found in project EGRO (1996) that high species density/rich grasslands occurred only within a narrow range of both extractable soil phosphorus and potassium (Figures 5 and 6). However, as Marrs (1993) points out what actually happens in species-rich semi-natural grasslands when site fertility is reduced below these apparent optima is largely speculative because of the lack of research on the subject. At present there is only rather general guidance available on what would constitute appropriate inputs for the long-term maintenance of species-rich mesotrophic grassland types (Simpson & Jefferson 1996). Empirical studies that could be of value in developing sustainable management guidelines for particular types of semi-natural grasslands often do not distinguish between the effects of change or cessation of a particular type of disturbance, such as cutting versus grazing, and the effects of declining nutrient availability.

In the unmanured plots (3) of the Rothamsted Park Grass long-term continuous hay experiment (PGE) there was a reduction in total species-richness, particularly in the early years (Brenchley & Warington 1958; Williams 1978) which as Williams (1978) pointed out, may have been influenced by the effects of cessation of aftermath grazing in 1872 as well as, or more so, than the absence of fertilizer inputs. Data from the Tadham project that was established on species-rich *Cynosurus cristatus-Centaurea nigra* and *Cynosurus cristatus-Caltha palustris* associations, MG5 and MG8 (Rodwell 1992), respectively, on the Somerset Levels provides some distinction between the effects of both disturbance and changes in nutrient status on botanical composition of these grasslands (Mountford *et al* 1994; Tallowin *et al* 1995; Kirkham *et al* 1996). Kirkham *et al* (1996) showed that considerable botanical change occurred in unfertilized plots that were cut for hay but where grazing had ceased. They also showed that botanical change occurred also under the traditional management with no fertilizer inputs. Both phosphorus and potassium availability were known to be low on these agriculturally unimproved peat soils (Kirkham & Wilkins 1994a and 1994b). Tallowin *et al* (in press) showed that under the traditional management without any fertilizer input potassium availability became significantly depleted over the eight year course of the Tadham project.

Although the species-rich meadows of Tadham had no history of inorganic fertilizer input anecdotes suggested that they had probably received periodic applications of farmyard manure. They were also regularly flooded. Either process was likely to have replenished potassium availability. Periodic inputs of nutrients by flooding has long been recognized as an important means of maintaining fertility and floristic diversity, as in the notable *Alopecurus pratensis - Sanguisorba officinalis*, MG4 (Rodwell 1992) flood meadows of the Thames valley (Baker 1937).

Long-term impacts on biodiversity of occasional strategic inputs of an inorganic form of a nutrient to correct for its reduced availability are largely unknown. Anecdotal evidence suggest that some existing species-rich grasslands may have received an input of inorganic fertilizers such as basic slag in the past. It is possible that providing the grasslands continue to receive appropriate extensive management, in the form of cutting and/or grazing, strategic periodic inputs of an inorganic fertilizer, such as muriate of potash, may have no long-term damaging effect. However, in light of the fact that surviving areas of semi-natural grassland of high conservation value are now such a scarce resource, to avoid the risk of undesirable long-term effects on the functioning of such grassland more research is needed before such strategic inputs are advocated. The research should examine the long-term effects of such factors as amount, frequency and timing on the botanical stability of communities.

In contrast the efficacy of using organic fertilizers, such as farmyard manures, to maintain productivity and the wildlife interest of semi-natural meadows is more widely accepted (Smith 1994; Crofts & Jefferson 1994; Simpson & Jefferson 1996). However, as Simpson and Jefferson (1996) point out, a lack of agronomic and ecological data exists on what would constitute optima for the frequency and the amount of farmyard manure that should be applied to safeguard conservation interests of different semi-natural grassland types. There is clearly an urgent need for information on what constitutes a sustainable management for many of the country's lowland semi-natural meadow communities.

Forage quality from semi-natural grasslands

Digestibility of hays

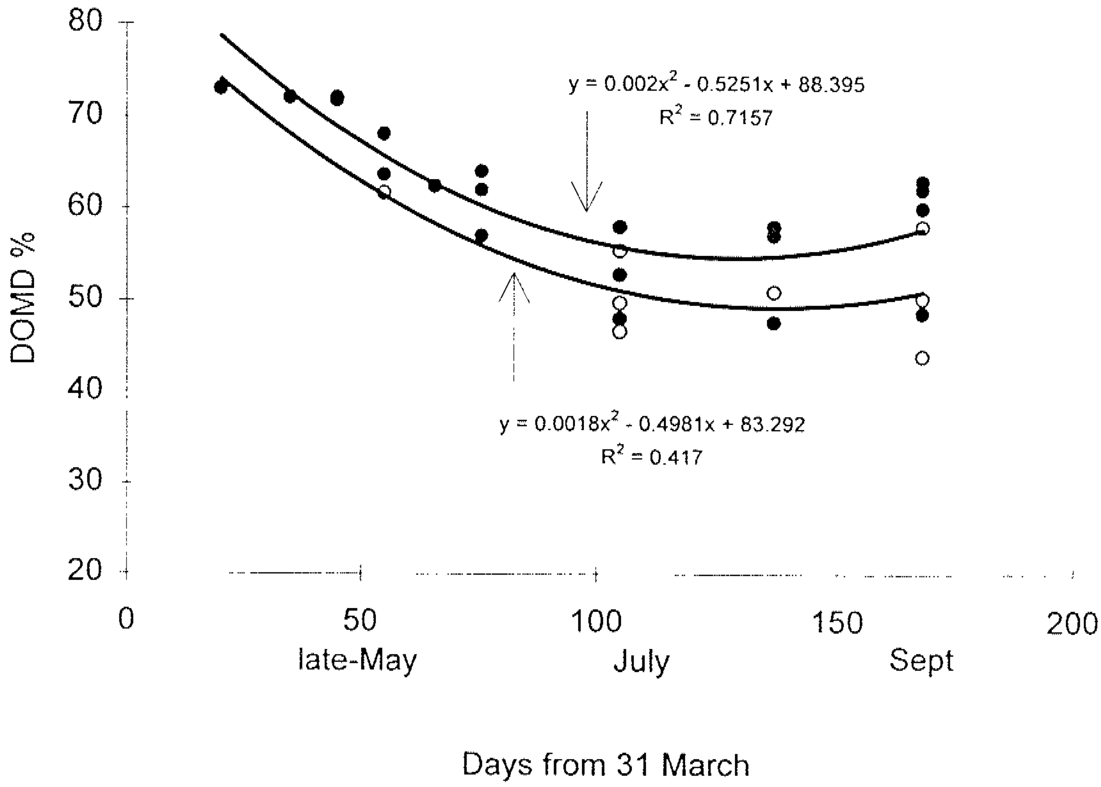
Where late hay cutting is required, ie when most of the constituent species in the grassland association have flowered and set seed, the quality of the hay as a feedstuff for ruminant livestock suffers, as indicated by the relationship between forage digestibility and cutting date in Figure 7. A consequence of cutting semi-natural grasslands in mid to late summer when most of the grasses are at an advanced state of phenological maturity means that there will be a high proportion of lignin and structural carbohydrates in the harvested dry matter. The chemical bonding of lignin to cellulose will form a barrier to microbial digestion in the rumen and hence lowers digestibility *per se* (Chesson *et al* 1995).

Digestibility is the proportional amount of nutrients extracted by an animal from the diet offered to it (Gill, Beever & Osbourn (1989). In practice the estimation of digestibility of conserved forages are commonly based on indirect *in vitro* techniques such as the two stage approach of Tilley & Terry (1963) or the pepsin cellulase assay (Jones & Hayward 1973; ibid 1975), these provide a value of digestibility of the organic matter in the dry matter, usually referred to as DOMD or D-value. This approach has received extensive evaluation for single species or simple mixture forages; Aerts *et al* (1977), for example, examined the relationship between *in vivo* and *in vitro* (using the Tilley & Terry (1963) procedure for estimating herbage organic matter digestibility of 42 grass hays. Relationships between cutting date (ie stage of maturity) and digestibility have long been well established (Minson *et al* 1960; Mwakatundu & Owen 1974; Gill, Beever & Osbourn 1989) and the principle has general application for evaluating potential forage species (NIAB 1987). However, there is a paucity of published digestibility data for hays from unimproved semi-natural grasslands of high nature conservation value. It is also apparent that there has not been a rigorous evaluation of the digestibility estimation techniques with species-rich hays cut at a late stage of crop maturity.

Limited evidence from a few semi-natural grasslands cut in mid-summer for hay indicates that the digestibility may be as much as 20%, or more, lower than the value that would be expected for the first cut of forage from intensively managed grassland. Hay cut in July on species-rich meadows at Tadham Moor on the Somerset Levels had an estimated *in vitro* DOMD value of 50-55% (Kirkham & Wilkins 1994; Kirkham & Tallowin 1995) and on a *Molinietum* fen meadow in Devon (Tallowin, unpublished) of 45-50%. These values are between 2 and 10% lower than the digestibility values obtained for hays from a wide range of species-rich grassland associations in Switzerland (Jeangros & Schmid 1991). In the Swiss study the digestibilities of the species-rich hays were between 5 and 10% lower than the values obtained for hays from intensively managed grasslands in the same locality.

Delaying the date of cutting in mid summer by 3-4 weeks, from early July to August, on the species-rich meadows at Tadham allowed the forage digestibility to decline by about 4% (Kirkham & Tallowin 1995). However, even with this further decline the digestibility value would be above that of some agronomically important grasses, such as cocksfoot (*Dactylis glomerata*) and early flowering perennial ryegrass (*L. perenne*) varieties when subjected to a hay cut in July (Minson *et al* 1960). The overall decline in digestibility during mid-summer in species-rich communities may be buffered to some extent by phenological amplitude within

Fig. 7. Relationship between cutting date and DOMD for unfertilized semi-natural (open symbols) and fertilized or agriculturally improved grassland (filled symbols)



the community, with late flowering species at an immature stage of reproductive development moderating the decline. Phenological amplitude is likely to be an intrinsic characteristic of most species-rich grasslands as demonstrated by Smith and Jones (1991) for the mesotrophic grasslands of the Pennine Dales. The tendency for forage digestibility to rise, or at least not to decline further, in September probably reflects a predominantly vegetative regrowth and the presence of young leaves in the sward.

In the early summer species-rich semi-natural grasslands may be incapable of producing cut forage with digestibility values equivalent to those of agricultural grasses. The presence of early summer flowering species and thus the presence of mature flower stems, the presence of dead leaves and old flower stems from the previous season and the persistence of old live leaves with a high proportion of cell wall may provide an intrinsic limit to the digestibility of cut forages from semi-natural grasslands in the early summer. Studies by Kirkham and Tallowin (1995) support this contention in that when cut in May forage from species-rich meadows at Tadham had a DOMD value of only 61.7. Agricultural grassland, in contrast, would be expected to achieve a DOMD value of at least 67 at this time (NIAB 1996/97).

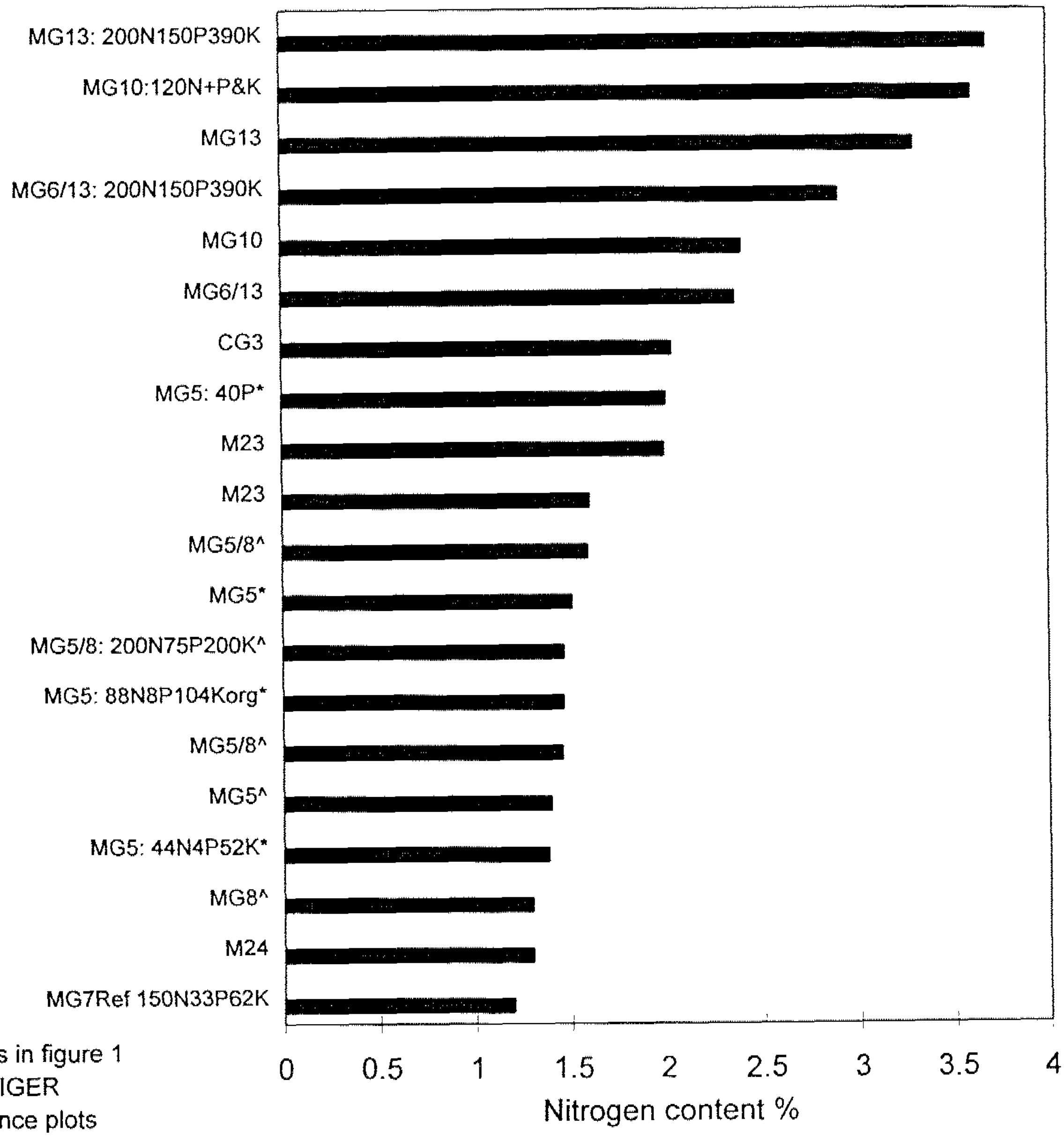
Studies by Frame *et al* (1993) and Wilman and Riley (1993) indicated that *in vitro* digestibility estimates *per se* have limitations for assessing the full agronomic potential of forages containing wild flower species as a feed for productive livestock.That some species of unimproved semi-natural vegetation appear to have a high feed value for ruminant livestock has long been recognized (Fream 1900; Ivins 1952; Fairbairn & Thomas 1959; Barber 1985). Derrick *et al* (1993) found that the voluntary intake of dried herbage of some common dicotyledonous species of semi-natural communities was higher than might have been predicted from their digestibility values. It was also found that the voluntary intake of some wild flower species was higher than for perennial ryegrass (*L. perenne*). It was suggested that the livestock could have been responding to factors such as the physical structure of the feed, affecting particle size and passage time through the rumen, and to palatability components such as mineral content. In the case of the latter, a specific appetite for sodium has been demonstrated for ruminant livestock (Denton 1982) and it appears, that there is an ability to detect non-volatile salts by some ruminants (Bell & Sly 1983). In the feeding trials by Derrick *et al* (1993) there was a particularly high intake of spurrey (*Spergula arvensis*) which also had a relatively high sodium content. However, apart from these specific studies there is a paucity of published data on feeding trials with hays from species-rich grasslands in the UK. Without such studies only broad and rather limited guidance can, therefore, be given on the feeding value of these hays and their potential for integration into the feed budget of productive ruminant livestock.

Mineral content of hays

Nitrogen

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. Low nitrogen content in the herbage of some mesotrophic grasslands may be largely due to limitation in availability of phosphorus (P) and possibly potassium (K) supply and not to a low soil nitrogen status *per se*. This was demonstrated by fertilizer experiments conducted on species-rich wet hay meadows (MG5 and MG8 associations) in the Tadham project on the Somerset Levels (Kirkham & Wilkins 1994b) and on the unimproved meadows (MG5 association) at Bratoft in Lincolnshire (English Nature, unpublished). At

Fig. 8 Nitrogen content (%) of herbage from some unfertilized and fertilized semi-natural and agriculturally improved grasslands cut in mid June to late July.



Key as in figure 1
Ref = IGER
reference plots

Tadham the uptake/availability of nitrogen was increased by the application of inorganic P and K fertilizer and at Bratoft by the addition of inorganic P fertilizer alone.

During the spring to mid-summer period nitrogen content in herbage appears to fall at a similar rate in both the species-rich and the agriculturally improved and/or fertilized grasslands (Figure 9).

As nitrogen content and crude protein content of forages are closely correlated the seasonal decline in nitrogen content will also mean a decline in crude protein content. This seasonal change reflects an increase in cell wall constituents in the dry matter (Gill *et al* 1989).

Low nitrogen (or crude protein) content of forages can reduce feed intake (Forbes 1995) and performance of productive livestock (Campling *et al*1962; Bortolussi *et al* 1996). Although the nitrogen content of hays from some of the more species-rich communities was lower than found in the sample of agriculturally improved grassland it is unlikely that it would be sufficient to depress voluntary intake. Studies by Bortolussi *et al* (1996) showed that intake and performance of steers was unaffected when offered feeds with a nitrogen content in excess of 13 g/kg of dry matter, provided that dietary phosphorus content was also adequate. All of the hays from semi-natural grasslands that were examined (Figure 8) had nitrogen contents either similar to, or in excess of, 13 g/kg (1.3%) of dry matter. If this range in nitrogen content is widely representative for hays from semi-natural grasslands then crude protein content would appear to be generally adequate for other than the most productive livestock, providing other dietary requirements are non limiting.

Phosphorus

The phosphorus content of the cut herbage from most of the semi-natural grasslands and particularly the more species-rich communities that were examined (Figure 10, Appendix table 6) appeared to be below estimated minimum metabolic requirements for growing cattle (ARC 1965; Cohen 1975; ADAS 1983). Even though the phosphorus requirements of cattle and sheep have received much attention (ARC 1965; ARC 1980; INRA 1989; AFRC 1991) there is still some uncertainty about the level of intake that would be required to ensure no deleterious effects of phosphorus deficiency (Ternouth *et al* 1996). For maintenance of the phosphorus balance of the body alone, that is without any liveweight change, forage diets with a phosphorus content of about 0.09-0.10 percent may be adequate for cattle (Ternouth *et al* 1996). For a liveweight gain of about 0.5 kg/day phosphorus contents in the diet of young cattle (less than 400 kg liveweight) should be greater than 0.15 percent. However, for maximum performance this type of animal would require a dietary content of over 0.18 percent. Hays from most of the species-rich semi-natural communities examined in this study (Figure 10) had inadequate phosphorus contents to sustain high performance and this appears to be a general phenomenon, as indicated by the studies of Jeangros and Schmid (1991) in Switzerland.

The potential agronomic value of hays from semi-natural grasslands with phosphorus contents below 0.15 percent will depend upon the age and type of livestock to which they will be fed. Non lactating and heavy/mature store animals are likely to show least effects of utilizing a diet of marginally sub-optimal phosphorus content. However, for forages with very low (<0.09 %) phosphorus contents the performance and/or condition of most productive ruminants are likely to be compromised. Examples found of such grasslands were some lowland fen-meadows, such as the M23 and M24 communities of the NVC classification (Rodwell 1991), however, these types of grassland are traditionally grazed and only occasionally may be cut for hay. By limiting the proportion of such forages in the overall feed ration of livestock, such as dry cows and mature store animals, it is perhaps assumed that no

Fig. 9 Changes in nitrogen content of herbage of semi-natural (open symbols), agriculturally improved and fertilized grasslands (filled symbols) during the early summer

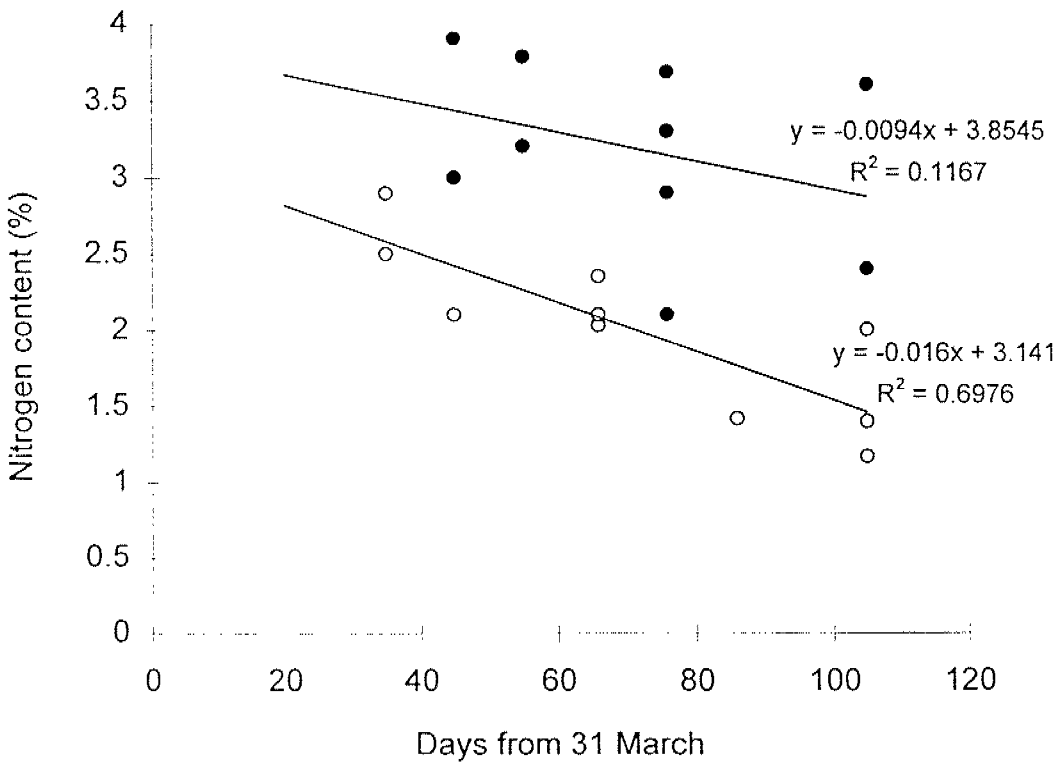
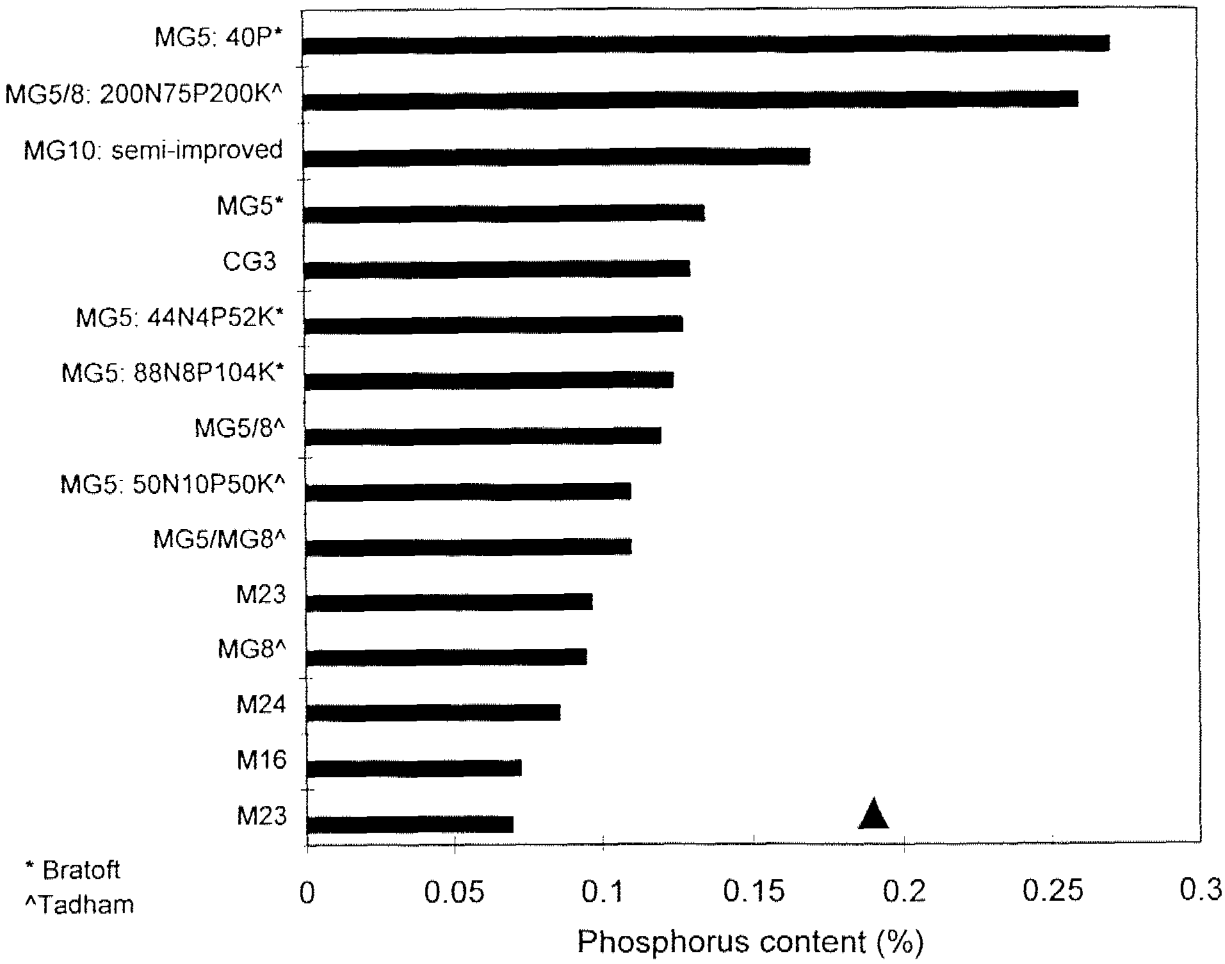


Fig. 10 Phosphorus content (%) of hay from some unfertilized and fertilized semi-natural and agriculturally improved grasslands cut in July.



Arrow indicates minimal content in the dry matter for a 250 kg bullock consuming forage with a D value of 50 (Ternouth et al., 1996).

long-term effects on performance, such as fecundity or finishing potential will be incurred. But, there is little empirical data to support this. In addition, supplementation with phosphate alone may have a limited effect on enhancing absorption and retention of this mineral due to relatively low nitrogen contents of some hays. Diets may, therefore, also need to include a high nitrogen supplement (Cohen 1975).

The efficiency of phosphorus absorption can vary considerably between individual animals (AFRC 1991). It is therefore likely that what would constitute a minimum amount of phosphorus in the overall feed ration will also vary between breed type. It may be that some more rugged traditional breeds have greater resilience/tolerance to periodic deficiency in phosphorus supply. However, as Wallis de Vries (1994) pointed out published evidence supporting such a contention is limited. It is certainly an area that would merit further study.

Potassium

The potassium content of most of the hays cut in July from the species-rich grasslands examined in this study (Appendix table 7) were adequate (above 0.8 percent in the dry matter) for productive ruminant livestock requirements (Erdman *et al* 1980; ADAS 1983;). However, for some semi-natural grasslands, such as the species-rich meadows on the peat soils of the Somerset Levels or some fen-meadow associations 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. A clinical symptom of sub-optimal potassium amounts in the diet is loss of appetite (Telle *et al* 1964) and thus poor growth of livestock. As adequacy of dietary potassium intake is particularly important for young growing or lactating animals then to avoid risk of deficiency it would be appropriate to feed late cut hays from semi-natural grasslands only to non-lactating and mature store animals.

Calcium

As with the other minerals the dietary requirement for calcium and therefore the daily amount that needs to be provided will vary with the type of livestock, its physiological state, age, the intake potential of the forage (which will be influenced by the digestibility of the forage) and the absorption of the calcium from the diet. The lowest calcium content found in the sample of semi-natural grasslands (Appendix table 8) was *c*0.20 percent. Although this content of calcium in the diet would be sub-optimal for most productive ruminants (AFRC 1991) it appears that cattle are able to tolerate this apparent inadequacy (Wallis de Vries 1994). However, it would too low by a substantial amount for sheep, such as lactating ewes (AFRC 1991). The risk of dietary calcium inadequacy of hays from lowland semi-natural grasslands having any deleterious effect appears to be low if fed, with adequate phosphorus supplementation, to dry cows or store cattle. Indeed there may be some benefit of including low-calcium forage in the feed ration of dry cows. There is now considerable evidence that feeding a low-calcium diet in the later part of the dry period can reduce the severity of parturient hypocalcaemia and the incidence of milk fever (ARC 1980). Deleterious effects on the performance of livestock fed on hays from species-rich semi-natural grasslands, particularly those from calcareous soils, may arise because of a relatively high calcium to phosphorus ratio of the forage. However, there is uncertainty over what constitutes an optimum Ca:P ratio, the general guidance being that a 1:1 to 2:1 ratio is safe (ARC 1980).

Magnesium

Magnesium is classed as one of the major minerals for ruminant nutrition (ARC 1980). Inadequacy in the diet incurs a risk of hypomagnesaemia, particularly in productive livestock, where tetany (lack of body co-ordination with the nervous system) and ultimately death can occur. A circumstance where there is a risk of this condition is, for example, with suckler cows being outwintered on low planes of nutrition and especially during cold spells of weather and 2-8 weeks after calving (ADAS 1975). Only a limited amount of published data on the magnesium contents of hays from semi-natural grasslands was available (Appendix table 9). Adequacy in the diet will depend, as with other minerals, on the digestibility of the forage. Assuming that the average digestibility of hays cut in July from semi-natural grasslands is between 45 and 50, then a magnesium content of 0.2 percent, or higher, would, on the basis of some recommendations (ARC 1980; ADAS 1983) be adequate for all classes of productive ruminant livestock. In general a forage containing a minimum of 0.25 percent magnesium will provide a safe dietary concentration of this mineral for productive ruminant livestock. The magnesium content of hays from some semi-natural grasslands is below the safe level. Therefore, winter feeding of such forage to animals such as suckler cows and calves would need to include some supplementation for this mineral.

Sodium

Sodium is also one of the major minerals for ruminant nutrition (ARC 1980). Inadequacy in the diet can cause inappetence and reduced efficiency of feed utilization. For growing beef cattle of between 200 and 400 kg liveweight a sodium content in their diet of about 0.065 percent appears to be adequate for their metabolic requirements (ARC 1980; ADAS 1983). For dry and lactating cows values in excess of 0.08 and 0.11 percent in the diet, respectively, would be adequate. Higher sodium contents in the diet appear to be required for sheep with contents in excess of 0.2 percent being required (ARC 1980). Of the few unfertilized semi-natural grasslands where data on sodium content of the hay was available most contained adequate amounts for productive ruminant livestock (Appendix table 10).

Metabolizable energy value of hay

The metabolizable energy (ME) value of feeds is defined as the digestible energy content minus the loss of energy in methane and urine (Gill, Beever & Osbourn 1989). The ME can be calculated using the DOMD and crude protein (CP) content of herbage (grasses and legumes) using the following formula (MAFF 1975):

$$\text{ME (MJ/kg DM)} = (0.138\text{xDOMD\%}) + (0.01\text{xCP}) + 0.23$$

or for grass hays (MAFF 1984):

$$\text{ME}=\text{DOMD\%x}0.155$$

Prediction of animal performance when provided with a particular forage requires estimation of voluntary intake and of the qualitative components of the feed which include, DOMD, crude protein content, protein degradability and the ME of the forage. It is important, therefore, that values for the ME of forages from semi-natural grasslands are obtained. Unfortunately few data exist of ME values of hays from species-rich semi-natural lowland grasslands in the UK.

Estimates of the ME value of hay cut in July from species-rich meadows on the Somerset Levels were between 7.5 and 9.0 MJ/kg dry matter (Kirkham & Wilkins 1994; Kirkham & Tallowin 1995) (Appendix table 11). Hay cut in July from a *Cirsio-Molinietum* fen meadow in Devon had an estimated ME value of about 6.5 MJ/kg dry matter (Tallowin & Smith 1996). In the Netherlands, in an extensification experiment where nil fertilizer was applied to an *Agrostis stolonifera-Alopecurus geniculatus* grassland, forage with an ME value of 8.6 MJ/kg dry matter was obtained (Korevaar 1986). The overall differences in estimated ME values of hays from semi-natural grasslands allow only rather generalised comparisons to be made with forages of intensively managed grassland. Agriculturally improved permanent pastures, reseeded perennial ryegrass leys and ryegrass + white clover leys at 8 sites widely distributed in the UK and under an 8 week cutting regime, with the first cut in early-mid June and the second cut in August, had an average ME value of between 10.2 and 10.6 MJ/kg dry matter (Hopkins *et al* 1990). The agriculturally improved grasslands received either 0, 150 or 300 kg of fertilizer nitrogen per ha per year. The differences in ME value between the semi-natural and agricultural grasslands indicate that energy contents of hays from the former could be between 10- 40 percent lower. The data also shows that by cutting semi-natural grasslands at the time of peak standing crop compared with cutting a month earlier, albeit with much reduced yields, the penalty in reduced ME value would be between 15 and 20 percent.

Potential for improving the quality of mature hays

The key problem with feeding hays of low digestibility to ruminant livestock is that lignin-carbohydrate complexes that develop as the grass crop matures reduce the accessibility of cell wall polysaccharides, cellulose and hemicelluloses to attack by rumen microorganisms. This, in turn, renders much of the energy and nutrients contained in the cell wall unavailable to the ruminant animal. A considerable amount of work has been done on finding ways to improve the digestibility of plant cell walls and fibrous feedstuffs (Wilkins 1981; Mason & Hartley 1988; Chesson *et al* 1995). There are three basic forms of treatment: oxidative, alkaline or hydrothermal and of these hydrothermal treatment appears to have least potential applicability, due to economic constraints, for upgrading mature hays from semi-natural grasslands. Therefore, only the potential of oxidative and alkaline treatments will be discussed.

Work by Mwakatundu & Owen (1974) showed that treatment with sodium hydroxide produced a 20-25 percent improvement in the digestibility of mature hays which, when untreated, had an *in vitro* OMD of only about 50 percent. This wet hydroxide treatment although providing a highly consistent improvement in digestibility, also resulted in significant losses of nutritionally valuable dry matter in effluent (Mason & Hartley 1988). Ammonia treatment was also found to provide a significant improvement in digestibility of fibrous feeds with less of the problems associated with using sodium hydroxide. Initially the application of the ammonia treatment on farms was limited by health, safety and cost constraints. However, with the development of a relatively safe and low cost ammoniation process (Mason & Hartley 1988) there is now considerable potential for its use in upgrading the quality of hays from semi-natural grasslands. The process involves the production of ammonia in the bale, stack or silo by reacting a dry mixture of ammonium salts (eg ammonium sulphate, ammonium phosphate) and cheap alkalis, such as quick or slaked lime or sodium hydroxide, with water. The elegance of the procedure is that it can be applied by the farmer saving the cost of using a contractor and, at the same time, it produces a residue (eg calcium phosphate or a mixture of salts) which could provide a mineral supplement for the animal. Furthermore, the treatment could provide an effective means of nitrogen supplementation in the ruminant diet (Sundstøl and Coxsworth 1984). This raised nitrogen content may, in turn, enhance the absorption and retention of phosphorus in the feed, as discussed earlier. The addition of ammonia may also have the added value of restricting the growth of bacteria, yeasts and moulds, reduce actinomycete counts and detoxify aflatoxin. However, there may be a risk that the process could also produce nitrogenous compounds such as imidazoles that are toxic to ruminants (Mason & Hartley 1988). To date these findings of potentially adverse effects on ruminant health from consuming upgraded forages are based on feeding trials with agriculturally improved species-poor or monoculture forages. There is clearly a need for further investigation to include upgraded mature hays from species-rich grassland.