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25 Potential production from grasses and legumes

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INTRODUCTION

This paper discusses, firstly for grasses and then for legumes, limits to the output of dry matter (DM) and metabolisable energy (ME) that can be achieved using existing genetic materials and technology. An assessment is then made of potential herbage production, throughout the UK, and the resources that would be required to increase production from current levels, (estimated by Green & Baker (1981) to be some 5–6 t DM/ha) to that potential.

POTENTIAL GRASS PRODUCTION

Harvested yields of 20 t DM/ha have been obtained from small experimental plots of perennial ryegrass cut five times annually and grown with liberal inputs of nutrients and water (Wright, 1978). These figures are in close agreement with an estimate of 20 t DM/ha, made by Leafe (1978), for maximum yield obtainable under these conditions at Cambridge. Leafe's estimate was based on the photosynthetic potential of the grass canopy, in relation to solar radiation receipts and light interception, and the partitioning of net photosynthesis between harvested yield, losses through respiration, death and decay and that in parts of the plants that are not harvestable. Only 27% of the photosynthetic production is realised in harvestable DM. Although further progress, through breeding or chemical control of plant metabolism, may lead in the future to reduced losses through respiration, and management may have some impact on losses through death and decay, it is unlikely that the percentage recovery of photosynthate can be increased appreciably at present from the figure given by Leafe.

The extent to which yield might be affected by grass genotype, deficiencies of nutrients and water, cutting management and pests and diseases is first discussed followed by consideration of seasonal distribution of yield.

Species and variety

Differences between the sown grasses, in annual production, are relatively small when they are grown with adequate nitrogen and water. In one experiment with irrigation, at Hurley, the range in yield of 12 varieties of timothy, cocksfoot, tall fescue and perennial ryegrass, when they received high rates of N fertiliser and were cut every four weeks, was only from 11.9–14.2 t DM/ha (Corrall *et al.* 1979). Mean yields of standard varieties of the main sown species from NIAB trials are given in Table 1. The range in yield between varieties within species in the recommended list is small, with a yield more than 10% above that of the standard variety occurring only in one species, timothy. Differences between species are greater with the conservation management which involves less frequent cutting than with the simulated grazing management, but even here the yield of Italian ryegrass is only 11% above that of S24 perennial ryegrass. With simulated grazing, the yield of Italian ryegrass is not higher than that of perennial ryegrass and the lowest yield in Table 1 is only 23% below the highest yield.

Table 1

Yields of grass species cut under simulated grazing and conservation managements (tonnes DM/ha)

	Conservation management	Simulated grazing management
Italian ryegrass, RvP	17.3	11.4
Perennial ryegrass: S23	14.8	11.2
S24	15.6	11.4
Timothy: S48	10.6	9.0
S352	12.3	8.8
Cocksfoot, S27	11.9	9.6
Meadow fescue, S215	11.7	9.4

Source: NIAB (1979a).

There is much less comparable information on the performance of the species that are normally unsown, but may be important components of permanent grassland. Wright (1978) concluded that, when grown in conditions of high fertility, the yields of rough-stalked meadow grass (*Poa trivialis*) and Yorkshire fog (*Holcus lanatus*) were 80 and 75% of the yield of perennial ryegrass respectively, whereas Haggar (1976), using high levels of N fertiliser and irrigation, reported yields relative to perennial ryegrass for Yorkshire fog, red fescue (*Festuca rubra*), creeping bent (*Agrostis stolonifera*) and rough-stalked meadow grass of 100, 91, 76 and 72% respectively.

It can be concluded that, within the sown grasses, the levels of yield that are obtained are relatively insensitive to the species and varieties present. Sward composition may limit the production of some long-term pastures to levels below those that can be achieved with sown species such as perennial ryegrass. However, sward composition reacts to changes in management and the content of perennial ryegrass usually increases with increased nutrient inputs, as discussed by Hopkins & Green (1979).

Nutrients

The key to increased production from grass has long been recognised to be nitrogen fertiliser. The average application of N to grassland in 1977, however, was only 106 kg N/ha whereas Morrison *et al.* (1980), in experiments on sites throughout England and Wales, have shown that with four-weekly cutting the quantity of N fertiliser required to give maximum yield varied from 540 to 678 (mean 624) kg/ha. When only four cuts were taken per year, the N required for maximum yield was rather lower at 396–754 (mean 561) kg/ha (Morrison, 1980). Yield increments to the higher rates of N were low and the N application at which the incremental response for a particular site fell to 10 kg DM/ha was calculated. The yield at this level is denoted Y_{10} and this was 91% of the maximum yield with both cutting frequencies. But Y_{10} was obtained with only 61 and 50% of the fertiliser N input required for maximum yield with frequent and less frequent cutting respectively. The N application required to achieve Y_{10} varied between sites from 260–520 (mean 383) kg/ha with frequent cutting and from 111–145 (mean 281) kg/ha with less frequent cutting.

Increased application of fertiliser N could result in enormous increases in grassland production. There is an interaction between the requirement for N and the quantity of water available to the sward (Garwood *et al.* 1980). Morrison *et al.* (1980) were able to relate Y_{10} (t DM/ha), and hence N requirement, to soil available water capacity (AWC, mm) and summer rainfall (RGS, mm)

$$Y_{10}=-0.3186+0.02996\ AWC+0.0392\ RGS-0.00004379\ RGS^2 \quad \text{.............} \quad 1$$

The N requirement, which can be supplied from either the soil (N_S, kg/ha) or from fertiliser (N_{10}, kg/ha) can then be calculated from Y_{10}.

$N_{10}+N_S=43.5\ Y_{10}-24.9$ 2

The contribution of N from the soil varied, between sites, from 11–135 (mean 60) kg/ha.

The apparent recovery of N varies considerably between sites. The scope for improving N recovery may, however, be limited, because there is little evidence of gaseous N loss through denitrification (Dowdell *et al.* 1980) and guidelines already exist for avoiding N loss by leaching (Garwood *et al.* 1980). The remaining N, that is not recovered in herbage, is probably incorporated in soil organic matter and much of it will eventually be mineralised and made available for use by the crop.

There is much less information for grazed swards but Richards (1977) found broadly similar yields and patterns of response to N up to 300 kg N/ha in swards that were either grazed by sheep or cut mechanically. There is, thus, little evidence that N recycled by grazing animals results in any opportunity for reducing N fertiliser inputs over that range of application rates. Where more than 300 kg N/ha was applied, yield levels were lower with grazing, and the authors attributed this reduction to damage to the sward by the grazing animals.

In order to sustain high yields from grassland, inputs of P and K, as well as N, are required. Hopkins & Green (1978) found in a survey of 900 permanent grass fields that 42% of the soils were low (soil index 0 or 1) in P and 44% low in K. The current average application of P_2O_5 and K_2O to grassland in England and Wales is 24 and 20 kg/ha respectively. These inputs would have to increase appreciably if there were a major increase in N fertiliser use. Hopkins & Green (1979) also noted that pH was below 6.0 – the recommended pH for permanent grassland – in 20% of the soils.

Water shortage

Water shortage reduces the grass growth at some times of the year in most of lowland Britain. At Hurley, the yields from perennial ryegrass without irrigation are, on average, only 80% of those with irrigation (Garwood, 1979). Taking data from experiments throughout the UK, Garwood related the increase in yield through irrigation (Y, kg DM/ha) to the maximum potential soil moisture deficit (SMD, mm):

$Y=18.57\ SMD-670\ (r=0.80)$ 3

Some response to irrigation would be achieved in most of lowland Britain. With full irrigation (to restore the soil to field capacity when the deficit exceeds 25 mm) 1 m^3 water gives about 1 kg extra grass DM, but partial irrigation schemes (Garwood, 1979), although giving somewhat lower yields, may double the efficiency of use of applied water for DM production.

An alternative to irrigation is to use grass species with better water-use efficiency. Garwood & Sheldrick (1978) noted that tall fescue was much less susceptible than perennial ryegrass to drought. In 1976 the production from tall fescue, cut at six-weekly intervals and without irrigation, was higher than that of perennial ryegrass receiving 200 mm irrigation water (Sheldrick *et al.* 1978). These responses arise from tall fescue having a greater effective rooting depth and thus being able to exploit a larger soil water reservoir. Thomas & Wilson (1979) are obtaining promising results in programmes selecting grasses for improved water-use efficiency.

Cutting management

It is well established that grass yield and quality are affected by cutting frequency: with frequent cutting, yield is reduced but the contents of ME and crude protein are higher. The reduced yield, with frequent cutting, arises both from the lower mean light interception and lower efficiency of light use for photosynthesis. A J Corrall (personal communication) has summarised the data from numerous experiments at Hurley and throughout the UK. Table 2 shows the effects of variation in cutting management on herbage yield and digestibility. Yields of ME were highest in swards cut three or four times per year. This information is drawn from swards in their first or second harvest year, but there are data to suggest that the advantage from

Table 2

Effect of cutting regime on the yield and composition of perennial ryegrass grown with irrigation and high levels of N fertiliser

Cutting regime[1]		Yield		Composition		
Date of first cut	Number of subsequent cuts	Dry matter (t/ha)	ME (GJ/ha)	*In vitro* D-value	CP (%)	ME[2] (MJ/kg DM)
2 May	8	11.5	135	70	17	11.7
15 May	5	14.8	161	66.5	14	10.9
24 May	3	16.6	171	64	12	10.3
2 June	2	17.2	170	61.5	11.5	9.9

1 Cutting regimes designed to produce cuts with constant digestibility within a treatment.

2 Derived from *in vitro* D-value and CP content according to Terry *et al.* (1974).

Source: Collated data from GRI, Hurley (A J Corrall, personal communication).

infrequent cutting may decline with increase in sward age (J Morrison, unpublished).

Pests and diseases

Epidemic damage by pests to grass swards is unusual, but recent work has shown that insect damage is widespread, both at establishment and in established swards. In a recent experiment, pest damage had major adverse effects on grass establishment at one-third of the sites investigated (W H Golightly, personal communication). The control of invertebrates in established perennial ryegrass swards, by treatment with *phorate,* increased yield by an average of 15%, with the response significant at eight out of ten sites (Henderson & Clements, 1977). The damage appears to be caused mainly by larvae of species in the frit-fly complex (Clements & Henderson, 1980). Damage is greater in the ryegrasses than in other grass species and there is some suggestion that damage is greater in the lowlands than in the uplands. The control of insect damage, in addition to increasing yield, has increased the persistence of Italian ryegrass (Henderson & Clements, 1979). The response in yield to control of insects is particularly interesting because it is possible that the experiments providing the basis for estimates of maximum grass yields were affected to some extent by insect damage.

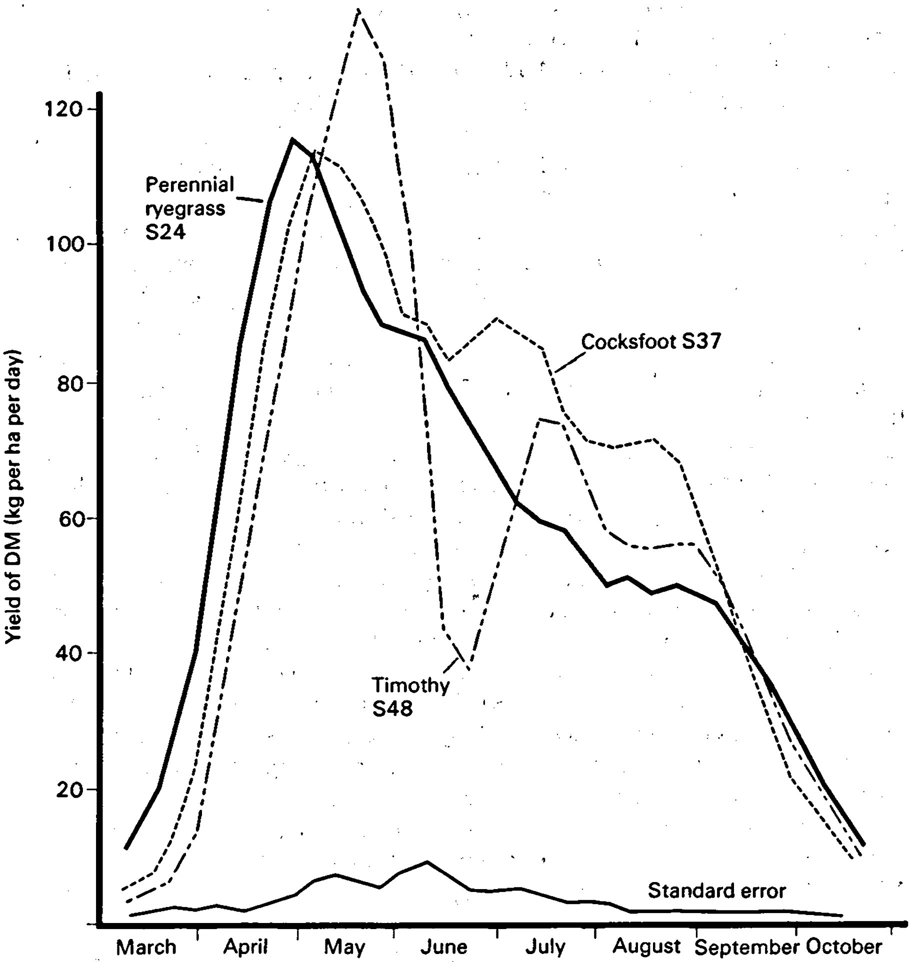
Glasshouse tests have shown variation between ryegrass varieties in their susceptibility to insect damage, with Fortis perennial ryegrass and Delecta Italian ryegrass being relatively resistant (Clements, 1980). The possibilities for breeding grasses with resistance to insect damage are being examined at the Welsh Plant Breeding Station. Chemical control may also be feasible. *Bendiocarb* provides good control at establishment and, with established swards, thrice yearly applications of the non-persistent insecticides, *permethrin* and *chlorpyrifos,* are likely to give responses in yield of around 10% (R O Clements, personal communication). The cost of this treatment would, at present, be high at around £60 per ha per year.

Damage to grass swards by disease is discussed by Dibb (1981) and has been reviewed by Carr (1975, 1979). Although, in particular situations, both fungus and virus diseases may have large effects on the grass yield and quality, it does not appear that disease is having an important limiting effect on either current grass production or on the yields considered earlier to represent maximum values. The use of fungicides on grass swards at three sites in England and Wales did not increase total annual yield (Broom *et al.* 1975). Yields of perennial and Italian ryegrass may be severely reduced by infection with ryegrass mosaic virus. A'Brook & Heard (1975) reported that the yield of plots consciously established with infected plants and receiving 400 kg N per ha was 39% below that of healthy plants. In most circumstances the extent of damage will be much less. In a survey of herbage seed crops, Heard *et al.* (1974) found that, although one-third of the crops had infection, only 10% of the plants in these crops were infected.

Seasonal distribution of yield

Information on the seasonal distribution of yield of grass species and varieties, grown in conditions of high fertility and adequate water, has been

Figure 1
Seasonal pattern of dry matter production



Note: High levels of fertiliser N; irrigated and cut every four weeks.
Source: Corrall (1978).

published by Haggar (1976) and Corrall *et al.* (1979). There is, characteristically, a peak of growth in spring followed by slower growth in summer and autumn as shown for perennial ryegrass, timothy and cocksfoot in Figure 1. This Figure also indicates that differences in the seasonal distribution of yield between these species are relatively small, although timothy has a particularly severe depression in growth in mid-summer and the production of cocksfoot is relatively high at that time. Haggar (1976) noted more even production during the growing season with red fescue and creeping bent than with perennial ryegrass.

When swards are grown in south and east England without irrigation, not only is average production reduced still further in mid- and late-summer, but also the variability in production from year to year at these times is increased. Corrall (1978) showed that, in perennial ryegrass swards cut at four-weekly intervals and grown with high levels of N fertiliser, the yield from 1 June to the end of the growing season, without irrigation, ranged in a 14-year period from 35 to 85% of that obtained with irrigation. In individual weeks in this latter period, the coefficient of variation was 60% without irrigation compared with 20% with irrigation.

Table 3 indicates the seasonal distribution of yield of swards of perennial ryegrass cut at four-weekly intervals and grown without irrigation at three levels of N fertiliser and at three contrasting sites in England and Wales. On all sites, yield was higher in early season and this was particularly marked at Hurley, where production later in the year was restricted by both low summer rainfall and low soil available water capacity. At Aylesbury and Wenvoe, where the supply of water to the crop was greater, the production in mid- and late-season was relatively higher. Nitrogen fertiliser level (applied in six equal applications) had little effect on seasonal distribution patterns.

Data reported by Morrison (1977) and Morrison *et al.* (1980) demonstrate that manipulation of cutting management and the pattern of N fertiliser input can result in substantial seasonal redistribution of yield with little sacrifice in total annual production. In an experiment at 21 sites, which involved six cuts annually at four-weekly intervals, annual rates of 300 and 600 kg N/ha were applied in three patterns (i) in six equal applications, (ii) with rates twice as high on the first two occasions as for the rest of the year or (iii) with rates twice as high for the two mid-season applications. Total annual yields did not differ between treatments but at an annual rate of 300 kg N/ha, 35% of the annual yield came from the third and fourth cuts for application method (iii), compared with only 29% and 25% for methods (i) and (ii) respectively. It appears that the pattern of N application can be used as a management tool to obtain more even production in the growing season with no sacrifice in total annual yield.

Table 3

Seasonal distribution of production of perennial ryegrass grown at three sites[1] in England and Wales and cut at four-weekly intervals. Four-year means, 1970–1973

	N fertiliser[2] (kg/ha)	% of total production in cuts			Total yield (t DM/ha)
		1 and 2	3 and 4	5 and 6	
Hurley, Berks	150	63	20	17	4.9
	300	53	24	23	7.6
	600	55	22	23	10.7
Aylesbury, Bucks	150	39	27	34	7.2
	300	40	26	34	10.1
	600	48	25	27	12.2
Wenvoe, South Wales	150	46	30	24	4.8
	300	42	32	26	9.7
	600	46	31	23	14.8

1 Summer rainfall (mm) and soil available water capacity (mm) were respectively 320 and 85 for Hurley, 255 and 161 for Aylesbury and 470 and 123 for Wenvoe.

2 N fertiliser applied in six equal applications.

POTENTIAL LEGUME PRODUCTION

There is less information on production potential in UK for forage legumes than for grasses. The major legumes in the UK are lucerne, white and red clover, and the consideration here is restricted to these species. Maximum yields would be expected to be lower than those for grasses, because of the generally shorter growing season for legumes and, in the absence of fertiliser N, the need for a proportion of the photosynthate to be used for providing energy for the nitrogen fixation process (Ryle *et al.* 1979). Sheldrick & Lavender (1978) have reported a yield of 18 t DM/ha for red clover grown in mixture with S24 perennial ryegrass, without fertiliser N but with irrigation and cut three times. Yields in Brittany of 20 t DM/ha for lucerne have been reported by Plancquaert & Raphalen (1973), but the highest published yield for lucerne in England is 17 t DM/ha (Anon, 1978). The highest yields from experiments at Hurley, with irrigated pure white clover, have been 10 t DM/ha (Morrison & Denehy, 1978). Yields are normally lower than these and factors responsible for limitations to yield are discussed below. Also, the productive life of swards of red clover and lucerne in Britain is limited, with red clover normally being harvested for two years and lucerne only rarely for more than four. White clover, in contrast, may be a component of permanent grassland. Unless red clover and lucerne are established under a nurse crop, total crop yields in the year of establishment will be less than in subsequent years.

Species and variety

The performance of different varieties of the legume species are given by NIAB (1979b). Total annual DM yields are 14.7 and 12.0 t DM/ha for lucerne and red clover respectively and markedly lower yields for white clover/grass mixtures. These values are not potential yields, because the crops were grown without irrigation and often in the presence of pests and diseases. However, differences in yield, both within and between species, are larger than with grasses.

Nutrients

Despite the energy cost of N fixation, forage legumes grown in pure swards in the field have rarely given any response to N fertiliser (Spedding & Diekmahns, 1972). The response of mixed grass/white clover swards to fertiliser N, reviewed by Chestnutt & Lowe (1970), average 10 kg DM/kg N fertiliser over the range 0–200 kg N/ha compared with 24 kg DM/kg N for pure grass swards. A response of the same order, at 7 kg DM/kg N, was reported for a sward of a long-petioled white clover variety, *Blanca,* grown with perennial ryegrass (Denehy & Morrison, 1979). For maximum exploitation of white clover it seems that N fertiliser should not be applied, or only at very low rates. P and K fertiliser is required by forage legumes in quantities at least as high as those needed for full production from grass. MAFF (1979) suggest that, with cutting for conservation, the P and K inputs should be rather higher with lucerne and red clover than with grass.

Legumes are generally less tolerant than grasses of acid conditions and the optimum pH for white and red clover is about 6.2 and that for lucerne from 6.2–7.8 (Spedding & Diekmahns, 1972). The production of lucerne has been concentrated on alkaline soils, but much wider distribution is possible. The rhizobial bacteria have a higher pH requirement than that for the lucerne plant and drilling low quantities of calcium carbonate with lucerne seed may improve nodulation and subsequent crop growth (White, 1966; Green, 1977).

Water shortage

Lucerne is extremely deep rooting and unless root growth is limited by soil conditions, the growth of the crop in the UK is unlikely to be restricted by water shortage. White clover, on the other hand, is more sensitive to water shortage than is grass (Stiles, 1966). Thus, at Hurley, in the three years 1977–1979, irrigation increased the yield of perennial ryegrass, with 400 kg N/ha, by 21% but increased that of perennial ryegrass/white clover, with no N, by 32% (E A Garwood, personal communication). The effects of water shortage on red clover appear to be similar to those with perennial ryegrass (Sheldrick & Lavender, 1978).

Cutting management

Comprehensive data on the effect of cutting frequency on the yield of pure white clover swards are not available. When clover was grown with grass, J Morrison & H Denehy (unpublished) found that DM yield increased by 20% with eight-weekly, compared with four-weekly cutting, a much lower response than occurs with pure grass swards. It appears that cutting at four-weekly intervals will give near maximum yields of ME from grass/white clover swards. Lucerne and red clover are normally cut three times annually and, with red clover, relative yields with three, four and five cuts annually were 100, 72 and 51 respectively (Sheldrick *et al.* 1980), changes greater than occur with grasses. These results thus support the current practice of infrequent cutting with these species.

Pests and diseases

Legumes may suffer serious damage from pests and diseases; stem eelworm and clover rot being particularly important with red clover and *Verticillium* wilt with lucerne. There has been progress in breeding varieties with increased resistance and this continues to be a main objective in legume breeding programmes. Clover rot has been controlled successfully in experiments by the application of *quintozene,* but the cost of this treatment is far too high for practical use. The possibility of damage through eelworm and clover rot restricts the proportion of red clover that can be used in a rotation.

It is not clear to what extent insidious pest and disease damage restricts legume production, but Clements *et al.* (1980) examined a large number of legume species and varieties and found that the control of insects by *phorate* application had little effect on yield.

Introduction of white clover into swards

The content of white clover in British grassland at present is very low, as indicated by Dibb (1981). Hopkins & Green (1979) reported that white clover provided more than 15% of the ground cover in only 3% of 8 000 grassland fields studied in England and Wales. Recent experiments, at the Weed Research Organisation and the Grassland Research Institute, indicate that, with mixed swards receiving no N fertiliser, some 30–40% of clover in the herbage DM is required for maximum production. However, if clover is present, its content can be increased by the rectification of nutrient deficiencies, management and by the application of herbicides to suppress grass growth. There are possibilities for the introduction of white clover into swards by sod- or slot-seeding (Squires *et al.* 1977). These techniques are not yet successful in all circumstances, but the results are sufficiently encouraging to suggest that the techniques could have widespread future importance.

POTENTIAL NATIONAL PRODUCTION

Estimates of the potential production of grass in the UK have been made. These are based on the relationship between yield and soil available water content and summer rainfall established with four-weekly cutting by Morrison *et al.* (1980). Equation 1 was used for summer rainfall up to 450 mm, but yield was not reduced for rainfall in excess of this figure. The calculated yields were then adjusted for differences in potential growing season (soil temperature above 6°C) at lowland sites, based on data for England and Wales from Smith (1976) and for Scotland from H A Douglas (personal communication). Potential growing season was taken to decrease by two days per 40 km eastwards and 2.5 days per 40 km northwards. The second adjustment was for differences in altitude, with calculated production reduced by 10% per 100 m increase in altitude above 100 m (Hunter & Grant, 1971; Morris & Thomas, 1972; Munro & Davies, 1973). The fertiliser N requirement was then calculated using equation 2, with the assumption that the soil supplied 80 kg N/ha.

Data on altitude, land use and soil-available water for 20x20 km squares in Great Britain were made available by B Wales Smith (Meteorological Office) and the areas of grassland were adjusted on a regional basis according to census data for 1978. Northern Ireland was considered as a single area in which output was not limited either by summer rainfall or soil available water capacity. The altitude for grassland in Northern Ireland was taken as 150 m and potential growing season was calculated as for Great Britain.

Rough grazings have been excluded from all these calculations. There is undoubtedly potential for large increases in the output from rough grazings, but data were not available to facilitate as detailed an approach as has been made for the remaining grassland area.

The calculated potential outputs of DM and ME from grass are given in Table 4 together with the quantity of N fertiliser that would be required to achieve these figures. Data are presented for perennial ryegrass cut at four-weekly intervals and cut less frequently to give maximum yield of ME/ha. The N fertiliser inputs, for the less frequent cutting regime, were adjusted

Table 4

Potential grass production from the existing grassland area in the UK[1]

	Per ha			Total for UK		
	Production			Production		
	DM (t)	ME (GJ)	N fertiliser (kg)	DM (Mt)	ME (PJ)	N fertiliser (Mt)
Four-weekly cutting						
Maximum yield	12.0	140	604	84.9	994	4.3
Y_{10}	10.9	128	371	77.3	904	2.6
Less-frequent cutting						
Maximum yield	17.3	178	543	122.3	1 260	3.8
Y_{10}	15.7	162	272	111.3	1 147	1.9

1 For swards grown without irrigation. No allowance made for utilisation losses.

Table 5

Potential grass production if all the existing agricultural land in the UK was devoted to grass[1]

	Per ha			Total for UK		
	Production			Production		
	DM (t)	ME (GJ)	N fertiliser (kg)	DM (Mt)	ME (PJ)	N fertiliser (Mt)
Four-weekly cutting						
Maximum yield	11.9	139	598	143.2	1 675	7.2
Y_{10}	10.8	126	367	130.3	1 525	4.4
Less-frequent cutting						
Maximum yield	17.1	176	537	206.2	2 124	6.4
Y_{10}	15.6	161	269	187.6	1 933	3.2

1 For swards grown without irrigation. No allowance made for utilisation losses.

according to the ratios of the mean values required for frequent and less frequent cutting detailed earlier (J Morrison, unpublished). The possible increase in yield of 10% through pest and disease control was not considered. Also the use of Italian ryegrass, rather than perennial ryegrass, would increase the yield obtained with less frequent cutting by about 10% but the present calculations refer to perennial ryegrass. Table 5 gives the potential output if grass occupied all the agricultural land in the UK and Table 6 details production on a regional basis.

Table 6
Potential grass output (Y_{10}) for regions in the UK

	Potential grass production[1] (t DM/ha)	Grassland area[2] (M ha)	Grassland area[2] % of land area	Potential UK grass production (Mt DM)
England				
Northern	10.3	0.69	35	7.1
Yorks and Lancs	10.7	0.43	28	4.6
West Midlands	10.7	0.70	42	7.5
East Midlands	10.3	0.44	29	4.5
Eastern	10.1	0.23	12	2.3
South Eastern	11.1	0.56	27	6.2
South Western	11.9	1.24	51	14.7
Wales	11.5	0.94	47	10.9
Scotland				
North West	9.2	0.14	5	1.3
North East	8.9	0.22	24	1.9
South East	9.2	0.27	19	2.5
South West	10.6	0.44	17	4.7
Northern Ireland	11.8	0.77	55	9.1
Total		7.07	29	77.3

1 Perennial ryegrass grown without irrigation and cut at four-weekly intervals with N fertiliser applied to a level at which the incremental response to N is 10 kg DM/kg N.

2 As in 1978, but with rough grazings excluded.

Particular features of the Tables are the increases in ME output and efficiency of N use with less-frequent cutting and the small increase in ME that results when N inputs are increased from the levels required to sustain Y_{10} to those needed for maximum yield.

Figure 2

Potential production (Y_{10}) from grass cut at four-weekly intervals without irrigation (t DM/ha)

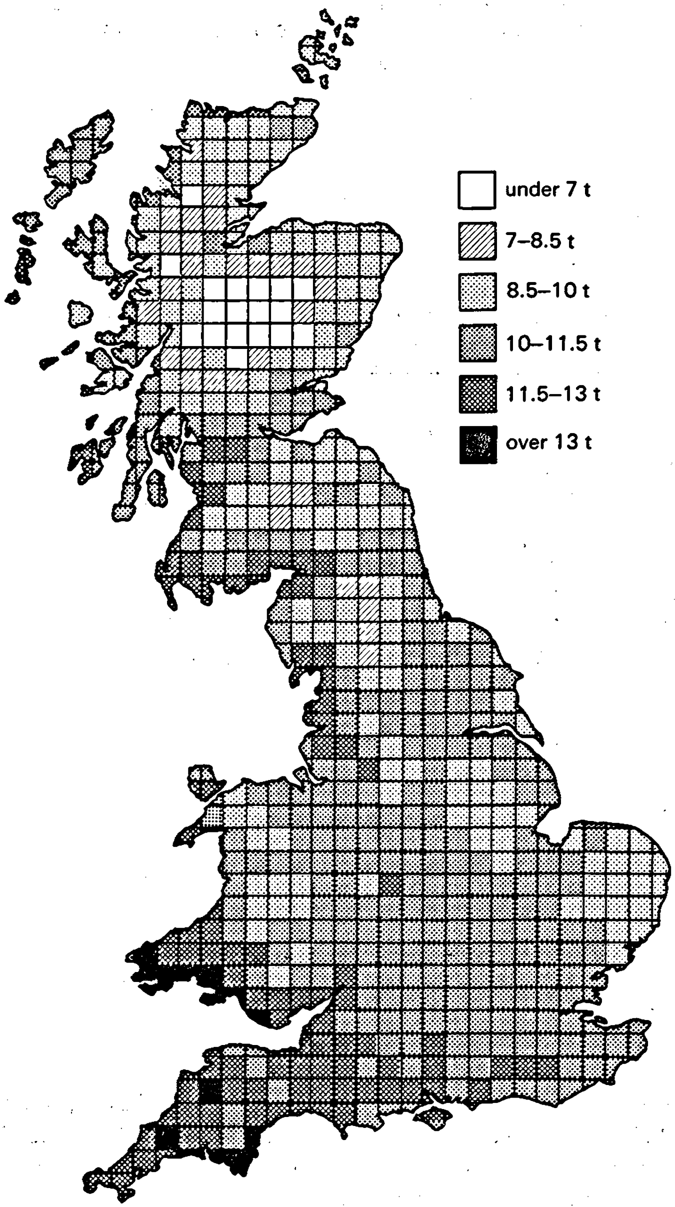


Figure 3
The percentage of the land area which is occupied by grassland, 1978 (rough grazings excluded)

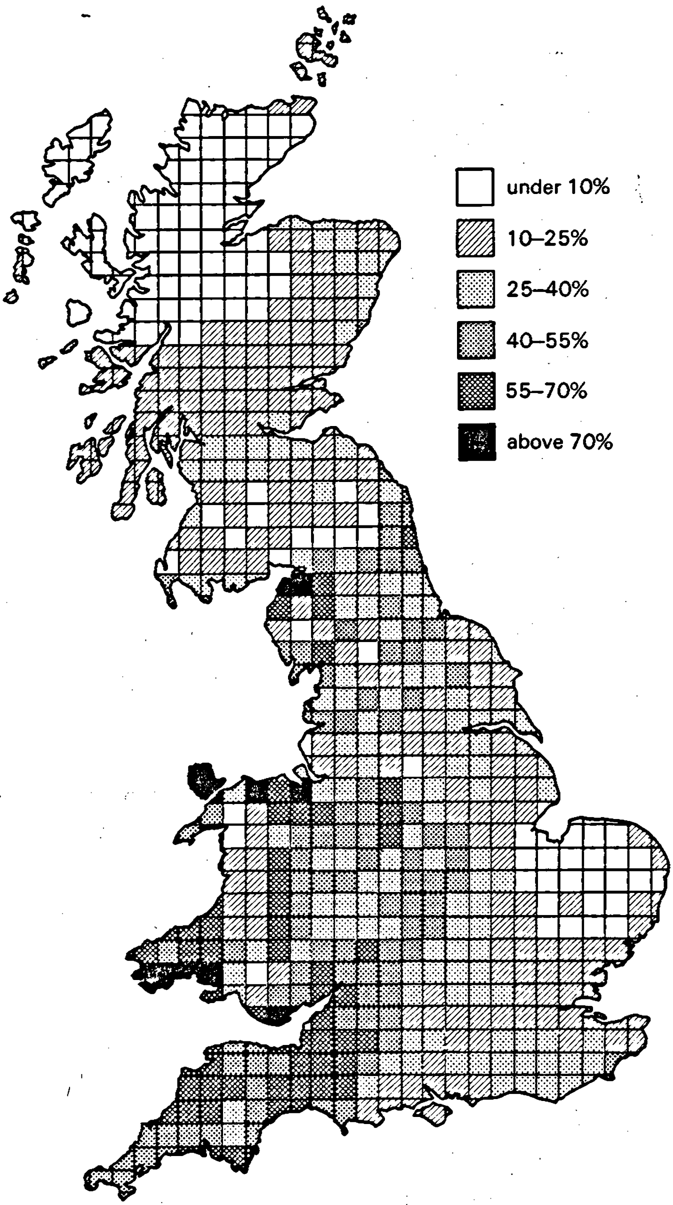
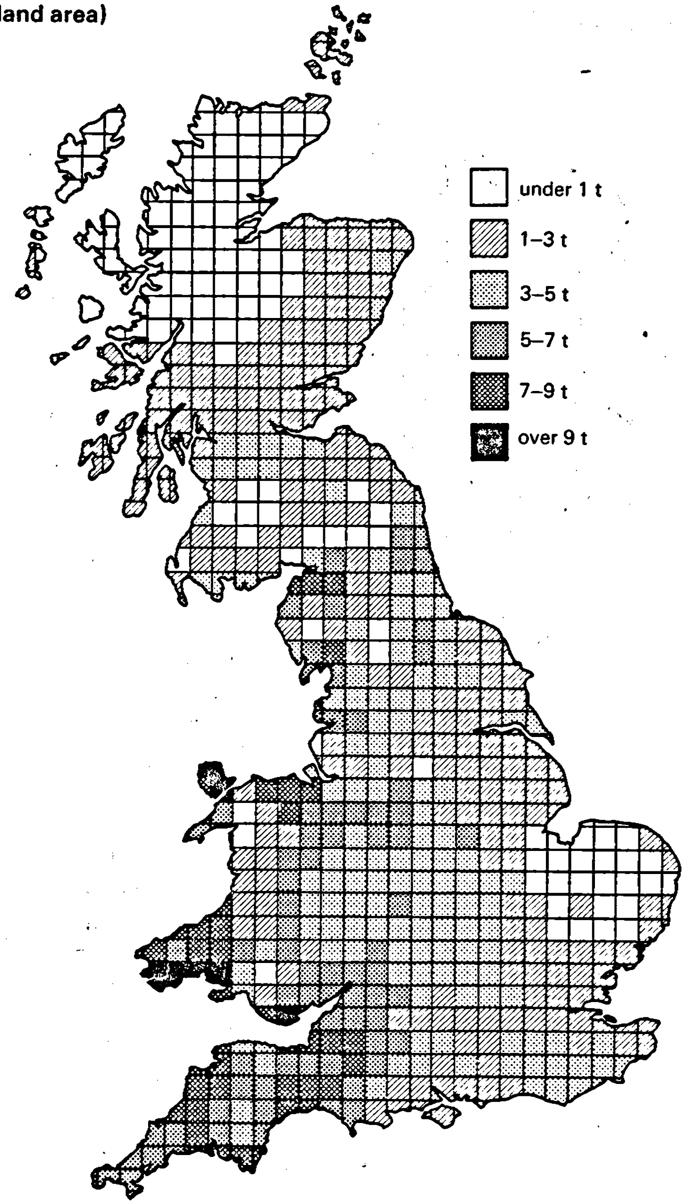


Figure 4

Potential grass production[1] based on the present land-use pattern[2] (t DM/ha land area)



1 Y_{10} for grass cut at four-weekly intervals without irrigation.

2 These data are derived by multiplying potential grass yields in Figure 2 by data in Figure 3 for proportion of the land in a particular area which is occupied by grassland.

DM yields (Y_{10}) per ha of grassland, for four-weekly cutting, are shown in Figure 2 and vary from 4.4 to 13.5 t/ha. Figure 3 illustrates the percentage of the land area which is occupied by grassland and Figure 4 the potential grass DM output per ha of land, based on the current land-use pattern, thus considering both output per ha of grassland and the percentage of the total land area occupied by grassland.

The potential output from the existing grassland area, of 904–1 260 PJ ME, may be compared with estimates by Green & Baker (1981) of the current grass contribution. They gave a figure for utilised ME of 297 PJ which, assuming that 70% of the grass grown is utilised, is equivalent to an output of 424 PJ. The basis for the increase in output is largely the use of fertiliser N which would increase from the current estimated use on grassland of 0.8 Mt (out of a total agricultural usage of 1.2 Mt) to 1.9–4.3 Mt. The high fertiliser N required to achieve a modest increase in yield from the Y_{10} level to maximum yield has already been noted.

The impact of irrigation on national potential yield was examined. Irrigated yields were derived on the same basis as non-irrigated yields, but a mean summer rainfall of 450 mm was assumed for all sites to avoid any restriction of yield through water shortage. This resulted in increases in the calculated yields for the UK of 6% for the existing grassland area and 8% if all the existing agricultural land were devoted to grass. These figures reflect the fact that summer rainfall is above 450 mm in much of the UK. However, somewhat higher national increases from irrigation would be predicted using the equation of Garwood (1979) (Equation 3) in which yield response was related to maximum potential soil water deficit. These relatively modest increases in yield from irrigation, predicted here, would require large quantities of water and high capital investment in irrigation equipment. Considering only the existing grassland area, irrigation of swards cut at four-weekly intervals and provided with N fertiliser to give Y_{10}, would provide, nationally, an extra 4.9 Mt DM. The requirement for irrigation water, assuming that 1 m^3 water results in an extra 1 kg grass DM, would be 2 720 Mm^3 – much greater than the present total use of water in agriculture in England and Wales given by the ACAH (1980) as 300 Mm^3.

An alternative development would be the more extensive use of legumes. Data on the potential production of legumes is, as discussed earlier, not as comprehensive as with grasses, and more approximations have to be made. Highest yields of ME are obtained with lucerne. This crop only occupies some 16 000 ha at present; it has fairly exacting soil condition requirements for good growth and can only be grown on land suitable for cultivation. Green (1974) reported that 64% of the grassland area in the eastern part of England had no impediments to cultivation. We assumed that 50% of this easily-cultivated grassland in the East, East Midland and South-east regions of England could be replaced with lucerne to give a yield of 14.7 t DM/ha, as in NIAB trials. The lucerne was taken to have a D-value of 60, CP of 18% and ME of 10.4 MJ/kg.

For the remainder of grassland in the country it was assumed that grass/white clover swards could be used without fertiliser N. Here, the potential yield, for a mixed sward without fertiliser N, was taken to be 75% of that achieved from pure grass with four-weekly cutting (Y_{10}). This is the mean yield of grass/white clover as a percentage of that from grass, with 400 kg N/ha, for a number of recent experiments at Hurley with and without irrigation. It is higher than the equivalent mean value of 63% found in the first year of the multi-centre experiment, GM23, for 19 sites throughout the UK (J Morrison, R D Russell, P F Chapman & J M Reeks, unpublished) but, in that experiment, the clover content was low at several sites. The composition of the grass/white clover herbage was taken to be 70 D-value, 20% CP and 12.0 MJ ME/kg DM. Potential national yields for legume-based herbage production are given in Table 7.

Table 7
Potential production from lucerne and grass/white clover swards in the existing grassland area in the UK

	Per ha		Total for UK		
	DM (t)	ME (GJ)	Area (Mha)	Production	
				DM (Mt)	ME (PJ)
Lucerne	14.7	153	0.39	5.8	60
Grass/white clover	8.2	98	6.68	54.9	659
Total	—	—	7.07	60.7	719

The national yields of DM and ME are below those for grass with high nitrogen, but well above the current estimated outputs of ME. There is then the possibility of obtaining increased output from grassland with N fertiliser inputs below those used at present. Inputs of P and K would, though, need to be above those currently used. Undoubtedly, there are problems with forage legumes in achieving reliable production and in utilisation, but the yield potential is certainly high enough for legumes to play an important part in UK grassland.

The average yield of ME for lucerne, at 153 GJ/ha in eastern England, may be compared with that achieved for grass without irrigation which, in these regions, averaged 124 GJ/ha with frequent and 159 GJ/ha with infrequent cutting. Thus, for efficient production of herbage in the dry eastern part of the country, lucerne has a large potential, irrespective of questions of efficiency of support energy utilisation.

CONCLUSIONS

Present grassland yields could be increased by provision of more fertiliser N, irrigation, pest control and the adoption of an infrequent cutting strategy; yields tend to be higher with Italian ryegrass than with other species. The most important factor is nitrogen nutrition and the ME yields from un-irrigated swards of perennial ryegrass, cut at four-weekly intervals and given N fertiliser up to a level at which the incremental response is 10 kg DM/kg N fertiliser, are at least twice current estimated yields from grassland. The use of higher N fertiliser levels would facilitate either increased ruminant animal production, increased reliance on grass in the diet of ruminant animals or a reduction in the area devoted to grassland. If these higher yields were obtained on all of the existing grassland, a large increase in the capacity for manufacturing N fertiliser would be required.

An alternative would be to develop systems based on forage legumes. Yields from lucerne and grass/white clover swards, higher than those obtained on average from grassland at present, could be attained. No N fertiliser would be required, but inputs of P and K would need to be increased. Also there would be greater problems with yield reliability and utilisation compared with present grassland production.

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