Regenerative management effects on pasture production: initial data from a dryland farmlet experiment

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Abstract

Data comparing pasture production in sheep farmlets subject to regenerative or conventional management and high or low soil fertility were collected in the first 1.5 years of a dryland experiment at Lincoln University. The data were retrieved from eight replicates of a 20-replicate design. In those replicates, the regenerative management combined diverse pastures and rotational grazing at high stock densities and frequent shifts. The conventional management combined lucerne pastures rotationally grazed at lower densities and frequencies. The high and low fertility treatments received 64 and 4 kg/ha P fertiliser respectively before sowing in December 2021. For July 2022–June 2023, regenerative management resulted in greater average pasture mass (2.6 versus 1.7 t DM/ha) of different botanical composition (5% prairie grass, 19% tall fescue and meadow fescue, 21% lucerne, 7% chicory, 7% plantain, a total of 10% cocksfoot, timothy, phalaris, white, red and sub clovers, 4% weed and 27% dead versus 70% lucerne, 11% weed and 19% dead) but lower annual pasture yield (8.7 versus 11.5 t DM/ha). Reducing P neither decreased pasture and legume yields nor increased weed. The two managements did not differ in their ability to produce pasture with less P. These initial results provide quantified evidence for farmers making decisions about regenerative agriculture.

Keywords: diverse, grazing, Medicago sativa, multispecies, phosphorus

Introduction

Regenerative agriculture (RA) is topical worldwide for its principles around sustainable food production while restoring the soil and environment (Schreefel et al. 2020; Giller et al. 2021; O'Donoghue et al. 2022). The practice has been adopted in New Zealand with limited formal research assessment of the total on-farm impact – soil, plant, animal and financial (Rowarth et al. 2020). It remains to be seen whether RA can match current best practices in a New Zealand context (Caradus et al. 2023).

Fundamentally, advocates of RA propose diverse pastures to improve soil, plant and animal components, particularly in rainfed systems (Rowarth et al. 2020). In contrast, conventional agriculture has promoted lucerne (*Medicago sativa*) as the most efficient pasture for maximising on-farm performance in low rainfall (350–700 mm) environments (Mills et al. 2015; Moot et al. 2019). Where irrigation is available, pastures are typically formed from mixtures of perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*), with herbs such as chicory (*Cichorium intybus*) and plantain (*Plantago lanceolata*) sometimes included. Results of an irrigated multispecies experiment at Lincoln University suggest two- and three-species mixtures of an appropriate legume, grass and/or herb for the environment can maximise pasture yield without nitrogen (N) fertiliser inputs (Shampasivam et al. 2024).

Equally proponents of RA have advocated rotational grazing of diverse pasture at high intensity and frequency (Rowarth et al. 2020). This practice involves allowing the pasture to reach a large pre-grazing mass and leaving post-grazing residuals above 2,500 kg/ha of dry matter (DM). The result is an increase in leaf and stem litter incorporated into the soil, but it might also result in an increase in pasture DM yield. In conventional agriculture, a six-paddock grazing rotation has been recommended for lucerne (Moot et al. 2016). This system allowed a sufficient period of recovery while also keeping the regrowth intervals short enough so that high-quality leaf and stem was always available. The aim is to maximise the DM yield and utilisation of pasture in every paddock.

The principles of RA suggest that the diverse pasture and grazing techniques used can increase soil carbon (C), microbial activity and health (Rowarth et al. 2020; Giller et al. 2021; Jordon et al. 2022; Montgomery et al. 2022). These same techniques are claimed to maintain productivity with minimal fertiliser input by recycling of nutrients between soil, plants and animals. The expectation is, also, that in doing so soils have greater water-holding capacity and therefore are more resilient to water deficits (Khangura et al. 2023). Given the east coast of New Zealand is expected to become drier and warmer as climate change occurs (Salinger 2003), finding resilient farm systems to cope with summer dry and drought conditions is a major step in future-proofing rural communities in these areas.

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Figure 1 Latin square design with five 4 × 4 Latin squares for regenerative (R) and conventional (C) management at high (H) and low (L) soil fertility. The data of this paper were retrieved from Squares 1 and 2 (Plots 1–32).

A new experiment at Lincoln University aims to investigate the total-farm impacts of regenerative management versus conventional best practice management for dryland sheep production. The two systems are replicated across soils of two phosphorus (P) fertility levels to determine their ability to operate with less P. This paper reports the effects on pasture production in the first 1.5 years of the experiment.

Materials and Methods

A dataset was collected from eight replicates of dryland pastures subject to regenerative or conventional management and high or low soil P fertility in a sheep farmlet experiment of 20 replicates (Plots 1–32 of 80 plots, Figure 1). The period was 1.5 years after sowing, with Year 1 defined as December 2021–June 2022 and Year 2 as July 2022–June 2023.

The experiment was located at the Field Research Centre farm of Lincoln University, New Zealand (43°38'54.20"S, 172°27'34.30"E, 9 m above sea level). The average annual rainfall of the site is 600 mm and potential evapotranspiration 950 mm. The soil type is a Templeton silt loam with a depth to gravel of 0.4–1.5 m and available water capacity (AWC) of about 140 mm to 0.5 m (Cox 1978). The area is 10 ha across seven adjacent paddocks. Hedges of mainly poplar trees of about 8–20 m height occurred around the perimeter of the experiment. There are gradients of depth to gravel in variable directions and distance to hedges in two directions across each paddock.

The treatments were a 2 × 2 factorial of regenerative and conventional management and high and low soil P fertility. The regenerative management combined diverse perennial and annual forages and rotational grazing with sheep at high stock densities and frequent shifts around 16–20 paddocks. The conventional management combined simple perennial and annual forages and rotational grazing with sheep at lower stock densities and less frequent shifts. The high and low fertility treatments had target soil Olsen P levels of 20 and 10 µg/mL respectively.

The layout of treatments was a Latin square design with five 4 × 4 Latin squares, to allow for effects of paddock, soil depth and hedge (Figure 1). The treatments were randomised with the restriction that each treatment occurred once in each row and once in each column of each square. Square 1 was assigned to paddock H17, Columns 1 and 2 of Square 2 to H19W and 3 and 4 to H19E, Rows 1 and 2 of Square 3 to H13 and 3 and 4 to H14 and Columns 1 and 2 of Squares 4 and 5 to H11 and 3 and 4 to H12. Plot size was 0.087 ha in Squares 1 and 2 (30 × 29 m), 0.132 ha in Square 3 (28.7 × 46 m) and 0.089 ha in Squares 4 and 5 (38.6 × 23 m). Each plot had netting fences around its perimeter and a water trough. Lanes between Columns 1 and 2 and Columns 3 and 4 of each square connected each plot to a corral near the centre of the experiment. Twenty plots of a treatment made up a farm of 1.936 ha.

The forages were categorised according to three types: diverse with lucerne, diverse without lucerne and diverse annual for regenerative management, and lucerne, cocksfoot (*Dactylis glomerata*)/subterranean (sub) clover (*T. subterraneum*) and either rape (*Brassica napus*, Year 1) or annual ryegrass (*L. multiflorum*, Year 2) for conventional management. The diverse with lucerne and lucerne pastures were compared in Squares 1, 2 and 4 (12 plots/farm), diverse without lucerne and cocksfoot/sub clover in Squares 3 and 5 (eight plots/farm) and diverse annual and either rape or annual ryegrass in two rows per annum in a rotation that started in Rows 3 and 4 of Square 3 (two plots/farm).

The experiment was established over 16 months as paddocks became available: Squares 1 and 2 in December 2021, Square 3 in March 2022, Square 4 in October 2022 and Square 5 in March 2023. The dataset of this paper was collected from Squares 1 and 2. The methods specific to Squares 1 and 2 are described below.

The crop history of Square 1 was lucerne from 28 November 2017, cultivated and fallowed from 26 August 2020, greenfeed oats (*Avena sativa*) from 6 May 2021 and cultivated and fallowed again from 18 October 2021. Columns 1 and 2 of Square 2 were Italian ryegrass (*L. multiflorum*) from 29 March 2019, Columns 3 and 4 were perennial ryegrass/white clover from 1 April 2019 and the whole square was cultivated and fallowed from 2 September 2021.

Superphosphate (9% P and 11% S) was applied at 200 kg/ha to the high P plots of Square 1 on 16 April 2021, Columns 3 and 4 of Square 2 on 30 July 2021, Columns 1 and 2 of Square 2 on 10 August 2021 and both squares on 14 October 2021 (a total of 36 kg P/ha). Lime was applied at 6 t/ha to Square 1 and 2 t/ha to Square 2 on 8 November 2021 based on previous soil pH levels.

Soil samples (0–75 mm) were collected across each plot and bulked by fertility treatment and Latin square on 9–10 November 2021. On average, Olsen P was 12.5 and 8 µg/mL and sulphate S 10 and 4 µg/g for high and low P respectively. Mean pH (water) was 5.5, Ca 7 Quick Test Units (QTU), Mg 18 QTU, K 7.3 QTU, Na 9.3 QTU and anaerobic mineralisable N 63 kg/ha across fertility levels.

Irrigation was applied at 50 mm on 15–25 November 2021. Roundup Ultra Max was sprayed on 26 November 2021 (glyphosate, 570 g/L at 2 L/ha in 200 L/ha water). Sulphur Super 20 (8% P and 20.6% S) was applied at 350 and 50 kg/ha to the high and low P plots respectively (28 and 4 kg P/ha) on 30 November–1 December 2021. The soil was cultivated into a seedbed on 3–9 December 2021. The pastures were sown (Flexiseeder plot drill) and the seedbed reconsolidated (Cambridge roller) in Square 2 on 10 December 2021 and Square 1 on 13 December 2021. The drill had 14 coulters set 150 mm apart and 10–15 mm deep.

The seed of the diverse pasture was a mixture of 12 species: 5 kg/ha ‘Jeronimo’ prairie grass (*Bromus willdenowii*), 1 kg/ha ‘Choice’ chicory, 0.5 kg/ha ‘Safin’ cocksfoot, 4 kg/ha ‘Hummer’ tall fescue (*Festuca arundinacea*), 4 kg/ha ‘Oakdon’ meadow fescue (*F. pratensis*), 6 kg/ha of either ‘Kaituna’ (Square 1) or ‘Takahē’ (Square 2) lucerne, 0.3 kg/ha ‘Maté’ phalaris (*Phalaris aquatica*), 2 kg/ha ‘WGB23587’ timothy (*Phleum pratense*), 0.5 kg/ha ‘Captain’ plantain, 1 kg/ha ‘Amigain’ red clover (*T. pratense*), 0.3 kg/ha ‘Legacy’ white clover and 1 kg/ha ‘Woogenellup’ sub clover. For the lucerne pasture, the seed was 15 kg/ha of either ‘Kaituna’ (Square 1) or ‘Takahē’ (Square 2) and for the lanes it was 20 kg/ha of ‘Arrow’ perennial ryegrass.

The sheep were moved around the plots in numerical order, starting in Row 1 of Square 2 on 15 February 2022. The class of sheep was Coopworth mature ewes (>4 years old) until 18 March 2022, then ewe lambs (7–12 months old) to 22 August 2022, ewe hoggets (12–19 months old) to 3 March 2023 and ewe lambs (7–10 months old) to 30 June 2023. The sheep were randomly assigned to each farm on 15 February 2022, 18 March 2022 and 3 March 2023. The mean live weight was 72 kg on 15 February, 72 kg (ewes) and 36 kg (lambs) on 18 March, 46 kg on 8 June and 56 kg on 12 August in 2022 and 80 kg (hoggets) and 36 kg (lambs) on 3 March and 52 kg on 5 July in 2023.

The grazing management was the same for all treatments in Year 1. The ewes were managed as one flock and the lambs as two flocks on each farm. The stocking rate (sheep/farm) and density (sheep/plot) were 12.9 and 287 ewes/ha (25/farm) from 15 February to 18 March 2022 and then 10.3 and 115 lambs/ha (two groups of 10/farm) respectively. This resulted in growth periods of 25–93 (mean 56) days, grazing periods of 2–8 (mean 6) days and a total grazing intensity of 18,333 animal days/ha over 2.5 rotations (Rotations 1–3) from 15 February to 8 June 2022 (Figure 2). The pasture was topped (mown to 6 cm height) after grazing each plot in Rotation 1 and the first two plots in Rotation 2.

In Year 2, the grazing was different for regenerative and conventional managements. For regenerative, the hoggets or lambs were managed as one flock. The stocking rate and density were 10.3 and 230 sheep/ha (20/farm), resulting in growth periods of 21–123 (mean 44) days, grazing periods of 2–4 (mean 2) days and a total grazing intensity of 34,023 animal days/ha over eight rotations (Rotations 3–11) from 19 August 2022 to 2 June 2023 (Figure 2). For conventional, the sheep were run as two groups. The stocking rate was the same

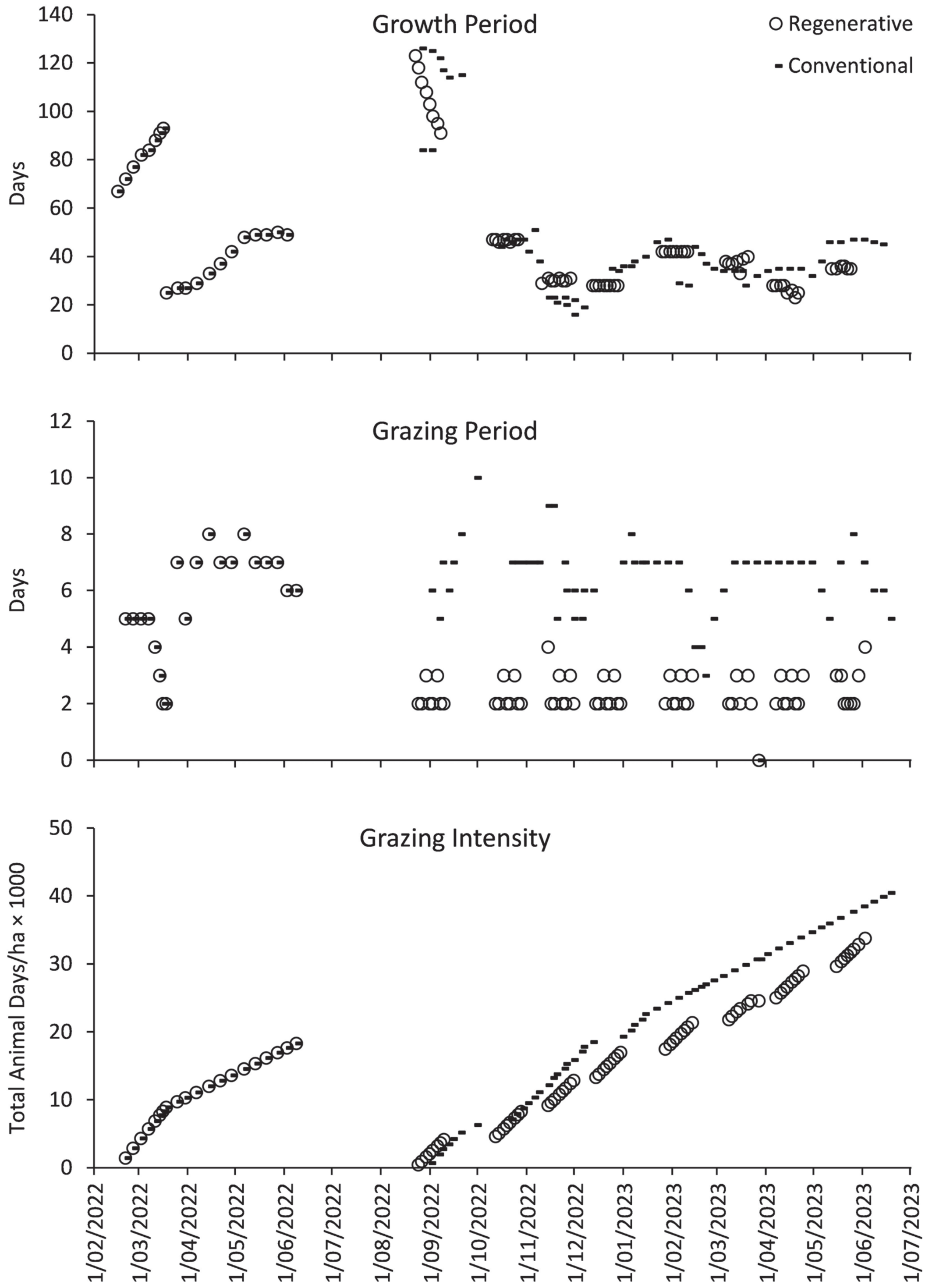

Figure 2 Growth periods and grazing periods of each plot and total grazing intensity across plots for regenerative and conventional management against date.

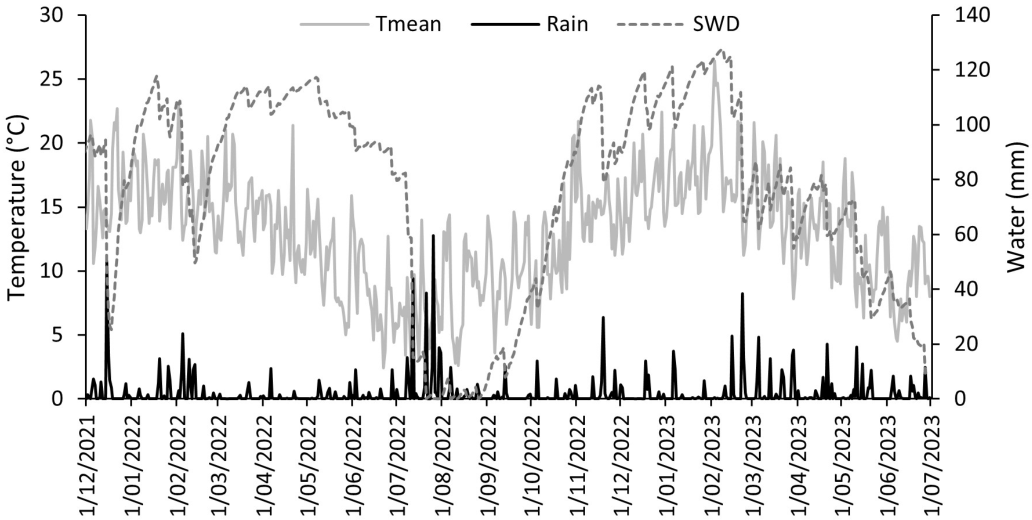

Figure 3 Mean air temperature (Tmean), rainfall and soil water deficit (SWD) against date.

as regenerative, but at half the stocking density (two groups of 10/farm). The result was growth periods of 16–126 (mean 47) days, grazing periods of 3–10 (mean 7) days and a total grazing intensity of 40,575 animal days/ha over 7.5 rotations (Rotations 3–10) from 25 August 2022 to 19 June 2023. Only the lucerne pastures were topped after grazing, between 31 December 2022 and 4 February 2023. Surplus pasture was cut and removed from all plots in Rows 3–4 of Square 2 on 15–27 March 2023.

Daily air temperature, rainfall and Penman potential evapotranspiration (PET) were obtained from a climate station at Broadfield, located about 2 km north of the site, in the CliFlo Database (https://cliflo.niwa.co.nz). Soil water deficit (SWD) was calculated daily based on the CliFlo water balance: yesterday's deficit + Day's PET – Day's precipitation, assuming no runoff. For deficits greater than half the soil AWC, the PET was linearly decreased by the proportion that the deficit was greater than half capacity. For example, if the deficit was 75% of AWC, only half the PET was added to the deficit. If the soil was dry (deficit = 100% of AWC), the effective PET was zero. If the deficit was less than zero, deficit was taken as zero and drainage was –deficit. The water balance assumed an AWC of 140 mm in the top 0.5 m of soil and a starting deficit of zero on 1 July 2021. Temperature, rainfall and SWD are shown in Figure 3.

Pasture mass and botanical composition (kg DM/ha) were measured to ground level before and after each defoliation for grazed/cut plots and each month for all plots. This was done by cutting a sample of three representative 0.5 m^2 quadrats along the longest axis of the plot, weighing the whole sample, drying (65°C for 48 h) a subsample of 100–200 g to determine DM proportion and separating and drying a second subsample of about 400 pieces for botanical composition. The botanical components were each sown species, with tall fescue and meadow fescue pooled together, weed (unsown species) and dead. The sown species were further categorised according to legume, grass and herb.

The pasture and component masses were calculated daily as linear interpolants between measured values. The changes in pasture and component masses from one day to the next within a growth period were defined as pasture and component yields. The accumulated yields across the growth periods were calculated for each year. The herbage mass and yield data were analysed at monthly intervals with general analysis of variance. The treatment structure was Management*Fertility, i.e., the two main effects and interaction between them. The block structure was Square/(Row*Column). All analyses were carried out in Genstat.

Results

The pattern of change of pasture mass between sowing and September 2022 was unaffected by treatment (Figure 4). There was a net increase in October and November 2022 that was about 1.5 t DM/ha greater ($P<0.05$) for regenerative than conventional management. This difference lasted as pasture mass declined between January and June 2023.

The botanical composition of pasture mass was different ($P<0.05$) between regenerative and conventional (Figure 5). In general, for regenerative, there were increases in cocksfoot (Dacglo), fescue (Fes) and dead, and decreases in chicory (Cicint), lucerne

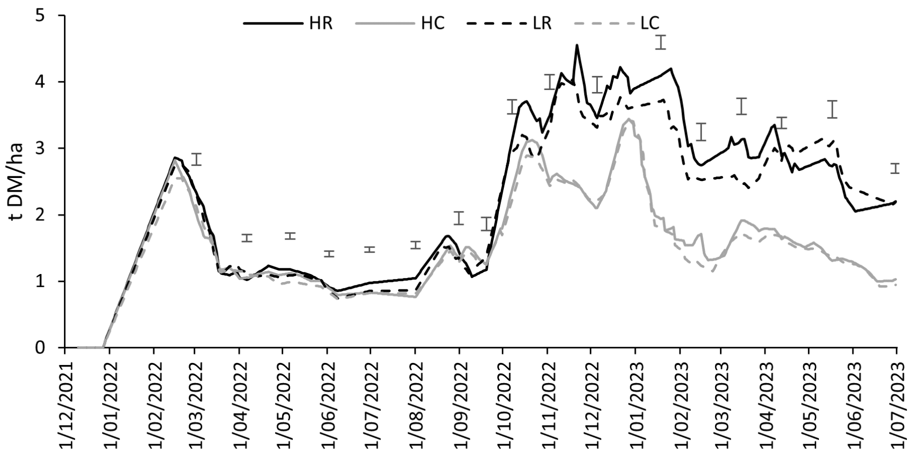

Figure 4 Mean pasture dry matter (DM) mass, averaged over all plots, for regenerative (R) and conventional (C) management at high (H) and low (L) P against date. Bars are standard errors of means.

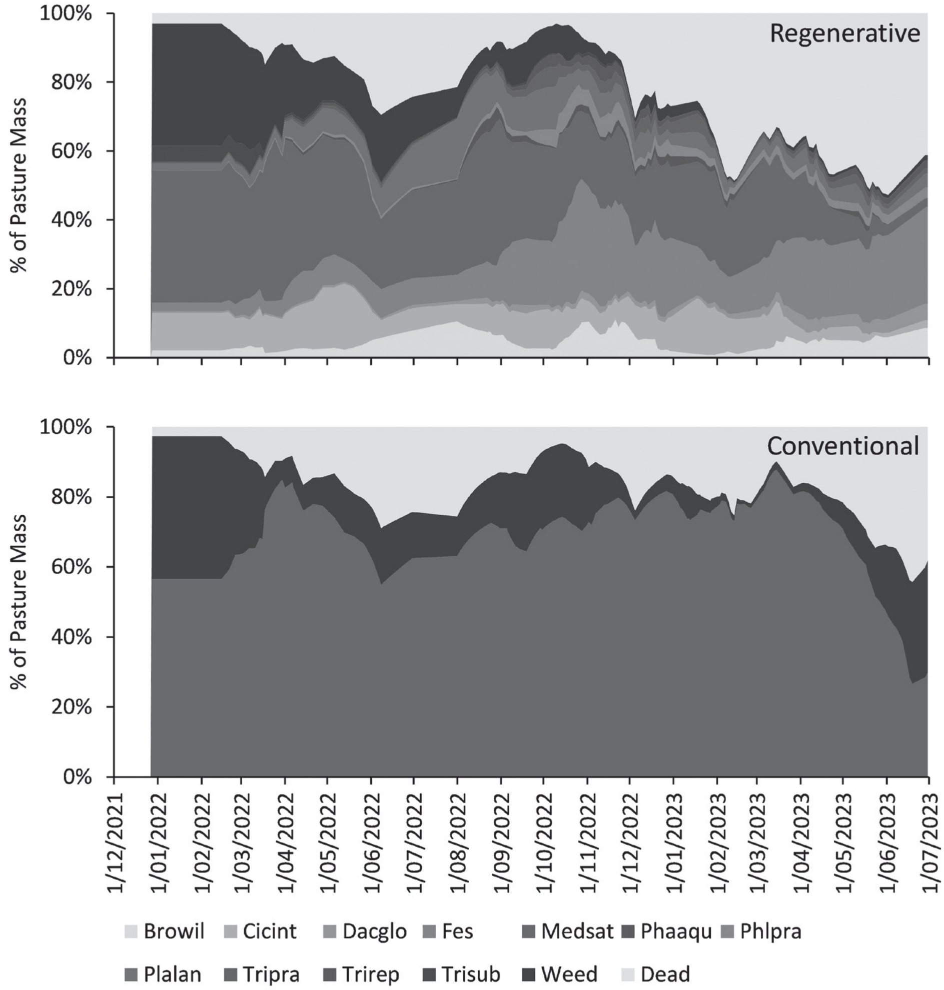

Figure 5 Mean botanical composition of pasture mass, averaged over all plots, for regenerative and conventional management at average P against date.

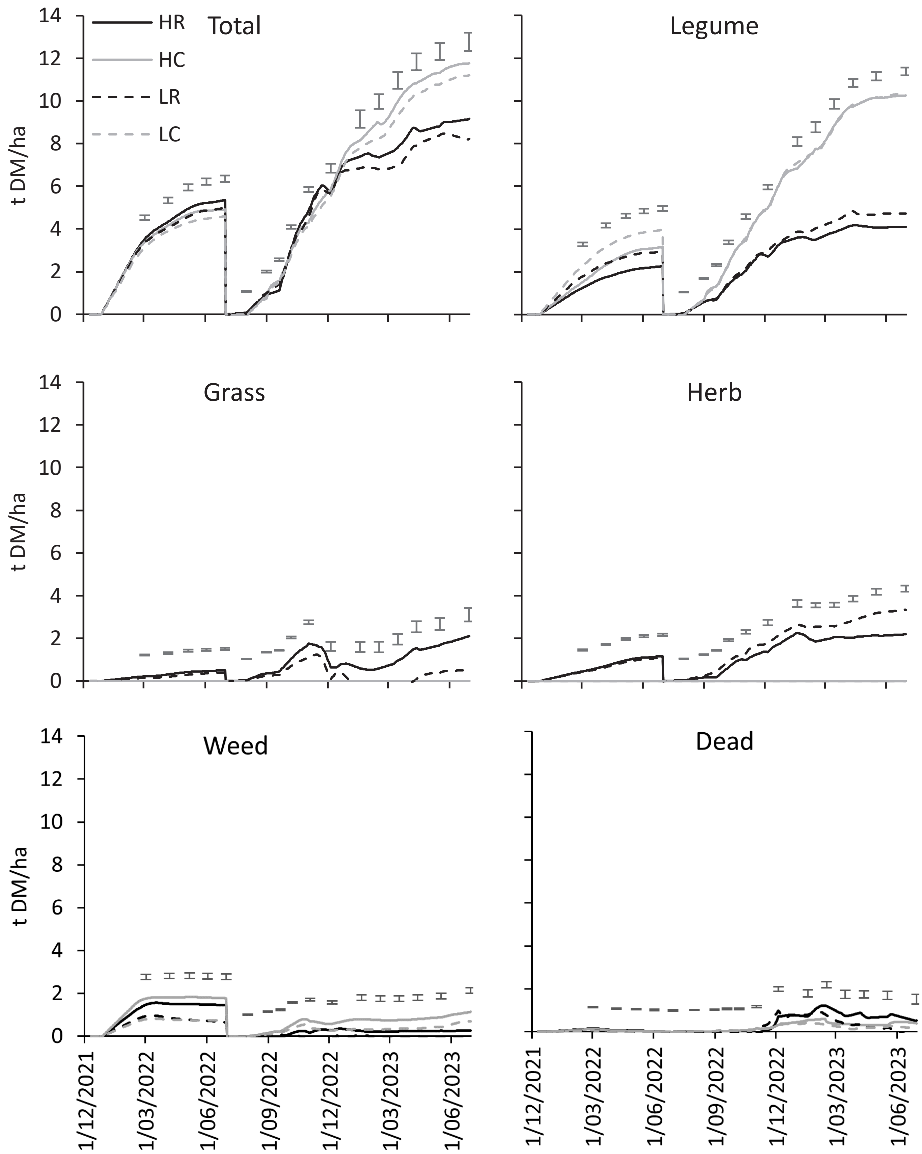

Figure 6 Mean accumulated total, legume, grass, herb, weed and dead dry matter (DM) yields of pasture for regenerative (R) and conventional (C) management at high (H) and low (L) P against date. Bars are standard errors of means.

(Medsat), plantain (Plalan) and weed between sowing and June 2023. Lucerne content was 20–40% until March 2023. Fescue was about 20–30% from October 2022. The other nine species were each 0–19%. For conventional, there was a general increase in lucerne (from 57 to 88%) and a decrease in weed (from 41 to 2%) between sowing and March 2023, and then a decrease in lucerne and increases in weed and dead to June 2023.

The accumulation of pasture yield between sowing and June 2022 was not different among treatments, averaging 5 t DM/ha in Year 1 (Figure 6). The yield of legume was lower ($P<0.05$) for regenerative than conventional and for high than low P. The yields of grass and herb were greater ($P<0.05$) for regenerative than conventional. Weed yield was greater ($P<0.05$) for high than low P. Dead yield was not different. In Year 2, the pasture yield accumulated between February and June was lower ($P<0.05$) for regenerative than conventional, which decreased ($P<0.05$) annual pasture yield by 2.8 t DM/ha. Legume was 50% lower ($P<0.05$), grass between August and December and herb at all months were greater ($P<0.05$) and weed was often lower ($P<0.05$) for regenerative than conventional.

Discussion

The impact of the regenerative management was a greater pasture mass (Figure 4) of different botanical composition (Figure 5), but a lower pasture yield 19 months after sowing (Figure 6). These differences were the combined effects of grazing diverse pasture with sheep at higher stock densities and more frequent shifts than conventional management with lucerne (Figure 2) in the low rainfall environment (Figure 3). The differences could be accounted for in a complete, whole-farm analysis of pasture growth, pasture eaten and animal production for each treatment (Matthews et al. 1999). The dataset of this paper provides initial evidence of differences in pasture growth that will have consequences on pasture eaten and animal production for the regenerative and conventional managements.

The decrease in pasture yield of 2.8 t DM/ha for the regenerative management (Figure 6) would have resulted from different species identity and diversity effects for the diverse and lucerne pastures (Kirwan et al. 2009). The identity effect reflects the ability of a species, including weed, to capture sunlight energy, water and nutrients and transform them into biologically useful compounds in plant tissues. The diversity effect is the excess of a pasture function (e.g., yield) over that expected from the identity effects. The same mechanisms have been found to explain effects of species diversity on pasture yield in irrigated and dryland experiments at Lincoln University (Black et al. 2017; Black and Lucas 2018; Shampasivam et al. 2024).

The diversity effect is the aggregate of interspecific interactions operating in a pasture and can involve two or more species (Kirwan et al. 2009). For example, the different leaf arrangements of species enable a more efficient canopy for light interception (niche partitioning), and legumes enhance the growth of grasses and herbs by increasing total N input (facilitation), which increases pasture yield. The number of possible interactions increases substantially with increasing number of species. In this experiment, the sown yield (total minus weed) for the regenerative management (Figure 6) was the product of 12 identity effects and 66 possible pairwise interactions in the diverse pastures. In contrast, the sown yield for the conventional management reflected the strong identity effect of lucerne in the summer dry conditions (Figure 3).

The degree of expression of identity and diversity effects may depend on the relative abundances of the species involved (Kirwan et al. 2009). They may also determine the changes in botanical composition from sowing (Figure 5). For the regenerative management, the seed mixture was 20% prairie grass, 16% each of tall fescue and meadow fescue, 23% lucerne and 1–8% each of the other eight species, calculated on seed weight. All species had the potential to interact positively with at least one other species in the diverse pastures, but many were not present in large abundances. Therefore, the expression of all interactions was not strong enough for the sum of identity and diversity effects to exceed the identity effect of lucerne, which decreased pasture yield for the regenerative management (Figure 6). A similar result has been found for lucerne-grass mixtures compared with lucerne in summer dry conditions on the Ashley Dene farm of Lincoln University (Moot et al. 2020). The addition of grass did not increase pasture yield, but it did reduce sheep production because of the lower quality of the grass compared with the lucerne.

The higher stock densities and frequent shifts for the regenerative management increased the pasture mass (Figure 4), but it did not increase the annual pasture yield (Figure 6). Paradoxically, there were fewer animal days between November and December 2022 for regenerative than conventional (Figure 2). This was because there were more animal days in Squares 3 and 4 for regenerative than conventional, and no differences in animal days across the whole farm for all treatments. This extended the duration of regrowth in Squares 1 and 2 for regenerative (28–31 days) compared with conventional (16–23 days) (Figure 2), which would have contributed to the greater pasture mass. This was consistent with RA approaches to extend the duration between grazing events and leave post-grazing residuals greater than 2,500 kg DM/ha (Rowarth et al. 2020).

The principles of plant responses to defoliation provide further insight into how the regenerative management affected pasture yield and how it might affect pasture eaten and animal production (Moot et al. 2021). Extending the regrowth phase leads to a greater pasture mass but results in a decrease in quality as leaves senesce and more fibre is required to support the taller herbage, particularly reproductive material. As the end of the regrowth phase approaches, the amount of assimilates (sugars) being produced each day reaches the amount lost through respiration to maintain the standing herbage. Additional C may be partitioned to storage, which increases root mass and provides resilience to stresses such as drought. Animals can select high-quality (vegetative) components of the pasture and trample excess herbage into the soil, which reduces the total feed on offer. In most cases, grazing management is a balance between maximising pasture growth to ensure a large quantity of high-quality pasture for animal intake while ensuring sufficient C and N reserves are allocated to storage to provide resilience to pasture plants. The RA approach emphasises the latter processes to restore soils.

Reducing the input of P fertiliser before sowing did not result in a decrease in pasture mass (Figure 4), it did not cause a decrease in legume content, or an increase in weed (Figure 5), and it did not lead to a decrease in pasture yield (Figure 6) in the first 1.5 years of the experiment. There appeared to be no difference between the regenerative and conventional managements in their ability to produce DM with less P. In conventional agriculture, soil Olsen P levels of 15–20 in the top 0–150 mm of the soil have been recommended for lucerne grown in sedimentary soils, such as the soil type at this site (Morton et al. 2020). If levels are below this range, 30–60 kg P/ha is required at sowing. The 36 kg P/ha applied to high P plots in April–October 2021 was incorporated in the top 0–250 mm of the soil during cultivation. This might explain why the soil Olsen P levels of 12.5 and 8 in the top 0–75 mm were below the recommended range. The Olsen P levels, and P applied, informed the decision to apply 26 and 4 kg P/ha to high and low P plots at sowing. These data suggest the diverse and lucerne pastures obtained enough P for annual pasture yields of 8.7 and 11.5 t DM/ha even when P fertiliser was reduced.

Conclusions

In the first 1.5 years of this dryland experiment, the regenerative management resulted in a greater pasture mass of different botanical composition but caused a lower annual pasture yield compared with the conventional management. Reducing the input of P fertiliser neither decreased pasture and legume yields nor increased weed yield. The two management systems did not differ in their ability to produce pasture with less P. These initial results provide quantified evidence for farmers making decisions about the implementation of RA.

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