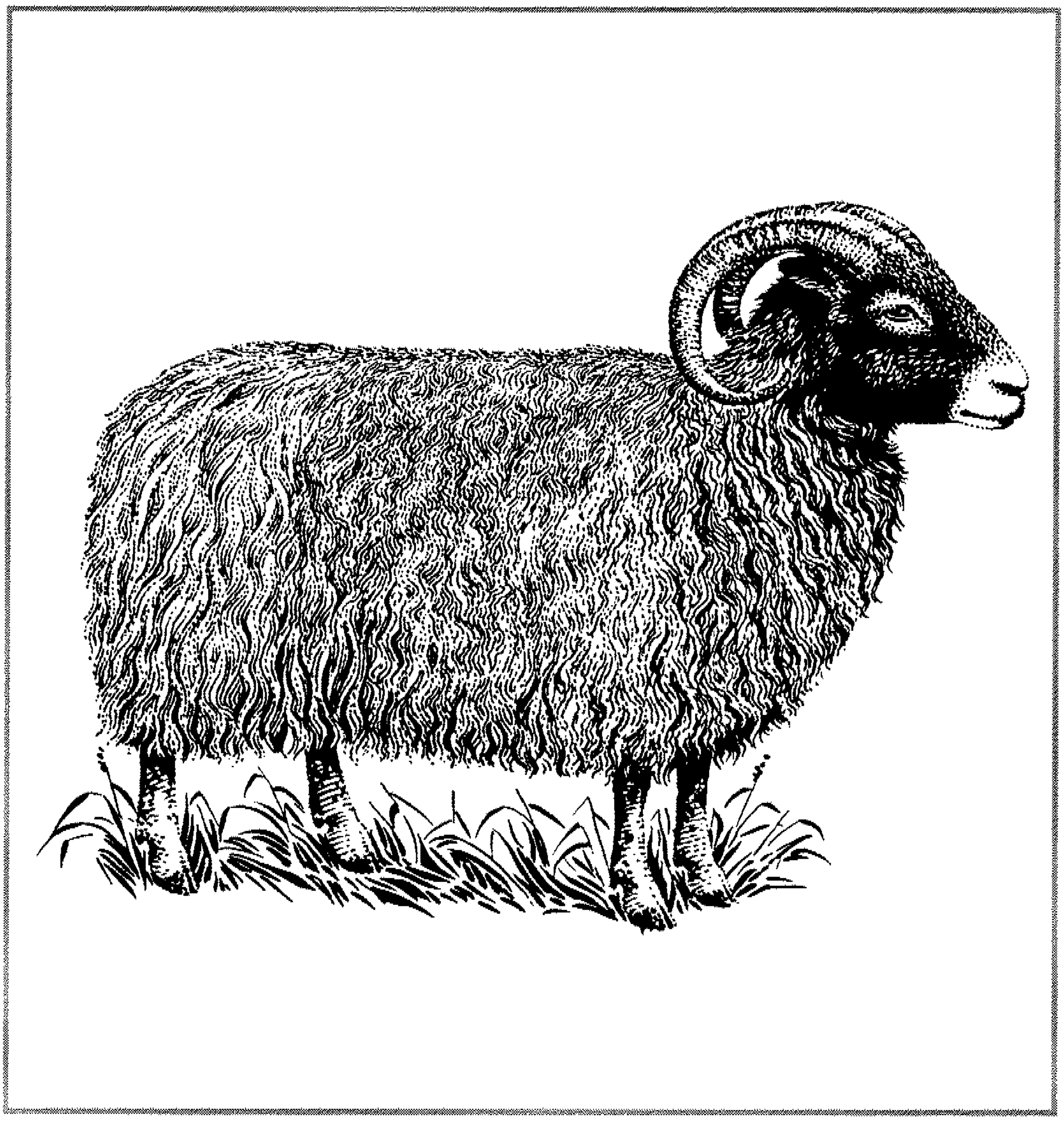
ENGLISH
NATURE

The agricultural productivity of lowland semi-natural grassland

A review

No. 233 - English Nature Research Reports



JOINT NATURE CONSERVATION COMMITTEE

SCOTTISH NATURAL HERITAGE

working today
for nature tomorrow

English Nature Research Reports

Number 233

The agricultural productivity of lowland semi-natural grassland: a review

J.R.B. Tallowin
Institute of Grassland and Environmental Research, North Wyke

ISSN 0967-876X

Contents

ERRATUM

Since reproduction of the report an error has been discovered on **Page 14.** The first sentence under the sub-title ***Nitrogen*** should be replaced with the following text:

"A wide range in nitrogen content (Figure 8) and nitrogen yield (Appendix table 4) was found in hay harvested from semi-natural, agriculturally improved and fertilized grasslands in June and July. The highest nitrogen contents found in unfertilized semi-natural grasslands were associated with relatively species-poor communities (MG10, MG13 and MG6) where soil nitrogen and other nutrient availabilities were assumed to be high and where moist soil conditions occurred."

Summary

A key premise is that management with adapted ruminant production systems will continue to be important for the future survival of much of the semi-natural grassland resource within lowland UK. It is also contended that the management of such grasslands needs to be integrated into farm systems in ways that do not compromise the overall performance of productive livestock. This review examines the agronomic value, in terms of both productivity and quality of forages from lowland semi-natural grasslands and discusses some economic and integrative constraints that their use imposes on livestock farmers.

Dry matter yields obtained from a sample of lowland semi-natural grasslands ranged from about 40 - 80 percent of the yields that might be expected from intensively managed agriculturally improved grass. A general characteristic of the unfertilized and particularly the more species-rich semi-natural grasslands is that they had a considerably lower growth rate in the early part of the growing season compared with agriculturally improved and/or fertilized grasslands. Observed variability in dry matter yields from semi-natural grasslands between years constitutes an unreliability risk that needs to be accommodated in feed budgeting for extensive livestock systems.

All semi-natural grassland soils are an inadequate source of nitrogen for highly productive grass growth and many soils are an inadequate source of other major nutrients. Low soil phosphorus availability appears to be a key factor in allowing high species-richness to be maintained in grasslands. Low nutrient availability in the spring/early summer also appears to be a key factor allowing high species-richness to be maintained. Application of fertilizers to correct for inadequacies in soil nutrient supply and to significantly boost agricultural output is likely to be incompatible with the maintenance of the floristic integrity of a semi-natural grassland. Sustainable management of semi-natural grasslands requires the maintenance of soil conditions that provide an optimum low supply of specific soil nutrients, such as phosphorus and potassium. Hay cutting management alone without any return of nutrients may if continued for many years reduce the soil nutrient supply, particularly potassium, below the optimum for maintaining the floristic diversity of some semi-natural mesotrophic meadow associations. At present only rather general guidelines are available with regard to nutrient inputs to species-rich meadows that would constitute a sustainable management practice. *There is a need for long-term ecological and agronomic studies on effects of occasional inputs of either farmyard manures or inorganic fertilizers: to develop sustainable management systems for semi-natural meadow communities.*

The *in vitro* digestibility of hays from semi-natural grasslands that are cut when most of the constituent species are at an advanced state of reproductive development may be more than 20% lower than cut forages from less phenologically mature, ie predominantly vegetative, intensively managed grassland. A paucity of data on feeding trials with hays from semi-natural grasslands limits the scope for any agronomic evaluation of the potential for such forages to be integrated into the feed budget of productive ruminant livestock. Crude protein content of the hays appeared to be generally adequate for productive livestock, providing other dietary requirements are non limiting. For most of the semi-natural communities of high conservation value the phosphorus content of the hay, or forage, was either below the metabolic requirement of livestock or inadequate to sustain high individual animal performance. Potential problems associated with supplementation of the diet with phosphorus are discussed. The potassium content of most of the hays cut from semi-natural grasslands in July were adequate for productive ruminant livestock requirements. There appears to be an increased risk of sub-optimal potassium contents for productive animals if hay cutting date is delayed until August or September. Deleterious effects on the performance of livestock fed on hays particularly from calcareous soils may arise because of a relatively

high calcium to phosphorus ratio of the forage. The magnesium content of hays from some semi-natural grasslands was below the safe level for productive livestock. Most hays appeared to contain adequate amounts of sodium.The metabolizable energy value of some hays from species-rich semi-natural lowland grasslands were between 10- 40 percent lower than the energy contents of forages cut from intensively managed grasslands. Ways of upgrading the feeding value of late cut hays and reducing losses at hay making are discussed and it is proposed that: *there is a need for research to evaluate treatments for upgrading the quality of late cut hays and to assess effects on intake, performance and health in ruminant livestock. There is also a need for research to identify the most effective mower-conditioner for use on mature species-rich hays to ensure rapid drying time and reduce losses of quality.*

A paucity of published information exists on performance and output from livestock systems based either in part or in full on semi-natural grasslands. Available information indicates that winter grazing of semi-natural grasslands is often only marginally suitable for the maintenance of livestock, such as heavy store animals or dry females, unless supplementary feeding is carried out. *Potential problems associated with supplementary feeding and/or free-range grazing causing long-term damage through nutrient import into semi-natural grasslands highlights a research need to quantify the risk.* An ability to withstand periodic nutritional deficiency would be an essential attribute of livestock used for unsupplemented winter grazing. During the summer most semi-natural pastures were able to sustain either maintenance requirements or modest growth of livestock. Some mesotrophic grasslands were able to support individual animal performances that were comparable to agriculturally managed improved pastures. Utilization levels, sward structural criteria and mineral deficiency problems are discussed in relation to sustainable management criteria for semi-natural grasslands. *There is a need to develop and evaluate models to assist in achieving sound grazing management strategies for lowland semi-natural grasslands.*

The total estimated utilized metabolizable energy (UME) output of unfertilized semi-natural grasslands cut for hay in mid-summer and then either cut or grazed in the autumn may be, at best, only about 60% of the output that is widely achieved from agriculturally improved and managed grasslands. A much larger divergence was found for some grazed lowland wet heaths and fen meadows where the estimated UME output was only *ca.* 20-25 percent of the output achievable from intensively managed permanent pastures.

An agronomically focussed economic case study on the management of a semi-natural grassland is detailed. The risk of such economic appraisals undervaluing the existence value of semi-natural grasslands in landscapes is highlighted. *There is a need for holistic socio-economic evaluation of semi-natural grassland maintenance in the countryside.*

Some potential ways for integrating the management of semi-natural grasslands into productive livestock systems are discussed. The possibility that the use of traditional/rare livestock breeds might offer advantages over modern breeds in the management of different semi-natural grasslands is discussed. *There is a need for research to evaluate potentially useful attributes of rare/traditional breeds, such as resilience/tolerance of periodic nutritional deficiency, behavioural traits and adding value to livestock product.*

The lack of agronomic data for a wide range of semi-natural grassland communities is seen as a severe impedance to the development of integrated livestock systems which might effectively use the forages that they produce.

Introduction

Management, whether by cutting, grazing or a combination of both, is essential to control successional change and maintain species-richness in most lowland semi-natural grasslands (Bakker *et al* 1980; Willems 1983; Ward 1990; Wells & Cox 1993). Whether cut or grazed the forages produced by these grasslands are commonly utilized by ruminant livestock. It is contended that management with adapted ruminant production systems will continue to be important for the future survival of much of the semi-natural grassland resource within lowland UK. For this to be the case, however, the forages will have to make a positive and predictable contribution to the feed budget of productive livestock. This means that forages from semi-natural grasslands need to be integrated into farm systems in ways that do not compromise the overall performance of productive animals, measured in terms of fecundity, milk yield and/or growth rate.

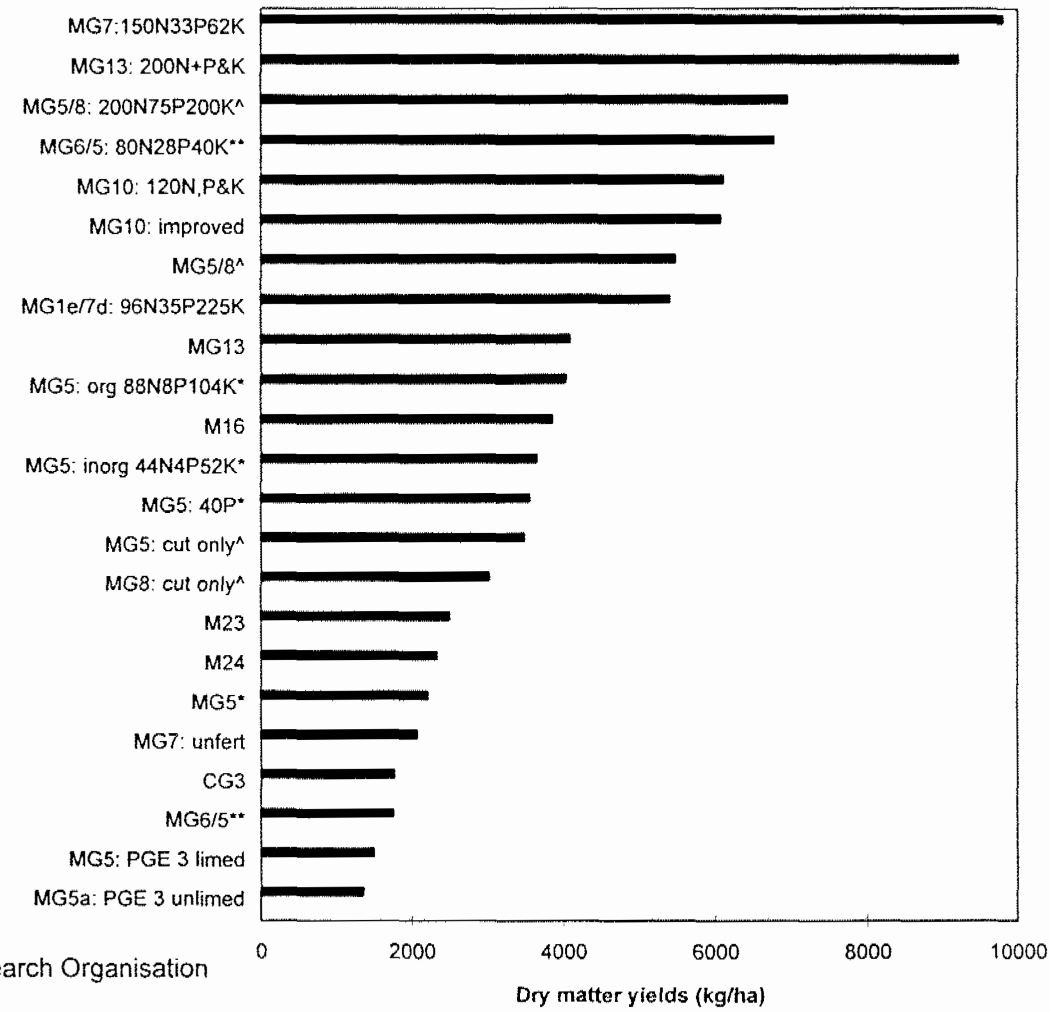
Intensively managed grassland is required to achieve consistently high yields of nutritionally high quality forage within a growing season. The use of inorganic fertilizers provides a means of achieving these goals with a considerable level of predictability. In contrast, the agricultural perception (Wilkins & Harvey 1994) of unimproved unfertilized semi-natural grassland is that agricultural output and predictability are low thus making them relatively unattractive forage resources for livestock farmers today. It has to be recognized, however, that this perception is conditioned by the much higher production expectations, which include a shorter production cycle, higher stocking rates and improved individual animal productivity, of livestock farmers today than of their contemporaries of 40, or more, years ago. It also has to be recognized that present day livestock farmers rely much more heavily on grass and forage as a production feed rather as a source of dietary roughage or maintenance feed. During the 19th and early 20th centuries nutritional requirements of livestock, particularly protein and minerals, were widely met from bought in feeds such as oil-seed cake, cereal grains and industrial bi-products (Duffey *et al* 1974). To improve the perception/acceptability of semi-natural grassland forages as components of the forage/feed budget of productive livestock there is a need to quantify their agronomic value in terms of total and seasonal productivity, forage quality and year to year variability of these parameters.

Dry matter yield from semi-natural grasslands

Primary measures of lowland semi-natural grassland productivity that have agronomic relevance are the yields of herbage that can be harvested either by cutting machinery or the output achieved by grazing livestock. In this review yields of cut herbage, unless stated otherwise, refer to the amount of herbage dry matter harvested above a cutting height of *c*5cm above ground level, this being the average cutting height of most conventional cutter bar and agricultural mowers.The harvested yield information will, therefore, be of limited value for estimating the net productivity of the grasslands (Weigert & Evans 1964; Williamson 1976).

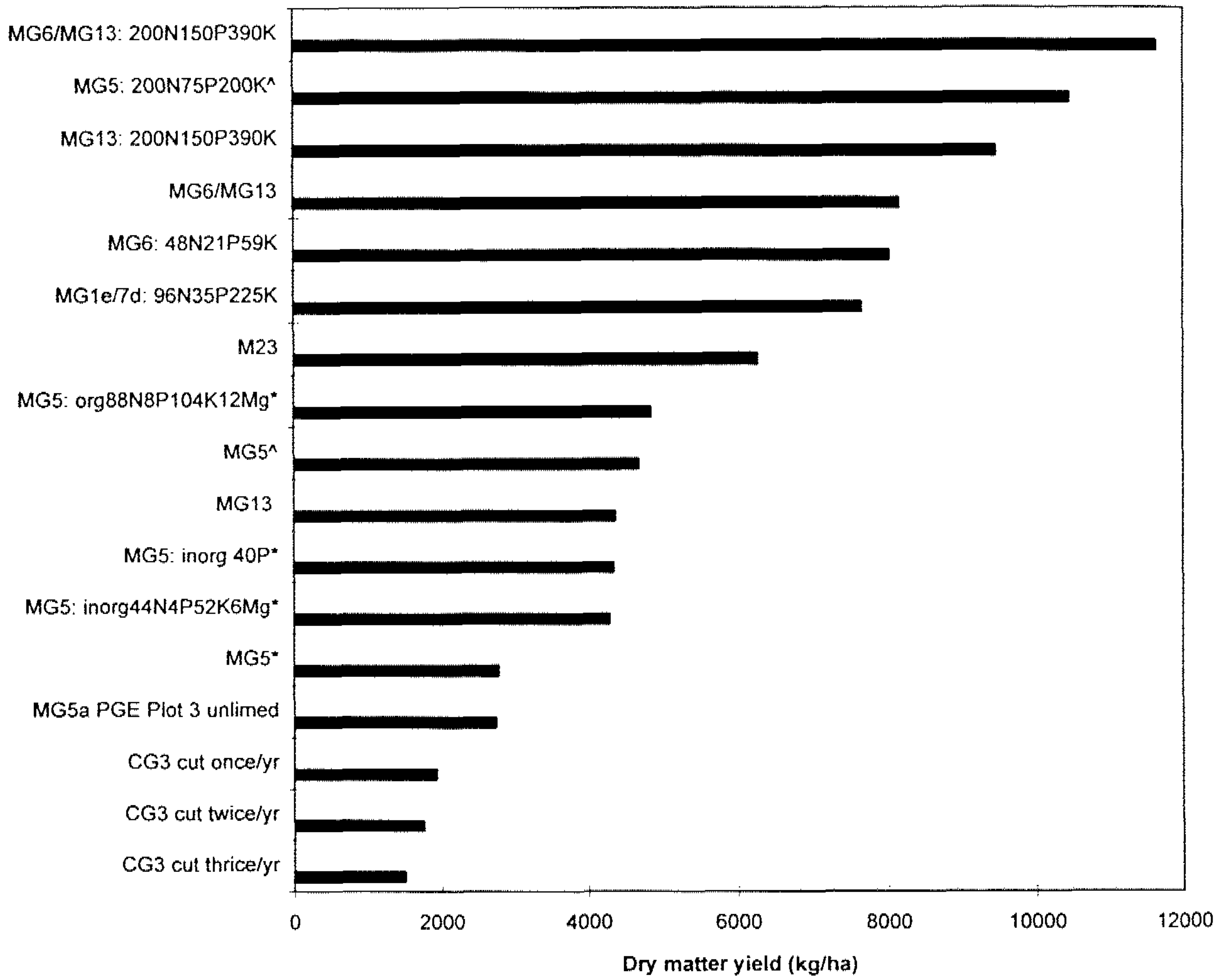
A considerable range in either mid-summer hay yields (Figure 1) or total annual yields, ie the product of one or more cuts during the growing season (Figure 2) can be found in lowland semi-natural grasslands. Data are presented for mesotrophic pastures and meadows of the *Arrhenatherion, Cynosurion* and *Lolio-Plantaginion* associations, chalk grassland and mire associations, representing MG1, MG5, MG6, MG7, CG3, M16, M23 and M24 community types of the National Vegetation Classification (NVC) (Rodwell, 1991 1992), respectively. The sources of data are provided in Appendix table 1. In some cases the yield data are the means of a considerable number of years, for example, the yields from plots 3 and 14 of the Rothamsted Park Grass long-term continuous hay experiment (PGE) represent the mean

Fig. 1 Dry matter yields at the time of hay cutting in June/July in a range of unfertilized semi-natural and fertilized semi-natural oragriculturally improved grasslands in lowland UK.



* Bratoft
** Weed Research Organisation
^ Tadham
PGE + Park Grass Experiment

Fig. 2 Total dry matter yield in a range of unfertilized semi-natural and fertilized semi-natural or agriculturally improved grasslands in lowland UK.



key as in figure 1

values for the 1960-92 period (Jenkinson *et al* 1994), for the Palace Leas plots 6 and 14 the yields are means for a 79 year period (Arnold *et al* 1976), for a chalk grassland at Knocking Hoe in Bedfordshire the yields represent means for a 23 year period (Wells & Cox 1993). In most of the other data sets examined the yield values represent the means of 3-4 consecutive years; for Bratoft meadows in Lincolnshire the means are for the 1972-74 period (English Nature, unpublished) and for the Tadham hay meadows on the Somerset Levels 4-8 years of data were used (Kirkham & Wilkins 1994; Tallowin & Smith 1994). Figures 1 and 2 illustrate the scale of differences in production between some fertilized agriculturally improved permanent pastures and leys and unfertilized semi-natural grasslands which, for a number of comparisons, were in the same locality and on the same soil types. The observed differences range from about 40-80 percent reduction in dry matter yield for the semi-natural grasslands from the yields obtained from intensively managed grass.

The selected yields of the fertilized agriculturally improved pastures are in line with yields observed in a wider study of the productivity of permanent pastures and reseeded grassland by Hopkins *et al* (1990). The data also indicate that only rather loose generalisations can be made on the yield/productivity of particular lowland semi-natural grassland types, presumably reflecting in this study the relatively wide range of climatic conditions represented. For example, the hay yields of unfertilized *Centaureo-Cynosuretum* (MG5) community types at Bratoft, plot 3 of the PGE and at Tadham, differed by up to 2000 kg/ha. Hopkins *et al* (1996) also highlight this considerable variation in yield due to locality in a study of hay yields from unfertilized meadows from six sites in the UK.

The yield of hay cut in July from the semi-natural grasslands examined in this study amounted to about 70 percent of the annual production of dry matter. This percentage accords with values reported elsewhere for semi-natural grasslands (Jeangros & Schmid, 1991).

Early summer growth

A general characteristic of unfertilized and particularly the more species-rich semi-natural grasslands is that they have a considerably lower growth rate in the spring and early summer compared with agriculturally improved and/or fertilized grasslands (Figure 3). Temperate grasses have a linear growth phase during the early part of the growing season (Robson 1981) and, consistent with this, a linear regression model provided the best fit for dry matter yield against time for both the semi-natural and improved grasslands that were examined. The relationships are based on sequential harvests of uninterrupted growth and not regrowths. The sources of data used in this study are provided in Appendix table 1. Lower growth rates of semi-natural grasslands during the early summer means that ceiling yield (Robson (1981)) is achieved later than in improved and/or fertilized grasslands. The later achievement of ceiling yield of semi-natural grasslands has implications for qualitative changes in the forage that will be discussed later.

Variability of yield

Dodd *et al* (1994) using data from the Rothamsted Park Grass 'long-term continuous hay experiment tentatively suggest that biomass variability in grassland may be lower in more species-rich than in the species-poorer communities. This suggestion is also supported by the studies of Olff & Bakker (1991) on an extensification experiment in the Netherlands, where yield variation was recorded for 14 years after cessation of fertilizer application. In their study Olff and Bakker found that variation between years in standing crop was larger at the beginning of the extensification period than in the later years and during this time species-richness increased. One of the possible reasons proposed for such a relationship is that

Fig. 3. Changes in dry matter yield during the early summer in unimproved, unfertilized semi-natural grasslands (open symbols) and agriculturally improved and/or fertilized grasslands (filled symbols)

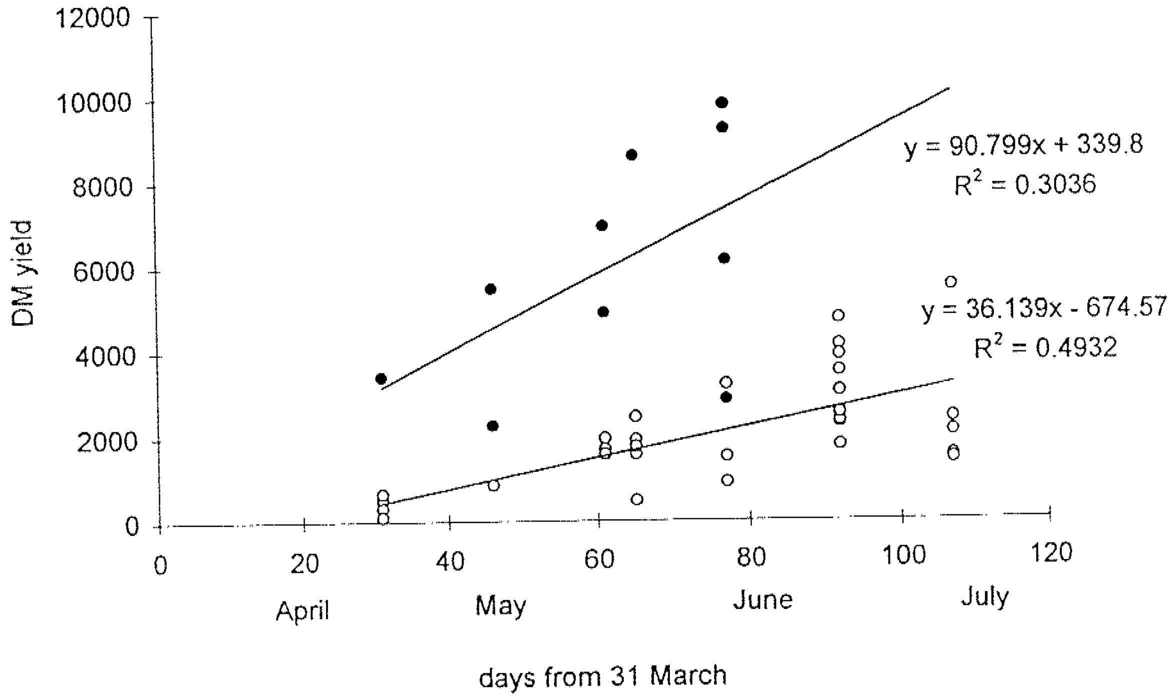
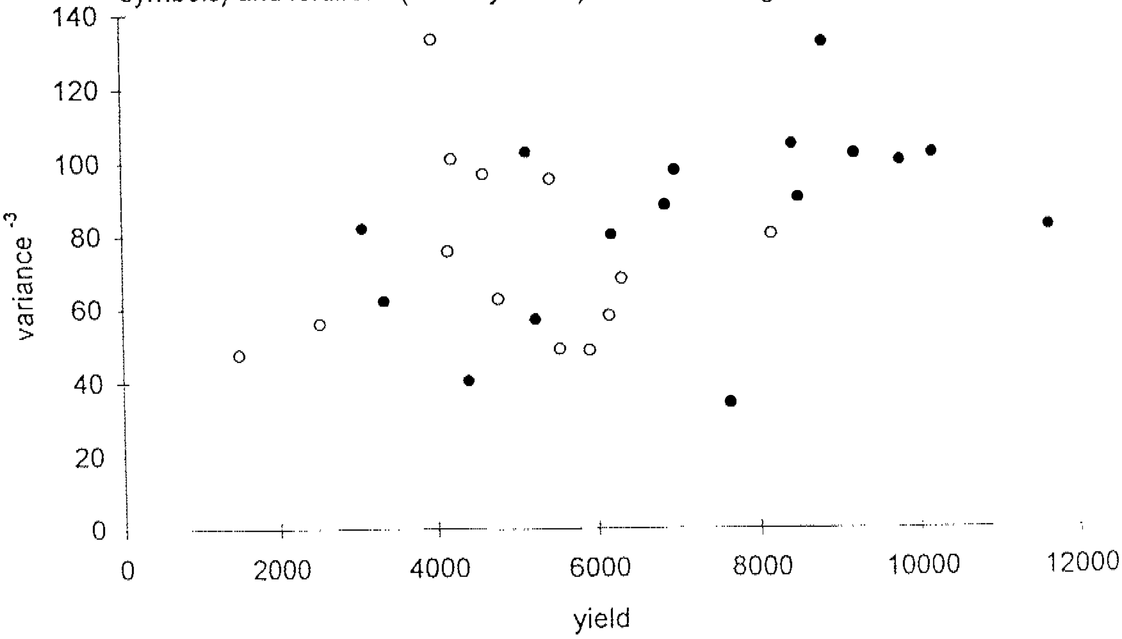


Fig. 4. Variance of yield against yield of dry matter of unfertilized (open symbols) and fertilized (filled symbols) semi-natural grasslands



species-richness may provide a greater buffer against climatic variation than can be expressed in species-poor grasslands. Dodd *et al* (1994) also suggest that there could be an interaction between species-richness, biomass production and soil moisture deficit, with soil moisture deficit being a key factor influencing variability in yield between years. The latter would accord with the findings of Smith (1960).

The variance of the yields of either unfertilized or fertilized semi-natural grasslands at a range of grassland sites including cut and grazed and cut only plots at Tadham Moor (Kirkham & Wilkins 1994a; ibid 1994b; Tallowin & Smith 1994), Bratoft meadows in Lincolnshire (English Nature, unpublished) and an extensification experiment in the Netherlands (Korevaar 1986) was examined (Figure 4; Appendix table 2). No significant relationship between variance and yield was found, although this may be a reflection of the size of the data set. It is apparent, however, that the variances for both species-rich and species-poor/impoverished communities occupied a similar range. It is also apparent that within the sample of species-rich unfertilized meadows higher variances could occur than in the fertilized species-poorer grassland in the same locality, ie under the same climatic and soil type conditions. The high variance in yield from the unfertilized meadows was associated with a particularly dry year. Studies on agriculturally improved grasslands established that the application of fertilizer nitrogen allows more effective use of water for growth (Garwood 1988). It is possible, therefore, that the difference between the fertilized and unfertilized meadows may have been in part due to a greater water use efficiency mediated by the use of fertilizer nitrogen. For semi-natural grasslands less variability of yield over time may occur where raised water levels are maintained through the growing season and thus severity and/or duration of soil moisture deficits are restricted. Low soil nutrient availability appears to provide a low buffer against the effects of water deficit on yield.

From an agronomic perspective greater variability of yield between years has relevance when feed budgeting for livestock systems. Observed differences, for example, between a yield of 5 tonnes of dry matter and 3 tonnes per hectare, constitute an unreliability risk that needs to be accommodated in extensive livestock systems.

Soil nutrient/mineral availability of semi-natural grasslands

Agricultural vs semi-natural grassland management

A fundamental aim of agricultural grassland management is to create and maintain soil conditions that are optimal for productive grasses to respond to applied nitrogen (or for legume nitrogen fixation to occur). All soils are an inadequate source of nitrogen for highly productive grass growth and many soils are an inadequate source of other major nutrients, such as phosphorus, potassium, magnesium and/or sulphur (Robson *et al* 1989). Inadequacies in the supply of nutrients are readily corrected by inputs of fertilizer. The amounts of fertilizer required to sustain high levels of growth are based on indices of estimated nutrient availability/adequacy derived from chemical analysis of the extractable amounts of nutrients in the soil (MAFF 1988). For example, the minimum index for soil phosphorus (P) and potassium (K) to sustain productive grass growth is 2, which is equivalent to a value of 16-25 mg extractable P per litre of soil and 121-240 mg exchangeable K per litre of soil, respectively.

The procedure used to estimate the nutrient status of agricultural grasslands is imprecise. This is largely because the 'standard' volume of soil used for the chemical analysis has taken insufficient account of actual volumetric differences between different soils or even between the same soil type under different managements. Caution is, therefore, needed for any but rather general comparisons of indices (or the mg per litre amounts) obtained for different grasslands or for the same grassland under different managements. Useful comparisons between the nutrient status of agriculturally improved and unimproved semi-natural grassland soils are rarely possible because of the use of different sampling and/or analytical procedures. For semi-natural grasslands lack of data on differences in soil bulk density data, for example, have limited the comparability between studies that could have proved useful. The effect of differences in soil bulk density on apparent differences in the extracted nutrient amounts can be important and needs to be taken into consideration (EGRO 1996). Standard soil sampling and analysis procedures clearly need to be more widely adopted.

Because of lack of bulk density data it was only possible to compare exchangeable/extractable amounts of potassium and phosphorus in terms of mg per 100 g of dry soil for a range of different semi-natural grassland associations (Figs 5 and 6, Appendix table 3). As previously argued it is difficult to compare these values in anything other than a rather general manner with the MAFF (1988) soil indices for these nutrients. Notwithstanding probable large differences in bulk density most semi-natural grassland soils of high conservation interest appear to be considerably below the minimum indices for potassium and/or phosphorus for productive grass growth. This finding accords with those of Marrs *et al* (1991) who showed that on chalk, clay or sandy soils under semi-natural grassland supplies of mineralizable nitrogen were considerably higher but exchangeable potassium and particularly extractable phosphorus amount were lower than under adjacent arable cultivation. The application of fertilizers to correct for inadequacies in soil nutrient supply and to boost grassland productivity is now generally recognized as incompatible with the maintenance of the floristic integrity and diversity of semi-natural grasslands (Brenchley & Warington 1958; Grubb 1977; Rabotnov 1977; Grime 1979; Tilman 1982; Mountford *et al* 1994).

The application of lime to raise soil pH in the improvement of acid soils and to counter acidification derived from nitrogen fertilizer use and rainfall inputs is a general practice for agricultural grasslands. For productive grass growth a soil pH of not less than 5.5 is required and for agricultural grasslands generally it is recommended that a pH of about 6.0 should be maintained by periodic inputs of lime (MAFF 1988). This pH is in fact close to the optimum value of 6.5 (Grime 1973; Ibid 1979) or 6.7 (EGRO 1996) for the maintenance of maximum species richness in grasslands. Raising the soil pH of semi-natural acidic grasslands or lowland heathland sites of high conservation interest is clearly to be avoided. However, for species-rich mesotrophic grasslands periodic applications of lime may be beneficial to counter the effects of acidifying inputs via rainfall. Indeed liming was part of the traditional management system for some mesotrophic semi-natural grasslands on base-poor soils in areas of high rainfall (Simpson & Jefferson 1996), such as the MG3 *Anthoxanthum odoratum-Geranium sylvaticum* upland meadows (Rodwell 1992).

Maintenance of productivity and floristic diversity of semi-natural grasslands

Semi-natural mesotrophic grasslands that are managed by cutting for hay each year and receive no fertilizer inputs (neither inorganic nor organic, such as farmyard manure) may, with time, show a reduction in site fertility. The reduction in fertility may be expressed as an increasingly limited availability/supply of one or more nutrients for plant uptake. Such a situation was predicted by Wells (1993) for the chalk grassland of Knocking Hoe National Nature Reserve where cutting and removal of the cut vegetation over a period of 30-40 years was calculated to cause potassium availability to become limiting. Apart from affecting dry matter yield a reduction in site fertility may also cause undesirable changes/losses to floristic composition. The principle that species density will decline with decreasing fertility below a certain optimum is implicit in the hump-backed relationship between species density and fertility (Grime 1979). There is evidence from project EGRO (1996) that for all the major nutrients, nitrogen, phosphorus and potassium, there is an optimum amount either in mineral or extractable form at which maximum species density is maintained. In particular, it was

Fig. 5. Number of species /100m² in different grasslands within western Europe vs extractable P in top 15cm of soil. Curve fitted to the maximum no. of species for given amounts of extractable P.

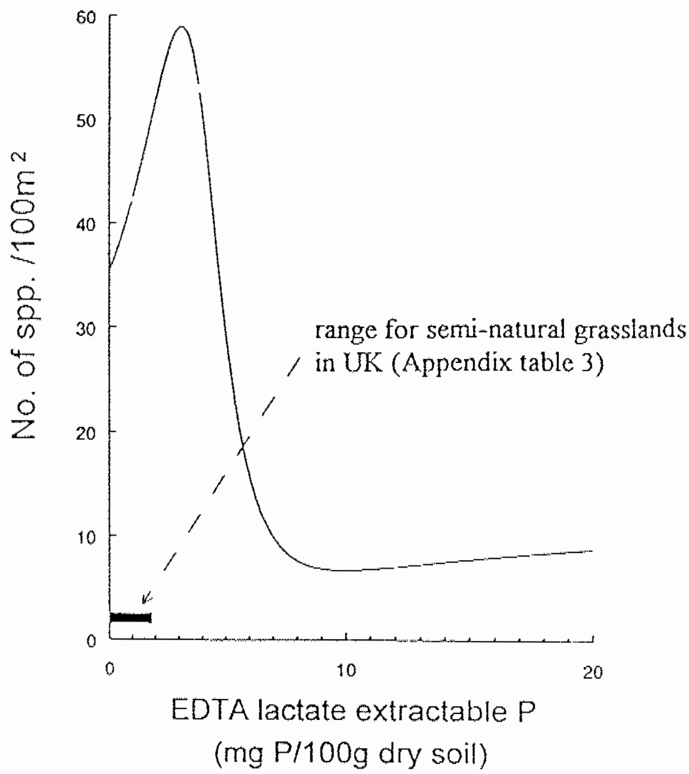


Fig. 6. Number of species /100m² in different grasslands within western Europe vs exchangeable K in top 15cm of soil. Curve fitted to the maximum no. of species for given amounts of exchangeable K.