Overcoming seasonality of production: opportunities offered by forage conservation technologies

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Key points

1. Seasonality of forage supply is a key contributor to the seasonality of meat and milk production.
2. Conserving forages as silage or hay can help reduce the seasonality of feed supply.
3. Forage conservation technologies make this contribution mainly through increases in the yield or quality of suitable crops, through an improved efficiency of the conservation process or by allowing a reduction in costs.
4. Future research needs differ considerably among regions of the world.

Keywords: silage, hay, conserved forage, animal production

Scale of seasonality

The pattern of national meat and milk output from ruminants often repeats in annual cycles and the magnitude of the disparity between the months of highest and lowest output varies considerably between countries (Table 1). Furthermore, significant seasonal patterns in output can be paralleled by seasonal variation in product quality (Keane & Allen, 1998; Lynch *et al.,* 2002; O'Brien *et al.,* 1999). The effects of seasonality are likely to be at their greatest where grazed forage is the main feedstuff used, and where its yield and/or quality exhibits large seasonal differences (Cummins *et al*., 1996). This paper outlines the opportunities offered by conserved forages to reduce the magnitude of the seasonality of meat and milk production. The principles covered are pertinent to hay and silage produced under tropical, semi-arid or temperate conditions. However, since most recently published research relates to silage production under temperate conditions, such research predominates the literature cited.

Table 1 Output of beef and milk from cattle during 2000 - highest month as multiple of lowest month

	Beef	Milk
Denmark	1.5	1.2
France	1.5	-
Ireland	2.9	6.0
Netherlands	1.4	1.1
New Zealand	-	82.9
USA	1.2	-

Causes of seasonality

Seasonality of meat or milk production is influenced by (a) the pattern of feedstuff supply, quality and cost; (b) animal type factors such as species/breed, genetic merit and physiological status; (c) animal response to influences such as climate, disease challenge and management practices; (d) the quality of animal produce and the farmers response to the market price available; and (e) the impact of limitations or opportunities provided by land, labour, capital or enterprise on farms.

The seasonality of forage production and quality is one of the most important technical constraints to overcoming the seasonality of animal production. However any response by farmers to address this problem, and increase out-of-season meat or milk production, will be heavily influenced by economic and social factors. Frawley (1980) itemised the difficulties perceived by Irish dairy farmers when presented with the opportunity of producing out-of-season milk. Economic barriers presented the biggest perceived difficulties (0.40 of total), and included factors relating to the additional costs of feedstuffs, animals, facilities and labour, and an inadequate milk price. Social barriers (0.32 of total) included factors related to the loss of a predictable seasonal respite in work-load, changing from a practised to a new system, difficulties integrating the new work demands into the overall work schedule and disincentives of moving into a higher taxation bracket. Technical barriers (0.28 of total) included perceived difficulties related to scale of operation and animal facilities, to reproductive efficiency and milk quality, and to making, storing and feeding adequate silage of appropriate quality. In principle, these barriers are similar to those outlined more recently for south-east Asian farmers by Chin (2002).

Opportunities for conserved forages

Reducing the seasonality of animal production by addressing the seasonality of forage production and quality is a key challenge for livestock producers. The extent of the seasonal timing of feed gaps varies significantly from region to region, and is driven in particular by climate and environment (altitude, soil, etc.). Forage supply can be increased through the use of irrigation, improved forage species and cultivars, and fertiliser application. However, at least some of the resultant forages usually need to be conserved in order to make the most effective contribution to filling seasonal gaps in feed availability. Clearly, the conservation option only works if the land is not overstocked (a problem in some extensive grazing areas).

Forage conservation can involve the storage of ensiled or dried grass, legume, cereal (whole-crop, straw/stover, grain/cob, etc.) or other crops. It is important that it be integrated into the overall farming system to allow the profitable and sustainable production of meat or milk (Doonan *et al.*, 2004). Depending on circumstances, the role of conserved forages can vary from providing the main forage source throughout the year, to systems where grazing and conservation of forages are integrated and conserved forages are used seasonally either as a supplement (O'Brien *et al.*, 1996) or the primary forage. In the latter case, forages can be conserved either opportunistically or as part of a planned management strategy specifically designed to produce forage for conservation. Within these integrated systems, the process of conserving some of the forage also provides the opportunity to make an important positive contribution to effective grazing management and improved forage utilisation by grazing animals, and to effective feed budgeting by farmers. It can also contribute to weed control in pastures (and crops in mixed grazing/grain farming systems), to maintaining the content of desirable species in pastures, to livestock not succumbing to pests and diseases at sensitive times of the year, and to avoiding soil erosion and helping conserve soil water. Furthermore, the optimal recycling of nutrients collected from housed livestock can often be best achieved by spreading the manures on the land used for producing the conserved feed.

Opportunities offered by forage conservation and associated technologies to overcome the seasonality of animal production can be considered in terms of (a) increasing the supply of feed to conserve; (b) improving the quality of feed to conserve; (c) improving the efficiency of the conservation process; (d) supplementation strategies to best complement the conserved forages; (e) mixing of complementary forages to maximise efficiency of use of nutrients; and (f) reducing the cost of providing livestock with nutrients from conserved forages through the use of the above strategies, and by restricting direct and fixed inputs and using available financial incentives (premia, subsidies, grants, bonuses etc.). The remainder of this paper will focus on new technologies relating to items (a), (b) and particularly (c).

Increase supply of feed to conserve

In many cases the yield of crops for conservation can be increased by improved management of resources (soils, water, fertilisers), better control of crop pests and diseases, altering the timing of when the crop is sown or is closed for conservation, or altering harvest dates. These higher yields can help reduce the seasonality of feed supply.

Achievements in the breeding of tropical and temperate grasses and legumes have been well documented (Miles, 2001; Quenesberry & Casler, 2001; and Wilkins & Humphreys, 2003). Forage crops that are particularly suited to producing high yields within a cutting regime can be grown, and conservation characteristics under a range of conditions have been outlined for many of these (Buxton & O'Kiely, 2003; Chin, 2002, Fraser *et al.*, 2001; Kaiser & Piltz, 2002; Panciera *et al.*, 2003; Suttie, 2000; Titterton *et al.*, 2002; and Wilkins & Jones, 2000). Significant interactions between potential yield and environment are normal for all of these crops. For example, studies on forage legumes at 12 northern European sites over two consecutive seasons, found the yield of individual legumes to be favoured or restricted at particular locations or in individual years (Halling *et al.*, 2002). New technologies can overcome some limitations - technologies related to mulching *Zea mays* L. (maize) with plastic film have allowed *Z. mays* grown in marginal climatic conditions to undergo substantial increases in dry matter (DM) yield (Easson & Fearnehough, 2003; Keane *et al.*, 2003), thereby making it a potentially viable crop for conservation. Options to seek a yield advantage by inter-cropping (Ghanbari-Bonjar & Lee, 2003; Maasdorp & Titterton, 1997) or bi-cropping (Marley *et al.*, 2003; Oyen, 1989) complementary crops are also available.

Feed supply can be increased by purchasing fresh (to ensile or dry) or conserved feed from other farms, or by ensiling purchased agricultural or industrial by-products such as apple pomace, corn stover, fruit rejects/waste, potato feed (steam peel), pressed citrus pulp, pressed sugar beet pulp, rice straw, wet brewers' grains, wet corn gluten feed and wet distillers' grains (including draff) (Chin, 2002; Crawshaw, 2001).

Increase quality of feed to conserve

Optimum crop management

The judicious use of established technologies usually provides scope to improve the quality of crops at harvest time, and this in turn can contribute to reducing the seasonality of animal production. Thus, the combination and timing of plant nutrient input, water supply and conservation, control of weeds, pests and diseases, choice of harvest date, portion of crop harvested, etc., can be optimised for specific crop species and cultivars.

Conserved forage made from a highly digestible crop can support superior rates of animal production (Steen *et al.,* 2002). It would be valuable if the natural decline in nutritive value that accompanies senescence in high-yielding forage crops could be arrested. However, the evidence to support such a mechanism following the introduction of the stay-green trait to *Lolium perenne* L. (perennial ryegrass) is not compelling (Wilman *et al*., 2004). Caution is needed when assessing forages from semi-natural grassland because the relationship between chemical composition and digestibility differs from that of *L. perenne*, sometimes leading to an underestimation of their potential nutritive value and useful role (Bruinenberg *et al*., 2002).

Much of the genetic variation in DM digestibility (DMD) within ryegrasses is the result of variation in the concentration of water-soluble carbohydrates (WSC) (Wilkins & Humphreys, 2003). Forages of elevated WSC concentration thus offer the potential to increase animal productivity and N use efficiency, as well as being easier to preserve, and retain a higher proportion of nutrients such as protein and WSC during ensilage (Davies *et al*., 2002b). For example, Miller *et al*., (2001) compared zero-grazed grasses of 126 and 165 gWSC/kgDM and recorded mean daily grass DM intakes by dairy cows of 10.7 and 11.6 kgDM, *in vivo* DMD's of 0.64 and 0.71 g/g, milk yields of 12.6 and 15.3 kg/day and urinary N excretion of 0.35 and 0.25g/g feed N.

Use of plastic film as a mulch with *Z. mays* can result in a substantial increase in the starch content of crops grown under marginal conditions (Easson & Fearnehough, 2003; Keane *et al*., 2003). This should markedly increase their feed value. Brown midrib (bmr) genotypes in *Z. mays* and *Sorghum bicolor* L. Moench (sorghum) usually contain less lignin and may have altered lignin chemical composition. This in turn can increase forage DMD. However, the subsequent effects on animal production have not been consistent (Cox & Cherney, 2001; Oliver *et al*., 2004) and may depend on the hybrid used. Leafy hybrids of *Z. mays* contain additional leaves above the ear, which should increase stover digestibility because leaves are more digestible than stalks. However, Cox & Cherney (2001) demonstrated that leafy hybrids had a higher neutral detergent fibre (NDF) content and a higher digestibility of NDF than normal hybrids. However, the lower harvest index was considered to reflect reduced grain fill, and resulted in similar calculated milk yields. Finally stay-green hybrids of *Z. mays* have an improved resistance to disease and leaf senescence, and can have superior yields. However, Wilkinson & Hill (2003) showed no benefit from stay-green hybrids grown under marginal conditions in terms of yield or within-plant DM distribution.

Legumes frequently offer the potential to improve the quality of forage available for conservation. Halling *et al.* (2002) in a comparison of 5 temperate legumes found that *Trifolium repens* L. (white clover) had the highest content of crude protein, digestible organic matter, WSC and metabolisable energy but the lowest content of crude fibre. *Medicago sativa* L. (lucerne) was the opposite for these traits, with *Trifolium pratense* L. (red clover), *Lotus corniculatus* L. (birdsfoot trefoil) and *Galega orientalis* (galega) being intermediate. The legumes had a higher quality than grass (except for WSC), with mixtures of legume and grass being intermediate. Bertilsson *et al.* (2002) ensiled legumes and grass separately. They were then offered to dairy cows alone or in mixtures of individual legume silages with grass silage. Intakes were higher for clover and clover-grass mixtures compared to pure grass silage, and milk production was higher for clover (particularly *T. repens*) than grass silage.

Many plants seek protection from herbivory by producing substances that may be bitter-tasting, poisonous, offensively odoured or anti-nutritional. High concentrations of secondary metabolites such as tannins, protease inhibitors and lectins can have anti-nutritional effects and plants with high concentrations of such compounds, or management practices that favour them, should be avoided. In contrast, low concentrations of some compounds can confer nutritional benefits. Thus, some naturally occurring condensed tannin-containing materials found in plants such as *L. corniculatus*, *Onobrychis viciifolia* Scop. (sainfoin) and *Hedysarum coronarium* L. (sulla) can help protect plant proteins from rumen degradation, resulting in increased post-ruminal protein supply, a reduction in urinary N losses and a reduced susceptibility to bloat (Butter *et al*., 1999). They can also confer anthelminthic properties and thus work to counter the effects of parasitism (Butter *et al*., 1999). Finally, reducing proteolysis during ensilage is an important goal to pursue, and it has been suggested that much of the relatively low rate of proteolysis during the ensilage of *T. pratense* may be due to polyphenol oxidases present in the crop (Jones *et al*., 1995). Thus if plant breeders can introduce the expression of appropriate amounts and forms of polyphenol oxidases into crops, the potential exists to restrict proteolysis during ensilage.

Co-ensiling

Co-ensiling compatible forages or forage and concentrates, can improve silage quality and thereby animal productivity. The addition of certain dry concentrate feeds to forage can increase the estimated nutritive value of the ensiled crop, reduce or eliminate effluent production and create conditions conducive to a lactic acid fermentation (O'Kiely, 2002). It can also facilitate meeting labour demands during feedout. Provided excellent silage-making practices are employed, most of the nutrients present in these concentrate feeds are available to livestock at feedout (O'Kiely, 1992; Ferris & Mayne, 1994).

Improve efficiency of conservation

Reduce conservation losses

Technologies that support efficient and practicable conservation of forage help reduce the seasonality of feed supply and quality. Thus, reducing quantitative conservation losses from 0.25 to 0.20 through improved management practices will provide an additional one weeks conserved feed during a 5-month feedout. Qualitative losses similarly need to be restricted. Bolsen *et al*. (2002) showed that replacing aerobically deteriorated silage by the corresponding non-deteriorated silage, increased DM intake by steers from 6.7 to 8.0 kg/day, organic matter digestibility from 0.68 to 0.76 and crude protein digestibility from 0.63 to 0.75.

Field losses are best minimised by shortening the duration between mowing a crop and removing it to where it will be stored. Prevailing weather conditions will have a major impact on this. A range of mechanical treatments are available to speed up field drying of crops (Muck & Shinners, 2001) thereby rapidly reducing the activity of plant and microbial enzymes and, if used optimally, restricting physical losses or soil contamination. In many circumstances wilting can result in successful preservation of silage, producing feedstuffs with high intake characteristics (Ingvartsen, 1992; Wright *et al*., 2000).

Storage losses associated with silage effluent only occur where relatively wet forage is ensiled. Methods for reducing or eliminating its production are described by O'Kiely (1989).

Silage fermentation is a complex process and, compared to industrial fermentations, can be difficult to control adequately. Fermentation needs to be guided to create conditions inhibitory to plant proteolysis and to the activities of preservation saboteurs such as *Clostridia* and *Enterobacteria*. It also needs to create conditions inhibitory to the development and activity of initiators (and their successors) of aerobic deterioration such as yeast, mould or *Bacilli*, and to the viability of pathogenic micro-organisms such as *Listeria monocytogenes* and *Cryptosporidium parvum*. This can be a particular challenge with tropical forages where the inherently low DM and WSC concentrations allied to the frequently high buffering capacities can produce crops that are difficult to preserve (Kaiser & Piltz, 2002; Buxton & O'Kiely, 2003).

Acid- and sugar-based additives have a long tradition of being used to facilitate the creation of conditions inhibitory to *Clostridia* and *Enterobacteria*. Lattemae *et al*. (1996) makes a case for simultaneously applying acid and molasses to crops such as *T. pratense*. Similarly, Davies *et al*. (2002a) have suggested that co-ensiling high sugar ryegrass with a legume such as *T. pratense* provides the opportunity to improve the preservation of the legume. Both the logistics of evenly applying the volumes of additive required and, in the case of acid-based additives, consciousness of their corrosive effects, have reduced their use. However, partial neutralisation of acid additives with ammonia can considerably reduce corrosion to machine components (Forristal, 1992), while at the same time retaining the ability to achieve satisfactory preservation (Randby, 2000). Inclusion of lignosulphonates from wood pulp liquor has also been shown to reduce corrosion (Randby, 2000). In addition applying chemical additives at mowing may reduce contact between the chemical and the harvester, without any negative effects on resultant silage conservation characteristics (Slottner & Lingvall, 2002). Other additives such as molasses could also be applied at mowing and this should be reasonably successful in the absence of rainfall.

Non-corrosive chemical additives based on hexamine and sodium nitrite in combination with sodium benzoate and sodium propionate can restrict both clostridial and yeast activity (Lattemae & Lingvall, 1996; Lingvall & Lattemae, 1999) when applied evenly and at appropriate rates of application. In contrast, the application of surfactants to grass at ensiling to reduce surface tension, aid dispersion of cell contents and thus stimulate the activity of lactic acid bacteria was not found to be successful (Pauly & Lingvall, 1999). Bacterial inoculants based on *Lactobacillus plantarum* have the potential to facilitate a fast and efficient fermentation in the silo (Muck & Shinners, 2001), particularly where competition from the natural population is limited and where adequate fermentable substrate is available. Inclusion of osmotolerant lactic acid bacteria in an inoculant can result in a considerably faster rate of acidification when applied to drier forage (Pobednov *et al*., 1997), while incorporation of bacteria with fructan hydrolase activity may facilitate more rapid acidification when applied to forages with a high proportion of WSC present as fructans (Merry *et al*., 1995). The co-application of a bacterial inoculant with sufficient molasses could also be attractive with some crops low in WSC content (Kaiser & Piltz, 2002). Similarly, inclusion of lactic acid bacteria that secrete an amylase that is optimally active in the silage pH range could facilitate the preservation of crops low in WSC, but containing starch (Fitzsimons & O'Connell, 1994) - the latter being unavailable to the bacteria in most conventional silage inoculants. Pahlow *et al.* (2003) have summarised a series of other novel approaches for improving silage fermentation and aerobic stability using inoculants. Good distribution of inoculated bacteria over the forage surface is normally considered important, and in practice can require the use of relatively large volumes of water. However, Kleinmans *et al.* (2002) have reported on the success of an ultra low volume applicator for concentrated suspensions of inoculum that gave comparable results to a more conventional system.

Moist feedstuffs are invariably susceptible to aerobic deterioration and the resultant quantitative and qualitative changes can lead to serious losses of nutrients. Minimising the opportunities for such losses with silage depends primarily on rapid filling and perfect sealing of silos, followed by minimising the duration of exposure to oxygen during feedout. Tabacco & Borreani, (2002) have shown that significant aerobic deterioration of silage is common on farms, particularly where feedout takes place during hot weather. They observed that farms with smaller areas of silage feed-face per livestock unit, coupled with higher linear rates of feedout and careful management of the feed-face had less aerobic deterioration in their silage. Growth stage of a crop at harvest can also be influential - in the case of *Z. mays*, Wyss (2002a) found that relatively immature crops of high WSC and crude fibre content, and low starch concentration, were less stable during feedout than more mature crops, whereas the effects of the variety sown were much smaller. Lactic acid assimilating yeast are the primary initiators of aerobic deterioration and are more frequent where delayed sealing of a silo accompanies a low packing density of the forage (Uriarte-Archundia *et al*., 2002).

Additives applied at ensiling can improve aerobic stability at feedout. Examples include formic acid or mixtures containing formic, propionic and acrylic acids (O'Kiely, 1993), sorbate or benzoate together with homofermentative lactic acid bacteria (Owen, 2002; Skytta *et al*., 2002; White *et al*., 2002) and *Lactobacillus buchneri* alone or with *Lactobacillus plantarum* (Driehuis *et al.,* 2001; Filya *et al*., 2002). Mo *et al.* (2002) restricted mould growth by applying adequate CO_2 to wilted forage at ensiling. Lowes *et al*. (2000) demonstrated that direct application of mycocins to grass silage could delay the onset of spoilage. Thus, inoculation with mycocinogenic yeast at ensiling presents the opportunity to biologically improve silage stability at feedout.

Preservation of moist hay, and the use of additives to assist in the process have been reviewed by Benhan & Redman (1980), and Pitt (1991).

Baled silage

Baled silage permits the expansion of successful forage conservation, and so can be important in overcoming seasonality of feed supply. Its nutritive value can be similar to conventional silage (Fychan *et al*., 2002; O'Kiely *et al*., 1999), and it can also be used for conserving by-products (Wyss, 2002b). However, its fermentation differs from conventional silage (Slottner, 2002) - this is likely due in particular to differences in chopping/laceration of forage, with differences in the extent of anaerobiosis being more important than differences in compaction during storage (O'Kiely & Forristal, 2002). However, slicing of forage at baling has relatively minor effects on fermentation even though it can increase bale density (Borreani & Tabacco, 2002; O'Kiely *et al*., 1999). Forages need to be rapidly and adequately wilted before baling (Heikkila *et al*., 2002) to reduce the number of bales per hectare, and to ensure good preservation, avoid effluent accumulation and produce bales that retain their cylindrical shape during storage. Lighter colour and 6 or more layers of conventional stretch-film appear to be important when seeking to maintain anaerobic conditions in sunnier climates (Lingvall, 2002), whereas a minimum of 4 layers of black film are usually considered adequate in more overcast, cooler conditions (O'Kiely *et al*., 2002). The integrity of the plastic wrap must be maintained through to feedout in order to prevent fungal activity (McNamara *et al*., 2002) - otherwise the latter can be excessive (Brady, *et al*., 2004; O'Brien, *et al*., 2004).

Predicting ensilability

Forages vary considerably in the ease with which they will undergo a lactic acid dominant fermentation during ensilage, and successfully predicting the outcome has important economic implications for farmers. Prediction systems range from the subjective where scoring of crop, weather and harvesting characteristics is conducted (Anon., 1983) to more objective systems based on analysing representative samples of forage for DM, WSC and buffering capacity (Weissbach *et al*., 1974). Advances on the latter allow a more reliable prediction of the risk of butyric acid production by incorporating nitrate content and clostidial spore count (Kaiser & Weiss, 2004). Finally, new technologies using NIRS for the rapid and accurate analysis of conserved feeds (Agnew & Park, 2002) provide the opportunity for practical feedback of the success of the practices employed. The rapid assessment of free amino acids in silage could also be useful (Winters *et al*., 2002)

Further research

Future research needs differ considerably among regions of the world. Investment is required in research facilities and expertise in many countries in order to develop technologies appropriate for reducing their seasonality of production. These resources would be foci for technology dissemination, and the participation of stakeholders in the development of these technologies is essential (Chin, 2002).

Where smallholders predominate in S.E. Asia, practical, reliable and low cost technologies are needed for successfully wilting and harvesting crops, and for packing them into relatively small storage containers (Chin, 2002). Kaiser & Piltz, (2002) identified key areas for tropical forage conservation research. They suggest post-harvest sward productivity effects of early cutting, selection of forage soybeans (or multiple-cut high leaf:stem annual legumes) that combine high yield and quality, development of efficient and effective wilting systems for humid climates, more pragmatic combinations of silage additives, and reliable strategies for improving hygienic quality and aerobic stability during feedout.

In semi-arid regions of Africa, research needs include development of strategic irrigation systems and guidelines for optimising time of harvest (Titterton *et al*., 2002). Emphasis is needed on intercropping forage tree legumes (rather than annual legumes) with perennial tropical grasses or cereal crops. The benefits of these technologies need to be demonstrated within whole-farm systems where there is sufficient conserved feed (emphasis on silage) to cope with individual years of severe drought. In order to achieve some of the benefits of scale of operation, collective or co-operative alternatives to individual farm production may need to be tested for socio-economic viability (Titterton *et al*., 2002).

Silage and hay are already an integral part of meat and milk production systems in many regions with a temperate climate, with the emphasis being on silage under more moist conditions. Muck & Shinners, (2001) identified needs and predicted likely trends in forage conservation technologies, and these will drive a considerable research effort for a number of years. New technologies in regions where silage and hay are already well established will need to support reliably achieving high yields of good quality crops, consistently conserving crops with minimal quantitative and qualitative losses (and in some cases with upgrading of feeds during storage), having relatively low inputs of manual labour and being cost competitive. New technologies from precision-agriculture should play a role in this regard (Marcotte *et al*., 1999). Farmers will need rapid access to quantified data (e.g. soil nutrient and water status, fertiliser uptake rates, predicted yields and digestibilities, ensilability estimates, predicted wilting conditions, etc.), and know the strengths and weaknesses (including costs) of alternative technology options. In the case of hay, Tallowin & Jefferson, (1999) noted a need for further research to examine nutrient supply from semi-natural grasslands so that their feed value for ruminant livestock could be assessed with more confidence.

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