Managing sheep and beef farm systems - where does pasture persistence fit in?

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Abstract
Pasture persistence is highly rated by sheep and beef farmers as an important factor determining whole-farm performance. Managing pastures to ensure the persistence of newly sown pasture species must be considered as a part of the decision making process of the whole farm. The farmer aims to optimise the outcomes of resource use over time, rather than maximise any single resource, and therefore grazing decisions must be considered in this context. Pasture renewal is a major event-driven disruption that replaces current pasture species with competitive species, creating a grass-legume complex that has a tendency to develop towards a community of plants that tolerate the local environmental stress. Pasture persistence can be improved through managing the impacts of and interactions between environmental stressors on the pasture. Interactions between pasture management options, such as grazing and fertiliser, and the major environmental stressors of soil moisture, temperature, soil fertility, grazing and pests are discussed.
Keywords: ecology, environmental stressors, farm systems, grazing management, pasture persistence.

Introduction
Pasture species persistence was ranked by farmers as the 4th most important factor in whole-farm performance (Daly *et al.* 1999) after pasture quality, animal health and soil fertility, scoring highly (17) on a scale of 1-20. So what influences the persistence of newly sown pasture species? To understand pasture persistence this paper considers the farm systems as a whole, the ecological drivers of pasture dynamics and the impacts of stressors such as grazing, soil fertility, and drought. Management practices that may influence the impacts of stressors are considered.

Pasture management is one of many processes that a farmer considers in managing a whole-farm system. Short- and long-term goals and outcomes are traded off to optimise, rather than maximise, whole-farm performance (Danckerwerts & Tainton 1993). This trade-off creates tension between the many management processes that are applied on-farm and needs to be understood when trying to develop approaches to improve pasture persistence.

The response of a pasture to its environment can be described by underlying ecological principles (Grime 1979). The establishment of a new pasture is just the beginning of an evolution of that pasture toward a dynamic equilibrium suited to the growing and grazing environment. An understanding of the major environmental stressors of soil moisture, temperature, soil fertility, grazing and pests (Scott *et al.* 1985) is required to ensure that appropriate trigger points are considered when imposing management alternatives.

Plants survive, and are managed, as pasture communities within our grazing systems (Briske 1989). How this occurs, and when these communities are vulnerable to environmental stressors, is another important aspect of how we, the graziers, manage pastures.

These first principles will be considered in this paper to help understand how major stress and disturbance can drive change in pasture species composition. Some strategies that may help maintain a chosen pasture mixture are suggested.

Developing an understanding of a whole-farm system
We need to consider how a farm system is developed before we can understand how to manipulate that system to aid pasture persistence.

The farmer operates at three distinct levels of planning: strategic, tactical and operational (Parker *et al.* 1997). The farmer chooses an animal production enterprise that may be breeding, breeding/finishing or finishing. They then choose the animal species (sheep, beef, deer, or goats) that fit both the enterprise, personal preference and the local environmental conditions. Age structures of the livestock develop over time, often depending on the enterprise and species. A stocking rate that matches the most likely feed supply conditions is chosen and performance outcomes are targeted. All of these factors are integrated with the base pasture resource, the climate (mostly as temperature and soil moisture profiles) and soil fertility. The farmer then applies various management practices aiming to optimise the use of the pasture resource and to meet the feeding requirements of the livestock.

Decisions within a farm system are made by examining probable outcomes from different management actions and choosing those that, in the experience of the farmer, have the greatest chance of attaining the farmers objectives (Provenza 1991). The ultimate goal of pasture management is to meet the feeding requirements required to attain animal production outcomes that meet the socio-economic goals of the farmer. This then translates into optimising pasture productivity and quality, both in the short and long-term, with the optimum being determined by the farmer (Danckerwerts & Tainton 1993).

Difficulties attaining an optimum level of pasture productivity and quality usually lie in the trade-off between short- and long-term goals, and an understanding of the impacts of short-term decisions on long-term outcomes (Danckerwerts & Tainton 1993). A simple example of this is the decision to control porina caterpillar (*Wiseana* spp.) in pasture. The short term problem is relatively inconspicuous and builds up incrementally, so a decision by the farmer to apply a timely control is often not taken. If the pest population develops alongside summer dry conditions then the result of over-grazing of the pasture can lead to a reduction in desirable pasture plant populations allowing weed species invasion in subsequent seasons, reducing overall pasture productivity in the long term (Barratt *et al.* 1990). More complicated trade-offs occur when whole-farm grazing decisions are made in the face of interacting stressors.

The desire to maintain the presence and productivity of a newly sown pasture is only a single part of the greater complex of the farm system. This puts the role of implementing farm system strategies to ensure pasture persistence into context.

Ecological principles underlying change in the botanical composition of pastures

The response of the pasture community to environmental stimuli must be understood when managing pastures at a whole-farm system level. Plant communities respond to stress and disturbance (Grime 1979). Once established, a pasture responds to five on-going stimuli. These are soil moisture, temperature, soil fertility, pests and grazing management (Scott *et al.* 1985). When applied on a continual basis they can generally be categorised as stressors. However, they can combine in more severe conditions to become a disturbance event, such as over-grazing combined with a pest attack during a drought. Further disturbance events such as soil loss or deposition, water-logging and pasture renewal can be added and these are often large and occasional in nature.

Pastures often begin, after re-sowing, as a binary mixture of grass and a legume (predominantly ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*)). Ecological principles suggest that a community of plants will develop that are best suited for that site (Grime 1979). The pasture renewal process can be considered a major disturbance of a site. Sowing a new pasture mimics general ecological principles to create a community in early succession.

Further development of this community, towards a dynamic equilibrium, will depend on the interaction between stress and disturbance, leading to the most appropriately robust species becoming resident in the long term. Most pastures have a significant reserve of these species through seed (Hume & Barker 1991) or vegetative regeneration (Hume 1999) that provide the basis for the development of the pasture community.

Development of a pasture towards a stable community is the result of the response of the individual plants and their growing units to the imposition of stressors and occasional disturbance events (Westoby *et al.* 1989).

Understanding the impacts of stressors

Pastures generally evolve from the original sown species through two main pathways: gradual succession and event or disturbance-driven change (Danckerwerts & Tainton 1993).

Gradual succession occurs when the application of continual stress is beyond the ability of the plant species to tolerate or adapt. An example of this comes from a long-term study where a single sown pasture mixture evolved into distinctly different communities of dominant species as a product of interactions between the fertiliser and grazing treatments applied (Scott *et al.* 1989).

Drought is a common event-driven change in New Zealand pastures. Drought played a major role in the step-wise reduction of sown clover contribution in over-sown hill country, being halved in a single drought event (Dodd *et al.* 2001). Changes in endophyte occurrence in ryegrass have also reflected event-driven change on sown cultivar presence (Stevens & Hickey 1990), and highlights the advantage of high endophyte ryegrass in avoiding grazing (Edwards *et al.* 1993) resulting in potential overgrazing of low endophyte grasses.

Gradual reversion of a pasture from the sown species to the previous resident species usually occurs when stressors on the pasture are on-going. This may be due to declining soil nutrient supply, soil moisture stress or grazing stress. Soil nutrient supply is often good in a newly sown pasture as extra fertiliser may be added, or have accumulated from a previous crop, or nutrients may have been released by soil mineralisation following cultivation. This will decline, especially if the original soil fertility was not adequate. 'Perpetual' soil moisture stress is a state where the chosen pasture species is placed in a situation that is beyond the climatic range it normally grows in. An example of this may be sowing ryegrass in a region where the annual rainfall is below 500 mm. Grazing stress occurs when the chosen pasture species cannot adapt to fit the grazing system. An example of this would be using a large leafed clover in a continuous grazing system. This strain of clover cannot reduce its growth unit size appropriately to adapt to the continuous defoliation and therefore disappears from the pasture. Combinations of all of the above lead to the final pasture mixture or community that develops.

Event-driven disturbances are rare in environments that have relatively predictable rainfall and temperature cycles. These environments help the farmer develop a farm system that matches the environment in most years, because climatic variation that leads to event-driven disturbance is minimal. It is the predictability of these environments that is important as this minimises year-to-year variation and so grazing systems can be designed that suit the environment most of the time. Examples of these in New Zealand may include Southland, Taranaki and the King Country. It could also include the West Coast and Central Otago as although these environments have extremes of rainfall and temperature, they are relatively predictable.

The major regions where event-driven disturbance is of importance are where climatic variation is large or unexpected. This includes many of the East Coast regions of both the North and South Islands where climatic variation is large (Greenwood & Sheath 1981; Radcliffe 1975), and the Manawatu, Waikato and Northland where unexpected climatic variation has occurred in recent times in the form of floods and severe droughts (Wilson & Valentine 2005).

The impacts of unexpected event-driven disturbance are often outside the experience of the farmer. This then means that they have relatively little knowledge of the long-term outcomes of their short-term decisions. Often these decisions are made during a time of extreme stress, for example in a drought or flood, and so are made with regard to livestock welfare and financial pressures rather than pasture persistence.

Controlling the major environmental stressors through the decision making of the farmer becomes a key part of designing farm management systems that can aid pasture persistence.

The role of plant physiology in creating pasture communities

Pastures are structured at a range of levels, from the individual unit, the tiller or stolon through to the plant, the clump and the community (Briske 1989). It is at the community level that the farmer views pasture persistence. The question becomes how do we maintain the pasture species chosen at sowing as a persistent community of plants?

A review by (Brock & Hay 1993) provided a succinct summary of the first principles of plant growth to develop pasture management systems. This summary outlined the role of leaf area index in early thinking about designing grazing management systems (Brougham 1958; Brougham 1960; Watson 1947), and then introduced the interaction between defoliation frequency and severity with the physical units of growth (Butler *et al.* 1959; Chu & Robertson 1974; Hunt 1989). This information about how plants strive for an equilibrium between intercepting light and responding to temperature (Brougham 1958) led us to understand why plants decrease leaf size, and allow for greater numbers of growth units to develop (i.e. the pasture sward becomes denser and shorter) when grazing intensity increases. This response means that maximum photosynthesis can be achieved over a broad range of pasture conditions, as farmlet studies under a range of conditions demonstrated during the 1980s (Bircham & Hodgson 1983; Chapman & Clark 1984; Chapman *et al.* 1983). This work provided a reappraisal of how individual growth units could change in size and density to buffer the pasture community against the effects of grazing while maximising the use of the resources of light, moisture, temperature and nutrients to provide a similar nutritional profile to the grazing animal (Brock & Hay 1993) across a range of grazing conditions.

Significant lessons about ryegrass grazing management emerged from this work. Net pasture production varies little when cover is maintained over the range of 1000 to 2500 kg DM/ha (Chapman & Clark 1984). Defoliation frequency of below 14 days will decrease herbage accumulation, but between 14 and 35 days net herbage accumulation is relatively unaffected (Hodgson & Wade 1978). Tying these together was the observation that rotational and continuous grazing methods vary relatively little in the rate at which tillers are defoliated when compared at the same stocking rates (Curll & Wilkins 1982).

This research gave us an understanding of how farmers could choose many systems of grazing management over a range of potential pasture cover levels, and have functioning, profitable farm grazing systems.

Perennial pasture plants, both grasses and legumes, exhibit seasonal cycles of regeneration. Understanding the continual fluxes of tillers and plants on a seasonal basis, and in response to disturbance, provides an understanding of when disturbance has the greatest effects and how managements can ameliorate or exacerbate the impacts of disturbance. Many of our common grasses follow patterns similar to ryegrass (Brock & Hay 1993). The regeneration process in grasses generally consists of an annual cycle from vegetative to reproductive and back to vegetative. During this process the creation of new plants from clonal processes tends to match the rate of tiller production (Brock & Hay 1993), so that each plant reaches and then maintains an optimal size depending on the grazing regime. Tiller production is highest before flowering during mid-spring, and again immediately post-flowering in early summer. Survival of these daughter tillers is paramount to the on-going longevity and productivity of the pasture (Matthew *et al.* 1991).

Our predominant perennial legume, white clover, also goes through a seasonal cycle of clonal regeneration, rarely relying on reseeding (Chapman 1987; Widdup 1985). Growth and death cycles are usually in balance during most parts of the year except mid-spring (Brock *et al.* 1988). At this time, old stolons die back resulting in a major breakup of plants into smaller units. These smaller plants still support a similar number of growing points at the expense of carbohydrate reserves (Hay *et al.* 1989), making them vulnerable to competition and disturbance at this time. By late spring, stolon growth is restored and the plants recover, stabilizing the population (Brock *et al.* 1988).

Therefore, mid spring to early summer is an important period of vulnerability for both ryegrass and white clover. Some of the interactions of this plant competition have been developed into management systems in sheep farming. The general recommendations that continuous grazing in spring can be used to promote white clover content in a pasture (Hay & Baxter 1989) reflects the outcome of reducing the competition for light at this time by keeping the pasture height short allowing white clover plants to recover while controlling the seed-head of the grasses. This approach also helps the daughter tillers of ryegrass to survive (Matthew *et al.* 1991; Matthew *et al.* 1989), which improves the number of ryegrass plants in the sward. Depending on the stocking rate, the frequent, lenient defoliation regime allows the plant density to build up and more of the pasture biomass accumulates in the base of the pasture (Webby & Pengelly 1985). This reduces the stress on the pasture and maximise survival of the plants helping to ensure persistence during the greatest time of vulnerability.

Designing farm management systems to improve pasture persistence

If our pastures are relatively plastic to grazing management then when do we need to modify our practices to ensure pasture persistence? As outlined, we start with a major disturbance event to establish a new pasture, create a community in early succession with few species and then want it to stay the same, even though principles suggest that it will develop towards a more complex and stable community with greater diversity (Grime 1979).

So what can we do as pasture managers to continue to maintain the balance that we want between high producing grass and legume without the ingress of 'weed' species? Three key management tools are under our direct control. They are choice of pasture species, fertiliser (soil nutrients) and grazing. A fourth, controlling pests, is also an important management decision that can be chosen by the farmer but is covered elsewhere in this symposium. Water inputs may be controlled through irrigation but will not be considered here.

This section attempts to offer some insight on the potential for farmers to maximise persistence. Many of the thoughts here have not been demonstrated in an experimental framework and are therefore the opinions of the author.

Pasture species

The choice of pasture species is important in setting the baseline of expectation and future production. Scott *et al*. (1985) provided a framework to choose pasture species based on their fit with the environment they would be sown in. This framework is still appropriate and should be used by farmers and advisors to identify species and cultivars most likely to succeed in any given environment.

Fertiliser

Soil fertility needs to be at an optimum to provide nutrients to the selected pasture species. This includes the addition of N, P, K, and S as fertiliser and modification of soil pH. Soil fertility provides the base for the chosen pasture species to be competitive in all soil moisture conditions.

Nutrient deficiency is often a common side-effect of drought, as limited soil moisture means that the availability of nutrients is also compromised (Cornish *et al.* 1984). Thus reduced inputs of fertiliser may compromise the competitive ability of the chosen pasture species when faced with drought, leading to the dominance of other species.

Grazing management

The outcomes of different grazing management approaches are to alter the structure of individual growing units of the plant, thereby altering the plant and the community structures as well. The two extremes of grazing management approaches, rotational and continuous grazing, are described here (Brock & Hay 1993). Rotational grazing tends to provide long spells between relatively short though severe grazing events. This leads to fewer, larger individual plant growth units, often with more bare ground in between. Continuous grazing tends to have shorter spells but less severe defoliation events. This results in more, smaller individual plant units with a more complete ground cover. The severity of defoliation here is being defined as the amount of the plant removed at any one time. The structure of these plant communities then sets a platform for the response of that pasture to other stressors as they occur.

As has already been said, maintaining pasture cover in a state between 1000 and 2500 kg DM/ha creates an environment where net pasture production is maximised in sheep and beef grazing systems. Therefore when the amount of pasture present goes beyond these boundaries there are opportunities for the pasture to change.

Over-grazing (cover goes below 1000 kg DM/ha) generally stresses the pasture species beyond their ability to adapt often allowing less productive species such as browntop (*Agrostis capillaries*) and annuals to take over. Often these events are seasonal or accompany adverse climatic conditions.

Sheep farms often have pasture cover levels below 1000 kg DM/ha in early to mid spring. While this may stress the pasture, it is at a time of year when soil moisture and soil fertility are usually adequate, and at a time when the plant is relatively robust. The long-term outcomes from over-grazing at this time of year are usually relatively minor as only the grazing stressor is in play. Extending this period of low pasture cover levels into late spring applies more stress on the pasture as the plant is more vulnerable, soil moisture becomes limiting and nutrient supply diminishes.

Under-grazing (cover goes over 2500 kg DM/ha) tends to lead to more open pastures that are more similar to rotationally grazed pastures. This means that they are more vulnerable when conditions change and more grazing pressure is applied.

When should we do anything different to what we do now? Current sheep farming systems are relatively well designed to provide nutrition for the grazing animal while maintaining a productive pasture. The current recommendations of a pasture cover level between 1400 and 1800 kg DM/ha during lambing over the spring meets the nutritional needs of the ewe, maintains the pasture in the optimum state to maximise net herbage accumulation, and provides an appropriate grazing stress to increase the number of growing units before the onset of the summer-dry period. Maintaining a relatively short pasture at this time also provides the opportunity for white clover to spread and contribute to animal nutrition and nitrogen fixation (Hay & Baxter 1989).

Problems come when conditions vary beyond 'normal', which is when covers vary outside the 1000 to 2500 kg DM/ha range. This is often when environmental conditions are also beyond the range of 'normal' and is when the stressors interact to create change.

How do we manage the effects of uncontrolled stressors?

The two major stimuli for stress that are beyond the immediate control of the farmer are soil moisture and temperature. Soil moisture can be a stressor when there is too little and too much, and at both times it interacts with grazing management.

When soil moisture content is low then over-grazing is the issue. Relatively little research has been done to define the most appropriate or cost-effective options when managing over-grazing. Over-grazing is often applied across the whole farm as the farmer attempts to meet the feed requirements of the animals. Two strategies may be appropriate to protect pastures from over-grazing. One is to know when grazing should stop to minimise damage to the chosen pasture species. The other is to restrict the damage to pastures that can be re-sown later to help their recovery. Often the latter is more appropriate on a farm as destocking options are limited. However, often the decision to stop grazing is taken much too late for the pasture, as the farmer manages the animal intake and the overall farm productivity and profitability. If the soil moisture deficit is a regular occurrence (e.g. 1 year in 3) then alternative feeding systems with appropriate buffers, such as home grown supplements, or a change in farm enterprise may better match the climatic variability. The impacts of drought can be managed (Gray *et al.* 2008) as onset is usually slow, and, as an environmental process, is an extension of a developing soil moisture deficit.

When soils are waterlogged then treading damage due to stock numbers becomes the issue. Stand-off areas offer a partial solution, but often waterlogging events create issues for long periods of winter in some regions and so other strategies are required. Sometimes managements such as self-feed silage pits, to get heavier stock like cattle or significant numbers of stock like breeding hinds off pasture, may reduce damage at these times (McDowell & Stevens 2006). An alternative being studied at the moment is changing grazing patterns of sheep in winter by changing the allowance and grazing duration. Shifting to 4-day feed allocations at maintenance has changed sheep grazing behaviour and reduced soil and pasture damage, resulting in improved early spring growth and reduced loss of sown grasses in Southland (Stevens unpub. data).

Controlling the impacts of temperature on pastures appears, at first glance, to be impossible. However, there are some principles that can be used to mitigate the impacts. One impact of high temperatures is a reduction in forage quality (Minson 1982) that may then lead to differential grazing pressures placed on different species within the pasture. Forage quality is also influenced by the age of the leaves at time of grazing, with older leaves being of lower quality (Buxton & Mertens 1995). Techniques to combat this reduction will then include any method that decreases the time between defoliations such as grazing interval and the use of fertiliser nitrogen to accelerate growth. At low temperatures the competitive advantage of perennial ryegrass can be enhanced again by the use of fertiliser nitrogen as perennial ryegrass begins active growth at 5°C while some of the major weed grasses like browntop do not begin active growth until soil temperatures reach above 7°C (Mitchell 1956).

The type of grazing management system chosen may also play a role in mitigating the effects of drought and high temperatures. Pastures under continuous grazing are more resilient to the onset of drought with clover stolon biomass being maintained and post-drought recovery being more complete than in pastures under rotational grazing (Brock *et al.* 1988). This appears to be due to a combination of improved shading (Brock & Kim 1994) and reduced soil surface temperatures (Brock & Hay 1993) due to a greater pasture biomass being below grazing height when continuous grazing is used.

Conclusions

Many of the processes that govern the evolution of a pasture community are under the control of the farmer, but need to be considered in the wider context of optimising the whole-farm system. Farmers make decisions about pastures based on the contribution of that pasture towards meeting the needs of the animal, while also meeting short- and long-term goals of the farm system.

Pasture renewal is a process that is a major event-driven disruption that replaces current pasture species with competitive, high producing species. This grass-legume complex may not be the climax community that fits the local growing environment, and therefore has a tendency to develop towards a community that tolerates the local environmental stressors. Even the grass legume balance requires the use of some on-going management interventions to ensure an appropriate equilibrium is retained.

Late spring is a crucial time when interactions between the five stressors of pasture, soil moisture, temperature, soil fertility, grazing and pest management, can have a profound effect on pasture persistence.

Pasture persistence can be improved through managing the impacts of and interactions between environmental stressors on the pasture. Approaches may include:

- Choosing the right species to suit the environment and the grazing system.
- Adding the right amount of fertiliser and lime.
- Controlling the grazing to maintain the optimum growth.
- Using triggers such as residual pasture cover levels in late spring to determine grazing decisions that will ensure good management of pastures going into moisture stress.
- Proactively modifying the grazing system during key periods (e.g. mid spring, late summer) to ensure that the competitive advantage of the chosen species is enhanced.
- Modifying the growing environment to improve the competitive advantage of the desirable pasture species (e.g. adding fertiliser).
- Creating feeding buffers such as hay or silage that will allow the objectives of the farming system to be met while maximising the productivity and persistence of the pasture in the long term.

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