Update on technologies for producing and feeding silage

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Key Points

1. Mechanisation and engineering inputs are key factors which contribute to silage costs.
2. Sensing technologies will improve management precision in many areas of ensilage.
3. While current harvesting machines have high output capacity reflecting mature design, there is a need to revisit the area of energy efficiency.
4. Baled silage technology, particularly in the areas of covering film and wrapping technology, needs further research.
5. Feeding systems are well researched but there is a need for systems research to underpin farmers' decisions concerning housing design and feeding system.

Keywords: silage, engineering, mechanisation, costs

Introduction

Silage making on farms requires technologies that ensure efficient conservation of forage. While the term technology could encompass all aspects of the application of science to ensilage, in the context of this paper it is restricted to the engineering- or mechanisation-related components of the ensiling and feeding processes. These technologies can reduce costs and labour requirements and improve work/process quality and timeliness. This paper has two main objectives:

1. Review recent developments in engineering-related technologies involved in the production, storage and utilisation of silage.
2. Identify engineering related areas that require further research and development in order to improve the ensiling process.

The scope of the paper is limited to those crops for ensilage that are normally grown in northern European climates. For a broad overview of ensiling technologies see Muck and O'Kiely (2002).

Costs and cost components

The cost or value of silage as a feed can be estimated as a cost per unit dry matter (DM) or energy consumed by an animal and this enables comparison with other feeds. Examples of cost breakdowns for a grass silage crop stored in a conventional silo, or stored as bales, and for a whole crop wheat crop using a crop costing model (O'Kiely *et al.,* 1997) with 2005 data, are given in Table 1. The yields and costs attributed are those appropriate for Ireland. The importance of mechanisation as a cost component is evident with between 52% and 64% of the production costs being attributable to machinery. These costs are averages around which there is considerable variation. They do not reflect the contribution that mechanisation technology can make to silage quality and value, or to labour-saving and convenience.

The science of silage is often thought of as the non-mechanisation processes directly involved with the production and preservation of forage, the effects of which are measured by various analyses of the forage and animal performance. While these are considered they are not the only factors that will influence a farmer's decision concerning choice or specification of forage conservation system. Machinery cost and logistical considerations in the supply of labour and mechanisation for the production, harvesting, storing and feeding of forage have a significant influence on forage conservation practised on farms.

Table 1 Forage production costs[1] and partitioning of cost components

	Conventional silage		Baled silage		Whole crop wheat	
Crop DM yield (t/ha)	6.64		6.64		14.13	
Crop DM (g/kg)	200		280		440	
Silage DM yield (t/ha)	5.31		5.64		12.44	
[2]Total cost/ha (€)	532.08		607.17		1193.67	
[2]Total cost/t DM (€)	100.20		107.65		95.95	
[3]Total cost/t DDM (€)	138.79		149.10		141.10	
Cost categories	Machinery	Materials	Machinery	Materials	Machinery	Materials
Production (%)	7	22	6	19	22	45
Harvest (%)	45	0	53	0	23	0
Additive (%)	0	13	0	0	0	0
Storage (%)	0	8	0	17	0	3
Feed (%)	5	0	5	0	7	0
Category total (%)	57	43	64	36	52	48
Total (%)	100		100		100	

[1]Excluding land charges [2]Cost of feed consumed [3]DDM: Digestible dry matter

Crop production

Mechanisation technology involved in the production of the forage crop can influence crop yield, quality and production costs.

Crop establishment

Grass establishment is expensive. Seed and mechanisation are the primary costs with sward longevity determining annual costs. While lower-cost establishment/improvement using minimal cultivation and direct drilling techniques continue to be developed, the techniques used, their success and application, depend on local soil, climate and machine availability factors.

The establishment cost for annual forage crops such as maize, cereals or fodder beet is significant. Rapid and successful establishment is essential. Over the last decade the use of polythene mulch systems with forage maize has been shown to give improved yields and higher dry matter and starch levels (Crowley, 1998; Keane *et al.,* 2003; Easson & Fearnehough, 2003). While traditional mulch systems required the seeds to be sown through a hole punched in the plastic mulch, an alternative complete cover system where the growing plant must push through a total polythene cover has been developed. While this system has given advanced early growth, the effect on performance of the harvested crop has been inconsistent (Keane *et al.*, 2003) (Crowley, 2005).

Nutrient application

The application of nutrients can affect forage costs and quality. Even application of nutrients aids the achievement of optimum yield, consistent quality and ensilability. Modern fertiliser spreaders are capable of very even spreading (coefficient of variation <0.05) at wide (>15 m) bout widths (Anon, 1999). These spreaders ensure more even application than that achieved by most spreaders marketed 20 years ago (Sogard & Kierkegaard, 1994). However, fertiliser physical quality has not improved over this time period, with farmers often purchasing product with physical characteristics that have a deleterious effect on spread patterns (Hofstee & Huisman, 1990). In addition to the improved technical performance of the spreaders, accuracy is today aided by the use of GPS technology which guides the driver along equidistant bout widths.

Newer organic nutrient application techniques can also play a role in improving the efficiency of nutrient use. The use of a trailing-shoe slurry applicator which places the slurry directly on the soil surface, increased grass yield by 23% compared to using a splash-plate spreader (Binnie & Frost, 2003). This was equivalent to 48% of the N in the slurry being available as fertiliser N compared to just 12% for the splash plate system. When slurry is applied at higher rates these systems are also less likely to adversely affect silage quality than splash plate spreading (O'Kiely *et al.*, 1994).

Crop sensing

The scope for the application of sensing technology to forage crops is vast, with the possibility of generating data to aid management and ultimately lead to more accurate application of inputs and improved forage quality.

Multi-spectral crop sensing

The development of precision farming technology, which allows spatial variability within fields to be assessed and managed, has increased research activity in the area of crop and soil multi-spectral sensing. Multi-spectral crop sensing can be carried out with sensors close to the crop on field machines, by aircraft mounted sensors, or from satellites. The prediction of required crop nitrogen input based on spectral imaging has been evaluated and has led to the marketing of a commercial sensing system (Wollring *et al.*, 1998). These technologies have limitations but developments in this area are proceeding. Development of complimentary soil and water status sensing technologies coupled with the use of historic spatial yield patterns should help improve the usefulness of crop sensing.

Yield sensing

The estimation of crop yield using real-time sensing technology offers potential benefits including improved feed budgeting, accurate additive application, a better base for contractor charging, and opportunities to utilise precision agricultural management techniques in forage crops. Various on-harvester yield-sensing techniques have been assessed mainly on metered chop type machines, but also on mowers, balers and silage trailers (Savoie *et al.*, 2002; Demmel *et al.*, 2002; Wild & Auernhammer, 1999). The accuracies of these yield sensors vary. Correlations of meter readings with actual mass-flow rates range from 0.60 to 0.98 (Savoie *et al.*, 2002). The uneven flow of forage through a forage harvester compared to grain flowing through a combine harvester, and the importance of grass dry matter content are factors which limit the usefulness of the sensed information. Fresh-weight yield data is adequate for silage additive application control and as a base for contractor charging (Forristal & Keppel, 2001a). Additive application accuracy can be improved by automating control and varying application rate in proportion to grass or crop throughput. Evaluation of a prototype system showed a decrease in coefficient of variation from 0.41 where fixed rate application was used to 0.12 where a throughput-based control was used (Forristal & Keppel, 2001b). Currently at least one forage harvester manufacturer is marketing a forage yield sensor.

Dry matter sensing

To provide yield data for feed management and precision-agriculture field applications, dry matter sensing technology is necessary. This will probably be in the form of a separate sensor to the mass flow sensors outlined above. The application of NIR sensing technology to real-time harvesting has been evaluated with some success (Paul *et al.*, 2000). The technology is expensive. Alternative less expensive microwave and capacitance systems have been evaluated but their accuracy has been much less than that of NIR techniques (Kormann & Auernhammer, 2002). The latter authors suggest that the ability of NIR techniques to predict various qualitative parameters during harvest may make the system economic in the future.

Harvesting

Mowing and wilting

Engineering developments in mowing and crop tedding to increase work rate have resulted in wider and faster machines. Tractor mounted, trailed and self-propelled mowers with working widths of up to 14 m are available. Almost all mowers used to cut silage crops are high cutting speed (knife speed >70m/s) rotary mowers which rely on the impact speed of the cutting flail to cut the crop stems. The cutting technology is simple, robust and fast, but requires high power inputs (O'Dogherty & Gale, 1986). The need to conserve energy for environmental and/or cost reasons will require shear mowing systems which are proven to be less power demanding (Copeland, 1993) to be developed. The concept of a light-weight saw-band mower, which can optionally be developed as a shear cutting concept, is at an early development stage (Ehlert & Kraatz, 2004).

Mowing research since the 1970s has focused on the development of conditioning systems to accelerate the wilting process. Early conditioning developments increased the wilting potential of the crop, but often narrow swath structures failed to exploit this potential. The development of rapid wilting systems using tedders led to successful and practical wilting systems. (Bosma & Verkaik 1987). Intensive conditioning using close-coupled differentially speeded rollers has been investigated since the 1980s. The drying rate of lucerne in good drying conditions can be dramatically increased by maceration (Hintz *et al.,* 1999). In north western Europe, high grass yields and variable weather have affected the performance of the technique. Research in Northern Ireland showed that rained-on macerated swaths dried more slowly than unconditioned grass and suffered greater losses (81.2 g/kg compared to 42.3 g/kg) (Binnie & Frost, 1996). While this research did show improved drying rates, it concluded that the expenditure on the equipment was not justified.

The success of the spreading and tedding wilting systems led to the development of mowers with semi-intensive conditioners coupled with spreading attachments (Bosma, 1995). From this research, European mower manufacturers have chosen to adopt simple spreading devices which spread the cut grass over 80 to 100% of the cut area thus increasing exposure to the natural drying elements. Spreading systems can speed up the crop drying process with high yielding crops in temperate climates (Forristal, 1996), achieving satisfactory wilts within 32 hours in all of the harvesting season provided it does not rain (Frost, 1988). However wilting continues to be difficult with high-yielding crops in unpredictable weather conditions. In these areas, extra harvesting capacity, in addition to specific wilting machines, would be necessary to consistently improve wilting performance. In practice wilting is carried out opportunistically in these areas, when weather conditions allow, with minimal investment in equipment. Anecdotal evidence suggests that the inability of swath tedding and raking equipment, working in high yielding crops, to present even swaths for harvesting results in a slower harvesting rate. There is scope to develop improved harvester and baler pick-up systems that incorporate active crop presentation components to improve the evenness of crop feeding to the chopping or baling mechanism.

Conventional harvesting

The principles of forage chopping on chopper-harvesters have changed little, with development concentrating on increased output self-propelled machines of up to 500 kW power output. These machines are now technologically mature and are capable of substantial annual and lifetime throughputs. However, the high-speed chopping and largely pneumatic grass delivery systems used are not power efficient. Alternative systems capable of working with 50% of the power input have been researched (Knight, 1984). Low speed chopping mechanisms and mechanical grass delivery systems such as those used in pick-up wagons are more power efficient (Tremblay *et al*., 1991). The popularity of the pick-up wagon system has been in decline as contractors preferred continuous harvesting systems of more robust construction. However there is renewed interest in the system with high-output, more robust pick-up wagons teamed with high-powered tractors. In a recent trial in Northern Ireland, a wagon system was shown to be twice as fuel-efficient and more labour efficient than a conventional self-propelled harvesting system (Frost & Binnie, 2005). If energy prices continue to increase and if CO_2 reduction policies are implemented, the need to adopt fuel-efficient systems will increase.

The pick-up wagon harvesting system involves two separate components: crop pick-up/chop and transport. The crop pick-up and chopping mechanism is idle during the transport part of the cycle. There would be benefit in developing a system with the low power requirement of the wagon coupled with the operation efficiency of a system with separate and continuously working harvesting and transport elements. An experimental system developed in the 1980s which used slow speed slicing and mechanical grass delivery, reduced power requirement by up to 62% compared to a conventional harvester (Knight, 1984). This concept is worthy of further development.

Baled silage

Baled silage, which is now a well-established conservation system, is characterised by its unique individual-package storage system. The characteristics of typical bales and bale wrapping practice in Ireland are outlined in Table 2. Until recently baling and wrapping were carried out by separate machines, thereby allowing wrapping to be carried out either in the field or following transport, at the storage site. Recently combined baler/wrapper units that can only wrap in the field, have become common.

Compared to clamp silage, baled silage often has a more restricted fermentation (e.g. Jones & Fychan, 2002), but the feeding value of the resultant silage is usually similar (O'Kiely *et al.*, 1998). Research on baled silage has focused on bale wrapping as the implications of an imperfect seal are more far-reaching than with conventional silage for a number of reasons:

- For a given quantity of silage stored, the surface area in contact with film in baled silage is typically 6 to 8 times that of conventional silage.
- With bales, 50% of the silage stored is within 12 cm of the polythene film whereas with conventional silage less than 10% of the volume would be within this distance.
- The normal thickness of stretched film on baled silage is 70 µm (4 layers), compared to 250 µm for a double-sheeted silage clamp.
- The porosity of baled silage is usually greater than clamp silage.
- Bales are allowed to drop to the ground and are handled after wrapping, exposing the polythene to a greater risk of damage.
- The grass ensiled in bales can often be stemmy, dry and is not lacerated and consequently presents a greater polythene puncture challenge.

Failure to maintain anaerobic conditions will result in aerobic deterioration. Survey results indicate that most Irish farms (87%) have bales with some mould growth (O'Kiely *et al.*, 1998; O'Brien *et al.,* 2004). In Norway the principal moulds found in baled silage were *Penicillium, Aspergillus, Mucor, Rhizopus, Geotrichum* and *Byssochlamys* (Skaar, 1996). The fungal growths found in Ireland were predominantly *Penicillium, yeasts, Geotrichum* and *Schizophyllum* species (O'Brien *et al*., 2004). Mould growth causes deterioration in the nutritive value of the silage, as well as being a direct source of potential health challenges through the production of spores and mycotoxins.

Table 2 Characteristics of round[1] bales and wrapping of grass for silage

	Typical	Range
Nominal bale size (m)	1.25 x 1.25	-
Bale weight (kg)	650	350 – 1000
Dry matter content (g/kg)	300	160 – 700
Porosity (% pore space)	60	50 – 80
Density (dry matter kg/m^3)	130	90-200
Film width (mm)	750	250[2]-750
Film thickness (µm)	25	12-30
Pre-stretch on wrapper (%)	70	25-70
No. of layers	4	4 – 8
Film weight per bale (g)	850	500 -1700

[1]Various sizes of large rectangular (e.g. 0.8 m x 0.8 m x 1.2 m) and small rectangular bales are also wrapped
[2] 250 mm only used on small rectangular bale wrappers

Research on baled silage has sensibly been focused on the creation and maintenance of anaerobic conditions. In particular the stretch film applied to bales and its effect on the preservation of silage has been the subject of much study.

Film cover

The quantity of film applied to bales, usually expressed as the number of layers, has a marked effect on the cost of silage production and is consequently the subject of evaluation. In Scandinavia, the application of six layers of 25 µm polythene film resulted in less mould than where four layers were applied (Lingvall, 1995). In the same climatic region, a significant reduction in mould growth on high dry matter forage (564 g/kg) was obtained when eight layers of film were used compared to six (Jacobsson *et al.*, 2002). Similarly Heikkila *et al.* (2002) showed less mould growth with six layers of film compared to four.

In more temperate conditions, such as in Ireland, increasing the level of cover from two to four to six layers of film progressively reduced mould levels from 21.5 to 1.7 to 0.7% respectively of the surface area (Forristal *et al.*, 1999). Carbon dioxide profiles in the bale are a good index of the integrity of seal achieved and this trial indicated that the use of more layers of film resulted in better retention of CO_2 levels. These results indicate that in these conditions a minimum of four layers of film were required. A recent study in the UK by Harrison *et al.* (2004) with four, six and eight layers showed that mould was reduced by increasing the number of covering layers.

Film colour

Black film is the least expensive to manufacture as the UV inhibitor (carbon black) does not interfere with the other properties of the film. The polythene film is technically permeable to gases – but at very low gas transmission rates. Dark films absorb heat and the consequent rise in film temperature increases the permeability of the individual film layers (Möller *et al.*, 1999). In temperate regions, film colour was not shown to influence baled silage quality or mould development (Forristal *et al.*, 1999; Harrison *et al.*, 2004). In mini silos where white, green and black films were used in natural and artificial light conditions, silage quality was not affected even where film temperature differences of up to 16^{o}C (black: 37.6^{o}C, white: 21.6^{o}C) were recorded (Snell *et al.,* 2003). Countries with high sunshine levels generally use white or light-coloured films which reduce film temperature and heat transfer.

Stretch level

The tension created by stretching film during the application process, typically to 1.7 or 1.5 times its original length, is essential to ensure that the film remains tight on the bale during the storage period. A trial that assessed the effect of three different stretch levels (1.4, 1.7 and 2.1 times original length) on silage composition, mould growth and gas composition showed no significant effect of stretch level (Forristal *et al.*, 2000). The effect of stretching on the films performance is complex. In laboratory trials, stretching has been shown to decrease the permeability coefficient (i.e. less permeable per unit of thickness), however it may also adversely affect the mechanical properties of the film (Laffin *et al.,* 2005).

Film type

A thinner (12-14 µm) polythene film that is pre-stretched in production has been evaluated (Forristal *et al.*, 2002). There was relatively little difference in performance between the thin film and a conventional film, however at certain points in the storage period, the thin film had a poorer gas profile indicating possible air entry. A stronger stretch film has been shown to give better sealing and less fungal growth in the silage compared to conventional film (Jacobsson *et al*., 2002).

Film damage

Polythene film can be damaged during wrapping in the field, or while the wrapped bale is being transported to, or in, storage. Machines, stubble and wildlife are sources of damage. The effect of relatively small holes in the film on silage preservation has been shown to be quite significant. A study of the effects of damage (McNamara *et al.,* 2002a) showed damaged film to allow greater levels of surface mould, more rotted silage, and more inedible silage.

A detailed study of the prevention of damage by birds to the film surrounding bales highlighted practical control strategies (McNamara *et al.*, 2002b). In the field, the most effective strategy was to remove bales from the mown field before wrapping. While the use of painted eye designs and red or transparent films had some deterrent properties, they were not completely effective. Chemical repellents had little effect. For season-long storage, the use of nets or closely spaced (0.5 m) monofilament lines placed 1 m above and to the side of the bales, were the only truly effective protection strategies.

Polythene film requirements and research needs

Because of the high incidence of mould, the current systems used for baled silage on farms can only be considered partly satisfactory. There is a need to devise improved wrapping methods which give better sealing. The move towards film standards similar to the 'P' mark in Sweden should remove inferior films from the market. However, there is a need to develop stretch film with improved qualities and to devise wrapping methodologies that give improved and more robust sealing compared to what is commonly used today.

Harvesting logistics

The logistics of harvesting influences the efficiency of utilisation of labour and machinery. Logistics include the selection of machine types and capacities and the organisation of the field operation to optimise the utilisation of all resources. Logistics can be examined on a single farm, or on a group of farms harvested by a single contractor, or on all farms in a region where many harvesting units operate. The aim should be to determine the optimum mechanisation supply to ensure satisfactory supply of forage. There has been relatively little formal research in this area. Ward *et al.* (1986) examined the seasonal capacity of harvester systems and calculated the opportunity cost for crop digestibility losses. Bernhardt *et al.* (2004) showed the importance of matching transport capacity to harvesting capacity for a range of dairy farm sizes in two regions of Germany. The effect of field size and transport distance on work rate, labour requirement and costs were calculated for baled silage (Wagner & Seufert, 2000). More information is needed to support mechanisation selection decisions including:

- comprehensive machine performance data for all crops and conditions, and support information such as trailer packing density for various forages
- crop growth models indicating changes with time in yield, ensilability and feed value
- regional information such as field size, farm harvest area, transport distance, feed quantity and quality requirement and weather patterns

A more formal approach to the subject would determine optimal logistical strategies at farm and at regional level.

Mechanisation and soil effects

As harvesting output has increased, the weight of the field machinery used has also increased with many of today's machines exerting individual axle loads in excess of 6 tonnes. Increased axle loading increases the risk of soil damage with possible effects on crop yield. Much of the early work studying the impact of traffic on crop performance was with cultivated crops. Early work on grassland assessed the impact of wheel traffic on grass, with first harvest yield reductions of 13 to 33% recorded directly in the wheeled area (Frost, 1988). In a complete harvesting system trial where the cumulative effect of traffic was examined, the use of low ground pressure tyres resulted in yield increases of between 9 and 16% in annual grass yield depending on site (Table 3) (Fortune *et al.*, 1995). This research showed that where grass was harvested without applying traffic on a low bearing capacity soil, annual yield increases of up to 32% were recorded. The crop response was accompanied by soil structure changes and reduced uptake of nitrogen.

The mechanisation changes required to achieve a significant reduction in ground pressure are considerable. Research on arable soils would also suggest that very heavy axle loads are capable of causing deep compaction even when low ground pressure tyres are fitted (Hakansson & Petelkau, 1994). Machinery developments through larger, heavier and more labour efficient machines are contributing to the compaction problem. Reducing ground pressure will increase machinery cost and as a result will add to the harvesting costs, and this must be considered. It may be necessary to rethink current transport systems which use three to five trailers in the field and on the road. To equip all of these trailers with low ground pressure tyres would be an expensive option. An alternative would be to couple the harvester with a dedicated single low ground pressure trailer which then transfers the load to a fleet of road-going trailers.

Table 3 Annual grass yield and nitrogen removal following three levels of silage harvesting traffic using a three-cut system on two sites (Fortune *et al.*, 1995)

Traffic system	Wet site		Dry site	
	DM yield (kg/ha)	N removed in crop (kg/ha)	DM yield (kg/ha)	N removed in crop (kg/ha)
Conventional	9500	211	12500	326
Low ground pressure	11100	263	13600	364
Zero traffic	13000	327	13700	362

Silage feeding

The feeding of silage utilises significant resources in the form of machine, labour and associated building costs. While the costs attributed to feeding (Table 1) are relatively low, costs can vary significantly with herd size and mechanical system used for feeding. Feeding systems used in different regions and for different animal rearing systems are influenced by a combination of tradition, labour demand, cost and suitability for the feeds being offered.

Mechanisation-based research has focused mainly on the requirements for processing in terms of chop length and grain cracking along with method of presentation including mixing of feeds.

Early work on chop length focused on the need for short chop. A range of chop lengths evaluated by Gordon (1982) with dairy cows and research by O'Kiely and Flynn (1991) with beef cattle showed little benefit from short chopping. As precision chop harvesters produced shorter chop lengths to make the harvested crop easier to handle, concerns about the effects of overly fine chopping were raised. For example, work on lucerne silage indicated that very fine chopping could negatively affect fibre digestion in the rumen (Grant *et al.*, 1990). However, the importance of chop length in rumen function is influenced by forage species with Mertens (1997) showing that grass silage particle size had less impact on chewing than with lucerne.

Where maize silage is harvested with well-developed cobs, the need for grain processing with corn-cracker rollers arises. Animal trials comparing processed with unprocessed maize silage have shown varied results. Processing can increase intake, starch digestion and performance (Bal *et al.,* 2000). However in many trials where processing is compared with different varieties (Moreira *et al.,* 2000) or different crops (Pressinger *et al.*, 1998) the response to processing is variable although generally showing some benefit.

Where forage alone is fed, the method of presentation (e.g. self-feeding or easy feeding) has no significant effect on animal performance provided the feed on offer remains fresh and sufficient feeding space is available. The benefit from mixing forage and concentrate components has been the subject of research for a considerable period with variable responses reported. The reported responses in animal production to total mixed ration feeding (TMR) have been variable. Trials in Northern Ireland have shown a positive response in milk production to TMR in two trials (Gordon *et al.*, 1995; Yan *et al.*, 1998) with no effect in another trial (Agnew *et al.*, 1996). In a beef trial where finishing steers were fed 3.5 kg or 7.0 kg supplementary concentrates daily, mixed or separate feeding gave the same animal performance (Caplis *et al.,* 2003). Overall, other than where very high levels of concentrate supplementation are fed (>50% of diet), mixed feeding of forage and concentrates is unlikely to give an animal performance benefit compared to careful separate feeding of the same feedstuffs.

For most farmers, the attractions of TMR feeding systems are associated with management and labour saving aspects. The ability to weigh, mix and accurately dispense feed-stuffs is particularly beneficial where a variety of feeds are to be fed including combinations of forages (e.g. maize and grass silage) or a number of concentrate feed components. The choice of feeding system coupled with building design can have a significant impact on the time and labour required to feed animals. For example in a study in Ireland, feeding with a mixer wagon required the same time and labour input as separate mechanical feeding of the diet components, but the task was easier with no manual handling (Forristal, 1992).

The labour associated with feeding tasks is dependent on mechanisation, feeding system and housing design and consequently differs among geographical regions being studied. For example in Ireland, a recent study showed that the time taken to feed livestock on beef farms with an average of 93 livestock units exceeded 2 hours per day over the winter period (Leahy *et al.*, 2004). In this work silage feeding accounted for 72% of that time.

There is renewed interest in developing low-cost animal wintering systems based on outdoor systems, or simple housing. Animal performance on these units is good (Hickey *et al.*, 2002) and the selection of appropriate feeding systems is now being considered.

There is a need for a comprehensive evaluation of feeding systems to include costs, labour and integration with house design which would allow farmers to make optimal choices concerning feeding mechanisation on their farm. More research is needed to underpin such evaluations.

Environmental constraints

Silage storage systems present a number of environmental challenges. While effluent production and control systems are well understood, the post-use fate of the large quantities of polythene used with baled and conventional silage is of concern. The baled silage system uses considerably more polythene at 23.5 kg/ha than clamp silage at 4.7 kg/ha (Hamilton *et al.,* 2005). Collection and recycling systems are effective but the current systems may not be the most effective means of handling used polythene. The use of biodegradable polythenes has been considered. However, development for this application is difficult since polythenes must maintain anaerobic conditions in silage up to the time of use (Keller, 2000).

Ensilage for non forage uses

The concept of using crops for energy purposes is not new. Anaerobic digestion of carbon-rich forages is always possible (Plochl & Heiermann, 2004). If a biogas plant using agricultural crops is to be effective, then the issue of crop storage prior to use must be considered. Ensilage is the obvious choice for many low dry-matter content crops. Efficient ensiling technologies for crops destined for biogas production may need to be developed.

Conclusions

Silage research has largely concentrated on the biological and biochemical aspects of the ensiling process. Engineering and mechanisation technologies are significant inputs which influence the cost and value of silage and which significantly impact on choices made by farmers. Research is needed to underpin the decisions concerning mechanisation and engineering that must be made at farm level, and to exploit new technologies which are becoming available. Developments in the areas of baled silage research and sensing technologies are continuing and offer scope to improve conservation efficiency. Energy efficiency must again become a topic in forage conservation research. In a broad context, energy efficiency applies to all aspects of silage conservation from production to feeding.

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