POST HARVEST MANAGEMENT OF GRASS SILAGE - EFFECTS ON INTAKE AND NUTRITIVE VALUE

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ABSTRACT

The objective of silage making is to preserve the grass crop whilst minimizing detrimental effects on feeding value and avoiding nutrient losses. This is best achieved by using harvesting systems designed to maximise either the rate of acid production within the silo, or the rate of increase in DM concentration in the first few hours following cutting. Addition of metabolically active lactic acid bacteria stimulates the rate of acid production and enhances feeding value, even in situations where there are no apparent beneficial effects on fermentation parameters as assessed at feeding. Rapid wilting systems reduce the production of silage effluent and can enhance the feeding value of silage, although given the wide range of responses that have been obtained, it is imperative that systems of grass analysis are developed to enable accurate prediction of responses to wilting and/or additive treatment, under a range of crop and weather conditions. The optimum chop length for grass silage differs with crop type and stage of maturity at harvest, animal species and the level and type of supplement offered. Current recommendations suggest an optimum chop length of 10 mm for silage offered to sheep, whereas with cattle, chop lengths up to 50 mm have no detrimental effect on intake or performance. Ensilage results in a reduction in food intake, which is primarily related to changes in protein and fibre fractions and the relative rates and extent of digestion of these components within the animal, rather than to the presence of fermentation end products. Numerous studies have shown reductions in amino acid N flow to the duodenum with cattle and sheep offered grass silage compared to that obtained with fresh forage, and this is attributed to a reduction in microbial protein synthesis. The extent of the reduction in microbial protein synthesis can be reduced by preventing protein hydrolysis in the initial ensilage period. Further studies are required to determine effects of ensilage on energy metabolism, with recent studies suggesting substantial increases in maintenance energy requirements with animals offered grass silage-based diets. Strategies to minimise aerobic deterioration during feedout include rapid filling and effective consolidation of silos during ensilage and rapid and complete sealing of the silo surface. One of the most important recent advances associated with silage making technology is the development of accurate systems for evaluating the feeding value of silage based on near infrared spectroscopy. Continued development of these techniques should facilitate the development of improved crop management techniques designed to minimise the effects of ensilage on herbage feeding value.

KEYWORDS

Grass silage, inoculant, proteolysis, feeding value, chop length, harvesting system, aerobic deterioration, ensilage period.

INTRODUCTION

The principle objectives of ensilage are to preserve grass with minimum loss of nutrients and to obtain a product of high feeding value. In recent years, grass silage production systems have been subject to increasing scrutiny due to:

(i) Reduced voluntary food intake and animal performance relative to grazed grass.

(ii) Increasing cost of grass silage, reflecting increasing costs of mechanisation and silo construction.

(iii) Increasing environmental concerns relating to effluent production during ensilage of low dry matter grass.

The feeding value of grass silage reflects both it's potential food intake and the nutritive value per unit food consumed, and is largely determined by factors relating to the ensilage process. These factors include a wide range of aspects associated with management of the grass crop prior to harvest, e.g. grass species and varieties used, fertilizer management and stage of development of the crop at the point of harvest. The objective of this review is to examine factors associated with post harvest management of the grass crop, i.e. from the point of cutting to the point of feeding, on the feeding value of the resulting silage.

THE ENSILAGE PROCESS

The primary objective in silage making is to preserve the grass crop whilst minimising nutrient losses and avoiding adverse changes in chemical composition (Thomas and Morrison, 1982). Consequently, effective ensilage systems should aim to minimise the activity of plant respiratory and proteolytic enzymes in the initial period following cutting of herbage, and to prevent the activity of putrefactive micro organisms, such as clostridia and bacilli, during the ensilage period. Charmley and Veira (1990) have shown that the activity of plant enzyme systems can be controlled either by rapid reductions in pH in the ensiled crop or by rapid increases in dry matter (DM) content. In general, the more rapid the decrease in pH or increase in DM content, the greater the reduction in enzyme activity. At the outset therefore, the objective of post harvest management is to maximise either the rate of acid production, or the rate of increase in DM concentration, in the first few hours following cutting, and to ensure that a stable fermentation is achieved quickly within the silo. Harvesting systems should be designed towards achieving either of these two key objectives, whilst minimising losses of herbage from field to silo.

HARVESTING SYSTEMS

Whilst a large range of harvesting systems for production of grass silage have evolved in recent years, they can be categorised primarily as either direct-cut or pre-wilting systems. The former are used extensively in Northern and Western Europe to overcome the problem of harvesting grass at an appropriate growth stage in adverse weather conditions, where pre-wilting systems can incur considerable field losses. For example, Gordon (1989) observed a consistently higher milk output per ha (up to 28% higher) in a comparison of direct cut and pre-wilted systems in Northern Ireland. This difference was attributed to the cumulative effects of differences in field losses, regrowth rates, food intake and animal performance across the various systems examined. In contrast pre-wilting systems have now been widely adopted in many central European countries, Australasia and on the American continent, where prevailing weather conditions at harvest may facilitate rapid increases in crop DM content.

In many situations, choice of harvesting system is influenced by the storage facilities available on the farm. For example, grass can be conserved either as direct cut or pre-wilted material in horizontal bunker or clamp silos, whereas pre-wilting is essential in tower silos and preferable for wrapped bale silage. Nonetheless, the same key principles apply to all storage systems including:

(i) Minimizing contamination of the crop with soil or other material during ensilage.

(ii) Ensiling the crop as quickly as possible

(iii) Ensuring anaerobic conditions are achieved as rapidly as possible (rapid sealing of bunker silos and effective wrapping of big bale material).

Direct Cut Systems. The principal challenges in direct cut silage systems are to achieve rapid decreases in pH of the ensiled crop, whilst controlling effluent output during storage. A number of approaches have been adopted to improve preservation of low DM herbage, including application of additional sugar to the crop, reducing pH by the addition of organic or inorganic acids, addition of homofermentative lactic acid bacteria and/or enzymes to the crop and the addition of absorbent materials to increase crop DM content.

Mayne and Steen (1993) in a review of 17 experiments, undertaken with low DM and low water soluble carbohydrate (21.2 g/kg fresh weight) herbage, concluded that addition of inoculant additives (10^6 lactic acid bacteria/g herbage) had little effect on silage fermentation parameters at the point of feeding out, whereas significant improvements were obtained with formic acid treatment (2.8 litres/t). However, despite the absence of effects on conventional parameters of fermentation (ammonia nitrogen and butyric acid concentrations), inoculant treatment produced similar responses to formic acid on silage intake and animal performance, with mean improvements in animal performance of 6.7 and 7.3% for inoculant and formic acid treatments respectively. These data confirm more recent observations (Steen et al., 1995) that conventional fermentation parameters are poorly correlated with food intake. Indeed, this is the basis for the current interest within the United Kingdom in developing improved systems for predicting the intake potential of grass silage.

The increases in food intake and animal performance observed with inoculant-treated silage appears to be mediated through effects on the activity of plant proteolytic enzymes in the initial stages of ensilage. This reflects the faster rate of decline in pH in inoculant-treated herbage, which is known to reduce activity of plant enzyme systems. For example, Williams et al. (1992) observed protein nitrogen (N) concentrations of 737 g/kg total N (TN) and 658 g/kg TN after 14 days of ensilage in inoculant-treated and untreated silages respectively, with pH values at day 4 of 3.8 and 4.0 respectively. In more recent studies Merry et al. (1995) have shown shorter lag times in the initiation of pH decline in herbage treated with freshly cultured inoculants of *Lactobacillus plantarum* than in herbage treated with freeze dried strains of the same bacteria. These authors also suggest that freshly cultured inoculants may well form the basis of a new generation of inoculants designed to supply large numbers of metabolically active bacteria at reduced cost relative to conventional freeze-dried preparations.

Most recent reviews (Parker and Crawshaw, 1982 and Gordon, 1989) suggest that improvements in food intake and animal performance with formic acid treatment are only obtained in situations where the untreated material undergoes a poor fermentation. This reflects the fact that treatment with formic acid, whilst reducing the initial pH, and improving overall silage fermentation, results in a lag phase during the initial ensilage period, as a consequence of an initial inhibition of the microbial population, enabling further proteolysis to occur.

More recently, there has been considerable interest in the use of high levels (6-9 litres/t) of organic acids to minimize plant enzyme activity at harvesting and restrict silage fermentation. Steen (1991), in a review of five comparisons, in which either formic acid or a mixture of organic acids were applied at 6 to 9.5 (mean 7.6) l/t grass, observed reductions in ammonia, butyric acid and lactic acid (47 vs 95 g/kg DM) relative to untreated silage. Acid treatment resulted in significant increases in silage intake (+11%) and animal performance, with evidence of greater responses to acid treatment with wet, direct cut silages.

Despite the widespread use of a range of silage additives with low DM herbage, there are no readily available, accurate guidelines for the farmer to indicate whether additive use is required, either to improve silage fermentation or animal performance from the resulting silage. However, with recent developments in the prediction of digestibility (Barber et al., 1990) and intake potential (Park et al., 1996) of grass silage, it should now be feasible to develop a rapid grass analysis system to assay the status of the standing grass crop and to predict the effect of changes in post harvest management (e.g. additive use) on silage feeding value.

Silage effluent. One of the major problems associated with conservation of low DM herbage as silage is the production of silage effluent, which results in nutrient loss from the silo and is a major potential pollutant of water courses. The production of effluent from ensiled herbage is highly variable, being influenced primarily by the DM content of the crop at ensiling, although other factors such as type of additive used, harvesting system and degree of consolidation in the silo are also important. Silage effluent is an extremely powerful pollutant having a Biological Oxygen Demand of 30,000 to 80,000 mg/l (Mason, 1992) and consequently it's retention within the silo, or complete collection and safe disposal, represents a major challenge in low DM silage systems. Strategies for disposing of effluent include collection and re-cycling through either dairy cows (Randby, 1993), beef cattle (Steen, 1986) or finishing pigs (Patterson and Walker, 1979) or spreading on grassland as a fertilizer (Binnie and Frost, 1995). However, one of the major difficulties remains the problem of collecting and storing silage effluent during the peak silage-making period, with up to 50% of effluent being released during the first 10 days post ensiling (Mayne and Gordon, 1986). This problem is exacerbated by the fact that silage effluent is highly acidic and rapidly corrodes concrete, reducing the service life of silos and incurring additional costs to farmers for new silo construction. Recent research, reviewed by Frost (1995), indicates that resistance of concrete to corrosion by effluent can be achieved by using aggregates with less than 3% calcium content, using pozzolanas as partial cement replacers and by using a low water to cement ratio (0.5) in concrete mixes. Further work is required to design durable silos which will facilitate complete collection of effluent during ensilage of low DM crops.

An alternative approach to effluent collection is to retain effluent within the silo by the addition of absorbent materials during ensiling. The potential absorbency of a wide range of materials including dried sugar beet pulp, barley, maize gluten and a number of acrylamide polymers has been examined by Ferris (1991). Of the feedstuffs, beet pulp has shown the greatest potential, with an inclusion rate of 40 kg beet pulp/t grass ensiled reducing effluent production by up to 2.9 litres/kg beet pulp added at ensiling (Ferris and Mayne, 1994). Much lower levels of ammonium polyacrylamide (1 kg/t grass ensiled) have shown potential as effluent absorbents, reducing effluent output from 213 to 166 litres/t grass ensiled (Mayne, 1990), although further work is required to evaluate the impact of these materials on animal performance.

Pre-wilting Systems. Field wilting of herbage prior to ensiling is increasingly being adopted in silage making systems throughout Europe, primarily as a means of reducing effluent and increasing field work rates. A number of previous reviews have shown that, whilst pre-wilting has generally increased intake of the resulting silage, on average it has marginally reduced animal performance (Rohr and Thomas, 1984; Wilkins, 1984 and Gordon, 1989). However these reviews include data from individual experiments in which grass has been 'wilted' for up to 5-6 days in adverse weather conditions, resulting in major reductions in nutritive value. For example, Carpintero et al. (1980) demonstrated that wilting in poor weather conditions resulted in accelerated proteolysis, relative to rapidly wilted grass (Table 1). Rapid wilting to 349 g/kg in 6 hours resulted in a reduction in protein N of 47 g/kg N, whereas a slow wilt to 375 g/kg over 144 h resulted in a reduction in protein N of 236 g/kg N. Furthermore, considerable oxidation of grass sugars, through the action of plant respiratory enzymes, markedly reduced the amount of soluble carbohydrate available for fermentation in the slowly wilted material.

Given the reduction in nutritive value under slow wilting conditions there is considerable interest at present in developing rapid wilt systems which will reduce the exposure of cut herbage to adverse weather conditions. Techniques to enhance the rate of grass drying in the field include either conventional procedures such as mowing low density crops, conditioning the crop at mowing and immediate spreading of the crop and tedding during the wilting period (Bosma, 1991 and Patterson, 1993) or novel forage mat making techniques involving maceration and pressing of herbage during cutting (Savoie et al., 1994 and Frost et al., 1995).

Yan et al. (1996) examined the effect of rapid wilting using conventional procedures on food intake and animal performance in lactating dairy cows over a total of 8 silage harvests. Pre-wilted material was conditioned during mowing and tedded twice during wilting, with a mean field wilting period of 39 hours, without rainfall. The results, presented in Table 2 indicate that, on average, wilting increased DM intake and milk yield by 20 and 6% respectively. These results are in contrast to those obtained previously with slower wilting periods and suggest that improvements in animal performance can be achieved with rapid wilting systems. However, analysis of individual harvest data within this experiment indicates increases in food intake as a result of wilting ranging from +10% to +35% and changes in fat plus protein yield of -1% to +18%, with no apparent correlation with grass composition at ensiling, rate of drying during the wilting period or fermentation characteristics of the unwilted material. Given the major range in responses obtained with wilting, it is imperative that a system of grass analysis is developed which will enable farmers to accurately predict the magnitude of response they will obtain to rapid wilting and/or additive treatment, given prevailing weather conditions. This will require development of models embracing prediction of crop drying rates for particular crop types, integrated with accurate local weather forecasts and assessments of the relative impact of different crop drying rates on plant enzyme activity.

Forage mats. The concept of forage mats to accelerate crop drying rates during wilting was first developed with hay-making systems, primarily as a means of increasing drying rates two or three-fold compared to conventional methods. Mat making involves processing fresh forage through a maceration device, such as grinding rolls, at the time of mowing the crop, in order to express the maximum proportion of intracellular water. The macerated forage is then compressed into a thin mat by a continuous compression device such as a belt press. Savoie et al. (1994) noted that forage mats enhanced drying rates of both lucerne and ryegrass, with greater increases in drying rate with low crop yields and low density forage mats. In other studies, Bosma and Gabriels (1992) observed that forage mats dried much more quickly than untreated herbage in the presence of radiant energy, but in the absence of radiant energy drying rates of the two treatments were similar. In more recent studies, Frost et al. (1995) examined the possibility of using the forage mat technique to achieve rapid increases in herbage DM content, to facilitate harvesting of herbage above 250 g DM/kg, within a 6-8 hour field wilting period. This work indicated that the rate of drying of forage matted grass and unconditioned herbage was highly correlated with solar radiation intensity, with faster rates of moisture loss from forage mats at high levels of solar radiation. These authors concluded that with a mean radiation over the wilting period of 450 W/m^2, it would take 4.8 h for forage matted or 6.4 h for unconditioned swaths, to raise grass DM from 160 to 250 g/kg. These results indicate that the forage mat technique has considerable potential to produce wilted silage (above 250 g DM/kg) within a few hours in those areas with high levels of solar radiation during the main grass growing season, although the technique does not appear to be as effective with very low dry matter crops (e.g. 160 g DM/kg). However, further development of the technique is required to examine the effects of adverse weather on drying rates and plant nutrient losses and to examine the effect of different mechanical systems for forage matting under low solar radiation conditions.

Whilst a number of reports have suggested that forage matting could improve fermentation characteristics and feeding value of grass silage (Savoie et al., 1994), Frost et al. (1995) observed no significant effects of matting on silage chemical composition, rate or extent of fermentation or intake and digestibility in sheep, relative to unconditioned herbage field wilted to achieve a similar DM concentration. However, under higher levels of solar radiation, it is possible that the faster drying rates of forage mats could reduce the activity of plant proteolytic and respiratory enzymes prior to ensiling, thereby enhancing silage feeding value. Furthermore, under low solar radiation conditions it may be possible to acidify the crop during maceration and/or compression, thereby reducing plant enzyme activity during the short field wilting period.

Degree of chopping. Given the wide range of harvesting equipment used in silage-making, there is considerable variation in the chop length of the grass crop at ensiling. However, within this range there is a tendency for shorter chop material in North America than in Europe, with recommendations for chop length in the former ranging from 5 to 10 mm (Beauchemin, 1996), whereas the range in chop length in Europe varies from 20-230 mm. Short chopping greatly increases the energy requirement for forage harvesting and the short chop recommendations in North America appear to be related more to requirements of feeding equipment, rather than to animal factors.

Marsh (1978), in an extensive review of the literature, concluded that chop length had little effect on silage fermentation in farm scale silos, with the exception of heavily wilted crops, where short chopping aided consolidation within the silo. Effects of chop length on animal performance have been extremely variable and this may be attributed to effects of chop length on fermentation characteristics of the silage, differences in response between animal species and interactions with the level of supplementation. Results of a number of studies have shown that cattle are less sensitive to chop length effects than sheep, with this effect related to the smaller diameter of the oesphagus and the reticulo-omasal orifice in sheep (Dulphy et al., 1984). Deswysen (1990) has shown that with sheep offered long particle length silage, long particles become interwoven, creating a 'mat' effect within the rumen and delaying the separation and backflow of small particles into the reticulum. This results in delayed rumination, longer retention time for silage digesta within the reticulo rumen and a reduced voluntary food intake. With cattle, Gordon (1989) concluded that chop length (range 52-230 mm) had a greater effect on food intake and feeding behaviour with high forage (85-100%) diets than with lower forage (50-70%) diets. In more recent studies with alfalfa silages, Beauchemin et al. (1994) observed a similar interaction between chop length (range 5-10 mm) and proportion of forage (35-65%) in the diet, with fine chopping increasing DM intake and milk yield on the high forage diet only.

These results suggest that the optimum chop length for grass silage differs with crop type and stage of maturity at harvest, animal species and the level and type of supplement offered at feeding. With major increases in energy required for short chopping, a fundamental objective of silage research programmes should be to develop clear guidelines on chop length specifications for particular crops, animals and feeding systems. On the basis of current information, data presented above suggest an optimum chop length of 10 mm for silage offered to sheep, whereas with cattle there is no evidence to suggest detrimental effects on food intake or animal performance with chop lengths up to 50 mm, providing silages are well preserved (Dulphy and Demarquilly, 1991).

CHANGES IN THE CROP DURING STORAGE

Major changes in the chemical composition of herbage occur during ensilage and these have profound effects on the feeding value of the resultant material. The typical changes in chemical composition and apparent digestibility coefficients, assessed in sheep, during ensilage of low DM herbage are presented in Table 3. The major changes are, firstly, an increase in DM content, reflecting effluent loss during ensilage and, secondly, changes in the soluble carbohydrate and nitrogen fractions. Ensilage has little effect on the overall N content of herbage but results in increases in the soluble N and amino acid N fractions as a result of proteolysis and deamination. Fermentation also results in a decrease in water soluble carbohydrate content and increases in lactic and acetic acid concentrations, reflecting activity of lactic acid bacteria. The increased modified acid detergent fibre concentration is related to losses of soluble constituents in silage effluent, whereas lower neutral detergent fibre concentration indicates breakdown of hemicellulose during ensilage (Uden, 1984).

A number of studies have reported increases in gross energy concentration and digestibility of gross energy following ensilage (Alderman et al., 1971 and Beever et al., 1971) with these increases related to losses of DM without concomitant losses of energy. In part this reflects the fact that several of the products of fermentation, e.g. ethanol, mannitol and butyric acid, have higher gross energy concentrations than the substrates present in fresh herbage. Recent studies (Yan et al., 1998), suggest that the efficiency of utilization of metabolizable energy for lactation with grass silage based diets is similar to that previously reported with animals offered fresh or dried forage. However, these authors noted that maintenance energy requirements were substantially greater, up to 46% higher, with animals offered diets involving *ad libitum* feeding of grass silage-based diets, which could be related to greater size and activity of the gastro-intestinal tract in animals offered such diets. Given the overriding effect of maintenance energy requirements on overall energetic efficiency within the animal, further research is urgently required to examine possible effects of system of forage conservation on overall energy metabolism.

Several studies have shown that nitrogen digestibility is increased in silage relative to that of fresh herbage (Donaldson and Edwards, 1976). This is related to effects of proteolysis and deamination during ensilage, resulting in an increase in the proportion of readily soluble N (a fraction). For example, Cushnahan et al. (1995b) observed increases in the 'a' fraction from 0.18 to 0.57, with decreases in the slowly degradable 'b' fraction from 0.77 to 0.39, resulting in effective degradability (P) values of 0.65 and 0.74 for herbage and extensively fermented silage respectively. However the magnitude of these changes is influenced by the extent of the fermentation process with lower 'a' values and higher 'b' values in restricted fermentation silages (Charmley et al., 1994).

Despite increases in the apparent digestibility of nitrogen following ensilage, Beever (1980) has shown marked reductions in amino acid N flow to the duodenum in sheep offered silage (both wilted and unwilted) relative to those offered fresh herbage. This was largely attributed to differences in microbial protein synthesis with values of 53, 39 and 41 g microbial N synthesised per kg organic matter degraded in the rumen for fresh herbage, wilted and unwilted silages respectively. The reduced microbial protein synthesis with ensiled herbage can be attributed to rapid degradation of soluble crude protein in the rumen, coupled with a reduction in readily fermentable carbohydrate supply, which results in an increase in rumen ammonia concentration and an inefficient incorporation of degraded nitrogen into microbial protein. Charmley and Veira (1990) have shown that plant enzyme systems are largely responsible for protein hydrolysis in the initial ensilage period. These workers demonstrated that inhibiting proteolytic activity in wilted alfalfa silage increased non ammonia nitrogen flow to the duodenum and the efficiency of microbial protein synthesis. Furthermore, in a subsequent production study, Charmley and Veira (1990) observed increased voluntary intake and rate of liveweight gain in sheep offered wilted silage which had been heat treated to reduce proteolysis. These data highlight the importance of achieving rapid increases in crop DM or rapid acidification following mowing of the crop, as these are the most effective methods of reducing plant enzyme activity.

EFFECTS OF ENSILAGE ON FOOD INTAKE

Numerous reviews have highlighted the reduction in food intake which occurs following ensilage. For example, data from 13 studies summarising 432 individual grass/silage comparisons were reviewed by Mayne and Cushnahan (1995). On average, ensilage reduced DM intake by 27%, although there was a wide variation in the extent of intake reduction, ranging from 1 to 64%. More recently a series of studies have been undertaken to examine effects of duration of the ensilage period on food intake embracing both sheep (Cushnahan and Gordon, 1995) and lactating dairy cows (Cushnahan et al., 1995a). Results of these studies indicate that duration of the ensilage period can have a marked effect on silage composition, food intake and animal performance with reductions in food intake of 5%, 14% and 35% following ensilage periods of 3, 9 and 52 weeks. The reductions in food intake appear to reflect changes in nitrogen and carbohydrate fractions during storage with an increase in soluble protein and reductions in the proportion of true protein nitrogen and readily fermentable energy supply. In the work of Cushnahan et al. (1995a) reduced food intake with animals offered ensiled herbage occurred largely within the first few hours following each daily feed, coinciding with significant increases in ammonia and total volatile fatty acid concentrations in the rumen between 4-6 hours post feeding.

Other studies, (Gill et al., 1986) have shown reductions in food intake with elevated rumen ammonia concentrations. These results indicate that further changes in chemical composition of herbage can occur during prolonged ensilage periods resulting in reductions in fermentable carbohydrate and continued proteolysis. Merry and Williams (1991) suggest that the continued proteolysis occurring beyond day 60 post ensilage could be attributed to acid hydrolysis rather than plant protease activity. Further studies are required to confirm this effect and to investigate opportunities to stabilize silage composition following the initial fermentation phase.

FACTORS AFFECTING THE INTAKE AND NUTRITIVE VALUE OF GRASS SILAGE

As highlighted in the previous section, ensilage can result in a wide range in the extent of depressions in food intake and nutritive value. A number of studies (Wilkins et al., 1978; Lewis, 1981; Rook and Gill, 1990) have attempted to produce multifactor relationships to predict the intake of silage when offered to sheep or cattle. However, the accuracy of these predictive relationships is limited by the fact that they are based on historical data across a range of experiments, which have confounded factors such as breed of animal, age, liveweight, physiological state and previous nutritional history of the animal. More recent studies (Offer et al., 1995 and Steen et al., 1995) have attempted to overcome these confounding effects by feeding large numbers of silages to sheep or cattle within a common feeding management and statistical design. Steen et al. (1995) in a study involving 136 grass silages, offered to growing cattle, observed that voluntary food intake was either unrelated, or poorly related, to factors previously considered to have a major effect on intake such as pH, buffering capacity, total acidity and lactic and volatile fatty acid concentrations. Factors of moderate importance included DM and ammonia nitrogen concentrations, with the key factors influencing intake being the protein and fibre fractions in silage, and in particular, the relative rates and extent of digestion of these components within the animal. However, the most exciting development in this study was the fact that near infrared reflectance spectroscopy (NIRS) on both dried and fresh silage samples provided the most accurate prediction of silage intake (Park et al., 1996).

NIRS has also been shown to be a rapid method for predicting both the chemical composition of forages (Norris et al., 1976) and the organic matter digestibility (OMD) of grass silage (Barber et al., 1990 and de Boever et al., 1996). For example, de Boever et al. (1996) observed that *in vivo* OMD was highly correlated with NIRS predicted OMD ($r = 0.89$) followed by factors such as cellulose digestion ($r = 0.83$), *in vitro* digestibility with rumen fluid ($r = 0.81$) and acid detergent lignin concentration (r = (0.73).

AEROBIC DETERIORATION OF SILAGE

A key objective in silage making is to obtain an oxygen-free environment as soon as possible in the early stages of ensilage. Respiration from plants and micro-organisms continues whilst oxygen is available, resulting in nutrient loss and enabling the development of yeasts which can cause problems during the feed out period. Honig (1991) summarised the key aspects associated with minimizing exposure to oxygen which include rapid filling, effective consolidation - particularly with high DM crops, and rapid and complete sealing of the silo surface - particularly at the shoulders of bunker silos. Whilst these factors markedly improve the aerobic stability of silage, further opportunity for aerobic deterioration occurs when the silage face is exposed for feeding. The rate of air entry is greatly increased following silo opening and there is considerable potential for aerobic microbial growth, particularly where slow feed out rates are used. The major consequences of aerobic deterioration are substantial DM losses, a reduction in intake and nutritive value and the proliferation of pathogens that are harmful to animals, e.g. *Listeria monocytogenes.* Silage produced in wrapped big bales is particularly prone to aerobic deterioration due to the high surface-area to volume ratio of the bale, the ease with which the cover can be damaged and the lower packing density of the ensiled grass (Ruxton and Gibson, 1995).

Kalzendorf and Weissbach (1993) have shown that simultaneous application of lactic acid bacteria and sodium formate to herbage at ensiling significantly improved the aerobic stability of a range of ensiled forages. These authors suggested that inoculant-treated, homolactic silages were less stable on exposure to air, as a consequence of reduced volatile fatty acid concentrations. Their approach involved achieving a rapid initial pH decline by addition of lactic acid bacteria. The increase in acidity triggers the anti-microbial activity of sodium formate as it becomes undissociated at low pH, i.e. combining the positive effects of both biological and chemical agents.

Up to the present, inoculant additives have been primarily used as a means of achieving a fast and efficient fermentation. However, other bacteria may also have an important role in future generations of silage inoculants. For example, it may be possible to select bacteria to produce compounds (e.g. propionic acid) which inhibit the activity of yeasts and moulds during the feed out period. Encouraging results have been reported by Honig (1991) using this approach. Recent research has also examined the effect of addition of bisulphite salts to grass silage or complete mixed rations during the feed out period. These salts minimize the activity of yeast organisms commonly responsible for initiating the aerobic spoilage process.

CONCLUSIONS

The production of grass silage has been subject to increasing scrutiny in recent years, given the increasing cost of silage production and reduction in feeding value relative to fresh herbage. The key factors influencing silage intake and animal performance with grass silage are related to protein and fibre fractions and the relative rates and extent of digestion of these components within the animal. Changes in these fractions during ensilage can be minimised by maximising the rate of acid production, or the rate of increase in DM concentration, in the first few hours following cutting. Whilst increases in food intake and animal performance have been obtained with ensiling systems involving rapid wilting and/or the use of inoculant additives, responses have been highly variable. Further research is required to develop accurate systems of grass analysis to enable prediction of responses in food intake or animal performance to additive treatment and/or pre-wilting under a range of crop and climatic conditions. Such systems could embrace the use of NIRS which provides rapid and accurate prediction of the nutritive value and intake potential of grass silage. Development of such systems should also facilitate more detailed investigation of the effect of crop manipulation, before, during and after cutting of the grass crop, on the feeding value of the resulting silage. Using the approaches outlined above marked improvements in silage feeding value can be obtained with both direct cut and prewilted grass silage. However, environmental pressures are likely to increase uptake of pre-wilting systems, given the major difficulties in collecting and disposing of silage effluent in direct cut systems. Consequently, further research is required to develop harvesting systems which will achieve rapid increases in crop DM content whilst minimizing field losses.

REFERENCES

Alderman, G., F.C. Collins and H.W. Dougall. 1971. Laboratory

methods of predicting feeding value of silage. J. British Grassland Soc. **26:** 109-111.
Barber, G.D., D.I. Givens, M.S. Kridis, N.W. Offer and I. Murray. 1990. Prediction of the organic matter digestibility of grass silage. Anim. Feed Sci. Tech. **28:** 115-128.
Beauchemin, K.A. 1996. Using ADF and NDF in dairy cattle diet formulation - a western Canadian perspective. Anim. Feed Sci. Tech. **58:** 101-111.
Beauchemin, K.A., B.I. Farr, L.M. Rode and G.B. Schaalje. 1994. Effects of alfalfa silage chop length and supplementary long hay on chewing and milk production of dairy cows. J. Dairy Sci. **77:** 1236.
Beever, D.E. 1980. The utilization of protein in conserved forage. Pages 131-143 *in* Forage Conservation in the 80's. British Grassld Soc. Occ. Symp. No. 11.
Beever, D.E., D.J. Thomson, E. Pfeffer and D.G. Armstrong. 1971. The effect of drying and ensiling grass on its digestion in sheep. Sites of energy and carbohydrate digestion. British J. Nut. **26:** 123-134.
Binnie, R.C. and J.P. Frost. 1995. Some effects of applying undiluted silage effluent to grassland. Grass For. Sci. **50:** 272-285.
Bosma, A.H. 1991. Efficient field treatment for silage and hay. Pages 71-85 *in* G. Pahlow and H. Honig, eds. Landbauforschung Volkenrode, Sonderheft 123. Forage Conservation towards 2000.
Bosma, A.H. and P.C.J. Gabriels. 1992. Optimal conditions for the drying of a grass swath. European Grassland Federation Conf., Finland, June 1992, pp. 153-158.
Carpintero, C.M., A.R. Henderson and P. McDonald. 1979. The effect of some pretreatments on proteolysis during the ensiling of herbage. Grass For. Sci. **34:** 311-315.
Charmley, E. and D.M. Veira. 1990. Inhibition of proteolysis at harvest using heat in alfalfa silages: Effects on silage composition and digestion by sheep. J. Anim. Sci. **68:** 758-766.
Charmley, E., R.E. McQueen and D.M. Veira. 1994. Influence of carboxylic salts on silage conservation and voluntary intake and growth of steers given lucerne silage. Anim. Prod., **58:** 221-229.
Cushnahan, A. and F.J. Gordon. 1995. The effects of grass preservation on intake, apparent digestibility and rumen degradation characteristics. Anim. Sci. **60:** 429-438.
Cushnahan, A., C.S. Mayne and E.A. Goodall. 1995a. Effect of stage of maturity of grass and period of ensilage on milk production with grass silage-based diets. Proc. British Soc. Anim. Sci. Winter Meeting 1995, p. 24.
Cushnahan, A., C.S. Mayne and E.F. Unsworth. 1995b. Effects of ensilage of grass on performance and nutrient utilization by dairy cattle. 2. Nutrient metabolism and rumen fermentation. Anim. Sci., **60:** 347-359.
de Boever, J.L., B.G. Cottyn, D.L. de Brabander, J.M. Vanacker and Ch.V. Boucqué. 1996. Prediction of the feeding value of grass silages by chemical parameters, *in vitro* digestibility and near infra red reflectance spectroscopy. Anim. Feed. Sci. Tech. **60:** 103-115.
Deswysen, A.G. 1990. Intake regulation by sheep and heifers fed silage of different chop length. In: Forage Conservation in the 80's. Occ. Symp. No. 11, British Grassld Soc., pp. 345-349.
Donaldson, E. and R.A. Edwards. 1976. Feeding value of silage : silages made from freshly cut grass, wilted grass and formic acid treated, wilted grass. J. Sci. Food and Agric., **27:** 536-544.
Dulphy, J.P. and C. Demarquilly. 1991. Digestibility and voluntary intake of conserved forage. Pages 140-160 *in* G. Pahlow and H. Honig, eds. Landbauforschung Volkenrode, Sanderheft 123. Forage Conservation towards 2000.
Dulphy, J.P., B. Michalet-Doreau and C. Demarquilly. 1984. Etude comparée des quantités ingerées et du comportement alimentaire et mercique d'ovins et de bovins recevant des ensilages d'herbe réalisés selon différentes techniques. Annales de Zootechnie **33:** 291-320.
Ferris, C.P.W. 1991. Studies on the effects of ensiling grass with absorbent materials on nutrient loss during ensilage and on feed utilization by dairy cows. Ph.D. Thesis, The Queen's University of Belfast.
Ferris, C.P.W. and C.S. Mayne. 1994. The effects of incorporating sugar beet pulp with herbage at ensiling on silage fermentation, effluent output and in silo losses. Grass For. Sci. **49:** 216-228.
Frost, J.P. 1995. Improving the resistance of concrete to attack by silage effluent. Pages 20-29 *in* 68th Annual Report of the Agricultural Research Institute of Northern Ireland.
Frost, J.P., R. Poots, A. Knight, F.J. Gordon and F.N.J. Long. 1995. Effect of forage matting on rate of grass drying, rate of silage fermentation, silage intake and digestibility of silage by sheep. Grass For. Sci. **50:** 21-30
Gill, M., L.R.S. Thiago and J.G. Buchanan-Smith. 1986. Intake problems associated with ensiled forages. Pages 341-352 *in* Feed Intake by Beef Cattle. Miscellaneous Publication No. 121, Oklahoma State University.
Gordon, F.J. 1989. The principles of making and storing high quality, high intake silage. Pages 3-20 *in* Silage for Milk Production. British Grassland Soc. Occ. Symp. No. 23.
Honig, H. 1991. Reducing losses during storage and unloading of silage. Pages 116-128 *in* G. Pahlow and H. Honig, eds. Landbauforschung Volkenrode, Sonderheft 123. Forage Conservation towards 2000.
Kalzendorf, C. and F. Weissbach. 1993. Studies on the effect of a combined application of inoculants and sodium formate. Pages 89-90 *in* Proc. 10th Int. Conf. Sil. Res., Dublin.
Lewis, M. 1981. Equation for predicting silage intake by beef and dairy cattle. Proc. 6th Sil. Conf., Edinburgh, pp. 35-36.
Marsh, R. 1978. A review of the effects of mechanical treatment of forages on fermentation in the silo and on the feeding value of the silages. New Zealand J. Exp. Agric. **6:** 271-278.
Mason, P.A. 1992. Farm waste storage: guidelines for construction. Construction Industry Research and Information Association, United Kingdom. Report No. 126.
Mayne, C.S. 1990. An evaluation of an inoculant of *Lactobacillus Plantarum* as an additive for grass silage for dairy cattle. Anim. Prod. **51:** 1-13.
Mayne, C.S. and A. Cushnahan. 1995. The effects of ensilage on animal performance from the grass crop. Pages 30-41 *in* 68th Annual Report of the Agricultural Research Institute of Northern Ireland.
Mayne, C.S. and F.J. Gordon. 1986. Effect of harvesting system on nutrient losses during silage making. 2. In silo losses. Grass For. Sci. **41:** 341-351.
Mayne, C.S. and R.W.J. Steen. 1993. A review of animal production responses to formic acid and inoculant treatment of grass silage in trials at the Agricultural Research Institute of Northern Ireland. Pages 178-179 *in* Proc. 10th Int. Conf. on Silage Res., Dublin.
Merry, R. and A. Williams. 1991. Proteolysis during ensilage. Pages 68-69 *in* AFRC Institute of Grassland and Environmental Research, 1990 Report.
Merry, R.J., M.S. Dhanoa and M.K. Theodorou. 1995. Use of freshly cultured lactic acid bacteria as silage inoculants. Grass For. Sci. **50:** 112-123.
Moisio, T. and M. Heikonen. 1989. A titration method for silage assessment. Anim. Feed Sci. Tech. **22:** 341-353.
Norris, K.H., R.F. Barnes, J.E. Moore and J.S. Shenk. 1976. Predicting forage quality by infrared reflectance spectroscopy. J. Anim. Sci. **43:** 889-897.
Offer, N.W., C. Thomas and R.J. Dewhurst. 1995. Validation of advisory models for the prediction of voluntary intake of grass silage

by lambs and dairy cows. Page 22 *in* Proc. British Soc. Anim. Sci. Winter Meeting, 1995.

Park, R., F.J. Gordon, K. Cooper and R.W.J. Steen. 1996. The prediction of intake potential and organic matter digestibility of grass silages by near infrared spectroscopy analysis of undried samples. Page 21 *in* Proc. British Soc. Anim. Sci. Winter Meeting, 1996.

Park, R.S., F.J. Gordon, R.E. Agnew, R.J. Barnes and R.W.J. Steen. 1996. The use of near infrared reflectance spectroscopy on dried samples to predict biological parameters of grass silage. Anim. Feed Sci. Tech. **68**: 235-246.

Parker, J.W.G. and R. Crawshaw. 1982. Effects of formic acid on silage fermentation, digestibility, intake and performance of young cattle. Grass For. Sci. **37:** 53-58.

Patterson, D.C. 1993. The effects of grass and swath treatment factors on the rate of drying of silage grass. Pages 52-53 *in* Proc. 10th Int. Conf. Sil. Res., Dublin.

Patterson, D.C. and N. Walker. 1979. The use of effluent from grass silage in the diet of finishing pigs. II. Assessment of nutritive value of fresh and stored effluent. Anim. Feed Sci. Tech. **4:** 275-293.

Randby, A.T. 1993. Silage effluent as a feed for dairy cows. Pages 145-146 *in* Proc. 10th Int. Conf. Sil Res., Dublin.

Rohr, K. and C. Thomas. 1984. *In* Eurowilt: Efficiency of silage systems - a comparison between unwilted and wilted systems. Landbauforschung Volkenrode, Sonderheft 69, pp. 64-70.

Rook, A.J. and M. Gill. 1990. Prediction of the voluntary intake of grass silages by beef cattle. 1. Linear regression analyses. Anim. Prod. **50:** 425-438.

Ruxton, G.D. and G.J. Gibson. 1995. A mathematical model of aerobic deterioration of big bale silage and its implications for the growth of *Listeria monocytogenes*. Grass For. Sci., **50:** 331-344.

Savoie, P., L.R. Burgess, A.C. Knight and M.B. McGechan. 1994. Drying and physical characteristics of matted ryegrass. Grass For. Sci. **49:** 257-263.

Steen, R.W.J. 1986. An evaluation of effluent from grass silage as a feed for beef cattle offered silage-based diets. Grass For. Sci. **41:** 39-45.

Steen, R.W.J. 1991. Recent advances in the use of silage additives for dairy cattle. Pages 87-101 *in* Management Issues for the Grassland Farmer in the 1990s. British Grassland Soc. Occ. Symp. No. 25.

Steen, R.W.J., F.J. Gordon, C.S. Mayne, R.E. Poots, D.J. Kilpatrick, E..F Unsworth, R.J. Barnes, M.G. Porter and C.J. Pippard. 1995. Prediction of the intake of grass silage by cattle. Pages 67-89 *in* P.C. Garnsworthy and D.J.A. Cole, eds. Recent Advances in Animal Nutrition, Butterworths, London.

Thomas, P.C. and I.M. Morrison. 1982. The chemistry of silage making. Pages 13-37 *in* Silage for Milk Production Technical Bulletin No. 2. National Institute for Research in Dairying and Hannah Research Institute.

Uden, P. 1984. Digestibility and nitrogen retention in dairy cows receiving hay or silage at varying concentrate levels. Anim. Feed Sci. Tech. **11:** 279-291.

Wilkins, R.J. 1984. *In* Eurowilt: Efficiency of silage systems - a comparison between unwilted and wilted silages. Landbauforschung Volkenrode, Sonderheft 69, pp. 5-12.

Wilkins, R.J., J.S. Fenlon, J.E. Cook and R.F. Wilson. 1978. A further analysis of relationships between silage composition and voluntary intake by sheep. Proc. 5th Sil. Conf., Ayr, pp. 34-35.

Williams, A.P., R.J. Merry, J.K.S. Tweed and D.K. Leemans. 1992. The effect of different additives on proteolysis during the ensilage of ryegrass. Proc. British Soc. Anim. Prod. Winter Meeting, 1992, Paper 149.

Yan, T., F.J. Gordon, R.E. Agnew, M.G. Porter and D.C. Patterson. 1998. The metabolizable energy requirement for maintenance and the efficiency of utilization of metabolizable energy for lactation by dairy cows offered grass silage based diets. Submitted to Livestock Prod. Sci. **51:** 143-153.

Yan, T., D.C. Patterson and F.J. Gordon. 1996. The effects of bacterial inoculation of unwilted and wilted grass silages on digestibility by sheep and intake and performance by dairy cows. Page 66 *in* Proc. British Soc. Anim. Sci., Winter Meeting.

Table 1
The effect of 'rapid' or 'slow' wilting on the major N components in herbage (after Carpintero et al., 1980)

	DM content (g/kg)	Protein N (g/kg total N)	Ammonia N (g/kg total N)
Fresh grass	173	925	1.2
Rapid wilt			
6 h	349	878	1.1
48 h	462	832	2.1
Slow wilt			
48 h	199	752	2.6
144 h	375	689	26.1

Table 2
Effect of rapid wilting over 8 harvests on silage composition and dairy cow performance (Yan et al., 1996)

	Unwilted	Wilted
Silage composition (g/kg)		
Dry matter	176	316
pH	4.14	3.92
NH_3-N (g/kg tot N)	130	74
Lactic acid (g/kg DM)	80	89
Animal performance		
Silage intake (kg DM/day)	10.6	12.7
Milk yield (kg/day)	21.8	22.4
Milk composition (g/kg)		
Fat	45.1	46.4
Protein	32.3	33.2
Fat + protein yield (kg/day)	1.68	1.77

Table 3
Effects of ensilage on the chemical composition of herbage (g/kg alcohol corrected toluene DM unless otherwise stated)
(After Cushnahan and Gordon, 1995)

	Days ensiled	
	0	51
Dry matter (g/kg)	179	194
Crude protein	151	147
Ammonia N (g/kg N)	60	73
Soluble N (g/l)†	1.9	3.3
Amino acid N (g/l) †	2.7	3.5
Water soluble carbohydrate	105.7	10.5
pH	5.31	3.88
Lactic acid	33.5	137.1
Acetic acid	11.9	24.4
MAD-fibre	325	348
NDF	600	562
Gross energy (MJ/kg DM)	18.5	19.4
Digestibility coefficients		
Dry matter	0.705	0.762
Nitrogen	0.675	0.733
Gross energy	0.705	0.754

† Expressed as g/l juice extracted from silage and determined by the titration method as described by Moisio and Heikonen (1989)