Using new insights in grazing management to buffer the impacts of climatic variability on pasture resilience

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Highlights

Pasture is the main source of nutrition for the New Zealand ruminant livestock industry. Changing climatic conditions and relentless intensification are putting the ability of pastures to provide that nutrition under pressure. Recent understanding of the interactions between grazing management and the life cycle of roots, leaves and seedheads of pasture species creates further opportunities to increase pasture resilience. Root production is directly related to, though lagging, leaf production and turnover. Tiller production is modified by temperature and seedhead production. Matching grazing patterns to maximise the production of each of these features is generally impossible at the farm scale. However, matching some of these characteristics on some of the farm can be achievable, and have long-lasting benefits for pasture resilience. Therefore, grazing management practices such as deferred grazing in late spring, summer and autumn may be used both to provide a boost to root and tiller production, and to transfer feed from one grazing period to another. Changing our winter management practices away from intensive daily allocations towards 4-day shifting may also increase early spring production, while reducing summer grazing pressure in droughts will aid pasture productivity and persistence in the long term. These techniques have the potential to ensure that the future nutritional needs of grazing ruminants will continue to be met by grazed pasture.

Keywords: deferred grazing, grazing intensity, root turnover, seedhead, tiller

Introduction

The production of feed from pasture is an important characteristic of New Zealand red meat production. Pasture production is, however, only a transition process in an animal production system. It is a means to an end, and that end is sustainable, cost-effective (profitable) animal production from a resource (land/soil) best suited to grow forage (pasture).

We need to feed animals from our pastures and we therefore need to compromise the management of pasture, even though the resilience of that pasture to recover and supply feed in the future is critical to success. First principles of grazing management have aimed at maintaining a green leafy vegetative state as the optimum state to provide fresh, high-quality forage for grazing animals (Lambert & Litherland 2000). However, our sheep and beef farmers understand that we live in a highly variable environment. This means that we can at times face a conflict between the first principles of caring for pastures and the first principles of feeding animals (Lambert et al. 2000). This leads to the need for resilience in our pastures, defined here as the need to maintain a high proportion of desirable pasture species (amount and quality) that can recover after stress such as droughts.

Our sheep and beef systems rely heavily on pastures for nutrition. The pastures in New Zealand have a legacy of being a mixture of grasses and legumes (Sears 1951). This has often been referred to as a ryegrass/white clover mixture, but our hill country pastures have long been recognised as a complex mixture of grasses and legumes (Cosgrove & Field 2016) that varies at a microsite level within paddocks (Gillingham & During 1973), seasonally through species differences in temperature optima (Mitchell 1956) and more generally between regions depending on the combination of soil fertility, soil moisture and temperature (Scott et al. 1985).

Feeding livestock from this complex mixture of pasture species is complicated by the variations in pasture growth that reflect the microclimatic and temporal and topographical variations inherent in the rapidly changing aspect and slope typical of hill country (Gillingham & During 1973). Climatic variability has also increased in the recent past with an increase in frequency of drought at 13 of 30 sites, and intensity at 14 sites, since 1972 (Stats NZ 2020). These increases have affected regions differently than in the past, with Hamilton, Dannevirke, Lake Tekapo, Napier, Reefton, Taupo and Whangarei demonstrating trends of both increasing drought frequency and intensity. This poses the on-going question of how will our pastures be managed to meet animal demand in the future?

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What does the future hold?

While the imposition of current societal demands to reduce the impacts of farming on the environment loom large in thinking and action, two issues will guide future thinking on farm resilience. These are increasing climatic variability and maintaining farm profitability.

Climatic variability

Climatic variability has always been a factor when managing pastures in hill country. However, changing frequency and intensity of both dry and wet periods pose significant issues in managing this variation. For example, when a cool, dry spring restricts pasture growth it allows little movement in pasture management as the grazier trades off the need to feed lactating stock to gain a saleable product at weaning with the future potential pasture recovery during what may be a dry summer (Gray et al. 2008). Livestock trading options are often touted as the way to manage feed deficits, but at this critical time, when revenue potentials are being created through the growth of suckling lambs and calves, there are few viable options available. Thus, while an agricultural drought is technically described as one extending for 6 months, meteorological droughts (3-month duration) are more significant for daily tactical management of pastures (Gray et al. 2008).

At the other extreme, long-term saturation of soils also poses a problem with damage both to the pasture and the soil, which often take a significant amount of time to recover from e.g., Stevens et al. (2011).

Productivity and profitability

Trends to increase the productivity of hill country, to enable on-going occupation of the land, are likely to continue. Fennessey et al. (2016) suggested that future productivity gains in the ewe flock could be as much as 40-50% in the next 15 years. This included increased lambing percentage, hogget mating, heavier ewes, higher weaning weights, lower ewe death rates and higher carcase weights. These have an estimated cost of 15% more feed required by the breeding ewe, and to a lesser extent her lambs. Can we add the feed required to capture these potential advances by the way we manage our pastures in a more volatile environment?

Potential to harness alternative grazing management approaches

Any attempt to increase the resilience of pastures must engage the management of both the plants and the animals. Farmers aim to maximise winter stocking rate, particularly of in-lamb, highly fecund ewes, to increase the potential to harvest the spring surplus and increase profitability (Hawkins & Wu 2011). Thus, winter stocking rate is a balancing act between maximising the potential number of lambs born per hectare, for more profit, and having enough feed for ewes to optimise performance in most years. Ewe numbers and their relative pregnancy rate predicts potential feed demand in the spring. However, ewe condition must also be maintained to maximise lamb survival and early lactation performance. These factors need to be balanced to maximise utilisation of the spring flush with multiple-bearing lactating ewes, as a formula for pasture utilisation and profit. This involves a rotational grazing system, initiated during autumn, to transfer feed into winter, through rationing of the animals' intake (Smeaton & Rattray 1984). Often, management during the rest of the year uses a combination of continuous grazing and semi-rotational grazing, relying more on using the sales of stock to alter feed demand (McCall & Sheath 1993).

To improve resilience of our pastures, we propose that management can be more closely aligned to typical seasonal patterns of tiller birth and death, with a strong focus on management during the reproductive period, to reduce tiller mortality, increase tiller birth and population growth and to enhance root growth. Furthermore, with increasing levels of abiotic and biotic stresses, increasing persistence benefits will be accrued by allowing perennial ryegrass-based pastures to undergo a longer period of reproductive development, when the climate is conducive to perennial ryegrass. Other strategies may be required for pastures that are not ryegrass dominant. This approach, however, must be kept within the concept of providing feed for grazing livestock, remembering that both quantity and quality are required, and at specific times of the year.

Roots and resilience

Roots supply the shoots with water and mineral nutrients and provide anchorage. They are the unseen component of pastures and are measured less often than leaf and tiller dynamics because of the practical difficulties of doing so. A greater understanding of root dynamics will assist in improving the ability of pastures to withstand and recover from stresses and improve pasture resilience.

In New Zealand, foundation knowledge on rooting behaviour of various forage species was provided by Evans and co-workers. For example, Evans (1978) demonstrated that regardless of topsoil depth, in a soil type with no subsoil rooting barriers, perennial ryegrass roots penetrated to 140 cm soil depth, 80.1% of the total root length was found in the top 20 cm and 1.1% below 100 cm. Substantive water extraction occurred to 70 cm depth and maximum soil moisture tension in summer was 1.8 MPa at 10 cm soil depth. In the same experiment, white clover achieved substantive soil moisture extraction to 90 cm depth with maximum soil moisture tension of 1.8 MPa at 30 cm soil depth, but otherwise had a root distribution similar to ryegrass.

A series of informative studies has been carried out by Crush and co-workers on single grass and clover plants in pipes. A comparison of root system distribution with depth and nitrate interception in 11 forage grass species (Crush et al. 2005) found crested dogstail to be strongly surface-rooted, browntop to have stronger nitrate interception per unit of root weight than other grasses, but otherwise only small differences between grass species in rooting patterns. Plants with greater nitrogen (N) interception had greater dry weight, but differences in N interception did not correlate with any measured rooting trait. An evaluation of individual genotypes in a mapping population (Crush et al. 2007) found that between genotypes the fraction of total root in the top 10 cm was 33-75% and the proportion of an added N pulse intercepted ranged from 12.4% to 43.1%, but once again the quantity of N intercepted could not be related to root distribution patterns. A comparison of root traits of bred and wild ryegrass populations (Crush et al. 2009) found considerable genotypic variation within populations and that root dry weight of single plants grown in pipes was not necessarily predicted from shoot dry weight. All these observations suggest that identification of and breeding for advantageous root traits may be possible, but the work is all ahead of us.

Recent work at Massey University on summer moisture deficit tolerance of perennial ryegrass (He 2016; Weerarathne et al. 2018) suggests that more negative plant osmotic potential (which theoretically should enhance plant extraction of soil water and reduce water loss by transpiration) may be important to both water relations and N uptake, since N can be passively acquired by plants through the transpiration stream. More recent cultivars with Spanish germplasm in their background are demonstrating more negative osmotic potential and improved water use efficiency in summer moisture deficit compared to ‘Grasslands Nui’ (Weerarathne et al. 2018) and some individual plants can develop osmotic potential exceeding 3.0 MPa under summer moisture deficit with indications that the trait is highly heritable. Solutes that provide osmotic suction for plant protection during a drought can also be metabolised by the plant for regrowth after a drought, so breeding for more negative osmotic potential has potential to improve ryegrass resilience when exposed to summer drought.

Roots exhibit a seasonal cycle of development, though efforts to document this are in conflict depending on the measurement techniques and growing conditions. For example, Caradus & Evans (1977) reported a primary peak of root production in spring, Wedderburn et al. (2010) reported an autumn peak and Matthew et al. (1991) reported both, with root growth preceding spring leaf production and following autumn rewetting after rain.

To reconcile these conflicting perspectives, it is useful to consider the morphology of root production. Roots are produced from inside the tiller axis at the base of a leaf once it has died. Thus, root production is directly related to leaf production and turnover. In ryegrass, for example, leaf appearance is related to temperature (101 °C.days; Black et al. 2002) and leaves die after approximately 3-4 leaf appearance intervals (Fulkerson & Donaghy 2001). Typically, two roots can potentially form at around the time of leaf senescence and, if initiated, grow on for about 12 leaf appearance intervals. This makes the root turnover cycle about 4 times longer than the leaf turnover cycle, and the root initiation at a particular site offset in time, typically by after 4 or 5 leaf appearance intervals from earlier leaf initiation at the same site. Young adventitious roots grow rapidly, since they are the first to draw from the photosynthate stream flowing down the tiller axis from the leaves and are small with low respiration demand. With the appearance of new roots above them, their photosynthate supply declines and more available photosynthate is used for root respiration due to their larger size as they age. Modelling suggests that the older, larger roots with reduced carbohydrate supply and increased respiration demand eventually die of carbohydrate deprivation (Robin et al. 2018). In spring, warming temperatures and resulting faster leaf appearance mean that up to 1.3 leaves feed the roots at each site, while in autumn the reverse occurs, and fewer leaves feed more root sites. Root numbers per site may also be greater at warmer temperatures in autumn than at cooler temperatures in spring. This results in a ‘plant architectural’ signal for a relative increase in root vigour in spring and suppression in autumn. This may well explain why Caradus & Evans (1977) counting new adventitious roots, and Wedderburn et al. (2010) counting total new root numbers and branches, observed peak root numbers in spring and autumn, respectively. In addition, in dry soil conditions in summer, initiation of new roots is suppressed (Troughton 1980), meaning that established roots do not lose their substrate supply and are able to continue growing for longer and reach greater depth. Thus there is a natural cycle that tends to reduce deeper root penetration when deeper soil layers are likely to be waterlogged and hypoxic in winter, and increase root penetration in summer when access to deeper water may benefit plant survival (Matthew et al. 2016). This understanding is still in the process of formulation so currently there are not specific grazing management guidelines to enhance the seasonal root replacement cycle, other than an intuitive recommendation to ensure that plants are protected from extreme stress such as close defoliation during drought so that they have sufficient reserves to maintain their continuous cycle of root turnover.

The potential of grazing practices

Grazing management practices may both attenuate the impacts of variable climate on feed supply and provide greater resilience of the pasture. Interactions between grazing frequency and intensity have been recorded and demonstrate the influence of the tiller and stolon production cycles on forage production. Hard, frequent grazing in summer, and in autumn during recovery from summer-dry conditions, has the greatest negative impact on pasture production and subsequent recovery. This was illustrated by Brougham (1960), who tested the imposition of frequent hard grazing (from 7.5 to 2.5 cm) on a mixed ryegrass, cocksfoot, red and white clover pasture during different seasons, with subsequent management using a more lenient 17.5 to 7.5 cm regime during the rest of the year, along with controls of each extreme. Pertinent to the discussion of energy flows and reproductive development are results from spring, summer and autumn defoliations. While Brougham (1960) originally used his data to propose sigmoid curves to define pasture height for optimum herbage accumulation, some other key points emerge on inspection of the data: during spring, frequent hard grazing reduced yield by approximately 30%, with no subsequent detriment to yield at other times of the year. During summer, previous hard grazing in winter provided an advantage through high legume yields, while hard summer grazing reduced yield by approximately 45%. During autumn, hard grazing had no impact on yield, while previous hard grazing in summer continued to suppress total production by 50%. Production of both white and red clover was also influenced by grazing frequency and severity. Greatest negative impact was caused by frequent hard grazing in autumn (-20%).

Investigations of the role of seedheads in ryegrass using radioactive 14-C CO_2 also showed that seedheads divert some of their photosynthetic resources to ‘feed’ daughter tillers at their base (Colvill & Marshall 1984; Matthew 2002). Tiller tagging and longevity studies by Korte (1986) showed that tillers produced pre-flowering in ryegrass have a shorter life span than those produced after flowering. From that perspective, encouragement of post-flowering tillering fed by photosynthate from emerging seedheads should be beneficial. Waller & Sale (2001), for example, found that the number of tillers produced from the base of reproductive stems was 15-fold greater than those produced from vegetative tillers that did not produce a seedhead.

However, each grass species has a unique seasonal tiller turnover strategy. Data are sparse for species other than ryegrass, though Matthew et al. (2013) reviewed published and unpublished information for several species. Notable examples are that timothy and prairie grass undergo near complete tiller population turnover during their flowering period so that post-flowering tillers are the key to persistence in these grasses (and this requires appropriate management), while in meadow fescue it is pre-flowering tillers that underpin the annual perennation cycle.

It is also now understood that a high tiller density induced by closer grazing incurs a leaf area index cost. Colloquially, we could say that the higher vegetative tiller density following a close grazing is not so much a healthy response with good indications for summer pasture performance, but a ‘desperation’ attempt by the sward to try to replace some lost leaf area by putting smaller tillers below grazing height. Overall, likely reductions in carbohydrate status may impact on root growth, with negative implications for summer root growth and the plants’ ability to extract deeper soil water in summer (see section on roots).

Areas where we can improve must include opportunities to move feed between seasons, acknowledging that we need to consider summer as an on-going feed deficit period, similar to winter, in future climate change scenarios due to emerging increases in meteorological drought (Stats NZ 2020). Traditional methods of forage cropping have a role in this approach (Stevens 2009), alongside techniques such as deferred grazing (Tozer et al. 2020).

Our discussions regarding root, tiller and seedhead dynamics suggest that the interaction between these components within the plant is critical in providing the resilience of favoured species such as ryegrass and white clover. This suggests then that the deferring of grazing during the heading phase would provide a double benefit when summer-dry conditions were imminent. The first would be to provide a significant release from grazing to strengthen the plant through accumulation of carbohydrate reserves and tiller, root and seed production. The second would be to provide a bulk of feed available in the latter stages of a dry period, for maintaining livestock. Studies have identified the advantage of shifting this bulk of feed (Devantier et al. 2017) from late spring to summer and autumn (Tozer et al. 2020).

If we were to generate systems where we deferred grazing of pastures from the heading period into autumn, do we potentially increase the ability of that pasture to recover from drought? The science on root development, reported here, suggests that this should be the outcome, together with additional benefits such as increased soil carbon which, in turn, would increase soil stability and water-holding capacity. More photosynthate supply to roots to ensure that they grow deeper into the soil should then mean that postdrought (dry) recovery should be greater. Traditional approaches of closely fitting animal demand to the pasture curve (e.g., Savage & Lewis 2005) are then challenged as profitability may no longer be as directly linked to maximum pasture utilisation.

Seed production from this approach would have variable outcomes. Studies in New Zealand have shown little long-term advantages to seed production (Bluett et al. 2004), except in drier environments especially where systems are developed to take advantage of any specific properties of the species involved (e.g., subterranean clover, Grigg et al. 2008).

Other techniques, such as N fertiliser use, may also have a role at non-traditional times to support this. Applying fertiliser N in late spring is often viewed as a waste, as pasture supply often exceeds demand at this time. However, if we consider stockpiling feed in summer/autumn as both feed for animals, and the opportunity for desirable plants to recover through post-flowering tiller production, then the previous metric of feed utilisation and return on the dry matter (DM) grown become obsolete in valuing N fertiliser use. Indeed, at this time, N applied as fertiliser has least environmental impacts, though the subsequent utilisation of areas of pasture with high herbage masses in autumn may generate potential hotspots for winter leaching from animal urine and dung deposition. This may be mitigated by the low N content in the mature pasture that has developed over the deferred period (Devantier et al. 2017).

Managing for white clover

While much has been made of the role of light intensity in potential fluctuations in white clover production in pasture swards, evidence suggests that it is grazing *per se* that drives potential loss of clover rather than light. Many studies using short and long defoliation intervals and lax and severe defoliation intensities under cutting regimes report relatively consistent white clover yields (e.g., Appadurai & Holmes 1964; Rhodes & Harris 1979). Clover also has a higher temperature preference than ryegrass (Mitchell 1956), so in winter tends to be shaded by long grass, but in summer can overtop the grass in many cases. Responses under a grazed situation suggest that manipulating the morphology of white clover using frequent, intense grazing regimens in spring to reduce internode length and boost total growing point number, results in greater total white clover production in a mixed pasture (Brock et al. 1988; Hay et al. 1991). Research in hill country supports this finding and goes further to identify both greater stolon growth (Chapman 1983) and total DM production (Boswell & Cranshaw 1978) under cattle grazing compared with sheep grazing.

The potential of animal management

Reducing stress on pastures to enable greater resilience must also involve the manipulation of animal demand at the farm scale. Sheep and beef farms are often the amalgam of breeding and finishing enterprises that results in 20-30 mobs of animals with different nutritional requirements, ranging from breeding ewes and cows in different condition, pregnant, lactating or dry, of different ages and of young stock growing at different rates depending on their fate. Managing this myriad of stock classes needs to be supported by pasture management options, rather than serve them.

Options to provide more precise management of the early spring/lactation deficit may include scanning to differentially feed twins and triplets, using greater amounts of winter supplementary feed, moving hoggets to a run-off after winter, and beef sales. This leaves more feed to support ewe lactation and lamb weight gain. Managements like this, which have resulted in higher pasture covers in spring, have been documented to increase overall ewe flock performance and profitability e.g., Johns et al. (2016). Spring productivity may also be significantly increased when winter grazing management is changed from daily to 4-daily shifting, potentially through reduced treading damage and increased post-grazing residuals, without compromising animal intake (Stevens et al. 2011). This ability to maintain intake and leave a higher residual after grazing demonstrates the impact of treading losses at high stocking densities. Treading losses have received little attention in understanding animal responses within the agronomic, rather than animal nutrition view of grazing management.

Expectations of high pasture quality during summer are often not met (Litherland et al. 2002) due to the decline in feed quality caused by high temperatures (Buxton & Mertens 1995). Feed quality will continue to decline during summer and autumn as temperatures increase with climate change. The relative value of increasing feed quality has greater estimated value (+16% Gross Margin) than increasing the availability of pasture during autumn and early spring (+12%, Webby & Sheath 2000), especially in sheep enterprises. Therefore, changes in grazing management to increase resilience may need to be accompanied by changes in enterprise and expectations. Beef enterprises may be more favoured by this approach as the timeframe over which growing cattle are retained on-farm makes the manipulation of their growth rate an option when modifying animal demands, such as recorded with bull beef systems (Ogle & Tither 2000).

Conclusions

Changes in grazing management go beyond leaf defoliation. They move to interactions with soil in both wet (risk of structural damage) and dry (effects on rooting depth) conditions. There is still scope to create management systems that recognise both the need for maximising pasture growth opportunity, and can increase the potential utilisation of that pasture as animal nutrition.

Questions remain. How much of a farm should be deferred? What pasture covers should be aimed for in spring? What trigger pasture covers should be used to make decisions? Will N fertiliser really help? All these questions need research to understand the responses of both pasture and animal at a whole systems scale, before recommendations suggested here can be incorporated into widespread practice.

This perspective provides a new interpretation of first principles of tiller dynamics that is yet to be employed at a farm systems scale though some opportunities present themselves. Given the increasingly variable climatic conditions, one approach may be to manipulate winter feeding regimes to ensure higher pasture covers (1500-1800 kg DM/ha) coming out of winter as a standard practice. In spring, as the surplus increases, decisions can be made on how much of the farm to defer based on the amount of surplus. This will also have the advantage of better matching feed demand and feed supply in the grazed pastures, so that there is less seedhead and more leaf, leading to an increase in pasture nutritive value. If a drought occurs and there is insufficient feed, the deferred pastures can be grazed earlier than envisaged (for example, in early rather than later summer). While this may not enable the benefits of deferring to be fully realised in the deferred pastures (for example, through compromising the amount of reseeding or tillering in autumn), the livestock feed demands are met and pasture quality on the rest of the farm will have benefitted over the deferred period. The ability to shift feed during a drought will also alleviate pressure on other pastures reducing overgrazing and thus contribute to their recovery once drought conditions are alleviated.

All these suggested changes must also be accompanied by livestock enterprises and animal nutrition decisions that both capture any advantages and mitigate any disadvantages created. These choices remain firmly in the hands of the farmer, as profitability and sustainability remain at the centre of their objectives. The authors hope that this explanation of the dynamics of pasture growth will assist in that selection.

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