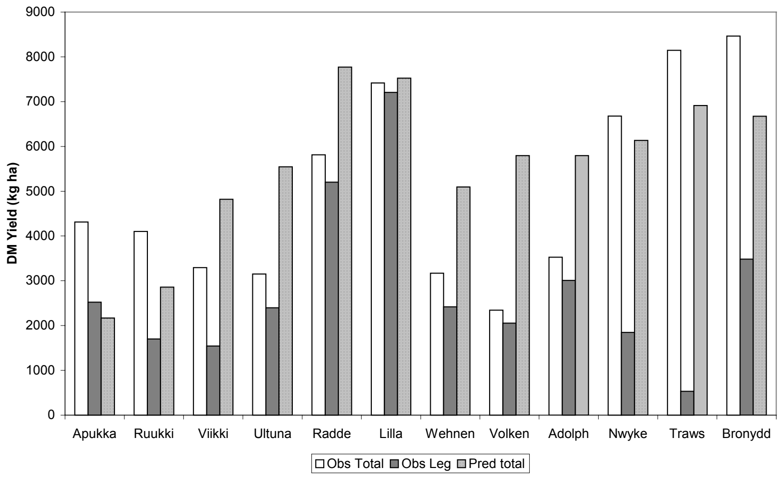

Fig. 4:
Comparative predicted and observed total yields for white clover in 1999

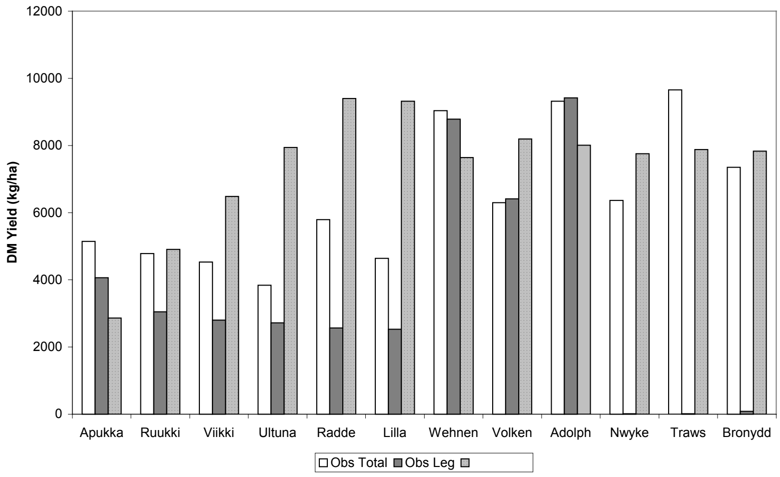

Fig. 5:
Comparative predicted and observed annual yields for galega in 1999

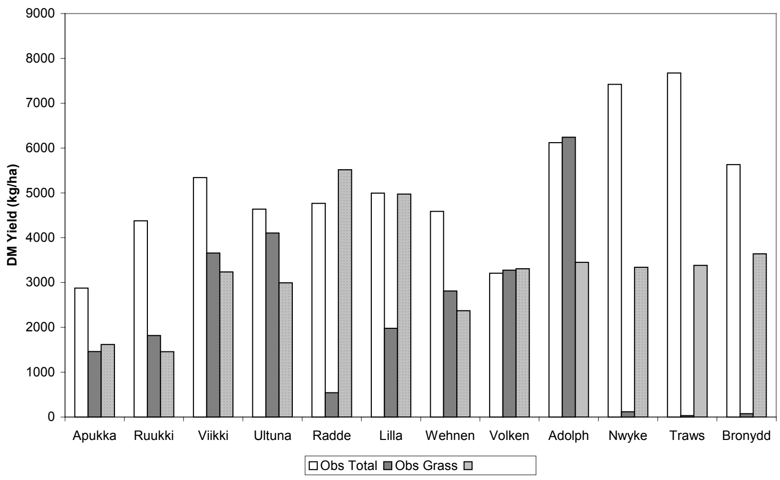

Fig. 6:
Comparative predicted and observed annual yields for lotus in 1999

Table 4
Values of Theil's inequality coefficient and the bias and variance proportions for total yield by crop

Crop	0.16	Bias	Variance
Red clover	0.24	0.10	0.10
Lucerne	0.16	0.01	0.20
White clover	0.20	0.11	0.03
Galega	0.31	0.10	0.02
Lotus	0.25	0.48	0.05
Grass, 0 kg N ha^{-1}	0.16	0.00	0.33
Grass, 200 kg N ha^{-1}	0.22	0.07	0.03
Red clover + Grass	0.26	0.54	0.02
Lucerne + Grass	0.18	0.42	0.13
White clover + Grass	0.24	0.43	0.02
Galega + Grass	0.23	0.46	0.03
Lotus + Grass		0.41	0.06

Table 5
Values of Theil's inequality coefficient and the bias and variance proportions for total yield by country

Country	Theil's Coefficient	Bias	Variance
Britain	0.23	0.42	0.21
Finland	0.25	0.36	0.07
Germany	0.25	0.31	0.21
Sweden	0.18	0.11	0.00

Definitions of agro-climatic zones

As a starting point for defining the agro-climatic zones, the work of Pelletier (1984) on the primary environmental determinants of forage yields was used to construct a framework. His work showed that *temperature* and/or insolation is the main climatic factor affecting growth in *spring*, whilst *water deficit* is the dominant *summer* factor. Data studied by him suggested that to reach a yield of around 4 t DM ha^{-1}, suitable for a first silage cut, required cumulative day degrees above 0°C from 1 January of just under 940°C. By comparison, during the summer, defined as the period from mid-June to mid-September, Pelletier found a reasonably linear relationship between average daily growth rates and the ratio of the actual to the potential evapotranspiration over this period. Using these two criteria, relevant to forage production, a methodology was developed for defining agro-climatic zones.

Taking northern Europe as the area depicted in Figure 7, for 43 sites in fourteen countries (Iceland, Norway, Sweden, Finland, Estonia, Latvia, Lithuania, Germany, Poland, Austria, Netherlands, Belgium, France and the UK) long-run monthly averages for mean daily temperatures, precipitation and pan evapotranspiration rates were collected. The temperature and precipitation figures were taken from Pearce and Smith (1994), while the pan evapotranspiration rates were obtained from the Website http://ingrid.idgo.columbia.edu/.

Using the weather data, estimates were made for each site of the average date by when the cumulative day-degrees above zero exceeded 940°C and the ratio of the mean actual to potential evapotranspiration during the summer months (June to September). Using the two criteria, the sites were classified into one of nine categories. However, in practice, some of the categories only had one site and, after further inspection of the data, it was decided to divide northern Europe into eight agro-climatic zones, as depicted in Figure 7. These agro-climatic zones are described in Table 6. Clearly, the boundaries between zones involve a measure of speculative interpolation. While the zonal boundaries are very approximate and clearly do not take account of orographic factors, the resultant map provides a basis for defining agro-climatic zones appropriate to forages.

Table 6:
Definitions of agro-climatic zones.

Zone	Description
A	Cold springs, late first silage cut; summers fairly moist with some water stress
B	Cold springs, late first silage cut; summers fairly wet with little water stress
C	Cold springs, late first silage cut; summers fairly dry with considerable moisture stress
D	Warm springs, early first silage cut; summers fairly wet with little moisture stress
E	Warm springs, early first silage cut; summers fairly moist with some moisture stress
F	Cool springs, first silage cut possible in June; summers fairly wet with little moisture stress
G	Cool springs, first silage cut possible in June; summers fairly moist with some moisture stress
H	Warm springs, early first silage cut; summers fairly dry with considerable moisture stress

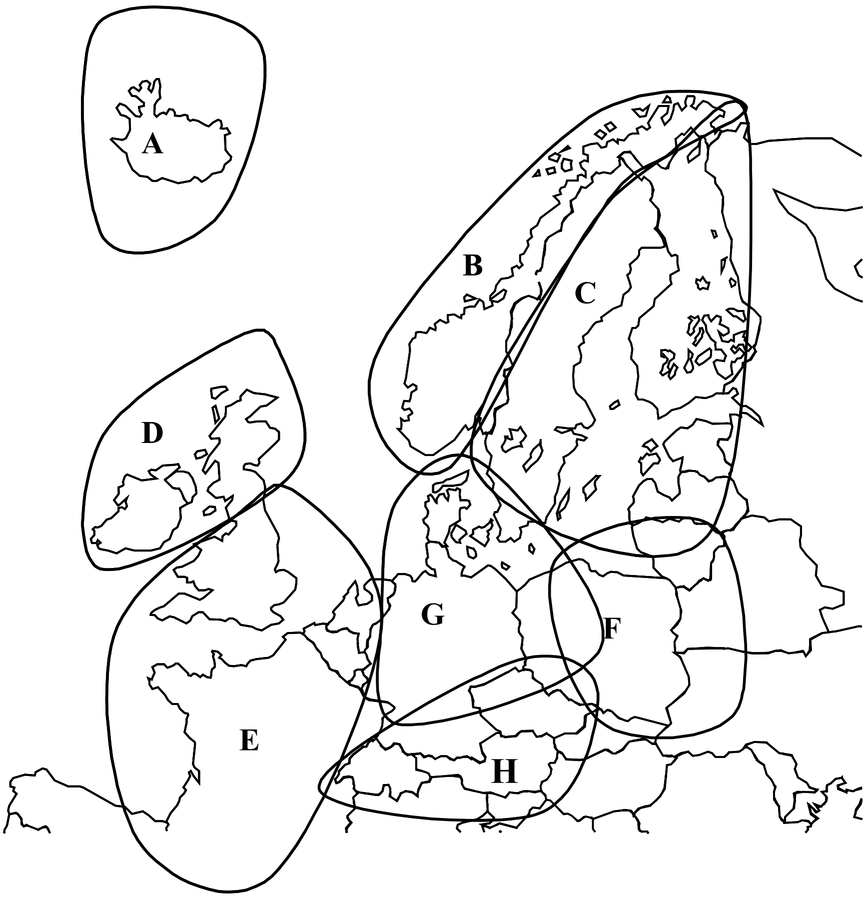

Figure 7:
Proposed agro-climatic zones for northern Europe

Estimation of forage legume yields for each agro-climatic zone

For each of the eight agro-climatic zones, three 'representative' weather stations have been selected (see Table 7) and daily weather data for three years extracted from the Website http://ingrid.idgo.columbia.edu. Because of missing values in some cases, it was necessary to estimate rainfall figures from 30-year means. In addition, in some cases it was necessary to estimate radiation from minimum and maximum temperature based on the methodology of Meza and Varas (2000). The simulated mean harvested yields within each agro-climatic zone for grass receiving 200 and 400 kg N ha^{-1}, together with those for the five legume and grass-legume mixtures, are presented in Table 8. In the case of pure grass swards, it was considered that limiting nitrogen use to just 200 kg N ha^{-1} was unrealistic and that many dairy farms would apply much higher levels, at least in areas of high yield potential. For this reason the yields at 400 kg N ha^{-1} were explored in order that the economics of applying that level of fertiliser could be assessed (see Doyle and Topp, 2002)

In general, the pattern of yields shows the expected north-south increase and, with the exception of Zone E, the inter-site variations within an agro-climatic zone were found to be reasonably small. In the case of Zone E, the generally high average yields are attributable to the simulated yields for one of the sites, namely North Wyke. However, though the yields at this site appeared out of line, it was the case that the relativities between grass and the other forage legumes at this site were not seriously distorted, with all forage yields projected to be high.

Table 7:
'Representative' weather stations selected for each agro-climatic zone

Agro-Climatic Zone	Weather Stations
A	Bolungavik, Egalsstadir, Reykjavik
B	Bergen, Narvik, Oslo
C	Appuka, Uppsala, Viikki
D	Aberdeen, Dumfries, Mullingar
E	De Bilt, North Wyke, Paris
F	Krakow, Przemysl, Warsaw
G	Adophshof, Lilla Boeslid, Poznan
H	Innsbruck, Kosice, Prague

Table 8:
Simulated mean yields for grass and grass-legume mixtures within each agro-climatic zone, kg DM ha^{-1}

Forage crop	Agro-climatic zones							
	A	B	C	D	E	F	G	H
Grass, 200 kg N ha^{-1}	3338	5535	6495	7214	10904	9149	9027	10253
Grass, 400 kg N ha^{-1}	5441	7257	8641	9720	14560	12154	11971	13483
White clover	2316	4163	4428	5522	6940	6500	6769	7241
Red clover	3231	5405	5910	6847	8677	8361	8606	8690
Lucerne	2206	4960	5925	6647	11083	9464	9642	10067
Lotus	1839	2817	2890	3083	3546	3834	4139	4224
Galega	3823	5068	5723	7198	10509	8554	8708	9684
Grass-White clover	1817	3842	4360	5526	8202	7067	7178	7759
Grass-Red clover	2080	4338	4979	5990	8826	7662	7619	8199
Grass-Lucerne	2265	4507	5515	5919	8590	6606	6682	7526
Grass-Lotus	1945	3440	3926	4957	7810	6454	6461	7322
Grass-Galega	2083	3744	4514	4873	6682	5318	5391	6080

Discussion and conclusions

In all agro-climatic zones, grass receiving fertiliser applications of 400 kg N ha^{-1} was projected to outyield legume swards grown as either monocultures or mixtures. Nevertheless, the yields obtained from red clover and galega grown as monocultures could potentially produce yields similar to a grass-based system receiving 200 kg N ha^{-1}. Moreover, this result appears to be true right across northern Europe. With the exception of agro-climatic zone A, lucerne grown as a monoculture or as a mixture, and red clover grown as a mixture perform relatively well. However, relative to the yield of grass, lucerne grown as a monoculture performs better in the four most southerly agro-climatic zones (E, F, G and H), while the reverse is true for red clover monocultures. In contrast, the grass-white clover swards tend to perform better in the agro-climatic zones that have their first cut in May or June (D, E, F, G and H) as opposed to July. The computer simulations, as well as the experimental trial results (Halling, *et al.*, 2002), suggest that the yield of lotus is probably too low for this legume to be worthy of consideration under the environmental conditions experienced in northern Europe.

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Summary of plenary discussion

1 Coefficient of inequality

Initial questioning concerned the definition of Theil's coefficient of inequality, which was not familiar to most of the audience. Theil's coefficient ranges from 0 to 1 and looks at how well the model is describing observed results: a value of zero indicates that the model provides a perfect fit to the data, whilst a value of 1 indicates that the model predictions are completely unrelated to measured values. Theil's values less than 0.35 are very good: it may be helpful to consider values as analogous in some way to 1 minus the correlation coefficient (r). There was also some questioning of the definition of bias, which was explained as the degree to which the model consistently over- or under-predicts observed values.

2 Agro-climatic zones

It was commented that the modelling based on agro-climatic zones was better than many national evaluations that follow political boundaries. It was suggested that the model could be used to 'translate' results for a particular crop into another agro-climatic region by calibrating the crop on the first trial and then using climatic information from a different zone. However, the discussion also highlighted dangers in this approach and the authors felt that it would not be appropriate, for example, to choose sites for agronomy experiments solely on the basis of their generating a wide range between the lowest- and highest-yielding plots. In this context it will be useful to run the sensitivity analysis (that was run alongside the agronomy experiment) to look at the predicted sensitivity in the yields of different species to site variations.

3 Validation of model

The scientists who conducted the agronomic evaluations were aware of biotic and abiotic factors that were not included in the growth model and which *explain some of the discrepancies between model and observed values. For example, low yields of galega in the UK were associated with failures during the establishment of the crop leading to very low plant populations, whilst damage by mice was an issue on some sites in Germany. Thus, it is important to make informed comparisons of predicted and observed yields in addition to the purely statistical evaluations. In some situations the model may be providing a better prediction of potential yields than was provided in the agronomy experiment.*

There was scepticism about the model predictions of lower yields for legume-grass mixtures than for corresponding pure legumes. This was in contrast to strong evidence from the agronomy experiment and suggests that the model does not yet properly incorporate some of the factors involved in grass-legume competition.

There was some questioning of the use of average daily temperatures as a major driver of the model, but this was not regarded as a limitation when working on a daily basis as there inevitably are strong associations between minimum, average and maximum temperatures. Water availability is another major driver of the model and the model is clearly limited by the quality of 'soil' information that is available. The model describes soil in terms of its abilities to hold water and to deliver N in the absence of any fertiliser and these were often assumed on the basis of soil type (sand, silt, loam, clay etc.). These limitations were partly overcome by running the model using three years of weather data for three representative sites to obtain average values within each agro-climatic zone.

Reporter: R.J. Dewhurst

An economic assessment of the potential for increasing the use of forage legumes in north European livestock systems

Chris J. Doyle[1] and Cairistiona F.E. Topp[1]

Abstract

A methodology to determine the production costs and economic values of a variety of forage legumes harvested for silage has been developed and applied to the experimental results from the LEGSIL trials, together with computer simulated yields, to determine the comparative profitability of the different forage crops. The results indicate that potentially red clover (*Trifolium pratense* L.), and to a lesser extent white clover (*Trifolium repens* L.) and lucerne (*Medicago sativa* L.), can produce higher profits per hectare than grass-based systems using high levels of inorganic nitrogen. This outcome appears to be true right across northern Europe. Galega (*Galega orientalis* Lam.) and lotus (*Lotus corniculatus* L.) can be, in certain circumstances, economically competitive with fertilised grass swards, but would generally not be the forage legumes of first choice. However, from an economic standpoint, forage legumes are probably best grown in a mixture with grass. Finally, forage legumes, with their ability to fix nitrogen biologically, are especially attractive for organic production systems. Under careful management, the use of forage legumes for silage can result in profits per hectare higher than those obtained from conventional grass-based systems.

Introduction

Using the forage yield data and animal performance figures recorded in the LEGSIL trials, an economic assessment of the potential for increasing the use of forage legumes in livestock systems in northern Europe has been undertaken. Thus, the first part of this paper reports on the methodology used in the economic assessment and the results. However, although the experimental trials cover 12 sites in four countries (UK, Germany, Sweden and Finland), it is difficult to extrapolate confidently the results to other areas in northern Europe. Accordingly, the process-driven mathematical model of grass-legume swards, described in Topp and Doyle (2002), has also been used to provide a broader economic assessment of the potential of forage legumes. In the second part of the paper, the results are reported for the eight agro-climatic zones, described in Topp and Doyle (2002). Finally, as some of the experimental sites in the LEGSIL trials involved organic treatments, the third part of the paper includes an assessment of the comparative economics of organic systems of production, based on forage legumes, relative to conventional grass-based systems.

Cost-benefit analysis of legume silages based on trial results

Methodology

Using the results from the first two harvest years of the LEGSIL trials (Halling *et al.*, 2002), the comparative costs and benefits of growing and feeding legume silages, both as sole feeds and mixtures with grass, in place of grass silage have been examined. To undertake this economic evaluation, it was necessary to devise a framework for both costing forage production and, more problematically, putting a value on silage, which is not traded and so has no reported price. The underlying methodology employed in the economic evaluation of forage legumes sought to address three issues, namely:

i. what were the cost elements involved in growing and producing legume silages and how should they be valued;

ii. what were the economic values to be attached to the different legume silages; and

iii. how were the net financial benefits to livestock farmers of replacing grass by legume silages to be objectively assessed.

In terms of estimating the costs of silage production, these were divided into three components, namely i) the annual costs of establishing the forage crop, ii) the annual costs of maintaining the crop and iii) the costs of harvesting and ensiling the crop per tonne dry matter (DM). Detailed data on the operations and costs involved were collected for the UK, while comparable costs for Germany, Sweden and Finland were extrapolated using published price indices for machinery, fuel, labour and other purchased inputs in the different countries.

Estimating the value of the silage produced was much more difficult, as very little forage legume

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silage is currently traded. Accordingly, two very different approaches to deriving economic values were explored. The first involved estimating the *theoretical* value by imputing the value of the silage from the prices paid for purchased hay and concentrate feeds. The second method involved estimating the *actual* value of the legume silage from the observed experimental responses in terms of milk yield (Bertilsson *et al.,* 2002). While the former method is subject to errors inherent in the models used, the latter suffers from errors associated with measurement and variation between cows and trials. Thus, it is not possible to pronounce one method as more accurate than another. For this reason both methods were employed and are explained in more detail in Wilkins *et al.* (2002).

For mixed grass-legume silages, the position was more complex, since the value of the silage is not independent of its composition. In the trials, the average composition of the herbage cut for silage over the two harvest years varied for the four countries. However, consistently in the UK, the percentage of leguminous material in the cut forage was lower than at the continental trial sites. Given this, it was decided to consider the value of grass-legume silages at two different compositions. For the high-legume silages, the percentage of legume in the silage was set close to the mean of the Finnish, Swedish and German data, while the low-legume silage was equated with the levels achieved in the UK. The assumed percentage of the silage dry weight accounted for by leguminous material for high- and low-legume silages is shown in Table 1.

Nevertheless, the attraction of growing forage crops is not determined by either the costs of production or the economic value of the feed, but by the profitability per hectare. To determine the comparative profitability of feeding the different silages to dairy cows, the costs per hectare were initially subtracted from the total imputed value of the ensiled crop. However, this calculation ignores the fact that, because of differential forage yields and silage intakes, a different number of cows per hectare can be supported by the different forage silages. To take account of this, it was necessary to estimate the opportunity cost of the land. Thus, if one forage crop required more land than grass silage to support a given herd size, then the opportunity cost of the land would measure the benefits foregone in terms of the next best alternative use for the land. In practice, deriving opportunity costs of land was difficult, because it depended strictly on farm-specific considerations. However, a proxy for it was taken to be the current annual rental values for grassland. In theory, a dairy producer short of land could lease additional land at this price.

Results of economic evaluation

Using the reported country mean yields for the first and second harvest years, the costs of producing silage from pure and mixed crops of grass, white clover, red clover, lucerne, lotus and galega are shown in Table 2 for all four countries participating in the LEGSIL trials. Specifically, the costs are expressed in € (kg DM)$^{-1}$ of ensiled material. There are some interesting differences between countries in the ranking of the crops. However, red clover silage consistently has one of the lowest costs of production per kg DM of ensiled material. Mixed grass-legume silages also tend to have lower unit costs of production than pure legume silages, even though grass silage tends to be the most expensive silage to produce, except in Finland. The corresponding estimates for the value of the silage produced are presented in Tables 3 and 4. The estimates of the theoretical value of the silage, based on the nutritional value of the crop and the prices of purchased substitutes (‘Method 1’), are presented in Table 3. For grass-legume silages, the values are presented for silages with low- and high-legume contents, as described in Table 1. The comparable estimates for silage values using the alternative method for imputing the value of the silage, based on silage intake and milk yield (‘Method 2’), are presented in Table 4. As there were no cow feeding trials in Germany, results are only given for the UK, Sweden and Finland and only for those forage combinations fed.

Except in the case of Finland, there is a reasonable measure of agreement between the two methods in terms of absolute values. In general pure legume silages have the highest economic value, with grass at the opposite end of the scale. In the case of Finland, it is apparent that the second method gives values which are about 30 to 50 € (t DM)$^{-1}$ higher. Perhaps the most significant difference between the two methods of approximating the economic value of the silage is with regard to grass. In general, with the second method, grass silage appears more competitive with legume silages.

However, the attraction of growing forage crops is not determined by either costs of production or the economic value of the feed, but by the profitability per hectare.

Table 1:
Assumed percentage of legume by weight in high- and low-legume silages

	High-Legume Silages	Low-Legume Silages
Grass-White clover	40	20
Grass-Red clover	70	40
Grass-Lucerne	40	10
Grass-Lotus	30	10
Grass-Galega	40	5

Table 2:
Average total costs per kg DM of silage for the various forage crops in the UK, Germany, Sweden and Finland, € $(kg\ DM)^{-1}$

Silage Crop	€ $(kg\ DM)^{-1}$			
	UK	Germany	Sweden	Finland
Grass	0.118	0.154	0.148	0.112
White clover	0.116	0.172	0.131	0.127
Red clover	0.107	0.119	0.123	0.113
Lucerne	0.108	0.121	0.142	0.132
Lotus	0.118	0.149	0.140	0.135
Galega	0.117	0.128	0.142	0.123
Grass-White clover	0.110	0.144	0.117	0.110
Grass-Red clover	0.107	0.121	0.118	0.107
Grass-Lucerne	0.109	0.123	0.127	0.117
Grass-Lotus	0.113	0.135	0.124	0.121
Grass-Galega	0.115	0.130	0.125	0.117

Relative to the estimated profits per hectare of grassland, Table 5 presents the projected increase in profits per hectare from growing and ensiling forage legumes either as sole crops or mixtures with grass. The figures are based on the unit production costs in Table 2, the unit value of the feed in Table 3 and the observed mean 'national' forage yields become reported in the LEGSIL trials. Some care is needed in interpreting the figures as clearly the methods used to derive costs and values are subject to significant qualifications. In particular, in quite a number of cases, the imputed value of the crop was less than the estimated costs of production, so that the projected profits were negative. However, this does not invalidate the absolute differences in profits, which do provide a measure of the relative economic attraction of growing and ensiling different forage legumes. On the other hand, it would be unwise to interpret the absolute differences too literally.

To provide some kind of reference framework for the differences in profits, these have been compared with the value of the grass silage crop; these figures are given in brackets. As such, the percentage figures can be equated with the percentage increase in the value of a kg DM of grass silage that would be required for grass to be competitive with the legume-based sward. Expressing the difference in profits as a percentage of the value of the ensiled grass crop, rather than the profits *per se* from the grass crop, was considered more meaningful largely because the estimated profits per hectare for grass silage were negative in two of the countries, as noted previously. In addition, as a residual of the difference between the value of the ensiled crop and the costs of production, profits show considerable fluctuations for small changes in the estimated crop value or production costs.

Table 3:
Estimated value per kg DM of silage using method 1, € (kg DM)$^{-1}$

Silage Crop	€ (kg DM)$^{-1}$			
	UK	Germany	Sweden	Finland
Pure Silages				
Grass	0.117	0.112	0.159	0.138
White clover	0.142	0.126	0.170	0.174
Red clover	0.139	0.121	0.175	0.174
Lucerne	0.131	0.113	0.180	0.168
Lotus	0.131	0.116	0.172	0.163
Galega	0.125	0.114	0.166	0.152
High-Legume Silages				
Grass-White clover	0.129	0.117	0.166	0.156
Grass-Red clover	0.132	0.117	0.171	0.163
Grass-Lucerne	0.124	0.112	0.169	0.152
Grass-Lotus	0.121	0.113	0.163	0.145
Grass-Galega	0.121	0.112	0.163	0.145
Low-Legume Silage				
Grass-White clover	0.123	0.114	0.162	0.147
Grass-Red clover	0.125	0.115	0.165	0.152
Grass-Lucerne	0.120	0.112	0.162	0.143
Grass-Lotus	0.120	0.112	0.162	0.143
Grass-Galega	0.119	0.112	0.162	0.143

Table 4:
Estimated value per kg DM of silage using method 2, € (kg DM)$^{-1}$

Silage	€ (kg DM)$^{-1}$		
	UK	Sweden	Finland
Grass	0.133	0.146	0.204
White clover	0.154	0.165	-
Red clover	0.142	0.151	0.209
Lucerne	0.124	-	-
Lotus	-	-	-
Galega	-	-	0.206
Grass-White clover	0.130	0.159	-
Grass-Red clover	0.143	0.146	0.206
Grass-Lucerne	-	-	-
Grass-Lotus	-	-	-
Grass-Galega	-	-	0.199

Table 5:
Projected economic benefit from growing and feeding a legume or grass-legume silage in place of grass silage[1]

Silage Crop	€ ha^{-1}			
	UK	Germany	Sweden	Finland
Pure Crops				
White clover	177.9 (17.8)	78.3 (7.8)	109.9 (11.0)	13.5 (1.4)
Red clover	292.1 (29.2)	258.4 (25.9)	220.2 (22.0)	143.6 (14.4)
Lucerne	206.6 (20.7)	151.7 (15.2)	68.6 (6.9)	-37.5 (-3.7)
Lotus	88.3 (8.8)	81.4 (8.1)	54.8 (5.5)	-70.2 (-7.0)
Galega	56.8 (5.7)	139.4 (13.9)	19.1 (1.9)	-44.6 (-4.5)
High-Legume Silages				
Grass-White clover	164.8 (16.5)	100.5 (10.1)	255.1 (25.5)	92.9 (9.3)
Grass-Red clover	224.7 (22.5)	203.0 (20.3)	285.6 (28.6)	181.3 (18.1)
Grass-Lucerne	129.0 (12.9)	146.7 (14.7)	141.5 (14.2)	2.85 (0.3)
Grass-Lotus	69.4 (6.9)	105.6 (10.6)	141.7 (14.2)	-58.3 (-5.8)
Grass-Galega	49.4 (4.9)	116.7 (11.7)	133.9 (13.4)	-29.1 (-2.9)
Low-Legume Silage				
Grass-White clover	116.7 (11.7)	85.1 (8.5)	227.7 (22.8)	44.3 (4.4)
Grass-Red clover	163.5 (16.4)	186.2 (18.6)	244.7 (24.5)	115.4 (11.5)
Grass-Lucerne	96.7 (9.7)	146.7 (14.7)	104.7 (10.5)	-37.5 (-3.7)
Grass-Lotus	62.1 (6.2)	99.6 (10.0)	136.0 (13.6)	-66.4 (-6.6)
Grass-Galega	36.0 (3.6)	116.7 (11.7)	128.3 (12.8)	-38.0 (-3.8)

[1]Value of forage derived using Method 1. Figures in brackets are increase in profits expressed as a percentage of the value of the grass silage crop on a grass only sward receiving 200 kg N ha^{-1}

From Table 5 it is possible to prepare a ranking in terms of the profitability of the different forage crops per hectare and this is presented in Table 6. This table shows a number of similarities and differences between countries in terms of the ranking of the forage crops, which may be summarised as follows:

i. Red clover and grass-red clover mixtures are consistently among the most profitable forage crops.

ii. With the exception of Finland, grass alone is projected to be the least profitable forage crop.

iii. With the exception of Germany, white clover, especially as part of a grass-clover ley, appears to be an attractive forage crop.

iv. Lotus and galega, whether as pure crops or mixtures, are generally projected to be less profitable than red clover, white clover and lucerne.

v. Except in the UK, forage legumes generally appear to perform better as part of a grass-legume mixture than as sole crops.

The equivalent estimates of comparative profitability, based on estimates of the crop value derived from observed silage intakes and milk yields ('Method 2'), are presented in Table 7. Because of the large number of missing values, it is difficult to assess whether the change in the method of valuing the crops realistically affects the relative ranking of them. However, it is clear that the differences, relative to grass, in profitability tend to be smaller than with Method 1 and grass is apparently at less economic disadvantage. Thus, the second method of valuing the forage crops produces less clear cut evidence of the economic attraction of growing and feeding forage legumes. Nevertheless, red and white clover do tend show some economic benefit compared to grass silage.

Table 6:
Relative ranking of forage crops, in terms of profitability, estimated using method 1 (1 = highest value)

	UK	Germany	Sweden	Finland
1	Red clover	Red clover	# Grass–Red clover	# Grass–Red clover
2	# Grass–Red clover	# Grass–Red clover	# Grass-White clover	Red clover
3	Lucerne	* Grass-Red clover	* Grass-Red clover	* Grass-Red clover
4	White clover	Lucerne	* Grass-White clover	# Grass-White clover
5	# Grass-White clover	* Grass-Lucerne	Red clover	* Grass-White clover
6	* Grass-Red clover	# Grass-Lucerne	# Grass-Lotus	White clover
7	# Grass-Lucerne	Galega	# Grass-Lucerne	# Grass-Lucerne
8	* Grass-White clover	# Grass-Galega	* Grass-White clover	Grass
9	* Grass-Lucerne	* Grass-Galega	# Grass-Galega	# Grass-Galega
10	Lotus	# Grass-Lotus	* Grass-Galega	Lucerne
11	# Grass-Lotus	# Grass-White clover	White clover	* Grass-Lucerne
12	* Grass-Lotus	* Grass-Lotus	* Grass-Lucerne	* Grass-Galega
13	Galega	* Grass-White clover	Lucerne	Galega
14	# Grass-Galega	Lotus	Lotus	# Grass-Lotus
15	* Grass-Galega	White clover	Galega	* Grass-Lotus
16	Grass	Grass	Grass	

# Denotes grass-legume silages with a high legume content
* Denotes grass-legume silages with a low legume content

Table 7:
Alternative projected economic benefit from growing and feeding a legume or grass-legume silage in place of grass silage [1]

Silage	€ ha^{-1}		
	UK	Sweden	Finland
White clover	115.0 (10.1)	176.4 (15.5)	-
Red clover	178.2 (15.7)	170.0 (14.9)	-72.7 (-6.4)
Lucerne	5.8 (0.5)	-	-
Lotus	-	-	-
Galega	-	-	-225.1 (-19.8)
Grass-White clover	33.5 (2.9)	296.5 (26.1)	-
Grass-Red clover	183.0 (16.1)	203.2 (17.8)	48.7 (4.3)
Grass-Lucerne	-	-	-
Grass-Lotus	-	-	-
Grass-Galega	-	-	-175.5 (-15.4)

[1]Value of forage derived using Method 2. Figures in brackets are increases in profits expressed as a percentage of the value of the grass silage on a grass only sward receiving 200 kg N ha^{-1}

Table 8:
Mean estimated values for silage and costs of production for different forage crops, € (kg DM)$^{-1}$

	Grass 200 kg N ha^{-1}	Grass 400 kg N ha^{-1}	Grass-White clover	Grass-Red clover	Grass-Lucerne	Grass-Lotus	Grass-Galega
Value	0.142	0.142	0.139	0.143	0.137	0.135	0.135
Cost	0.133	0.132	0.120	0.113	0.119	0.123	0.122

Economic Assessment of Forage Legumes Using Mathematical Simulations

Estimation of forage legume yields for each agro-climatic zone

From the inception of the study, it was always intended to develop a mathematical model of the herbage production and conservation for legume and grass-legume swards, which could be used to explore the sensitivity of the results to changing economic and environmental circumstances, as well as to extrapolate the trial results to all regions of northern Europe. In particular, a model offers the opportunity to undertake an economic assessment of the potential of forage legumes in countries not included in the trials. To this end, the model developed by Topp and Doyle (2002), as part of the LEGSIL project, was applied to the 8 agro-climatic zones into which Topp and Doyle (2002) divided northern Europe. Three 'representative' weather stations were selected for each agro-climatic zone (see Topp and Doyle, 2002, Table 7) and daily weather data for 3 years was extracted for each site. The simulated mean harvested yields within each agro-climatic zone for grass, white clover, red clover, lucerne, lotus and galega, along with grass-legume mixtures, were derived (see Topp and Doyle, 2002, Table 8). In the case of pure grass swards, it was considered that limiting nitrogen use to just 200 kg N ha^{-1} was unrealistic and that many dairy farms would apply much higher levels, at least in areas with high yield potential. For this reason the yields at 400 kg N ha^{-1} were also simulated.

Economic evaluation of forage legumes

As the agro-climatic zones do not coincide with nation states, it was decided to conduct the economic evaluation using a 'standard' set of prices and costs. These 'standard' prices and costs were equated with the average of the unit values and costs for the UK, Germany, Sweden and Finland, derived using Method 1. The standard prices and costs used are shown in Table 8. Assuming 20 per cent dry matter losses in ensiling and applying these costs and prices to the simulated mean ensiled yields in each zone produced the estimated increases in profits per hectare presented in Table 9. In each case the increase represents the anticipated improvement in profits relative to growing pure grass fertilised at a rate of 200 kg N ha^{-1} and ensiling it. In determining profits, allowances were made for the opportunity cost of land, as explained earlier. This was equated with the mean land rental value of 183 € ha^{-1}.

Using the estimated mean value of the silage crop obtained from pure grass swards receiving 200 kg N ha^{-1} as a reference point, Table 10 expresses the projected gains in profitability from growing the alternative forage crops, including grass receiving 400 kg N ha^{-1}, as a percentage of this base figure From Tables 9 and 10 six things are evident:

vi. Red clover, whether grown as a pure crop or in a mixture with grass, appears to outperform silage systems based on pure grass swards receiving 400 kg N ha-1.

vii. White clover and lucerne, either as pure crops or mixtures, appear to outperform consistently silage systems based on pure grass receiving 200 kg N ha^{-1} and are generally competitive economically with heavily fertilised (400 kg N ha^{-1}) grass systems.

viii. Relative to lucerne, white clover appears a more attractive legume in the north and west of the region. However, moving south and east, the attraction of growing lucerne increases.

ix. In contrast to the trial results, galega sown as a pure crop is also predicted to be competive with grass-based systems. However, grass-galega systems consistently yield slightly lower potential profits than grass systems receiving 200 kg N ha^{-1}.

x. Systems based on lotus, whether sown as a pure crop or as a mixture, tended to be outperformed by grass-based systems, even when the latter only received 200 kg N ha^{-1}.

xi. In contrast to the results based on the LEGSIL trials, legume-grass mixtures are not projected to confer an advantage over pure legume crops, when fed as silage.

xii. Overall, these conclusions bear out the earlier findings, based on the economic evaluation of the trial data that white clover, red clover and lucerne in particular have potential to replace grass as silage crops in northern Europe.

Profitability of organic legume-based systems

As some of the experimental sites involved organic treatments, the analysis has been extended to include an assessment of the comparative economics of organic systems of production based on forage legumes, relative to conventional grass-based systems. Fundamentally, production costs will differ through having no fertilisers and sprays, as well as more mechanical treatments during establishment. Ensiling will also differ in that an inoculant, rather than formic acid, will be used for crop preservation. On the other hand, it is justifiable to assume similar crop yields (see Halling *et al.,* 2002) and forage quality, as well as similar milk yields. However, the milk prices can be expected to differ from those for conventional systems, due to the premium paid for organic milk. In the UK the current organic milk price premium is about 80 per cent. The comparable premiums in Germany, Sweden and Finland are lower at 40, 20 and 10 per cent respectively. The corresponding costs of producing organic silage are presented in Table 11. In this case, the comparison is made with a conventionally grown crop of grass silage, receiving 200 kg N ha^{-1}. While the ranking of the legume and grass-legume silages is unchanged from that for conventionally grown forage, it can be seen that, so long as equivalent yields to conventionally managed crops can be obtained, unit costs of production would appear to be reduced by between 15 and 20 per cent, making grass an even less attractive crop. Alternatively, the costings can be interpreted to suggest that silage yields from organic forage legumes could be reduced by between 15 and 20 per cent, compared to conventionally grown crops, and still be competitive with fertilised grass swards in terms of the costs of producing a given volume of silage.

Table 9:
Projected increase in mean profits per hectare, relative to a growing and feeding grass silage fertilised at a rate of 200 kg N ha^{-1} for different ensiled forage crops by agro-climatic zone, € ha^{-1}

Forage Crop	Agro-climatic zones							
	A	B	C	D	E	F	G	H
Grass, 200 kg N ha^{-1}	-	-	-	-		-	-	-
Grass, 400 kg N ha	19.4	18.2	22.4	25.8		31.4	30.8	34.0
White clover	11.2	23.4	20.5	32.0	27.0	32.9	37.9	36.2
Red clover	53.5	89.9	95.1	112.4	129.7	134.8	141.5	134.7
Lucerne	7.7	31.6	38.6	43.8		70.4	73.9	71.1
	-6.4	-12.8	-19.0	-22.3	-44.5	-29.1	-25.3	-33.3
Galega	15.7	12.9	12.8		30.8	23.1	25.6	26.9
Grass-White clover	3.6	18.5	19.5	32.1	46.2	41.5	44.1	44.1
Grass-Red clover	25.8	64.3	72.7	91.8	133.3	118.0	117.9	123.0
Grass-Lucerne	8.5	25.0	32.6	33.3	45.2	29.3	31.2	34.6
Grass-Lotus	-5.4	-6.8	-9.1	-4.4	-14.4	-3.9	-3.0	-3.5
Grass-Galega	-2.4	-0.9	0.2	-1.3	2.7	-10.6	-8.9	-10.6

Table 10:
Improvement in profits over systems based on grass swards receiving 200 kg N ha^{-1}, expressed as a percentage of the value of the ensiled grass crop

Forage crop	Agro-climatic zones							
	A	B	C	D	E	F	G	H
Grass, 200 kg N ha^{-1}	-	-	-	-	-	-	-	-
Grass, 400 kg N ha^{-1}	5.1	2.9	3.0	3.2	3.1	3.0	3.0	2.9
White clover	2.9	3.7	2.8	3.9	2.2	3.2		3.1
Red clover	14.1	14.3		13.7	10.5	13.0	13.8	11.6
Lucerne	2.0	5.0	5.2		6.5	6.8	7.2	6.1
Lotus	-1.7	-2.0	-2.6	-2.7		-2.8	-2.5	-2.9
Galega	4.1	2.0	1.7	2.8	2.5	2.2	2.5	2.3
Grass-White clover	0.9	2.9	2.6	3.9	3.7	4.0	4.3	3.8
Grass-Red clover	6.8	10.2	9.9	11.2	10.8	11.4	11.5	10.6
Grass-Lucerne	2.3	4.0	4.4	4.1	3.6	2.8	3.0	3.0
Grass-Lotus	-1.4	-1.1	-1.2	-0.5	-1.2	-0.4	-0.3	-0.3
Grass-Galega	-0.6	-0.1	0.0	-0.2	0.2	-1.0	-0.9	-0.9

Table 11:
Average total costs per kg DM of silage for organically-grown forage crops in the UK, Germany, Sweden and Finland, € (kg DM)$^{-1}$

Silage crop	€ (kg DM)$^{-1}$			
	UK	Germany	Sweden	Finland
Grass (*Grown conventionally)*	0.118	0.154	0.147	0.112
White clover	0.095	0.151	0.110	0.106
Red clover	0.086	0.098	0.102	0.092
Lucerne	0.087	0.100	0.121	0.111
Lotus	0.097	0.128	0.119	0.114
Galega	0.096	0.107	0.121	0.102
Grass-White clover	0.089	0.123	0.096	0.089
Grass-Red clover	0.086	0.100	0.097	0.086
Grass-Lucerne	0.088	0.102	0.106	0.096
Grass-Lotus	0.092	0.114	0.103	0.100
Grass-Galega	0.094	0.109	0.104	0.096

Table 12:
Estimated value per kg DM of organic silage using second method, € (kg DM)$^{-1}$, expressed relative to grass silage grown conventionally

Silage	€ (kg DM)$^{-1}$		
	UK	Sweden	Finland
Grass	0.133	0.146	0.203
White clover	0.276	0.198	-
Red clover	0.255	0.181	0.230
Lucerne	0.223	-	-
Lotus	-	-	-
Galega	-	-	0.226
Grass-White clover	0.234	0.191	-
Grass-Red clover	0.257	0.175	0.226
Grass-Lucerne	-	-	-
Grass-Lotus	-	-	-
Grass-Galega	-	-	0.219

Table 13:
Projected economic benefits of organic legume-based production systems compared to conventional grass-based systems of production [1]

Silage	€ ha^{-1}		
	UK	Sweden	Finland
White clover	1048.3 (92.2)	437.1 (38.4)	-
Red clover	1367.3 (120.2)	465.5 (40.9)	133.2 (11.7)
Lucerne	1030.8 (90.7)	-	-
Lotus	-	-	-
Galega	-	-	-65.4 (-5.7)
Grass-White clover	1034.7 (91.0)	652.8 (57.9)	-
Grass-Red clover	1366.5 (120.2)	544.1 (47.9)	292.7 (26.2)
Grass-Lucerne	-	-	-
Grass-Lotus	-	-	-
Grass-Galega	-	-	7.5 (0.7)

[1]Value of forage derived using Method 2. Figures in brackets are the increase in profits expressed as a percentage of the value of the grass silage crop on a grass only sward receiving 200 kg N ha^{-1}

With organic production systems, the value of the forage silages might be expected to be enhanced, at least under the second valuation method, due to the higher price paid for organic milk. The results of applying the organic milk price premium to the estimation of silage values for legume and grass-legume silages is shown in Table 12. In this case the comparison is with grass silage grown conventionally, receiving 200 kg N ha^{-1}, and no organic milk price premium. It can be seen that, although the relativities are not altered, silage values for the legume forages are increased by nearly 100 € $(t\ DM)^{-1}$ in the UK, 30 € $(t\ DM)^{-1}$ in Sweden and 20 € $(t\ DM)^{-1}$ in Finland.

Obviously, forage legumes, with their ability to fix nitrogen biologically, are especially attractive for organic livestock production systems. Using the estimated values of organic silage in Table 12 and the production costs in Table 11, it is possible to project the economic benefits of growing and feeding organically produced forage legumes in place of fertilised grass silage. The economic benefits relative to conventional fertilised grass systems are presented in Table 13. This shows that, using forage legumes in place of fertilised grass, organic systems could achieve profits in excess of those for conventional grass-based systems for selected legumes. In particular, organic systems based on red clover and white clover, whether grown as sole crops or in mixtures with grass, look especially promising, showing improvements in profits, expressed as a percentage of the value of the equivalent silage crop harvested from a grass sward receiving 200 kg N ha^{-1}, in excess of 75 per cent in the UK. Much the same picture is evident in Sweden, but the improvements are smaller (around 10-30 per cent), due to the much lower price paid for organic milk. Only in Finland is there some evidence that systems based on forage legumes and organic milk production may not consistently outperform conventional grass-based dairy systems.

Conclusions

From the economic analysis of both the trial data and the model results, the following general observations can be made:

i. Red clover and, to a lesser degree, white clover and lucerne potentially could produce higher profits per hectare than grass-based systems using high levels of inorganic nitrogen. Moreover, this result appears to be true right across northern Europe.
ii. In contrast, legumes, like galega and to a lesser extent lotus, can be economically competitive with fertilised grass crops, but would not generally be the forage legumes of first choice.

iii. In general, from an economic standpoint, forage legumes are probably best grown in mixtures with grass rather than as sole crops, although the simulated yields did not confirm this finding from the experimental trials.

iv. The use of forage legumes in organic systems, under careful management, may result in these livestocks systems producing profits per hectare equal to those obtained on conventional grass-based ones.

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Summary of plenary discussion

1 Soil improvement and N-transfer to subsequent crops

No account was taken of these effects in the economic analysis.

2 Reeseeding costs

These are likely to be higher with legumes than with grass, but represent a minor part of total cost.

3 Cutting strategy

It was accepted that the cutting strategy used in LEGSIL may not have been biologically and economically optimum for all species.

4 Variability

It was suggested that variability in establishment and production from year to year may be higher for legumes than for grass, thus giving higher economic risks.

Reporter: J. Nousiainen

Report of Working Groups

Three Working Groups discussed the importance of forage legumes and relevance of the LEGSIL results to different regions of northern Europe. The Chairmen of the Groups gave brief reports to the whole Workshop and major points are summarised here.

The discussion within the Nordic and Maritime Groups centered around five questions provided by the Workshop organisers as a possible framework for the discussion and their reports follow a similar format. The Continental Group followed a slightly different approach and identified and discussed a number of points of key importance for the further development and importance of legume-based systems.

Report of Working Group – Nordic Region

Chairman: Magne Mo

What are the major remaining problems with forage legumes ?

- *Establishment of galega and lotus* Problems with galega establishment in the LEGSIL experiments, particularly at southern sites may have arisen from (a) unsuccessful inoculation (b) a large proportion of hard seeds or (c) strong competition from unsown species. Lotus competes poorly with weeds, but weeds may be retarded by use of a suitable nurse crop, which may stimulate lotus growth during the establishment year.
- *Persistence* The period of two trial years is too short time for the comparison of legume species with different growth habits. During so short a time the real persistence and yield characteristics cannot be solved. As extreme examples, red clover may last for only two years, but galega will persist for more than six years.The poor resistance of red clover against diseases and frost and its sensitivity to trampling damage are weaknesses with this species.
- *Ensiling* It was accepted that successful ensiling techniques had been identified and that baling may be attractive in many situations. However, farmers need a quick analytical method at the point of harvest for determining the fermentation coefficient and thus the requirement for preservatives.
- *Animal health* Problems with animal health (bloat, cyanogenic compounds in white clover etc.), are much greater with grazing than with silage. However, in some cases, problems in fertility have been caused by a high content of plant estrogen in red clover. Also, feeding legumes to cows during the period preceding calving has resulted in milk fever, because of the high content of calcium in the forage and some metabolic problems may result from the high protein content in legumes.
- *Milk flavour* In Sweden, flavour defects have been found in milk from organic farms. The abundant use of clover has been blamed, but there could be other reasons. Flavour defects have been noticed at the very beginning of the grazing season. In Finland, silage containing red clover has not caused flavour defects in dairy milk. It was suggested that flavour defects could be avoided by balanced feeding.
- *Environmental effects* The high mineral N content in soil in autumn with pure legumes could be a problem in some areas.

Will the use of legumes for silage increase ?

It was agreed that the use of forage legumes would increase.This would occur particularly with organic farming, but the high levels of production which could be obtained, were also attractive for non-organic systems. It was suggested that on large farms the use of white clover for grazing was decreasing whilst the use of red clover for silage was increasing. It is sensible to use fields close to the farm buildings for grazing, with white clover, whilst the further fields could be sown with red clover harvested for silage.

What species will be most important ?

- In all Scandinavian countries, red clover is considered the most useful silage legume. White clover is commonly grown in Denmark, but it is becoming more important also in Norway and Sweden. In Sweden, the cultivation of lotus is considered possible for certain particular purposes.
- In Baltic countries, the cultivation of lotus and lucerne is increasing together with red and white clover. Galega is still a significant fodder plant and it is harvested for hay as well as for silage. In

discussion, *Trifolium ambiguum* was mentioned as a possible new forage legume.

In what sectors will the increase occur?

- The use of forage legumes containing much protein will primarily increase in feeding milk and suckler cows. However, it has to be kept in mind, that protein content can be too high.
- The use of forage legumes is closely associated with organic farming, but good effects on production are increasing interest in forage legumes also in non-organic farming, provided the cultivation of legumes results in economic advantage.
- The use of legumes is increasing in farms of different sizes, but it was thought that the share of legume silage will increase especially in large farms where there are practical problems grazing with big herds.

What actions would accelerate the rate of adoption of forage legumes ?

- *Technical* Adoption would be increased particularly by the availability of new persistent species and varieties, by more effective inoculation and the development of feeding practices (mixing wagons etc.) which make possible the use of different fodders (e.g.to combine forage legumes containing much protein with other forages, such as whole-crop cereals, containing little protein).
- *Economic* The relative attraction of different systems will be influenced by the provision of subsidies for the production of particular crops (e.g. arable aid payments) or for particular production systems (e.g. organic farming). Also any increase in the price of fertiliser N or of protein concentrate feeds would favour the adoption of legume-based systems.
- ***Technology transfer*** There is a requirement for the provision and promotion of good information on the characteristics of the different legumes and on methods for production, ensiling and utilisation. The featuring and demonstration of good examples of legume utilisation in farm practise would make a major contribution.

Reporter: O. Nissinen

Report of Working Group - Maritime Region

Chairman: Padraig O'Kiely

What are the major remaining problems with forage legumes?

- *Legumes in whole systems* Need to identify the contribution of legume swards (relative to grass swards) during the grazing period (since most silage swards are also grazed) and to establish what incorporating legumes does for the *whole system.*
- *Need to demonstrate reliability and profitability* There are many perceived problems with legumes, including poor spring growth, difficult weed control, limited perenniality, disease, N utilisation, protein degradability and animal health issues (bloat, estrogens). All of this adds up to concern about the reliability of legume systems. The research results are promising, but farmers need to be convinced that there is potential for improvement in profits through the use of legumes relative to N-fertilised grass.
- *Availability of seed and knowledge* There are problems with the availability of seed of suitable cultivars, particularly for minor species, such as lotus. Agronomic knowledge on management and, particularly, seed establishment, including introduction into permanent swards, needs to be more widely available.

Will the use of legumes for silage increase?

It was agreed that the use of legumes, particularly red clover, for silage would increase. It was thought that this would be principally in systems with predominance of cutting rather than grazing.

What species will be most important?

Representatives from the different countries present reflected different views.

- In UK it was thought that white clover would be the most important, with an increase in red clover, and possibly lucerne, on ex-arable land.
- In Ireland white clover and possibly some red clover.
- In the Netherlands there is the possibility for some increase in both red and white clover for cutting.
- In France there was scope for more red clover.

It was also pointed out that there is potential for whole-crop silage based on peas, and for the use of annual medics.

In what sectors will the increase occur?

- Legumes are central to the sustainability of organic systems and there is growth in this sector.
- There are conventional systems that are likely to use more white and red clover, e.g. where there is a need to improve soil structure. In Ireland there is potential for greater use of legume silage on the larger beef and dairy farms.
- In the Netherlands there will be an increase in legumes, because of the adoption of nutrient budgeting systems. At present, no allowance is made for input of N by fixation.

What actions would accelerate the rate of adoption of forage legumes?

- *Economic* Changes in the arable aid framework could encourage greater use of legume crops; policy changes are needed at both national and European levels.
- *Legislation on nitrogen inputs* See comment above concerning impact of nutrient budget systems in the Netherlands
- *Technology transfer* There is still a technology transfer challenge and this needs to be tackled, e.g. by publicity and by demonstration farms and farmlet-scale plots. In the UK, the Forage Legume Special Interest Group of the British Grassland Society was cited as an example of specialist technology transfer. The fundamental question for farmers is: will the adoption of legumes increase profits? Information has to be provided that will enable farmers to make that decision.

Reporter: A. Hopkins

Report of Working Group – Continental Region

Co-Chairmen: E.M. Poetsch and K.H. Suedekum

The discussion focussed on future activities that appear promising based on the reports and outcome of the LEGSIL project as demonstrated in the Workshop. The following seven items were discussed intensively by the Working group.

Competition between maize- and legume-based forage production

Economic and ecological benefits of legume-based forage production systems need to be put forward and publicised in support of integrating these systems into concepts of agricultural policy. At the moment, silage maize is much better supported than grass-clover mixtures and is therefore in strong competition with legume-based forage production in Europe.

Impact on the nutrient budget

From an ecological point of view, there is no doubt that legume-based forage production is an efficient tool to decrease external nitrogen input and can improve nutrient circulation on farms. Self sufficiency with nitrogen is of great importance for organic farming but also for low-input systems in integrated and conventional farming. But, at the same time, aspects of manure management to reduce nutrient losses should be considered to avoid environmental problems and to improve manure usage efficiency.

As regards biological N-fixation, more detailed studies should be carried out to evaluate the N-fixation properties of the different legume species (especially lotus and galega) and the N-transfer to the partner grasses.

Aspects of cultivation and time of utilisation of legume-grass mixtures

To improve the competitive power of grass-clover mixtures, they should be grown as an underseed or with a covering crop and used for a longer duration to compensate the costs of establishment and relatively low productivity in the first year. Research in Alpine regions (Austria and Switzerland) has already shown that legume-grass mixtures can be sustained and utilised for up to five years provided that more than two forage species are involved. Several grass and clover species (a number of up to ten) have been used for such seed mixtures with special consideration of productivity and forage quality (digestibility of organic matter and energy value). Such diverse seed mixtures also reduce the risk of unforeseeable problems with unfavourable weather conditions. In terms of the harsh climatic conditions in Alpine regions, aspects of persistence, endurance and winter hardness are of great interest. Only the best varieties of the different grass and clover species should be used for such quality seed mixtures - the official procedure of variety testing in Austria has therefore been prolonged to six or even seven years to identify the top varieties.

Definition of yield variables

In addition to dry matter and crude protein yields, assessment of yield should include quality traits (digestibility, energy content, protein quality), because dry matter and crude protein yields are not always closely related to forage quality.

Aspects of utilisation and conservation

Utilisation of forage legumes should comprise both silages and green crops, the latter either grazed or cut. Whether legumes can be grazed or not is important for defining production systems that allow best utilisation of forage legumes. Both pure legume and mixed grass-legume swards need to be considered, because pure legume swards are very prone to soil contamination of harvested forage bearing the risk of butyric acid (clostridia sp.) fermentation during ensiling and, when ensiled at higher dry matter concentrations, growth of listeria may occur, which may cause listeriosis, a disease of humans and animals. Pure legume stands also may cause some crop rotation disease (clover weariness) if used for a longer period without an interval.

Protein quality

As a first step in a detailed investigation of legume protein quality, the partitioning of non-protein nitrogen (NPN) fractions of green and ensiled legumes and grass-legume mixtures into amino acid-N and ammonia-N is highly desirable. Further, microbial fixation of degradable crude protein in the rumen and ruminally undegraded protein (UDP) are key aspects of protein quality, which show much variation among legume species. Microbial fixation of ruminally degradable N fractions can be achieved by matching rates of ruminal crude protein and carbohydrate degradation. *Lotus* species have higher proportions of UDP in the total crude protein due to ruminal protein-binding by condensed tannins. Plant breeders may be involved in transferring favourable quality traits of low-yielding species like *Lotus* into high-yielding species, e.g., *Trifolium* species.

Health effects

Phytoestrogens, e.g., in clover species, may restrict the proportion of legumes in rations for sheep and cattle. Moreover, cyanogenic compounds in white clover are also a matter of concern when white clover contributes significantly to total dry matter intake. Observation of health effects, however, requires long-term studies to be conducted.

Concluding comments

R.J. Wilkins[1]

The vigorous discussion at the Workshop confirmed great interest in forage legumes and in the LEGSIL results. All Working Groups forecast increase in the use of forage legumes, with the organic sector likely to be particularly important.

Information and experience currently available is sufficient to justify the promotion of legume-based systems to increase farm profitability. Actions required to increase the rate of adoption were identified, as were priorities for research to further improve the efficiency and environmental impact of such systems.

Rate of adoption would be increased by financial measures and by improved information dissemination. Financial measures could include making forage legumes eligible for arable aid payments, increasing support for conversion to organic farming, taxation on N fertiliser and further actions to restrict farming methods in order to satisfy nutrient budget targets. It was recognised that the Workshop and publication of Proceedings will make an important contribution to information dissemination, as will the production and distribution within the LEGSILIMPACTS project of booklets for farmers and advisors. There is a role for farmer discussion groups to be set up to focus on forage legumes and a case for demonstration farms, funded either nationally or through the EU.

A number of important research topics were identified. The problems of crop establishment and persistence are clearly greater with forage legumes than with grasses. Agronomic research and plant breeding is needed to reduce these problems and thus increase further the reliability of legume-based systems. In relation to the different legume species, lotus presents an enigma. It was shown in the project to be outstanding in producing silages with high levels of feed intake, but disappointing in terms of herbage production. Further research is needed to explore the possibilities of increasing yield by altering management or the variety used and to establish whether the high intake characteristic established with sheep also applies with dairy cows and results in enhanced performance. A coordinated EU programme would be particularly appropriate.

Probably the most important area for further research emerging from the project and the Workshop is the need for further research on nitrogen use efficiency within legume-based systems. The project results indicated that the risk of losses of N compounds to the environment may be greater in legume-based systems than in systems based on grass with modest levels of N fertiliser input. Quantities of mineral-N in the soil in autumn were often higher with pure legumes than with grass receiving N fertiliser, whilst, with the feeding treatments used in the project, the proportion of N in excreta relative to that in milk was increased with legume silages. Several possible approaches to adapt legume-based systems to reduce the risk of N loss were identified and discussed. The requirement for studies at the systems level was recognised, in view of the many possible interactions between summer and winter feeding regimes, different crops and feeds and different strategies for manure management. Such studies should involve both modelling and experimentation and should have high priority for EU funding.

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