Strategies to mitigate seasonality of production in grassland-based systems

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Key points

1. Fertilisation use and manipulation can cost-effectively alter species composition, increase seasonal herbage production and improve herbage quality.
2. Choice of suitable grassland species, varieties and mixtures offers opportunity to mitigate limitations of seasonal grassland production.
3. Special purpose fodder crops, cereals, shrubs and trees offer alternative or supplementary feed sources.
4. Manipulation of stocking rates, grazing systems, transhumance and pasture management at various times of the season are significant advantageous options.
5. Integration of different strategies is essential to mitigate seasonality in systems of animal production that must be inherently more sustainable over a longer time frame.

Keywords: sward manipulation, animal production, fertilisers, plant choice, resource integration

Introduction

Seasonal patterns of herbage production and quality, result from variations in climate (temperature, rainfall and radiation) and environmental conditions (e.g. altitude, soil depth and fertility). Seasonality is an important limit to animal production, and total annual grassland production can be less meaningful than its distribution throughout the year.

Areas with large differences in seasonal rainfall (Mediterranean areas and the semi-arid tropics) exhibit the most extreme patterns of seasonality, but is also important in humid temperate areas where in general terms, forage production is mainly limited by low winter temperatures and occasionally by summer drought. In Mediterranean environments, the most critical periods for grassland production are during summer/early autumn (moisture limited) and winter (temperature limited); moreover, forage quality may be low during summer/early autumn. In semi-arid tropical areas, the critical period is the dry season (when both pasture quality and quantity may be limiting), and the early part of the 'wet' season until sufficient new herbage is available for animals.

This paper considers the opportunities for, and limitations to reducing seasonality of forage production and quality. It highlights strategies to match forage production and animal requirements, and strategies aimed at optimising combinations of feed resources to overcome critical periods and reduce production costs e.g. for fodder conservation. These problems require a system-based, farm-specific approach, since every farm is unique in terms of environment, available resources and management objectives.

Changing how pastures grow

Fertiliser

Fertilisation can cost-effectively alter species composition, increase herbage production, and improve seasonal growth rate and herbage quality. Fertilisers are mostly used in intensive temperate grassland systems, but they are also important for some sown tropical pastures and can be used to achieve higher levels of production from natural Mediterranean pastures (Seligman, 1996).

Early spring growth for grazing can be improved by strategic application of fertiliser nitrogen (N). However, periods of active growth are also those periods of greatest response to fertiliser N. If N is applied too early there is little yield response; if it is applied too late, pasture growth is not fully exploited. Therefore application dates that produce the highest N use efficiency and give the greatest total yield response, will not necessarily deliver herbage biomass 'out of season' for extended grazing, and may produce undesired effects such as excess biomass in spring (Morrison, 1987). Moreover, following an initially large herbage mass response, negligible and finally depressed yield responses to autumn N may occur due to the effect of legume depletion of the swards (Elliott & Abbott, 2003).

Precise weather forecasts and methods for predicting the best timing of N application in late winter to provide early spring grazing (e.g. 'T-sum 200') have been suggested (Frame, 2001). In these areas, there is also potential to extend the grazing season in autumn/early winter. Time of fertiliser application is important, e.g. in Ireland, when fertiliser was applied after late September on previously grazed swards, the response was poor and the probability of N loss by leaching and denitrification increased (Laidlaw *et al.*, 2000). Herbage grown from late autumn N applications can be prone to winter damage, especially if ryegrass swards are not well grazed, or if grazing is delayed (Frame, 2000).

Phosphate is important for maintaining the legume content of pastures, thus improving sward quality, promoting N-fixation and increasing sustainability of grassland-based systems. In New Zealand superphosphate increased legume production (predominantly *Trifolium repens* – white clover) by up to 72%, with most response in summer when improved feed quality is valuable for finishing lambs (Roach *et al.*, 1996). In Mediterranean conditions, Bullitta *et al.* (1987) showed that N-P fertilisation increased autumn-winter pasture production from 20% to 50% of total annual yield, giving a 1-2 month longer period of utilisation, and reduced year-to-year yield variation.

Farmyard manure and animal slurry are important sources of N and other nutrients. In temperate pastures, nutrients from animal slurry (particularly potash and N) are most effective when applied in early spring (Humprhreys *et al.,* 1997).

Pasture species, varieties and mixtures

In areas with high production potential but undesirable sward botanical composition, productivity and seasonal distribution can be improved by species introduction through various methods of oversowing. Breeding pasture species and varieties for increased growth at the start and/or end of the growing season has been, and continues to be an important objective in selection criteria (Gonzalez-Rodriguez *et al.*, 1996).

Low temperatures usually limit early spring growth. In temperate and sub-tropical areas species or varieties able to grow faster at this time of year have been selected e.g. *Lolium perenne* (perennial ryegrass) cv. Aberalan (Wilkins, 1995) and *Cenchrus ciliaris* (buffel grass) cv. Viva (Hacker, 1994) respectively. In several countries, Recommended Variety Lists contain information on seasonal yield distribution. In temperate climates *Lolium multiflorum* (Italian ryegrass), *Lolium hybridum* (hybrid ryegrass) and *L. perenne* are the most valuable species for early bite. *Phleum pratense* (Timothy) can produce valuable early growth in cold and wet upland conditions.

Herbage production and quality can be higher in perennial species that remain growing or green longer into the late spring and early summer in Mediterranean areas, e.g. *Dactylis glomerata* (cocksfoot) or the dry season in the tropics (McIvor, 1982). Under Mediterranean conditions deep root systems are important for maintaining high growth rates at these times. Preliminary results using mixtures of different functional types (grass/legume and annual/perennial) promise to extend the growing season and reduce variability between and within years (Porqueddu & Maltoni, 2004). The full potential of perennial grasses in Mediterranean environments has yet to be realised, particularly in drier regions, and will require greater exploitation of native germplasm, with an emphasis on selecting characteristics such as summer dormancy. Warm season grasses, both in pure stands or in mixtures with cool season species, can extend forage production in Mediterranean areas, e.g. *Eragrostis curvula* (weeping lovegrass), *Panicum virgatum* (switchgrass) and *Sorgastrum nutans* (Indian grass) showed good winter survival and high summer growth rates (Bonciarelli *et al.*, 1990). However, there are problems regarding forage quality, seed availability and cost, lack of evidence on their reliability in marginal areas and possible weed potential (Humphries *et al.*, 1991). For example *E. curvula* has been listed as a weed in Australia (Batianoff & Butler, 2002).

New thinking is required about forage herbs, e.g. the inclusion of *Cichorium intybus* (chicory) in grass/legume swards increased late season production (Kunelius & McRae, 1999). *C. intybus* was more productive than *Phalaris acquatica* (bulbous canary grass) in the warmer part of the year (Kemp *et al.*, 2002), and fine-leaved forbs such as *Plantago lanceolata* (narrowleaf plantin) and *Taraxacum officinale* (dandelion) can increase and stabilise the yield of unfertilised grass-clover swards (Isselstein, 2002).

Inter-seeding perennial cool-season cultivars with winter wheat can provide grazing during the first season and still allow good establishment of the perennial species (Kindiger & Conley, 2002). In temperate climates, subtropical grasses such as *Digitaria sanguinalis* (large crabgrass) and *Paspalum dilatatum* (dallisgrass) are used in mixture with temperate species to give higher summer yields. However, in New Zealand, subtropical grasses increase summer and autumn production, but may compete with species such as *L. multiflorum* and *T. repens,* thus reducing nitrogen fixation and rates of pasture production in the cooler season (Baars *et al.*, 1991).

Retention of nutritive value at the end of the growing season is important. The rate of decline in herbage quality with maturity is slower for legumes than grasses, and legume-based pastures can support higher animal growth rates than grass pastures at this time (Gardener *et al.*, 1993). Gloag *et al.,* (2004) found that *T. vesiculosum* (arrowleaf clover) extended the growing season by 3-4 weeks, had higher digestibility than *T. diffusum* (diffuse clover) and *T. subterraneum* (subterranean clover) from mid-December onwards, and could increase lamb liveweights in late summer by more than 10%.

A possible way to extend seasonal production is to use species with secondary compounds that limit intake in early growth stages, e.g. in late spring when the herbaceous species dry up, *Bituminaria bituminosa* (pitch trefoil) remains green and is intensively grazed by cattle (Gutman *et al*., 2000). For the same reason some annual legumes are not readily grazed at flowering but are well utilised in late spring and are preferred to the dry pasture in summer, e.g. *Biserrula pelecinus* (biserrula) and *Melilotus alba* (white sweetclover).

'Forage chains' can be devised using species and varieties with different maturities. These may include local ecotypes, although multiplication constraints sometimes hinder their wide-scale use (Roggero *et al*., 1990). Bullitta *et al*. (1991) set up simple forage chains (e.g. 3 rings = 3 sown pastures) for sub-climatic regions of Italy. They identified local ecotypes of annual legumes *Medicago polymorpha* (burr medic) and *T. subterraneum*, and perennial legumes, *Lotus corniculatus* (birdsfoot trefoil) and *L. tenuis* (narrowleaf birdsfoot trefoil) that allowed both spring utilisation and extension of autumn utilisation. Unfortunately, such theoretical studies are sometimes difficult to transfer to farm level, and successful use of temperate perennial cultivars has only been achieved in areas with limited summer drought (e.g. France). Clearly in devising such forage chains, some consideration need to be paid to factors other than pasture species. Many species growing as weeds on cultivated land are grazed by animals. Their exploitation and introduction into forage chains could improve forage resources and feed supply e.g. use of *Chrysanthemum coronarium* (gardland chrysanthemum) (Sulas & Caredda, 1997).

Fodder crops and special purpose pastures

These are used as an alternative to permanent grasslands. A novel special purpose pasture used on a limited scale in central Queensland is the growth of flood tolerant grasses (*Brachiaria mutica, Hymenachne amplexicaulis, Echinchloa polystachya*) in shallow ponds to provide green herbage during the dry season, when dryland areas have matured and senesced, and provide only low quality herbage.

Annual forage crops can complement pasture production in Mediterranean and temperate climates, as some species show high growth rates in winter and/or in late summer/early autumn. Under Mediterranean conditions, mixtures of cereals, *L. multiflorum* and annual legumes (e.g. *Vicia spp.*, *T. incarnatum*) provide winter grazing. *Hedysarum coronarium* (sulla) has recently re-gained interest for its flexible utilisation. In dairy-sheep forage systems, using two varieties with different growth patterns allows grazing in early autumn and late spring. Sulas *et al*. (1997) suggest mixed sward management entailing winter grazing and hay or silage making during spring for the first year, and year-round grazing in the second year.

In Sardinian cereal-based farming systems, the winter growth and forage quality of local landraces of barley and oats are often exploited by grazing up to mid-February, with almost no negative effects on grain yield. Special purpose pastures with a productive life of 2-3 years may occupy a small proportion (10-20%) of a farm. Kennedy *et al*. (2004) showed that special purpose pasture mixes can increase lamb seasonal carrying capacity and improve digestibility in late spring.

Secale cereale (rye) is the most winter-hardy small grain and the first to break dormancy in spring. It shows potential to extend grazing into late autumn and winter (Samples *et al*., 1996). Combining *S. cereale* with stockpiled perennial pastures can reduce reliance on high-cost stored feeds, but *S. cereale* is too competitive for water and minerals to be used in mixtures (A. Hopkins, *pers. comm*). Mixtures of cultivars with different maturities can be sown together to prolong the grazing season, e.g. the combination of different *S. cereale* cultivars with *X triticosecale* (triticale) in Switzerland for green forage production (Mosimann, 1998).

Forage *Brassica spp.* are highly palatable, energy rich feeds. Their high digestibility does not markedly decrease with maturity, and their ability to retain leaves makes them suitable for stockpiling, or for late summer and autumn/early-winter grazing (Koch *et al.*, 2002). Brassicas and spring cereals can be combined, e.g. *B. rapa* and spring oats for late autumn and winter grazing, and adding *S. cereale* for early spring grazing.

Fodder shrubs and trees

The contribution of fodder shrubs and trees to livestock diets varies between regions. In less favourable environments the contribution of native shrubs to animal diets is very high (Papanastasis *et al*., 1997). In more favourable areas, shrubs are generally used on a seasonal basis. In the tropics, fodder trees and shrubs (e.g. *Leucaena*) can be particularly productive and produce high quality feed during the dry season as a result of their deep rooting characteristics.

Fodder trees have a dual role in mitigating seasonality of pasture production: they provide fodder when herbage is not available, and they complement ruminant diets with protein and energy at times when grass is rich in fibre, enabling animals to make better use of dry pastures or cereal stubble (Abel *et al.*, 1997). Moreover, their growth is more stable between years than annual or even perennial forages. In Mediterranean regions woody fodder species (including *Quercus suber* (cork oak), are key components in traditional silvopastoral systems, e.g. 'Dehesa' (Spain) and 'Montado' (Portugal). In these systems, animal requirements are met by a combination of grasslands, crops, shrubs and trees. When oaks are pruned, the leaves and fine branches can overcome summer and winter forage gaps, while autumn acorns are reserved for fattening pigs that graze rotationally on the same pastures as cattle, sheep and goats. Other woody species (e.g. *Retama sphaerocarpa*) provide some green feed, including pods and seeds, when all other feed is dry. A greater role could be played by these native shrubs and trees if they were better studied (e.g. role of anti-nutritional characteristic) and managed (Porqueddu & Sulas, 1998). Based on experimental results, several authors have suggested introducing fodder shrubs and trees (e.g. *Atriplex* spp., *Chamaecytisus palmensis, Salsola vermiculata*, *Opuntia ficus-indica*) into forage systems in the Mediterranean basin and other regions (McMillan *et al.*, 2002). However, in several cases they failed at field level because of establishment difficulties, high planting costs, low persistence under heavy grazing, and low palatability.

Other strategies to change how pastures grow

Irrigation can provide high quality feed to fill seasonal feed gaps, e.g. *M. sativa* for hay and summer grazing in Mediterranean areas, irrigated permanent pastures for dairy cows in southern Australia and New Zealand, and irrigated temperate pastures during the cooler dry season in sub-tropical areas. In Mediterranean regions, occasional irrigation of pastures in late summer and early-autumn can provide early autumn feed or sustain pasture production after a false start to the growing season; even low water volumes can significantly increase and stabilise autumn production. Moreover, irrigation can give opportunities for double cropping. For example *L. multiflorum* is often grown for late autumn/winter/early spring feed in rotation with a summer-annual grass e.g. *Sorghum vulgare* (forage sorghum), *Pennisetum glaucum* (pearl millet). Orloff and Drake (2001) described systems using *X triticosecale* and/or mixtures of *X triticosecale* and *L. multiflorum* for autumn and early spring grazing, to complement cool season perennial irrigated pastures for the High Plains and intermountain region of the USA. However community concerns may lead to a reduction in water available for pasture irrigation.

Fire has many uses (e.g. control of woody plants and weeds, altering grazing distribution, pest control) and can influence seasonality of animal production by changing pasture composition and the availability of high quality feed. Fire removes mature, low quality, dry material so that the young, high quality regrowth is more available to animals, and diet quality is improved. In the central Great Plains in the USA, burning in late spring reduced undesirable grasses, and increased the desired warm-season species, thus alleviating summer forage imbalances (Mitchell *et al*., 1996).

Application of herbicides (spray-topping) to annual grasses at seed head emergence can delay loss of digestibility during late spring and summer. Gatford *et al*. (1999) in Southern Australia, showed that the loss of digestibility of stems, leaves and seed heads was slowed, but not that of leaf blades. Loss of digestibility was delayed by 5 weeks, but pasture yield decreased by 45%.

Changing how pastures are utilised

Stocking rate

The choice of stocking rate is one of the most important grazing management decisions. Low stocking rates can prolong the grazing season and also allow maximum selection by animals, so they can select the highest quality diet possible from the herbage available. This enables high production per head but production per hectare is low due to the low levels of utilisation (Troxler & Chassot, 2004). Constantly high stocking rates in areas with strong fluctuations in forage availability are dependent on forage resources from outside the farm, through transhumance or purchase of fodder or other supplements. Stocking rates can be set at moderate levels and varied seasonally by varying animal numbers, buffer grazing or harvesting surplus forage as hay or silage. Flexible management is required to closely match grass supply and stocking rate, e.g. using sward surface height guidelines (Frame, 2000). An intermediate choice is a constant moderate stocking rate, where periods of reduced pasture growth are compensated through purchase or cultivation of forage, forage storage and conservation, and use of standing crops.

Grazing systems

There is a lot of interest in grazing systems throughout the world. Generally, fertilisation, species choice and stocking rate have a much greater impact on animal productivity than changes in the grazing method (Waller *et al.*, 2001). Animal performance under rotational (intense defoliation with low frequency) and continuous grazing (frequent but light defoliation) is generally similar at low stocking rates, with rotational systems exceeding continuous grazing only at high stocking rates. Many producers claim large increases in animal production when adopting ‘cell’ grazing. Although this increase could be due to other factors (in addition to grazing system), the improved uniformity of utilisation with smaller paddocks is a reasonable explanation of the increases in production (Norton, 1998).

Strip grazing enables a greater control over pasture intake than longer rotations or continuous grazing. This allows more feed to be conserved to carry animals through periods of feed shortage e.g. Doyle (1999).

Saving pastures as standing hay for out-of-season grazing is a well known practice, e.g. summer/autumn-saved pasture for *in situ* winter feeding in temperate areas, and spring-saved pasture in Mediterranean areas (Sulas *et al.*, 1995). In *T. subterraneum* based pastures of the 'Dehesa' agro-silvopastoral system, summer grazing relies on dry pasture deferred from spring with pods and seeds providing an important protein source. Not all cool-season species are adapted to stockpiling. Frame (2000) indicated *D. glomerata*, *Festuca pratensis* and *P. pratense* as the most suitable species for autumn-saved pasture. In the USA, stockpiled perennial grasses were suitable for maintaining beef cattle, dry dairy cows and sheep over winter, but for animals with higher nutrient requirements or under extreme environmental conditions, protein and energy supplementation was required (Hedtcke *et al*., 2002). While stockpiling can provide low cost feed for the autumn and early winter months, it delays spring recovery of the stockpiled plots. An alternative to stockpiling is windrow or swath grazing where animals graze directly from windrow-stored forage, usually together with packaged hay. This can lower livestock production costs, and maintain herbage yield, diet quality and meat gains (Volesky *et al.*, 2002).

There is generally a trade off between evenness of production and total herbage production. Frequency of grazing can have a major influence on the pattern of pasture growth. More intense or more frequent defoliations interrupt the reproductive development, reducing seasonal variation by lowering the spring or summer peak, but also lowering total production (Korte & Harris, 1987). To accumulate herbage to build up a reserve ('bank') for autumn/winter use, it is recommended that the rotation length increase gradually. If the rest interval is excessive, herbage mass may be reduced because the rate of senescence approaches or exceeds the rate of leaf growth. Excessive accumulation of *L. perenne* herbage (over 2 t DM/ha) into winter, adversely affected forage quality and the state of the sward in spring, resulting in a decline in tiller density (Laidlaw *et al.*, 2000). Saved pastures should be changed from year to year to avoid possible negative effects on forage quality and sward composition (Gonzales-Rodriguez *et al.*, 1996).

Autumn and winter sward management will influence earliness of spring growth. Fields designated for early grazing should be grazed first and then shut off for the rest of the winter. Although O'Kiely & O'Riordan (1994) in Ireland recorded a reduced herbage mass in spring swards either cut or grazed in early winter (December) compared with those remaining ungrazed since autumn, later studies (Laidlaw & Mayne, 2000) observed that early winter defoliation had no effect on subsequent spring herbage mass. In any case, the detrimental effect of late defoliation on spring growth may be compensated for by increasing N application (Binnie *et al.,* 2001).

Grass growth in midsummer is influenced by the intensity of defoliation earlier in the year. Close early grazing ensures the development of densely tillered swards capable of leafy growth into summer, since the ensuing tillers will be vegetative rather than reproductive.

Considerable research effort is being devoted to 'side-by-side' grazing, based on animals' free choice of adjacent grass and clover monocultures. Preliminary results by Venning *et al.* (2004) showed that lambs grazing *L. perenne* and *T. subterraneum* sown as 'side-by-side monoculture', grew faster than those on mixed grass/clover pasture (20% clover) or ryegrass monoculture, but not on clover monoculture. Side-by-side grazing allows the use of grassland species and varieties that do not grow well in mixtures and could also be used for a range of plant species.

'Zero grazing' may be used for special purpose crops or for short periods in early or late season to avoid poaching of swards (Frame, 2000). It is based on cutting and carting forage to housed or partially housed stock, and involves high capital costs of machinery but gives a higher efficiency of forage utilisation.

Transhumance

This is a well-known solution to seasonality in several regions of the world. Traditionally, the heterogeneity of the vegetation is exploited by early-season grazing on warmer slopes and sites, late-season grazing on cooler and wetter sites, and dry-season utilisation of deeper-rooted perennial species, evergreen shrubs and other woody species. There is also integrated use of high (mountain) pastures in summer and lowland forage resources at other times. Transhumance grazing systems in temperate regions of Asia have been reviewed by Suttie & Reynolds (2003). Transhumance has potential to be integrated in multifunctional grassland systems in less favoured areas e.g. by reducing biomass to prevent summer wildfires and summer grazing of skiing lines. Moreover, the integrated and strategic use of upland pasture may confer added value to traditional and high quality animal products, through the exploitation of local breeds and knowledge.

Animal management

Matching animal biology and pasture growth

Seasonal grazing with dairy cows that calve just before the spring growth peak, and conserving surplus herbage as hay or silage, can produce economic benefits by reducing costs (Winsten & Petrucci, 2003). However, the successful application of seasonal grazing requires a high level of management skills, a thorough knowledge of animal husbandry, a keen observation of pasture growth and flexible time management.

In many extensive grazing systems, producers accept that animals will gain weight during the growing season and then lose weight at other times of the year. Rapid gains following a period of weight loss may compensate for the loss. However, care must be taken that body condition does not fall below a minimum threshold, as under-nutrition in early or critical life stages may reduce later performance. There have been contrasting results according to animal species, breed and category, type of production and grazing system (Stockdale, 2001; Hennessy & Morris, 2003).

Animal breeds

Differential selection between animal types under mixed grazing can greatly modify sward state, and may benefit species with a wider growing season, e.g. *T. repens* content is greatly affected by grazing regime (cattle > mixed > sheep) influencing availability of forage during summer (Nolan *et al.*, 2001). Animal breeds in extensive farming systems need to be matched to environmental limitations. The short green season is one of the main factors for the preponderance of small ruminants in the Mediterranean basin and in most other dry Mediterranean-type regions. *Bos indicus* animals are better adapted to tropical conditions than *Bos taurus* animals – the better adapted animals forage further and have a higher forage intake (Siebert, 1982). If local breeds are to have a role in sustaining grassland-based systems a critical analysis of inputs, feeding policies and quality of the products must be carried out (Mills *et al*., 2004).

Supplements and alternative/additional feed stuffs

Nutritional supplements (energy, protein or N, and minerals) can provide nutrients that may be limited in the herbage. In dry tropical areas, pastures growing on phosphorus (P) deficient soils based on *Stylosanthes* spp. can produce large quantities of herbage during the wet season, with reasonable levels of digestibility and protein but inadequate P levels. Thus, supplementation of animals with P during this time can greatly increase weight gains. During the dry season large quantities of herbage with low protein levels and digestibility are often available, but rumen activity of grazing animals is low. Supplementation with protein or urea (and sometimes molasses) can counteract this leading to increases in intake of dry pasture; this can reduce or eliminate dry season weight losses and reduce mortalities.

Molasses is important in Australia and elsewhere in the tropics where it is locally available and is widely used for survival feeding, and may have an increasing role in production feeding (Hunter, 2000).

The presence of tannins in many shrubs and tree leaves, limits their utilisation as animal feeds. Decandia *et al*. (2000) showed polyethylene glycol (PEG) increased the proportion of tannin-rich species in the diet of goats browsing a Mediterranean shrubland during summer, allowing better utilisation of woody species, increasing crude protein digestibility and enhancing the efficacy of concentrate supplementation.

Integration

Overcoming seasonality of grassland production has been, and will continue to be a challenge for land managers. In extensive areas (e.g. semi-arid tropics) there is often acceptance of seasonality and little attempt to overcome it. In contrast in intensive areas (e.g. moist temperate regions) there has been much more study and practice of overcoming seasonality, sometimes leading to farming systems potentially 'challenging' to the environment. However, recent trends on sustainability, product and environmental quality and animal welfare are veering towards mitigation strategies rather than overcoming seasonality.

The challenge is to integrate what is available to each farm considering local constraints, the objectives for the farm, and consumers' requirements and demands. Farmers are in the best position to do this. Since there are many management factors, climates, variable prices etc., computer models can play a role in optimising best management policy. Many models have been developed although they are little used or validated in practice.

Management practices have associated risks and costs, e.g. establishing sown pastures over large areas is expensive if cultivated seedbeds are used, compared with lower costs if species can be established by surface sowing without soil preparation. However, this decrease in costs is accompanied by an increase in the risk of establishment failure (Cook *et al.*, 1993).

Grasslands are inextricably linked with crops and their residues in many farming systems with numerous examples of mixed farms with the integration of pasture, annual forage crops and cereals (Roggero *et al.*, 1996; Talamucci & Pardini, 1999). For efficient grassland-based forage systems, integrating more than one feed resource will be necessary to mitigate seasonality of production and achieve satisfactory feed quality. This adds complexity to the farming system, but flexible though complex systems of resource use, may be inherently more stable and sustainable over a longer time frame.

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References

Abel, N., J. Baxter, A. Campbell, H. Cleugh, J. Fargher, R. Lambeck, R. Prinsley, M. Prosser, R. Reid, G. Revell, C. Schmidt, R. Stirzaker & P. Thorburn (1997). Design principles for farm forestry: a guide to assist farmers to decide where to place trees and farm plantations on farms. Barton, ACT, Rural Industries Research and Development Corp., Canberra, 102pp.

Baars, J.A., G.J. Goold, M.F. Hawke, P.J. Kilgarriff & M.D. Rollo (1991). Seasonal patterns of pasture production in the Bay of Plenty and Waikato. *Proceedings of the New Zealand Grassland Association,* 53, 67-72.

Batianoff, G.N. & D.W. Butler (2002). Assessment of invasive naturalized plants in south-east Queensland. *Plant Protection Quarterly*, 17, 27-34.

Binnie, R.C., C.S. Mayne & A.S. Laidlaw (2001). The effects of rate and timing of application of fertiliser nitrogen in late summer on herbage mass and chemical composition of perennial ryegrass swards over the winter period in Northern Ireland. *Grass and Forage Science,* 56, 46-56.

Bonciarelli, F.Z., A. Cardinali & R. Santilocchi (1990). Prove di adattamento di specie erbacee foraggere ad accrescimento "differito" (Adaptation trials on herbaceous forage species with differentiated growth). *Agricoltura Ricerca*, 106, 81-92.

Bullitta, P., S. Caredda & G. Rivoira (1987). Influenza dell'andamento metereologico e della concimazione azotata sulla produttività totale e stagionale di un pascolo in Sardegna (Climatic trend and nitrogen fertilisation influence on total and seasonal productivity of Sardinian pastureland). *Agronomia*, 2, 146-151.

Bullitta, S., M. Falcinelli, S. Lorenzetti, V. Negri, A. Pardini, S. Piemontese, C. Porqueddu, P.P Roggero, P. Talamucci & F. Veronesi (1991). Prime osservazioni su specie perenni ed annua autoriseminanti in vista della organizzazione di catene di foraggiamento in ambienti mediterranei (First observation on perennial and annual self-reseeding species for the organisation of forage chains for the Mediterranean environment). *Rivista di Agronomia*, 2, 220-228.

Cook, S.J., R.L. Clem, N.D. MacLeod & P.A.Walsh (1993). Tropical pasture establishment. 7. Sowing methods for pasture establishment in northern Australia. *Tropical Grasslands*, 27, 335-343.

Decandia, M., M. Sitzia, A. Cabiddu, D. Kababya & G. Molle (2000). The use of polyethylene glycol to reduce the anti-nutritional effects of tannins in goats fed woody species. *Small Ruminant Research*, 38, 157-164.

Doyle, P.T. (1999). Strip grazing to control wool growth rate of sheep grazing green annual pastures. *Australian Journal of Experimental Agriculture*, 39, 247-258.

Elliott, D.E. & R.J. Abbott (2003). Nitrogen fertiliser use on rain-fed pasture in the Mt Lofty ranges, south Australia. 1. Pasture mass, composition and nutritive characteristics. *Australian Journal of Experimental Agriculture*, 43, 553-577.

Frame, J. (2000). Improved grassland management. Farming Press, Tonbridge, UK, 353p.

Frame, J. (2001). Extending the grazing season. *Forage matters*, spring 2001, 1-3.

Gardener, C.J., M.R. McCaskill & J.G. McIvor (1993). Herbage and animal production from native pastures, and pastures oversown with *Stylosanthes hamata*. 1. Fertiliser and stocking rate effects. *Australian Journal of Experimental Agriculture*, 33, 561-570.

Gatford, K.L., R.J. Simpson, C. Siever-Kelly, B.J. Leury, H. Dove & T.A. Ciaravella (1999). Spray-topping annual grass pasture with glyphosate to delay loss of feeding value during summer. I. Effects on pasture yield and nutritive value. *Australian Journal of Agricultural Research*, 50, 453-64.

Gloag, C., A. Thompson, A. Kennedy & K. Venning (2004). Long season annual legumes to increase lamb production. Proceedings of the Grassland Society of Victoria, Albury, July 2003, 93pp.

Gonzalez-Rodriguez, A., J. Pineiro & M. Cropper (1996). Extending the grazing season. In: G. Parente, J.Frame & S. Orsi (eds.) Grassland and Land use systems - *Proceedings of the 16th EGF Meeting,* Grado (Gorizia), Italy, (September 15-19), 941-948.

Gutman, M., A. Perevolotsky & M. Stenrberg (2000). Grazing effects on a perennial legume *Bituminaria bituminosa* (L.) Stirton, in a Mediterranean rangeland. In: L. Sulas (ed.) Legumes for Mediterranean forage crops, pastures and alternative uses - Proceedings of the 10th Meeting FAO-CIHEAM, Sassari, Italy, (April 4-9), 299-303.

Hacker, J.B. (1994). Buffel grass *Cenchrus ciliaris* 'Viva'. *Plant Varieties Journal*, 7, 31-32.

Hedtcke, J.L., D.J. Undersander, M.D. Casler & D.K. Combs (2002). Quality of forage stockpiled in Wisconsin. *Journal of Range Management*, 55, 33-42.

Hennessy, D.W. & S.G. Morris (2003). Effect of preweaning growth restriction on the subsequent growth and meat quality of yearling steers and heifers. *Australian Journal of Experimental Agriculture*, 43, 335-341.

Humphries, S.E., R.H. Groves & D.S. Mitchell (1991). Plant invasions: the incidence of environmental weeds in Australia. *Kowari*, 2, 1-134.

Humphreys, J., T. Jansen, N. Culleton, F. MacNaeidhe, M.B.H. Hayes & W.S. Wilson (1997). Comparative effects of organic manures on spring herbage production of a grass/white clover (cv. Grasslands Huia) sward. In: M.H.B. Hayes (ed.) Humic substances in soils, peats and waters: health and environmental aspects. *Royal Society of Chemistry; Cambridge,* UK, 446-461.

Hunter, R.A. (2000). High molasses diets for intensive finishing of steers. *Asian-Australia Journal of Animal Science*, 13 (B), p112.

Isselstein, J. (2002). Effect of perennial ryegrass variety on the performance of grass/clover and grass/clover/forb mixtures. In: J.L. Durand, J.C. Emile, C. Huyghe & G. Lemarie (eds.) Multi-function grasslands. Grassland Science in Europe, 7, 312-313.

Kemp, D.R., D.L. Michalk & M. Goodacre (2002). Productivity of pasture legumes and chicory. *Australian Journal of Experimental Agriculture*, 42, 15-25.

Kennedy A. J., C. Gloag , A.N. Thompson & L. North (2004). High performance pasture systems to increase lamb production in southwest Victoria. *Proceedings of the Australian Society of Animal Production*, Melbourne, July 2004, 273p.

Kindiger, B. & T. Conley (2002). Competition and survival of perennial cool-season grass forages seeded with winter wheat in the southern Great Plains. *Journal of Sustainable Agriculture*, 21, 27-45.

Koch, D.W., C. Kercher & R. Jones (2002). Fall and winter grazing of *brassicas*, a value-added opportunity for lamb producers. *Journal of Sheep and Goat Research*, 17:1-13.

Korte, C.J. & W. Harris (1987). Effect of grazing and cutting. In: R.W. Snaydon (ed.) Ecosystems of the World 17B. Managed grassland analytical studies. Elsevier, 71-77.

Kunelius, H.T. & B. Mc Rae (1999). Forage chicory persists in combination with cool season grasses and legumes. *Canadian Journal of Plant Science,* 79 (2), 197-200.

Laidlaw, A.S. & C.S. Mayne (2000). Setting management limits for the production and utilization of herbage for out-of-season grazing. *Grass and Forage Science*, 55, 14-25.

Laidlaw, A.S., C.J. Watson & C.S. Mayne (2000). Implications of nitrogen fertilizer applications and extended grazing for the N economy of grassland. *Grass & Forage Science*, 55, 37-46.

McIvor, J.G. (1982). Agronomic potential of introduced grasses grown in north-east Queensland. CSIRO Tropical Agronomy Technical Memorandum No. 29, p14.

McMillan, Z., C.B. Scott, C.A. Taylor & J.E., Huston (2002). Nutritional value and intake of prickly pear by goats. *Journal of Range Management*, 55, 139-143.

Mills, J., N.H. Yarrow, M. Lherm, K.U. Röver & D. Pasut (2004). Effect of livestock breed and stocking rate on sustainable grazing systems: 6. Socio-economic impacts. In: A. Lüscher, B. Jeangros, V. Kessler, O. Huguenin, M. Lobsiger, N. Millar & D. Sutter (eds.) Land use systems in grassland dominated regions. Grassland Science in Europe, 9, 629-631.

Mitchell, R.B., R.A. Masters, S.S. Waller, K.J. Moore & L.J. Young (1996). Tallgrass prairie vegetation response to spring burning dates, fertilizer, and atrazine. *Journal of Range Management*, 49, 131-136.

Morrison, J. (1987). Effects of nitrogen fertilizer. In: R.W. Snaydon (ed.) Ecosystems of the World 17B. Managed grassland analytical studies. Elsevier, 61-70.

Mosimann, E. (1998). Rye and triticale cut as green forage. *Revue Suisse d'Agriculture*, 30: 2, 57-59.

Nolan, T., J. Connolly & M. Wachendorf (2001). Mixed grazing and climatic determinants of white clover (*Trifolium repens* L.) content in a permanent pasture. *Annals of Botany*, 88 (Special Issue), 713-724.

Norton, B.E. (1998). The application of grazing management to increase sustainable livestock production. *Animal Production in Australia*, 22, 15-26.

O'Keily, P. & E.G. O'Riordan (1994). Effects of defoliating grass in winter or spring on first cut yield and grass and silage quality, and on second cut yield. *Proceedings of the 4th research conference,* British Grassland Society, Reading, UK, 55-56.

Orloff, S.B. & D.J. Drake (2001). A grazing and haying system with winter annual grasses. *Proceedings 31st California Alfalfa and Forage Symposium,* Modesto, CA, (Dec. 11-13), 143-150.

Papanastasis, V.P., P.D. Platis & O. Dini-Papanastasis (1997). Productivity of deciduous woody and fodder species in relation to air temperature and precipitation in a Mediterranean environment. *Agroforestry Systems*, 37, 187-198.

Porqueddu, C. & S. Maltoni (2004). Evaluation of a range of rainfed grass-legume mixtures in a Mediterranean environment. In: B.E. Frankow-Lindberg (ed.) *Proceedings of the Workshop on Adaptation and management of forage legumes - strategies for improved reliability in mixed swards.* Ystad, Sweden, September 20-22, 2004 (in press).

Porqueddu, C. & L. Sulas (1998). Mediterranean grassland systems. In: G. Nagy, K. Peto (eds.) Ecological aspects of grassland management. Grassland Science in Europe, Debrecen, Hungary, (May 18-213), 335-345.

Roach, C.G., E.K.K. Nemaia, S.F. Ledgard, G.J. Brier & C.D.A. McLay (1996). Effects of long-term differences in fertiliser history on hill country: seasonal pasture production, legume growth and soil phosphorus status. *Proceedings of the New Zealand Grassland Association*, 57, 105-109.

Roggero, P.P., S. Bellon & M., Rosales (1996). Sustainable feeding systems based on the use of local rersources. *Annales. Zootechnie*, Elsevier/INRA, 45 (Suppl), 105-118.

Roggero, P.P., C. Porqueddu, S. Bullitta & F. Veronesi (1990). The choice and varieties for rainfed Sardinian forage systems. *Proceeding of the 6th Meeting FAO on Mediterranean pastures and fodder crops.* Bari, Italy, 77-81.

Samples, D.H., H.M. Bartholomew & R.M. Sulc (1996). Cereal rye to extend the grazing season. *Proceedings of the New Zealand Grassland Association,* 57, 115-118.

Seligman, N.G. (1996). Management of Mediterranean grasslands. In: J. Hodgson & A.W. Illius (eds.) The ecology and management of grazing systems. CAB International, Wallingford, UK, 359-391.

Siebert, B.D. (1982). Research findings in relation to future needs. *Proceedings of the Australian Society of Animal Production*, 14, 191-196.

Stockdale, C.R. (2001). Body condition at calving and the performance of dairy cows in early lactation under Australian conditions: review. *Australian Journal of Experimental Agriculture*, 41, 823-839.

Sulas, L. & S. Caredda (1997). Introduzione in coltura di nuove specie foraggere: produttività e composizione bromatologica di *Chrysanthemum coronarium* L. (crisantemo) sottoposto a pascolamento simulato (Introduction of new species as fodder crop: forage production and quality of a *Chrysanthemum coronarium* L. population under simulated grazing). *Rivista di Agronomia*, 31 (4), 1021-1028.

Sulas, L., S. Caredda & C. Porqueddu (1995). Evolution of the standing hay chemical composition in natural and improved Mediterranean pastures. In: Sylvopastoral Systems. Cahiers Option Mediterreenennes. 12, 155-158.

Sulas L., G.A. Re, L. Ledda & S. Caredda (1997). The effect of utilization frequency on the forage production of sulla (*Hedysarum coronarium* L.). *Italian Journal of Agronomy*, 2, 89-94.

Suttie, J.M. & S.G. Reynolds (2003). Transhumant grazing systems in temperature Asia. *Plant Production and Protection Series No. 31*, Food and Agriculture Organization of the United Nations, Rome, 353pp.

Talamucci, P. & A. Pardini (1999). Pastoral systems dominated by fodder crops harvesting and grazing. In: L. Etienne (ed.) *Dynamics and sustainability of Mediterranean pastoral systems - Proceedings of the* 9^{t}*th Meeting FAO-CIHEAM*, Badajoz, Spain, (Nov. 26-29), 1997, 29-44.

Troxler, J. & A. Chassot (2004). Effects of the stocking rate on steer performance and vegetation patterns on mountain pastures. In: A. Lüscher, B. Jeangros, V. Kessler, O. Huguenin, M. Lobsiger, N. Millar & D. Sutter (eds.) Land use systems in grassland dominated regions. Grassland Science in Europe, 9, 587-589.

Venning, K., A. Thompson, A. Kennedy & D. Chapman (2004). Effects of separating grass and clover on ewe and lamb production. *Proceedings of the Grassland Society of Victoria*, Albury, July 2003, 81-82.

Volesky, J.D., D.C. Adams & R.T. Clark (2002). Windrow grazing and baled-hay feeding strategies for wintering calves. *Journal of Range Management*, 55, 23-32.

Waller, R.A., P.W. Sale, G.R. Saul & G.A. Kearney (2001). Tactical versus continuous stocking in perennial ryegrass-subterranean clover pastures grazed by sheep in south-western Victoria. 1. Stocking rates and herbage production. *Australian Journal of Experimental Agriculture*, 41, 1099-1108.

Wilkins, R.J. (1995). Improved technology for production efficiency and utilisation efficiency. In: G.E. Pollot (ed.) Grassland into the 21^{st} century. BGS Occasional Symposium no. 29, 210-224.

Winsten, J.R. & B.T. Petrucci (2003). Seasonal dairy grazing a viable alternative for the 21st century. American Farmland Trust. Washington, DC.22. <http://grassfarmer.com/papers/studies/casestudies.pdf>