Centre for Agricultural Strategy

University of Reading

Grassland Research Institute

GRI

Grassland in the British economy

Edited by J L Jollans

Published as
CAS Paper 10 January 1981

Jollans, J L (Ed) (1981) *Grassland in the British Economy.*
CAS Paper 10. Reading: Centre for Agricultural Strategy.

26 Potential changes in efficiency of grass and forage conservation

J M Wilkinson

INTRODUCTION

The objective in the conservation of grass and forage crops is to harvest, transport, store and remove the crop from store to animal with minimal loss in nutritive value. In most cases, losses can be influenced by the skill of the farmer, though there are instances, such as the unpredictable occurrence of rain during the field drying of hay crops, where little can be done to improve the situation, no matter how skilful the farmer, other than to change to a different system of conservation.

In this paper, losses in forage conservation are considered for the three main systems; haymaking, silage-making and artificial dehydration. Since most grasses and legumes contain adequate amounts of crude protein for ruminant livestock, attention will be concentrated on the energetics of the processes. Thus, the scope for improvement in the recovery of dry matter and energy in conserved forages compared to that in the crop at cutting, is first discussed. Then follows a consideration of the energy balance of forage conservation systems and some ways in which the efficiency of use of energy may be increased. Finally, some possibilities for more efficient use of capital in forage conservation are suggested.

LOSSES IN THE CONSERVATION OF GRASS AND FORAGE CROPS

Haymaking

The extent to which losses of dry matter (DM) can occur during haymaking is, of course, largely dependent upon the weather during field drying. Spatz *et al.* (1970), Tetlow & Fenlon (1978) and Jones (1979) have described the exponential relationship which exists, during drying, between the moisture content of the cut crop and the accumulated vapour pressure deficit of the air. Thus, as drying proceeds, the rate at which water is lost from the crop decreases. Not surprisingly, losses increase at an increasing rate, as indicated by Zimmer (1977) and Wojahn (1977), for crops drying in the field under a range of weather conditions. The losses reflect both plant respiration (Wood & Parker, 1971) and the effects of mechanical treatment, including mowing (Klinner, 1976) tedding, windrowing and baling (Parke *et al.* 1978).

Clearly, losses can be reduced by accelerating the rate at which water is lost from the cut crop by, for example, the use of a mower-conditioner or a flail mower rather than a reciprocating mower (Klinner, 1976). They can be further reduced by removing the crop from the field at a relatively high moisture content, and then either drying the baled hay in the barn (see review by Klinner & Shepperson, 1975) or adding a chemical preservative (see review by Benham & Redman, 1980) to prevent heating and spoilage. There is evidence that the nutritive value of chemically-preserved hay is similar to that of barn-dried material (Strickland, 1979; Tas, 1979), provided application of preservative is uniform (Lacey *et al.* 1978).

Recently, promising results have been obtained in Denmark with hay baled at 67% DM and treated with anhydrous ammonia at 35 kg per tonne of hay fresh weight (Mølle & Winther, 1979). Apart from preserving the hay whilst in sealed storage, there was an increase in the energy value of the product compared to similar material stored aerobically after barn-drying. Assessment of organic matter digestibility (OMD), using sheep, indicated a 4.5 unit increase associated with addition of ammonia (from 69.5 to 74.1% OMD). This represents an increase in ME content of 0.7 MJ/kg DM.

Typical losses of DM during the conservation of grass hay under conditions of good management are indicated in Table 1 for field-dried and barn-dried material. Likely losses from similar material treated with NH_3 and stored in sealed stacks are also shown, but more work is required to verify these initial estimates. It can be seen from the Table that losses can be quite markedly reduced by application of either existing technology (such as barn-drying) or by the introduction of new technology (addition of NH_3). Of the two possibilities, the latter is likely to be preferred in practice. Klinner & Shepperson (1975) concluded that major disadvantages of barn hay drying were associated with matching the capacity of the drier to the handling and storage methods on the farm, and to the seasonal pattern of hay production. Thus, barn-drying of hay has remained relatively unpopular on farms. Addition of preservatives, on the other hand, has attracted attention since the technique does not require major capital investment or major changes to the haymaking system.

Table 1

Losses likely to occur from field-dried, barn-dried and ammonia-treated grass hay made under conditions of good management (% DM)

	Field-dried[1] hay	Barn-dried[2] hay	NH_3-treated[3] hay
In field			
Respiration	8	8	8
Mechanical losses	14	4	4
During storage			
Respiration	1	4	—
Fermentation	2	3	3
Surface waste	2	1	—
During removal from store	1	1	1
Total	28	21	16

1 Six days in field, no rain – from Wilkinson (1980).

2 Baled at 60% DM, losses during storage based on data of Nilsson & Jeppsson (1979).

3 35 kg NH_3 per t DM, losses during storage based on data of Mølle & Winther (1979).

In the case of hays made from leguminous crops, in contrast to grasses, there is greater risk of loss of leaf material due to mechanical damage during the later stages of field-drying. In four experiments at the NIAE, losses between cutting and baling, for lucerne crops mowed by reciprocating mower and given four post-cutting treatments between cutting and baling, averaged 38.9% (Klinner, 1976). With the use of a mower-conditioner to accelerate drying, fewer tedding treatments should be necessary, and losses probably average around 32% for conditioned legume crops field-dried under good conditions without rain. Barn-drying of legume hay crops will reduce losses in the field compared to field-dried material, so that total losses from cutting to feeding probably average about 24% of the DM present at the time of cutting.

Losses of DM are reflected in losses in digestibility and in ME content. Shepperson (1960) found that the mean reduction of nine comparisons, in the organic matter digestibility of barn-dried and field-dried hays was 3.4 and 8.1 percentage units, respectively, compared to that of the crop at cutting. These decreases correspond to reductions in ME content of 0.5 and 1.2 MJ/kg DM for barn-dried and field-dried materials, respectively. Thus the conservation of grasses and legume crops, as hay, involves not only loss of dry matter, but a reduction in the energy value of the remaining material compared to that at cutting.

Silage making

Losses during the conservation of grass and forage crops as silage can be greatly influenced by application of existing knowledge and management skills during the filling, sealing and subsequent unloading of the silo. Zimmer (1980) listed the major sources of loss during the storage and feed-out of silage and indicated that the total losses of DM can be as low as 7%, or greater than 40%, depending on the degree to which existing technology is successfully applied (Table 2).

Table 2

Losses during the ensilage of grass and forage crops (% DM)

	Approximate % loss
Unavoidable losses	
Field losses during wilting	2 to >5
or	
Effluent	5 to >7
Residual respiration in the silo	1 to 2
Avoidable losses	
Fermentation	2 to 4
Secondary fermentation	0 to >5
Aerobic deterioration during storage	0 to >10
Aerobic deterioration during feed-out	0 to >15
Total	7 to >40

Source: Zimmer (1980).

Losses during storage are generally lower with crops ensiled in tower silos than with crops ensiled in bunkers or clamps (Zimmer, 1980). But towers require a higher level of capital investment, which is often not feasible on smaller farms.

From a survey of the literature, Zimmer (1980) concluded that loss of DM during storage was greater for direct-cut grass crops than for wilted crops. Losses averaged 20% and 14% for direct-cut and wilted materials, respectively. However, losses in the field during wilting tend to result in relatively little difference in total DM loss between the two methods of ensilage (Wilkinson, 1980). However, the probability of secondary butyric fermentation is greater at low contents of DM than in wilted crops (Weissbach *et al.* 1977) with consequent elevation in loss of both DM and energy (McDonald *et al.* 1973). For this reason, additive-treatment is recommended for direct-cut crops and for species of high buffering capacity and low water-soluble carbohydrate content. It is now well established that treatment of crops with formic acid, prior to ensilage, is reflected in improved recovery of energy (Waldo, 1977), increased voluntary intake (Wilkins, 1978) and enhanced animal performance (Wilkinson, 1978a). Typical losses of DM, likely to occur during the conservation of grass as silage under conditions of good management, are shown in Table 3 for direct-cut and wilted materials.

Table 3

Losses likely to occur from grass silage made under conditions of good management (% DM)

	Direct-cut[1]	Wilted[2]
In field		
Respiration	—	2
Mechanical loss	1	4
During storage		
Respiration	—	1
Fermentation	5	5
Effluent	6	—
Surface waste	4	6
During removal from store	3	3
Total	19	21

1 Formic acid added at 2 l/t fresh crop, ensiled in a bunker silo.

2 36 hours wilt in the field, ensiled in a bunker silo.

Source: Wilkinson (1980).

Similar losses are likely to occur with leguminous crops ensiled after a period of field wilting, but also with the addition of formic acid (3 litres/t fresh crop) to ensure good preservation without secondary fermentation.

In the case of forage maize, however, the crop is normally direct-cut at a DM content of between 25 and 30%. In only a few years, when cool weather prevents crop maturation, would effluent production constitute a significant source of loss. Further, the maize crop has a low buffering capacity and a relatively high content of fermentable carbohydrate (Wilkinson, 1978b); consequently, an additive to enhance fermentation quality is not necessary. Typical losses are likely to be slightly less than those shown in Table 3 for wilted grass silage, and probably amount to 17% of the DM yield at cutting under conditions of good management.

Losses of DM during ensilage are reflected in a rather different pattern of energy change than in the case of haymaking. McDonald *et al.* (1973) demonstrated that, whilst DM may be lost as CO_2 during fermentation, the loss of energy from silages which do not undergo secondary fermentation is close to zero. Thus, since loss of DM can exceed that of energy, there is a concentration of energy in the silage which probably amounts to a 10% increase in the gross energy content of direct-cut silages and a 5% increase in the case of wilted materials.

With well-preserved, direct-cut silages there is little decrease in digestibility compared to the crop at cutting (Harris & Raymond, 1963). However, field-wilting is likely to be associated with a decrease in digestibility of about 2 units (Wojahn, 1977). It seems reasonable to conclude that the ME content of direct-cut silages, made under conditions of good management, may be higher (by about 0.3 MJ/kg DM) than that of the crop at cutting. With wilted silage, the decrease in digestibility probably balances the increase in gross energy content, so that there is likely to be little change in ME value as a result of the conservation process.

Artificial dehydration

Losses during artificial dehydration are relatively low in comparison with the methods of forage conservation considered previously. Christensen (1967) stated that losses during drying and pelleting, measured on 12 occasions, varied from a loss of 6.5% to a gain of 4.6%, with an average loss of 1.8%. To this must be added loss due to plant respiration during storage of the crop prior to dehydration (about 1%) and losses during wilting in the field. For 'direct-cut' crops, which undergo only a short (<12 h) field-wilting period, a realistic total loss between cutting and feeding is probably the value of 5% used by Wilkins (1976). However, it is desirable to wilt crops for longer periods (24 to 48 h) to reduce the fuel required for drying and processing (Butler & Hellwig, 1973; White, 1980). Wilting for 36 to 48 hours is likely to give field losses of a similar order to those shown in Table 3 for wilted silage. Total losses involved, in the harvest and dehydration of material wilted to 35% DM content, probably average 11% of that present at cutting.

Though there appears to be relatively little decrease in ME content associated with the artificial dehydration of direct-cut grass (Ekern *et al.* 1965; Blaxter, 1973) there is likely to be a greater decrease in the ME value of dehydrated material made from wilted crops, reflecting the losses incurred during field-wilting. The decrease probably amounts to a reduction in ME content of 0.5 MJ/kg DM.

POTENTIAL CHANGES IN EFFICIENCY OF ENERGY USE IN FORAGE CONSERVATION

The conservation process involves the use of specialist equipment which is not cheap, either in monetary or energetic terms. White (1980) has recently evaluated the support energy cost of haymaking, silage making and artificial dehydration, and the following calculations are based on his estimates together with those of Wilkins (1976).

The foregoing discussion of losses has been used as the starting point for an analysis of efficiency of energy use, which here means the ratio of the support energy consumed in the production, harvest and storage of the crop to that of the output of ME in the conserved feed.

The yields of DM used in this paper are lower than those quoted by Wilkins & Bather (1981) for grass and legume crops harvested for conservation. Those used here are field yields which reflect those achieved in practice with good management.

Haymaking

The energy balance for haymaking is in Table 4; for a grass crop of 10 MJ ME per kg DM and a legume crop of 9.3 MJ ME per kg DM at cutting.

In terms of efficiency of energy use, technical 'improvements' such as barn-drying or chemical preservation are retrograde steps rather than advances. But it is important to note two features; firstly, that in all the examples shown in Table 4 the yield of ME exceeds the support energy used. Secondly, the use of NH_3 with grass hay is reflected in an improvement in efficiency of energy use over barn-drying and also yields the highest output of ME per ha of land. As White (1980) noted, fertiliser (100, 98 and 146 kg/ha of N, P_2O_5 and K_2O respectively) comprises a major source of support energy consumption, representing 68%, 34% and 32% of total energy used in the conservation of field-dried, NH_3-treated and barn-dried grass hays, respectively. Energy used in barn-drying is similar to that used in the addition of NH_3 to the hay.

Comparison of field-dried grass hay with field-dried legume hay shows a large increase in efficiency of energy use. Despite having a lower yield of ME per ha the legume has a much lower input of energy in the form of

Table 4
The energy balance of various systems of haymaking

	Grass			Legume	
	Barn-dried	Treated with NH_3 (35 kg/t DM)	Field-dried	Barn-dried	Field-dried
Number of cuts	2	2	2	2	2
Support energy input (GJ/ha)					
Fertiliser	12.6	12.6	12.6	2.0	2.0
Field operations	4.4	4.4	4.8	4.4	4.8
Drying	21.0	—	—	21.0	—
Ammonia	—	19.6	—	—	—
Storage	1.2	0.8	1.2	1.2	1.2
Total	39.2	37.4	18.6	28.6	8.0
Output					
Yield at cutting, (DM t/ha)	7	7	7	7	7
Losses during conservation (from Table 1 and text) (%)	21	16	28	24	32
Conserved feed (DM t/ha)	5.5	5.9	5.0	5.3	4.8
(ME MJ/kg DM)	9.5	10.2	8.8	8.7	8.0
(GJ/ha)	52.5	60.0	44.0	46.1	38.1
Input:output	0.75	0.62	0.42	0.62	0.21

Sources: Support energy inputs calculated from White (1980) and Wilkins (1976).

fertiliser than grass. When, on the other hand, grass and legume hays are compared as barn-dried rather than field-dried materials, the energetic advantage of legume over grass largely disappears. In the absence of information on the effects of treating legume hays with NH_3, this comparison has been omitted. There is evidence, however, that the response in digestibility by legume to treatment with alkali is less than with barley straw or maize stover (Ololade *et al.* 1970).

Ensilage

Comparable energy balances for the ensilage of grasses, legumes and forage maize are in Table 5. Fertiliser inputs are 400 kg N, 98 kg P_2O_5 and

146 kg K_2O per ha for grass; 100 kg P_2O_5 and 150 kg K_2O per ha for legume and 100 kg N, 50 kg P_2O_5 and 50 kg K_2O per ha for maize. The energy used in field operations does not involve the shared use of machinery between crops. In practice this would almost certainly occur, and would reduce the energy used in field operations proportionately more for maize than for other crops because the maize crop is only cut once.

Table 5
The energy balance of various systems of ensilage

	Grass		Legume	Maize	
	Direct cut + additive	Wilted	Wilted + additive	Inorganic fertiliser	Slurry
Number of cuts	3	3	3	1	1
Support energy input (GJ/ha)					
Fertiliser	35.1	35.1	2.8	9.2	—
Field operations	13.0	13.0	13.0	12.4	12.6
Silage additive	6.9	—	7.3	—	—
Storage	3.4	3.4	3.0	2.7	2.4
Total	58.4	51.5	26.1	24.3	15.0
Output					
Yield at cutting (DM t/ha)	11.3	11.3	10	9	8
Losses during conservation (from Table 3 and text) (%)	19	21	21	17	17
Conserved feed (DM t/ha)	9.1	8.9	7.9	7.5	6.6
(ME MJ/kg DM)	10.8	10.5	8.7	10.8	10.8
(GJ/ha)	98.8	93.7	68.7	80.7	71.7
Input:output	0.59	0.55	0.38	0.30	0.21

Sources: Support energy inputs calculated from White (1980) and Wilkins (1976).

Energy used in fertiliser comprises 60% and 68% of total support energy inputs to direct-cut and wilted grass silage, respectively. The use of additive (formic acid) with direct-cut grass (2 litres/t fresh crop) and the legume crop (3 litres/t fresh crop) comprises 12% and 28% of total support energy input, respectively. Both the legume and maize crops are superior to grass in terms of efficiency of support energy use, because both crops use less fertiliser. The complete replacement of inorganic fertiliser by cow slurry (applied at 40 t per ha) enhances the energetic efficiency of a crop already relatively efficient in use of energy (see also Phipps & Pain, 1978). Sheldrick & Wilkinson (1980) calculated a similar benefit to maize grown with slurry, over grass or barley grain, in terms of cost per unit of ME produced per ha.

Artificial dehydration

Energy balances for the production of artificially dehydrated grass and legume crops are given in Table 6.

Table 6

The energy balance of various systems of artificial dehydration

	Grass			Legume		
	Oil-fired		Straw-fired	Oil-fired		Straw-fired
	Direct-cut	Wilted	Direct-cut	Direct-cut	Wilted	Direct-cut
Number of cuts	5	5	5	4	4	4
Support energy input (GJ/ha)						
Fertiliser	35.1	35.1	35.1	3.0	3.0	3.0
Field operations	11.6	11.6	14.2	9.2	9.2	11.8
Depreciation of capital	11.5	11.5	11.5	9.6	9.6	9.6
Fuel for drying	206.9	81.5	—	172.4	67.9	—
Auxiliary equipment	10.1	10.1	10.1	8.6	8.6	8.6
Storage of straw	—	—	14.4	—	—	14.4
Total	271.7	149.8	85.3	202.8	98.3	47.4
Output						
Yield at cutting (DM t/ha)	12	12	12	10	10	10
Losses during conservation (%)	5	11	5	5	11	5
Conserved feed (DM t/ha)	11.4	10.7	11.4	9.5	8.9	9.5
(ME MJ/kg DM)	11.0	10.5	11.0	10.0	9.5	10.0
(GJ/ha)	125.4	112.3	125.4	95.0	84.6	95.0
Input:output	2.17	1.33	0.68	2.13	1.16	0.50

Sources: Support energy inputs calculated from White (1980) and Wilkins (1976).

The most striking feature of the Table is the very high input of support energy to the dehydration of direct-cut crops. Not surprisingly, therefore, wilting is advocated as a means of reducing oil consumption. White (1980) calculated that primary energy required, to dehydrate green crops, decreased from 17.2 to 6.8 MJ/kg DM when the incoming crop DM was increased by field-wilting from 18% to 35%. Despite this reduction in energy requirement, the dehydration of wilted grass and legume crops consumes more support energy than it produces in ME.

An alternative strategy might be to use another renewable source of fuel for the drier, as Israelsen & Nielsen (1979) have suggested. They considered that the production of wood, in association with dried lucerne, would be an attractive alternative to using oil as fuel for dehydration. The wood might yield 4 t of oil equivalent (160 GJ) per ha. However, since artificial dehydration is often operated on large arable farms, the utilisation of straw as a fuel is worth consideration. At a yield of 4 t DM/ha (72 GJ), the land area of straw required to fuel a dehydrator is three times that of the grass or legume crop. Approximately one tonne of straw is needed to produce one tonne of direct-cut dehydrated crop (B Wilton – personal communication).

Despite increased energy used in field operations (baling straw, moving straw to stack and from stack to drier) and in plastic sheeting for the straw stacks (estimated at £200 per annum at 72 MJ/£; White, 1980), which would be very large, the use of straw as fuel increases energetic efficiency markedly. Further, the change from oil to straw allows artificial dehydration to compete in energetic efficiency with ensilage and haymaking.

The use of wood to fuel the drier involves utilising land which might otherwise grow a grain or forage crop: thus, the calculations of Israelsen & Nielsen (1979) indicated that the output of ME from dried lucerne was 88 $MJ \times 10^3$ per ha, excluding the area of land devoted to fuel crop production, but only 57 $MJ \times 10^3$ per ha when the land used to grow the fuel crop was included. If straw is used as fuel, then the question of including the land used to produce it does not arise, since its occurrence is as a by-product of cereal grain production.

Energetic efficiency of conservation systems

Thus, there is a wide range in energetic efficiency between different methods of forage conservation. Paradoxically, the system involving the highest loss during conservation – field-dried legume hay – is the most efficient in terms of energy balance, followed by maize silage grown with slurry. These two systems form the basis of much of the ruminant feed production of the mid-west of the USA, where losses in the making of legume hay are likely to be lower than in UK as a result of favourable weather for drying. The analysis indicates, however, that a combination of maize silage and legume silage is worth attention for European conditions, because the two crops complement each other with regard to their suitability as feeds for ruminants (Wilkinson, 1978c).

POSSIBILITIES FOR INCREASED EFFICIENCY OF CAPITAL UTILISATION

Two clear trends in forage conservation have emerged which typify the development of farming in general over the past 50 years. Firstly, farm operations have become increasingly mechanised; secondly, machinery has become increasingly specialised. Only recently has this latter trend started to reverse with the introduction of the mower-conditioner to replace the mower and the conditioner, and the introduction of the self-loading/unloading forage wagon to replace the forage harvester and trailer.

It is likely that, in future, greater reliance will be placed upon multi-purpose machines which can undertake more than one task. For example, a forage wagon, or a baler, could be adapted to harvest grass for ensiling, or for storage as hay, depending on the suitability of the weather for field-drying. Since both machines can be operated by one man and a relatively small tractor, they are both well-suited for use on the small livestock farm.

Other developments may involve the use of a forage harvester for crops other than conventional grasses and legumes. For example, whole-crop cereals have been successfully harvested by forage harvester. Thus, the harvester can be used at a time of year when it would otherwise be idle and the combine harvester (a very expensive capital item) is made redundant. By threshing the cereal crop in the barn, use can be made (as sources of feed) of fractions which are normally lost in the field such as chaff and broken grain.

There is clearly considerable potential for improvement in the efficiency of use of capital invested in machinery. Other possibilities might involve the use of alternative methods of storage to the conventional silo or hay barn, to reduce the need to invest capital in buildings. By application of existing technology, silage can be made in unwalled clamps and effectively sealed to prevent surface wastage (Raymond *et al.* 1978). Addition of NH_3 to hay involves injection of the chemical into sealed stacks of bales (Sundstøl *et al.* 1978) which can be built outside and do not require barns for their storage. Stacks may be sited close to livestock (in fields if animals are outwintered) to give economies in the demand for labour for feeding.

CONCLUSIONS

Artificial dehydration, the ultimate in technical efficiency in forage conservation, involves low losses but inefficient use of support energy in the production of a high-value, saleable commodity. Alternatives to fuel oil may enable artificial dehydration to compete with ensilage in terms of energetic efficiency, but capital requirements will remain very much higher than those for ensilage.

Application of existing technology could result in reduced DM losses in ensilage and haymaking to less than 10% and 20% of initial DM yield, respectively. There is scope for improvement in efficiency of energy use in ensilage by the use of legumes and forage maize. Addition of NH_3 to sealed stacks of baled hay appears an attractive proposition.

Research to develop multi-role machinery, suitable for harvesting and storing crops as either silage or hay, should give fruitful advances in efficiency of use of labour and capital in forage conservation.

REFERENCES

Benham, C L & Redman, P L (1980) Hay preservation. In: Thomas, C (Ed) *Forage conservation in the 80's.* Occasional Symposium No 11. British Grassland Society.

Blaxter, K L (1973) Artificially dried herbage as a source of energy for ruminant animals. *Proceedings First International Green Crop Drying Congress,* Oxford, 64–72.

Butler, J L & Hellwig, R E (1973) Dehydrating, grinding and pelleting forage grasses. *Proceedings First International Green Crop Drying Congress,* Oxford, 266–276.

Christensen, B H (1967) Losses on drying. In: Wilkins, R J (Ed) *Occasional Symposium No 3,* British Grassland Society, 86–88.

Ekern, A, Blaxter, K L & Sawers, D (1965) The effect of artificial drying on the energy value of grass. *British Journal of Nutrition,* **19,** 417–434.

Harris, C E & Raymond, W F (1963) The effect of ensilage on crop digestibility. *Journal of the British Grassland Society,* **18,** 204–212.

Israelsen, M & Nielsen, H Ø (1979) Consumption of energy and yield of protein for dried lucerne, rapeseed and barley. *Report for KI-SAM, Danish Association of Green Crop Dryers,* July.

Jones, L (1979) The effect of stage of growth on the rate of drying of cut grass at 20°C. *Grass and Forage Science,* **34,** 139–144.

Klinner, W E (1976) *Mechanical and chemical field treatment of grass for conservation.* Report No 21. Silsoe: National Institute of Agricultural Engineering.

Klinner, W E & Shepperson, G (1975) The state of haymaking technology – a review. *Journal of the British Grassland Society,* **30,** 259–266.

Lacey, J, Lord, K A, King, H G C & Manlove, A (1978) Preservation of baled hay with propionic and formic acids and a proprietary additive. *Annals of Applied Biology,* **88,** 65–73.

McDonald, P, Henderson, A R & Ralston, I (1973) Energy changes during ensilage. *Journal of the Science of Food and Agriculture,* **24,** 827–834.
Mølle, G & Winther, P (1979) Effect of ammonia and ammonium compounds as a hay preservative. *Proceedings, Hay Research Discussion Group.* Burchetts Green, Maidenhead: Berkshire College of Agriculture.
Nilsson, E & Jeppsson, R (1979) Barn drying of hay. *Proceedings, Hay Research Discussion Group.* Burchetts Green, Maidenhead: Berkshire College of Agriculture.
Ololade, B G, Mowat, D N & Winch, J E (1970) Effect of processing methods on the *in vitro* digestibility of sodium hydroxide treated roughages. *Canadian Journal of Animal Science,* **50,** 657–662.
Parke, D, Dumont, A G & Boyce D S (1978) A mathematical model to study forage conservation methods. *Journal of the British Grassland Society,* **33,** 261–273.
Phipps, R H & Pain, B F (1978) The efficiency of energy use in forage maize production. In: Bunting, E S (Ed) *Forage Maize.* London: Agricultural Research Council, 323–336.
Raymond, W, Shepperson, G & Waltham, R (1978) *Forage Conservation and Feeding* (3rd Edition). Ipswich: Farming Press.
Sheldrick, R D & Wilkinson, J M (1980) Recent developments in the production and utilisation of forage maize. *ADAS Quarterly Review* (in press).
Shepperson, G (1960) Effect of time of cutting and method of making on the feed value of hay. *Proceedings of the 8th International Grassland Congress,* Reading, 701–708.
Spatz, G, Elmern, J Van & Lawrynowicz, R (1970) Variation of drying rate of hay in the field. *Bayerisches Landwirtschaftbuches Jahrbuch,* **47,** 446–464.
Strickland, M J (1979) Comparison of barn-dried and chemically treated hay for dairy cattle. *Proceedings, Hay Research Discussion Group.* Burchetts Green, Maidenhead: Berkshire College of Agriculture.
Sundstøl, F, Coxworth, E & Mowat, D N (1978) Improving the nutritive value of straw and other low-quality roughages by treatment with ammonia. *World Animal Review,* **26,** 13–22.
Tas, M V (1979) Comparison of the feeding value of barn-dried and chemically treated hay for Friesian steers. *Proceedings Hay Research Discussion Group.* Burchetts Green, Maidenhead: Berkshire College of Agriculture.
Tetlow, R M & Fenlon, J S (1978) Pre-harvest desiccation of crops for conservation. 1. Effect of steam and formic acid on the moisture concentration of lucerne, ryegrass and tall fescue before and after cutting. *Journal of the British Grassland Society,* **33,** 213–222.

Waldo, D R (1977) Potential of chemical preservation and improvement of forages. *Journal of Dairy Science,* **60,** 306–326.
Weissbach, H F, Schmidt, L & Hein, E (1977) Method of anticipation of the run of fermentation in silage making, based on the chemical composition of green fodder. *Proceedings 13th International Grassland Congress,* Leipzig, GDR Vol III Part II, 663–673.
White, D J (1980) Support energy use in forage conservation. In: Thomas, C (Ed) *Forage conservation in the 80's.* Occasional Symposium No 11. British Grassland Society.
Wilkins, R J (1976) The potential for increased use of ensiled crops for animal production with particular reference to support energy inputs. In: Tayler, J C & Wilkinson, J M (Eds) *Improving the nutritional efficiency of beef production.* Publication EUR 5488e. Luxembourg: Commission of the European Communities, 224–234.
Wilkins, R J (1978) Ensiled forages and their utilisation by ruminants. *Proceedings 3rd World Congress on Animal Feeding,* Madrid, 403–412.
Wilkins, R J & Bather, D M (1981) Potential for changes in support energy use in animal output from grassland. In: Jollans, J L (Ed) *Grassland in the British economy.* CAS Paper 10. Reading: Centre for Agricultural Strategy.
Wilkinson, J M (1978a) Physical and chemical methods to improve the utilisation of forage crops by beef cattle. *Proceedings European Congress for Improved Beef Productivity.* Paris: Elanco Ltd.
Wilkinson, J M (1978b) The ensiling of forage maize: effects on composition and nutritive value. In: Bunting, E S (Ed) *Forage maize.* London: Agricultural Research Council, 201–237.
Wilkinson, J M (1978c) New thoughts on winter feeding. In: *Intensive grassland use and livestock health.* BGS/BVA Conference. Burchetts Green, Maidenhead: Berkshire College of Agriculture, 55–65.
Wilkinson, J M (1980). Losses in the conservation and utilisation of grass and forage crops. *Annals of Applied Biology* (in press).
Wojahn, E (1977) Review of 50 years grassland farming and trends of development in the further intensification of forage production in the German Democratic Republic. *Proceedings 13th International Grassland Congress,* Leipzig, GDR. Plenary papers, 1–61.
Wood, J G M & Parker, J (1971) Respiration during the drying of hay. *Journal of Agricultural Engineering Research,* **16,** 179–191.
Zimmer, E (1977) Factors affecting fodder conservation. *Proceedings, International Meeting on Animal Production from Temperate Grassland.* Dublin, 121–125.
Zimmer, E (1980) Efficient silage systems. In: Thomas, C (Ed) *Forage conservation in the 80's.* Occasional Symposium No 11. British Grassland Society.