Sheep liveweight and dry matter production from Year 3 of the Regenerative Agriculture Dryland Experiment

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Abstract
Sheep liveweight and dry matter (DM) production from Regenerative and Conventional dryland systems under two levels of soil fertility (Olsen P 20-25 and 10 mg/kg) were measured in Year 3 (July 2023-June 2024) of an on-going experiment at Lincoln University. The Regenerative system comprised multispecies pastures and winter forage crops, and short-duration, high-density rotational stocking at 12.9 ewes/ha. The Conventional system had lucerne and cocksfoot/sub clover pastures, annual ryegrass as the winter forage crop, and longer-duration, lower-density rotational stocking at the same stocking rate. There were no effects of soil fertility. Sheep liveweight production was 131 kg/ha (23%) less for Regenerative than Conventional (496 vs. 627 kg/ha), but DM production was 1,550 kg/ha (22%) greater (8,490 vs. 6,940 kg/ha) with lower crude protein (13% vs. 19%), lower metabolisable energy (9.5 vs. 10.0 MJ/kg DM) and higher neutral detergent fibre (51% vs. 40%). This contributed to lower liveweight gains of priority lambs compared with the legume dominant Conventional system.

Keywords: *Dactylis glomerata, Medicago sativa*, multispecies, soil fertility, sustainability, *Trifolium subterraneum*

Introduction
Regenerative agriculture (RA) has gained popularity in the media and in cited literature in the past decade (Giller et al. 2021). It promotes principles and practices that "go beyond" a sustainable agriculture mindset with the objective to "regenerate" the land, animal and soil system (Giller et al. 2021; Grelet et al. 2021). However, often these publications have neither quantified the claimed benefits, nor shown direct relevance to New Zealand agricultural systems (Rowarth et al. 2020; Giller et al. 2021).

To date, RA in New Zealand has commonly been promoted without evidence from formal peer reviewed research. This means current claims are anecdotal in relation to the economic and environmental benefits of RA (Rowarth et al. 2020). Therefore, the New Zealand Government commissioned research under the "Whenua Haumanu" programme to investigate the impact of RA practices compared with conventional best practices. These RA practices include regenerating the soil and diversification of forage species within multispecies pastures and crops to increase dry matter (DM) yield and soil health (Rowarth et al. 2020; Khangura et al. 2023). In cropping systems, soil is often left bare post-harvest, so use of a cover crop in a rotational crop system can increase crop yield, decrease soil erosion and increase soil organic C (Munkholm et al. 2013; Kelly et al. 2021). However, for rainfed temperate livestock production systems in New Zealand, multispecies pastures do not always provide efficient pasture production and utilisation (Shampasivam et al. 2024), with monocultures such as lucerne (*Medicago sativa* L.) shown to be the most productive pasture option in areas of low rainfall (Mills et al. 2019; Smith et al. 2023).

Adaptation of grazing systems is another practice for increasing soil health in RA. Short-duration, high-density stocking of livestock on high pasture covers in a rotational grazing system has been advocated to retain plant litter and plant cover to protect soil from erosion and allow rapid plant regrowth (Teague and Kreuter 2020; Cosgrove et al. 2024). Rowarth et al. (2020) explained a "long-grass" grazing system as one that allowed pastures to accumulate more than the commercially recommended target pre-grazing mass of about 2,500 kg DM/ha. The stated objective of this practice is to increase soil organic matter from leaf litter deposition.

It is unclear if multispecies pastures and forage crops, and short-duration, high-density stocking benefit any of the soil, plant, animal, environment and financial aspects of New Zealand's livestock production systems. Therefore, the Regenerative Agriculture Dryland Experiment (RADE) was initiated in December 2021 at Lincoln University with the aim to investigate aspects of RA applicable to rainfed (dryland) east coast regions. The hypothesis is that a RA system based on multispecies pastures and forage crops, combined with short-duration, high-density rotational stocking, can either maintain, or increase, animal production from reduced agricultural inputs (e.g. fertiliser, weed control and labour) and have a reduced environmental footprint. The two systems are replicated across soils of two P fertility levels to determine their ability to operate with less inputs of P fertiliser.

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Figure 1 Field layout of the 2 × 2 factorial experiment with two agriculture systems, Regenerative (R) and Conventional (C), and two levels of soil fertility, High (H) and Low (L), arranged in five 4 × 4 Latin squares, with Square 1 composed of plots 1-16 and so on.

The pasture DM production for eight replicates of the 20-replicate experiment, for Year 1 (defined as December 2021-June 2022) and Year 2 (July 2022-June 2023), was reported in Watson et al. (2024). This paper reports on the sheep liveweight and DM production for Year 3 (July 2023-June 2024) of the full, on-going experiment.

Materials and Methods

The experiment is located at Lincoln University, New Zealand (Plot 1: 43°38’54.20”S, 172°27’34.30”E, 9 m above sea level). It is a 2 × 2 factorial of two agriculture systems, Regenerative and Conventional, and two levels of soil fertility, High and Low, arranged in five 4 × 4 Latin squares (Figure 1). The treatments are randomised with the restriction that each treatment occurs once in each row and once in each column of each Latin square. Plot size is 0.087 ha for Squares 1 and 2, 0.132 ha for Square 3 and 0.089 ha for Squares 4 and 5. Twenty plots of the same treatment make up a farm of 1.936 ha, giving four autonomous farms. Watson et al. (2024) reported DM yield data for Squares 1 and 2.

The Regenerative treatment combines multispecies pastures and winter forage crops with short-duration, high-density rotational stocking of sheep. The Conventional treatment follows current best-practice recommendations for dryland pasture production. Specifically, lucerne and cocksfoot/subterranean (sub) clover pastures, annual ryegrass as the winter forage crop, and longer-duration, lower-density rotational stocking of sheep than the Regenerative treatment.

The experiment was established in stages as land 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. A multispecies pasture with lucerne (Regenerative) was compared with lucerne (Conventional) in Squares 1, 2 and 4. A second multispecies pasture, with balansa clover instead of lucerne (Regenerative), was compared with cocksfoot/sub clover (Conventional) in Squares 3 and 5. A multispecies winter forage crop (Regenerative) was compared with annual ryegrass (Conventional), usually in two rows of plots per annum (one row in 2023), in a pasture-crop-pasture rotation around the experiment. The 2023 crops were in Plots 45-48, and the 2024 crops were in Plots 1-4 and 49-52. The total forage system was therefore 18 plots of multispecies pasture and two plots of multispecies winter forage crop per farm for Regenerative and 10 plots of lucerne, eight plots of cocksfoot/sub clover and two plots of annual ryegrass per farm for Conventional. The sowing rates are listed in Table 1.

The soil fertility treatments were defined as target Olsen P levels of 20-25 (High) and 10 (Low) mg/kg in

Table 1 Sowing rates used to create the pastures and winter forage crops for Regenerative and Conventional systems.

Sowing Rates (kg/ha), Cultivars and Species
Regenerative
Multispecies with lucerne pasture: 5 'Jeronimo' prairie grass (*Bromus willdenowii* Kunth), 1 'Choice' chicory (*Cichorium intybus* L.), 0.5 of either 'Safin' (Squares 1 and 2), or 'Greenly II' (Square 4) cocksfoot (*Dactylis glomerata* L.), 4 'Hummer' tall fescue (*Lolium arundinaceum* (Schreb.) Darbysh.), 4 'Oakdon' meadow fescue (*Lolium pratense* (Huds.) Darbysh.), 6 of either 'Kaituna' (Square 1), 'Takahē' (Square 2), or 'Force4' (Square 4) lucerne (*Medicago sativa* L.), 0.3 'Maté' phalaris (*Phalaris aquatica* L.), 2 'WGB23587' timothy (*Phleum pratense* L.), 0.5 'Captain' plantain (*Plantago lanceolata* L.), 1 'Amigain' red clover (*Trifolium pratense* L.), 0.3 'Legacy' white clover (*Trifolium repens* L.) and 1 'Woogenellup' sub clover (*Trifolium subterraneum* L.) (25.6 total).
Multispecies with balansa clover pasture: 5 'Jeronimo' prairie grass, 1 'Choice' chicory, 0.5 of either 'Safin' (Square 3), or 'Re-define' (Square 5) cocksfoot, 5 'Hummer' tall fescue, 3 'Oakdon' meadow fescue, 0.3 'Maté' phalaris, 0.5 'Captain' plantain, 2 'WGB23587' timothy, 1 'Taipan' balansa clover (*Trifolium michelianum* Savi), 2 'Amigain' red clover, 0.5 'Legacy' white clover and 1 'Woogenellup' sub clover (21.8 total).
Multispecies winter forage crop: 0.75 'Titan' rape (*Brassica napus* L.), 0.5 'York Globe' bulb turnip (*Brassica rapa* L.), 1 'Pasja' leafy turnip (*Brassica rapa* L.), 5 'Devour' annual ryegrass (*Lolium multiflorum* Lam.), 1 phacelia (*Phacelia tanacetifolia* Benth.), 1 'Captain' plantain, 1.25 'Taipan' balansa clover and 1.25 'Lightning' Persian clover (*Trifolium resupinatum* L.) (11.75 total).
Conventional
Lucerne pasture: Either 15 'Kaituna' (Square 1), 'Takahē' (Square 2), or 'Force4' (Square 4) lucerne.
Cocksfoot/sub clover pasture: 4 'Greenly II' cocksfoot, 10 'Denmark' sub clover and 10 'Narrikup' sub clover (24 total).
Winter forage crop: 25 'Devour' annual ryegrass.

the top 75 mm of the soil. On 25 August 2023, mean soil pH, Olsen P and sulphate S, averaged across all plots, were 6.4 and 6.4, 15 and 13 mg/kg and 5 and 3 mg/kg for High and Low fertility, respectively. Therefore, P and S fertilisers were applied at different rates across all plots between 29 September and 9 November 2023 (mean: 11 October). The mean fertiliser input was 461 kg Superphosphate (9% P and 11% S)/ha and 110 kg Sulphur 90 (90% S)/ha, equating to 41 kg P/ha and 150 kg S/ha, for High fertility, and 17 kg Superphosphate/ha and 110 kg Sulphur 90/ha, giving 1.5 kg P/ha and 101 kg S/ha, for Low fertility. On 11 July 2024, mean soil Olsen P was 22 and 8 mg/kg for High and Low fertility.

During the establishment phase (Years 1 and 2), Coopworth ewes grazed Squares 1 and 2 from 16 February to 18 March 2022, then Coopworth ewe lambs, growing to hoggets, grazed the full experiment to 3 March 2023, and then new Coopworth ewe lambs grazed to 7 August 2023. In Year 1, the method of rotational stocking was the same across farms, with stocking rates of 12.9 ewes/ha as one group of 25/farm and then 10.3 lambs/ha as two groups of 10/farm. In Year 2, the two methods of rotational stocking were initiated on 25 August 2022. For Regenerative, the lambs/hoggets grazed as one group of 20 around 16-20 plots/farm, resulting in a mean stocking density/plot of 207 sheep/ha and a mean stocking duration/plot of 2-3 days. For Conventional, the lambs/hoggets grazed as two groups of 10, each around 8-10 plots/farm, resulting in half the stocking density/plot, twice the stocking duration/plot and the same stocking rate (10.3/ha) as Regenerative. In winter, the pastures and crops were subdivided into 2-day breaks using temporary electric fences and the lambs break-grazed each pasture and crop at least once between mid-May and early August.

In Year 3, 80 Bohepe ewes were introduced to the experiment between 1 and 30 August 2023 (mean: 6 August). The Bohepe breed is a composite of wild sheep breeds, East Friesian, Finnish Landrace, Wiltshire and Merino, bred to create a short tail, bare breach, low-cost, easy-care sheep (Beattie, 2022). There were six primiparous (2 years old) and 74 multiparous (3-6 years old) ewes with a mean initial live weight of 55.6 kg. Most of them had been mated with Bohepe rams and some with Suffolk rams. The individual rams and how many lambs each ewe was carrying were unknown. The ewes were allocated evenly across farms based on age and live weight. They grazed as one group of 20 around 16-20 plots/farm for Regenerative, and as two groups of 10, each around 8-10 plots/farm, for Conventional, to continue the two methods of rotational stocking.

The mean lambing date was 28 August 2023. Weaning occurred on 6 December 2023. The numbers of ewes lambed, and lambs raised on each farm are given in Table 2. From weaning, the lambs grazed ahead of the ewes in a leader-follower system until 15 January 2024 for Conventional and 7 February 2024 for Regenerative, and then they grazed exclusively around Plots 49-64. Terminal 'prime' lambs ≥36 kg were sold to a local meat processor on 12 December 2023, 15 January 2024 and 12 February 2024. Terminal lambs <36 kg were removed as 'stores' on 7 February 2024. Maternal (Bohepe) lambs were retained for

Table 2 Number of ewes that lambed and lambs raised for Regenerative (R) and Conventional (C) systems at High (H) and Low (L) soil fertility in Year 3 (July 2023-June 2024).

	HR	HC	LR	LC
Ewes lambed	20	20	14	19
Lambs weaned	33	26	20	29
Lambing %	165	130	143	153

Table 3 Hay dry matter (DM) made (one 0.132-ha plot/farm) and fed out for Regenerative (R) and Conventional (C) systems at High (H) and Low (L) soil fertility in Year 3 (July 2023-June 2024).

	HR	HC	LR	LC
Hay cut (kg DM/ha)	10,320	8,230	5,630	8,190
Number of bales made	44	36	23	27
Hay fed out (kg DM)	1,053	1,423	1,022	1,495

breeding: six ewe lambs/farm, one ram lamb for each Regenerative farm and High Conventional and three ram lambs for Low Conventional. The maternal ram lambs were removed on 15 January 2024 for Low Conventional and 7 February 2024 for the other farms. The ewe lambs and ram lambs were shorn on 5 March 2024. The ewe lambs were removed on 10 and 24 May 2024 for Low and High Conventional, respectively, and 28 May 2024 for each Regenerative farm.

The ewes grazed as one group on each farm from weaning, making the grazing regimes the same across treatments during the dry season (Figure 3). The ewes were shorn on 23 December 2023. Five Bohepe hoggets (17 months old) were introduced to each group of ewes on 24 January 2024, increasing the ewe stocking rate to 12.9/ha. They had been shorn 2 weeks prior and had a mean initial live weight of 47 kg. The ewes and hoggets were mated with the maternal ram lambs—one for each Regenerative farm, one for High Conventional and two, which were lighter, for Low Conventional—on 29 March-15 April 2024, and then with one terminal South Suffolk ram lamb/farm on 15 April-10 May 2024. The winter break grazing by the ewes started on 17 May 2024, with 2-day breaks around all pastures and crops.

The Regenerative pastures were typically not topped (topping involved cutting to 6-8 cm post-grazing to remove reproductive stems, with the clippings left on the pasture to decompose). The Regenerative pastures in Squares 4 and 5 were topped on 29 May-2 July 2024 to remove stems of chicory. Spring-sown pastures were topped after the first grazing to remove stems of the annual weed fathen (*Chenopodium album* L.) for all four farms. The Conventional pastures were typically topped at least once and no more than twice between October and March each year.

Surplus feed was conserved as hay each year. In Year 3, the hay was made in Plots 33-36. The Regenerative pastures (multispecies with balansa clover) were closed on 8-9 September 2023, and the Conventional pastures (cocksfoot/sub clover) were closed on 26-28 September 2023. The hay was cut to 6-8 cm on 7 December 2023, wilted and then baled into conventional small bales, typically 18-24 kg, on 16 December 2023. The bales were stored in separate stacks for each farm and fed to sheep on the same farm when necessary. The total hay made and fed out on each farm in Year 3 is summarised in Table 3.

The 2023 winter crops, in Plots 45-48, were sown back into pasture. For Regenerative, the two multispecies crops (Plots 47-48), which had regrowth dominated by annual ryegrass, were tilled on 18 September-6 October 2023 and drilled into the multispecies with balansa clover mixture (Table 1) on 10 October 2023. At the same time, two multispecies pastures in Plots 41-42 were tilled and resown with the same pasture mixture. These two pastures failed to establish after our attempt to direct drill them, to minimise soil disturbance, on 17 March 2023 into hard-grazed aftermath of 2022-sown multispecies crops, resulting in annual ryegrass-dominant and open canopies. Therefore, these pastures had to be resown and all subsequent pastures and crops were sown into cultivated seedbeds. For Conventional, the two annual ryegrass crops (Plots 45-46) were tilled on 20 February-12 March 2024 and drilled into cocksfoot/sub clover (Table 1) on 21 March 2024.

The 2024 winter crops, in Plots 1-4 and 49-52, followed multispecies with lucerne pastures for Regenerative and lucerne pastures for Conventional. The plots were tilled between 20 February and 3 April 2024, with most of the tillage occurring after 20 mm of rain on 15-18 March and seedbed preparation after 5 mm of rain on 27-29 March. The seed (Table 1) was eventually drilled on 4 April 2024.

Weed control involved only hand grubbing for

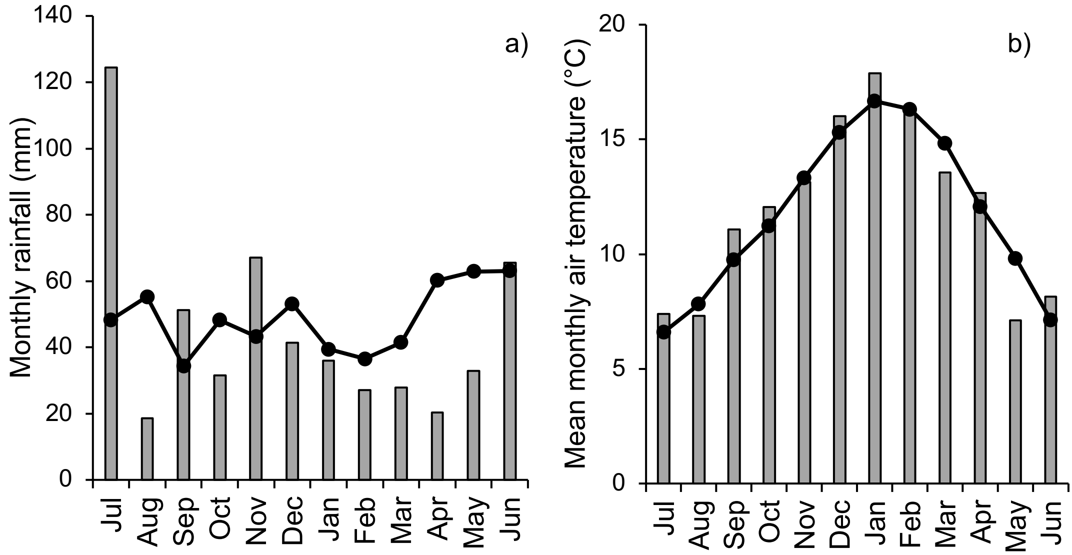

Figure 2 Monthly a) rainfall and b) mean air temperature in Year 3 (July 2023-June 2024). Lines indicate long-term means (2002-2021).

the Regenerative pastures, and hand grubbing and herbicides for the Conventional pastures. In Year 3, the weed control was:

- Hand grubbing of nodding thistle (*Carduus nutans* L.), Scotch thistle (*Cirsium vulgare* (Savi) Ten.) and horehound (*Marrubium vulgare* L.) across all four farms throughout the year.
- 0.5 L/ha Gallant Ultra (520 g/L haloxyfop-P-methyl) + 1 L/ha Uptake Spraying Oil + 200 L/ha on each lucerne pasture in Squares 1 and 2 on 18 July-9 August 2023.
- 0.5 L/ha Gallant Ultra + 2.5 L/ha Flowable Atrazine 500 (500 g/L atrazine) + 1 L/ha Uptake Spraying Oil + 200 L/ha water on each lucerne pasture in Square 4 on 11 August 2023.

Climate data were obtained from the NIWA meteorological station at Broadfield (Agent No. 17603), 2 km north of the experiment (NIWA 2024). The long-term (2002-2021) mean annual rainfall is 576 mm with between 34 mm in September and 64 mm in June. For Year 3, the annual rainfall of 544 mm was near average, but its distribution was erratic with below-average rainfall in 8 months, mostly between mid-summer and late autumn (Figure 2a). A July rainfall of 124 mm was 88% above average. Above-average rainfall also occurred in September and November.

Long-term mean annual air temperature is 11.7°C and follows a seasonal pattern typical of temperate environments (Figure 2b). The maximum monthly temperature was 16.6°C in January and the minimum was 6.4°C in June. Monthly air temperatures generally followed the expected seasonal pattern, but notable variations occurred in September (11.1°C; 1.7°C above average), January (17.9°C; 1.3°C above average) and May (7.1°C; 2.1°C below average). Long-term mean annual Penman potential evapotranspiration (PET) totalled 944 mm, which is nearly 400 mm more than average annual rainfall. For the period September-March, the long-term mean PET exceeds mean rainfall by 32 mm in September to 109 mm in January.

A soil water budget was calculated for Year 3 using daily rainfall and PET data and a plant-available water content (PAWC) of 148 mm in the top 1 m of the soil profile, which was estimated for the site's Templeton silt loam soil (Sibling Templeton_4a.1) based on data in S-Map (https://smap.landcareresearch.co.nz/). The soil water budget showed the top 1 m of the soil profile did not recharge fully until 27 July 2023 (Figure 3). The maximum deficit of 142 mm was reached on 10 March 2024.

Live weight was determined for each animal when they were added to and removed from a farm, at birth and monthly. Liveweight gain per head was the change in live weight over time for each animal. Liveweight gain per head and the number of animals in each stock class were applied to calculate liveweight gain per hectare.

Herbage mass was determined before and after defoliation (e.g. grazing, cutting, tillage) and monthly. A representative 0.5 m^2 quadrat was selected within each third of the longest axis of the plot. Any brassica plant with a bulb inside the quadrat was pulled out of the soil, cleaned and ground level was marked on the bulb. The rest of the herbage inside the quadrat was cut

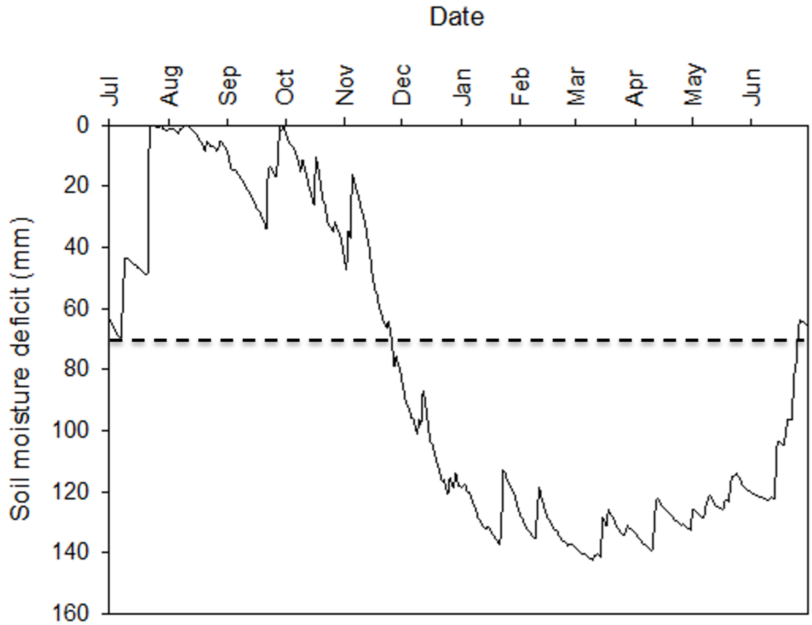

Figure 3 Soil moisture deficit in Year 3 (July 2023-June 2024). Values greater than 50% plant-available water content (dashed line) indicate water stress.

to 1-2 cm above ground with an electric sheep-shearing handpiece and placed with the bulb plants in one sack per plot. At the laboratory, any bulb was removed from the sample, washed, separated into species (bulb turnip or leafy turnip), cut latitudinally at the ground level and weighed in an oven tray. The rest of the sample was weighed fresh and thoroughly mixed. A subsample, typically 200 g for a pre-defoliation sample and 100 g for each other sample, was weighed into another oven tray and it, and any bulb were dried in a 65°C-oven for at least 48 h. Another subsample of about 400 pieces was separated into each sown species, weed (unsown species) and dead material and dried at 65°C to determine the mass of each component. The total and component herbage masses were calculated daily as linear interpolants between the measured values. The change in herbage mass from one day to the next was the herbage yield and this was summed across growth periods within the year to calculate annual yield.

The dried composite samples of pre-grazing herbage were ground to pass through a 2-mm sieve and analysed for crude protein, neutral detergent fibre (NDF) and metabolisable energy (ME) contents by near-infrared spectroscopy.

The animal data were analysed with one-way and two-way analyses of variance, and with linear regression to quantify mean growth rates. When there was a System*Fertility interaction, the different means were identified by Fisher's Least Significant Difference test ($P<0.05$). Where relevant to interpretation, differences at the 10% level of significance ($P<0.1$) are also reported. The pasture data were analysed with general analysis of variance, with a treatment structure as System*Fertility and a block structure as Square/(Row*Column). All analyses were carried out in Genstat.

Results

There were no effects of soil fertility on sheep liveweight gain and DM production in Year 3 of the experiment. Therefore, the results and discussion focus on comparing the Regenerative and Conventional systems.

Total liveweight gain per hectare was 131 kg/ha (23%) less ($P<0.1$) for the Regenerative than the Conventional system (Table 4). This difference was the product of 109 kg/ha less liveweight gain from the maternal ewe lambs ($P<0.01$) and 154 kg/ha less liveweight gain from the prime lambs ($P=0.105$).

The ewes were on average 4 kg lighter ($P<0.1$) on the Regenerative system than the Conventional system (Figure 4). Their mean live weight decreased in early lactation, but recovered in October, as the lambs began to graze more pasture, and remained reasonably stable for the rest of the year. The mean growth rate of the ewes was not different between Regenerative and Conventional at 3 g/hd/d ($R^2=0.03$).

The mean live weight of the lambs increased from about 4 kg at birth to 29 kg at weaning for Regenerative compared with ($P<0.05$) 34 kg for Conventional (Figure

Table 4 Mean sheep liveweight gain per hectare for Regenerative and Conventional systems in Year 3 (July 2023-June 2024).

Stock Class	Regenerative	Conventional	SEM	P Value
	kg/ha			
Total	496	627	24	0.061
Mature ewes	62	46	13	0.497
Hoggets	–3	–7	1.5	0.256
Maternal ewe lambs	110	219	7.5	0.010
Maternal ram lambs	14	45	13	0.246
Prime lambs	160	314	34	0.105
Store lambs	153	10	83	0.347

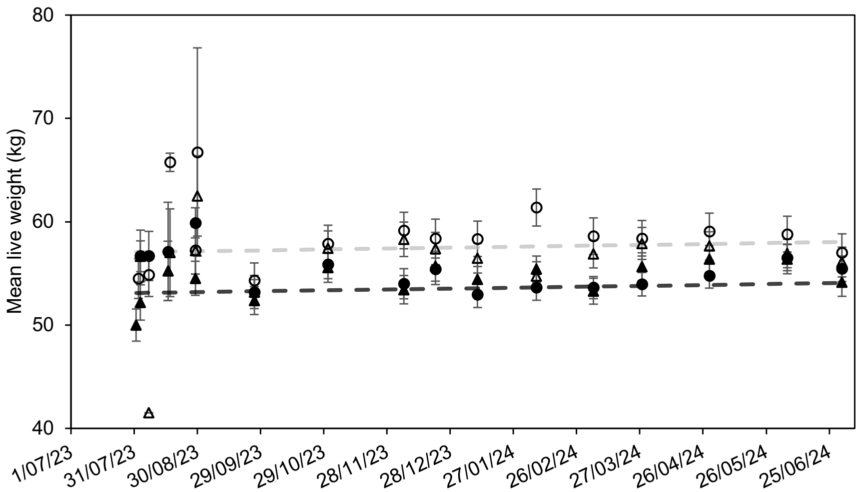

Figure 4 Mean live weight of ewes for Regenerative (black symbols, black dash) and Conventional (open symbols, grey dash) systems at High (circle) and Low (triangle) soil fertility in Year 3 (July 2023-June 2024). Mean liveweight gain was 3 g/hd/d for Regenerative and Conventional (R^2=0.03). Error bars are ±SEM.

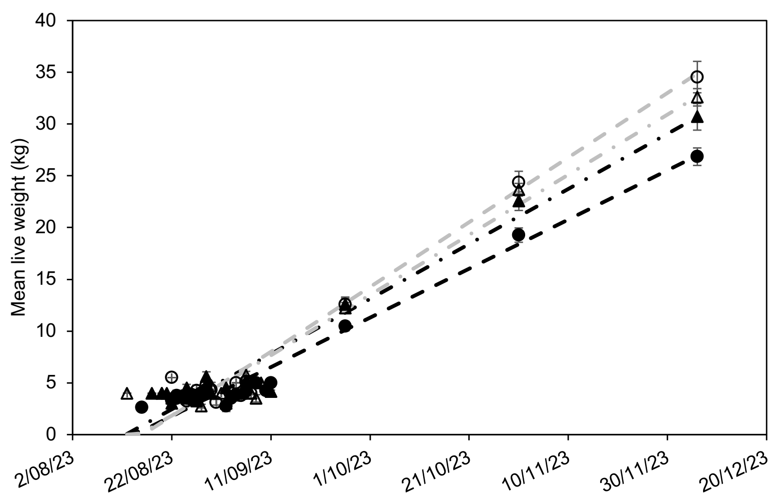

Figure 5 Mean live weight of lambs for High Regenerative (black circle, black dash), Low Regenerative (black triangle, black dash dot), High Conventional (open circle, grey dash) and Low Conventional (open triangle, grey dash dot) from birth (mean: 28 August 2023) to weaning (6 December 2023). Mean liveweight gain was 237, 266, 312 and 291 g/hd/d, respectively (R^2=0.89). Error bars are ±SEM.

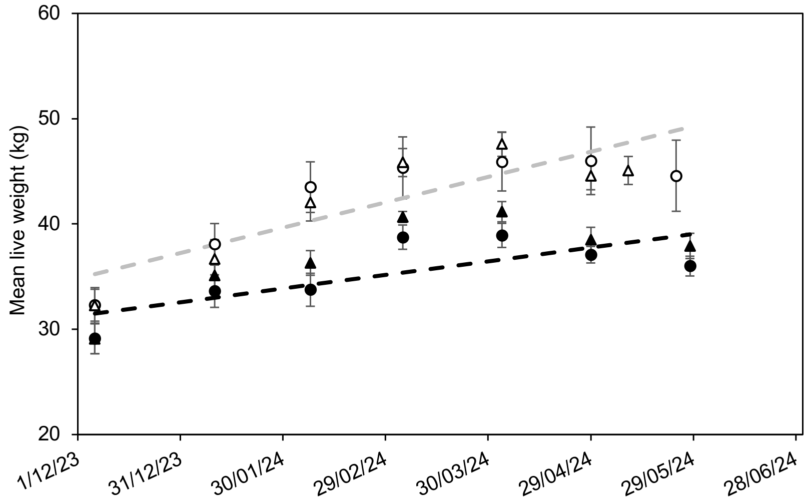

Figure 6 Mean live weight of maternal ewe lambs for Regenerative (black symbols, black dash) and Conventional (open symbols, grey dash) systems at High (circle) and Low (triangle) soil fertility from weaning (6 December 2023) to removal (mean: 20 May 2024). Mean liveweight gain was 43 g/hd/d for Regenerative and 80 g/hd/d for Conventional (R^2=0.42). Error bars are ±SEM.

with (P<0.001) 312 and 291 g/hd/d for High and Low Conventional, respectively (R^2=0.89). This meant that six less lambs were sold at the first slaughter date (12 December) for Regenerative than Conventional.

After weaning, the maternal ewe lambs gained less weight on the Regenerative system than the Conventional system (Figure 6). Their mean live weight increased until early April and then declined until mid-late May, when they were eventually removed from the experiment for the winter. Their mean growth rate was 43 g/hd/d for Regenerative compared with (P<0.001) 80 g/hd/d for Conventional (R^2=0.42).

The mean live weight of the prime lambs was not different across the four farms at each slaughter date (Table 5). The store lambs were on average heavier (P<0.05) for each Regenerative farm and Low Conventional than the one store lamb for High Conventional. There were 16 less prime lambs and 23 more store lambs for the Regenerative than the Conventional system.

Table 5 Mean live weight and number of prime lambs removed on 12 December, 15 January and 12 February and store lambs removed on 7 February for Regenerative (R) and Conventional (C) systems at High (H) and Low (L) soil fertility in Year 3 (July 2023-June 2024).

Stock Class	HR	HC	LR	LC	SEM	P Value
			kg (number)			
Prime lambs on 12 Dec.	39 (2)	43 (8)	43 (3)	38 (3)	2.9	0.295
Prime lambs on 15 Jan.	38 (1)	41 (4)	41 (2)	40 (10)	3.2	0.803
Prime lambs on 12 Feb.	38 (3)	41 (4)	42 (6)	41 (4)	2.1	0.348
Store lambs on 7 Feb.	27_a (22)	15_b (1)	27_a (3)	31_a (1)	3.8	0.015

Means with different letters are significantly different (P<0.05).

Table 6 Mean annual herbage dry matter (DM) yield and mean annual herbage mass (average farm cover), averaged across all pastures and winter forage crops, for Regenerative and Conventional systems in Year 3 (July 2023-June 2024).

	Regenerative	Conventional	SEM	P Value
	kg DM/ha			
Herbage yield	8,490	6,940	467	0.022
Farm cover	2,670	1,790	36	<0.001

Table 7 Mean annual botanical composition, crude protein, neutral detergent fibre (NDF) and metabolisable energy (ME) of herbage dry matter (DM) offered, averaged across all pastures and forage crops, for Regenerative and Conventional systems in Year 3 (July 2023-June 2024).

Component	Regenerative	Conventional	SEM	P Value
Grass (%)	34	15	<0.1	<0.001
Legume (%)	13	37	<0.1	<0.001
Herb (%)	10	0	0	<0.001
Dead (%)	39	31	<0.1	<0.001
Weed (%)	4	18	<0.1	<0.001
Protein (%)	13	19	0.2	0.002
NDF (%)	51	40	0.2	<0.001
ME (MJ/kg DM)	9.5	10.0	0.02	0.004

The total annual herbage production for Year 3 was 1,550 kg DM/ha (22%) greater (P<0.05) and the average farm cover was 880 kg DM/ha greater (P<0.001) for the Regenerative than the Conventional system (Table 6).

The botanical composition and nutritive value of herbage mass, averaged across all pastures and forage crops, were different (P<0.05) between Regenerative and Conventional systems (Table 7). There was on average more grass, less legume, more herb and dead and less weed, and therefore less crude protein, less ME and more NDF in the herbage for the Regenerative than the Conventional system. The mean grass content of the Regenerative system reached 55% in October whereas the mean legume content of the Conventional system reached 65% (Figure 7).

Discussion

The Regenerative system produced 131 kg/ha (23%) less sheep liveweight gain (Table 4), despite producing 1,550 kg/ha more DM and having an 880 kg DM/ha greater average farm cover (Table 6) than the Conventional system. The lower liveweight production resulted from a combination of different lamb numbers (Table 3) and lower feed quality for the Regenerative system (Table 7). Specifically, the ewe allocation without scanning information resulted in more lambs weaned for High Regenerative (33) than the Conventional farms (26-29), which reduced individual lamb performance, and fewer lambs raised for Low Regenerative (20), which also resulted in fewer prime lambs. The lower crude protein, lower ME and higher NDF of the feed for the Regenerative system would have met the requirements of the ewes for lactation, but limited the growth rates of the lambs before and after weaning (Brookes and Nicol 2017). For the priority stock, this translated into lower lamb growth rates before weaning (Figure 5), with a 5 kg lower weaning weight, and fewer prime lambs (Table 5) than the legume dominant (Table 7 and Figure 7) Conventional system.

Increasing lamb growth rates to weaning is a more profitable strategy to increase farm production (kg/ha) compared with increasing lambing percentage, when lambing percentage is above 140% (Moloney et al. 2023). This is consistent with the lower lamb growth rate and weaning weight observed for the High Regenerative treatment (Figure 5). Despite the influence of lambing percentage, both Moloney et al. (2023) and Muir et al. (2000) highlight pasture quality to both the ewe and the lamb before and after weaning as key determinates of farm profitability. The lower lamb growth rates before (Figure 5) and after (Figure 6) weaning show that the Regenerative system did not fully meet the nutritional demands of the lambs.

Most of the previously published research on RA has been based primarily on cut and carry systems in Europe and North America. This means there is little direct comparative research for temperate grazed systems. Consequently, the principles of RA are explored to further explain the results presented here.

The Regenerative system of multispecies forages and short-duration, high-density rotational stocking increased the annual DM production by 22% (Table 6), as suggested by Rowarth et al. (2020) and Khangura et al. (2023). However, this neither maintained nor increased animal production and pasture quality in this dryland, direct-grazed, closed-system comparison, even with a greater demand for feed from the High Regenerative treatment. The greater annual DM yield and average farm cover for the Regenerative system demonstrated the ability of its pastures to recover more rapidly post-grazing. This aligns with the principles around short grazing periods, and leaving behind higher post-grazing mass as reported in Teague and Kreuter (2020). Physiologically, more leaf area post-grazing means the pastures have a shorter lag phase, compared with that of Conventional systems, which increases the leaf area index to allow more light interception (Moot et al. 2017). The impact of maintaining canopy cover

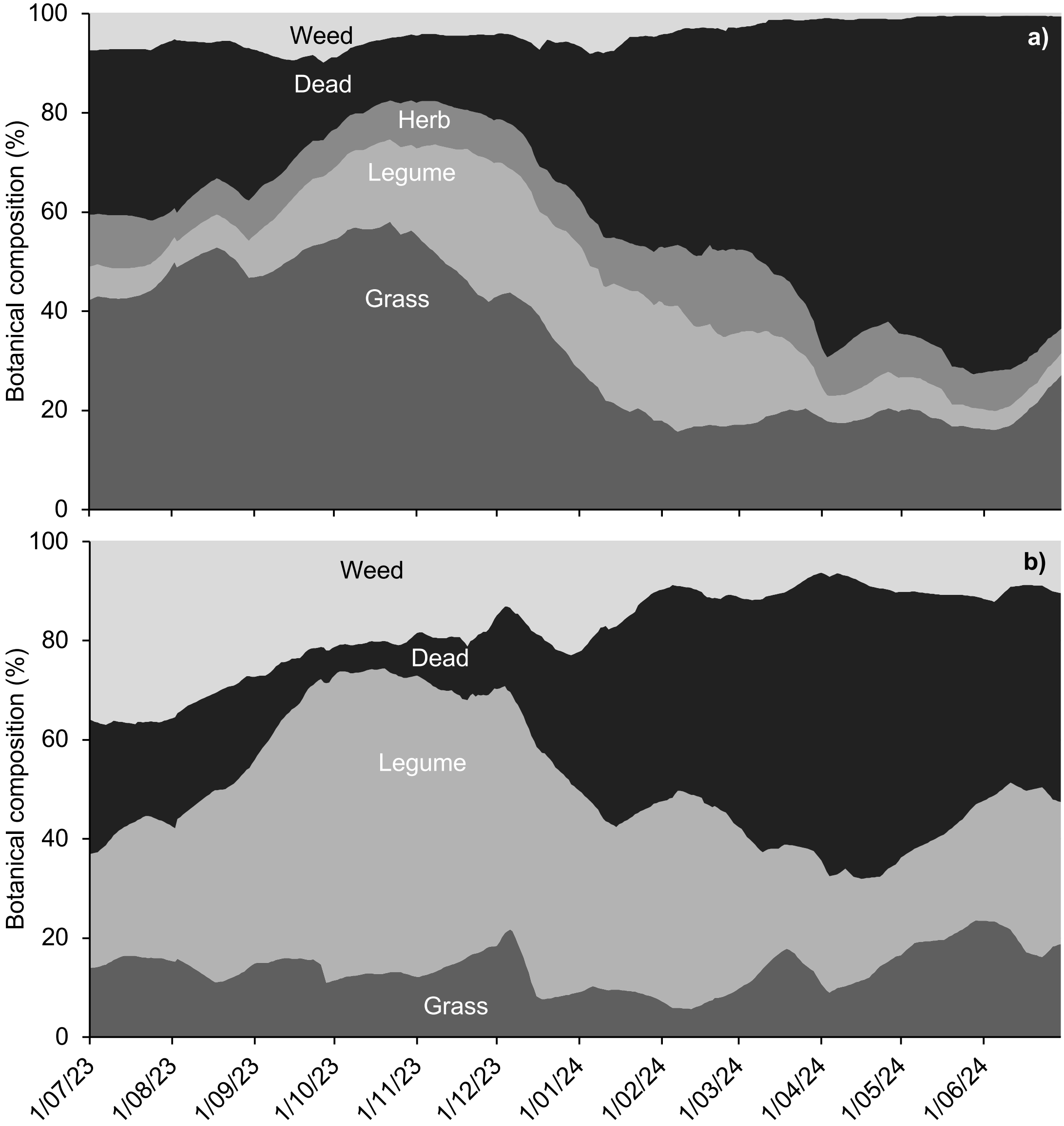

Figure 7 Mean botanical composition of herbage mass, categorised as grass, legume, dead and weed and averaged across all pastures and forage crops, for a) Regenerative and b) Conventional systems against date in Year 3 (July 2023-June 2024).

on soil processes is outside the scope of this paper. Soil health and quality measurements are part of longer-term reporting with the results from the initial years of the experiment reported previously (Watson et al. 2024).

The high proportion of dead herbage in the Regenerative system (Table 7 and Figure 7) is consistent with previous research on deferred grazing, which showed that longer closure periods (i.e. longer intervals between grazing) increased the proportion of dead and reproductive material (stems and seedheads) in pasture (Devantier et al. 2017). The RA principles that dictate fewer grazing days per paddock, but longer regrowth time between grazing events, are expected to allow for improved pasture recovery. However, a consequence of this was an increased level of senescence and reproductive material, leading to more dead material in the Regenerative pastures. This accumulation of dead and reproductive material meant topping was required, particularly for the control of chicory stem in the multispecies pastures.

The greater DM production for the Regenerative system (Table 6) is consistent with previous reports of multispecies mixtures (e.g. Black et al. 2017; Grace et al. 2018). A multispecies pasture is expected to have a range of potential benefits that includes increased weed control, provision of a range of forage plants with increased nutrition and selection by grazing animals, and potential to aid in animal health (Sanderson et al. 2005; Jaramillo et al. 2021). This was apparent with the lower weed content for the Regenerative system (Table 7 and Figure 7), but there were no nutritional benefits with lower crude protein, lower ME and higher NDF measured (Table 7).

This investigation compares a RA system based on multispecies pastures with a conventional system based on commercially recommended dryland pastures, which have been shown to have high water use efficiency and long-term persistence (Moot 2012). Further analysis of soil water, light interception and nutrient data from the experiment are required to compare resource use efficiencies in the current systems.

A feature of the Regenerative system was the dynamic nature of the botanical composition of its pastures. This may influence the long-term production of a sheep grazing system with on-going changes in relative abundances of individual component species over time. Therefore, multi-year analysis of the botanical persistence of multispecies pastures is required to determine whether species such as chicory and red clover, which were initially present (Watson et al. 2024) remain as part of the sward in the longer term. It is expected that over time their botanical contribution may decline, while in dryland environments the drought tolerant grasses, such as cocksfoot and tall fescue may become dominant (Sanderson et al. 2005). Thus, it would be expected that in the long-term, the trends observed in the annual change in botanical composition under RA practices (Figure 7) would increasingly favour grass dominance as sheep seek to fulfil their 70% legume preference (Penning et al. 1997). The associated reduction in legume content, either due to competition and/or increased preferential grazing pressure, may then further reduce the quality of feed consumed (Parsons et al. 1994).

The disparity in sheep production and DM production observed under the RA practices, may be explained by the inability of the system to provide sufficient nutrition for the sheep at different times of the year. The seasonal production pattern of the Conventional system supports lamb liveweight production during lactation by allowing ewes to buffer lamb growth by a net loss of live weight during lactation (Figure 4), and ewe recovery post-weaning (Moot et al. 2020). Specifically, 65% of total feed on offer was from legumes (Figure 7) during the peak lamb growth period (Figure 5). This is supported by previous research. Moot et al. (2020) demonstrated that the quantity of legume available on offer annually was able to account for 84% of the difference in liveweight production when lucerne monocultures were compared with lucerne-grass mixtures. Whilst the multispecies mixtures of grasses, herbs and other legumes sown with lucerne were able to yield 22% more when compared with the Conventional system, they were unable to substitute for the overall lower quality feed on offer to ewes and lambs during the critical lactation period.

Conclusions

In Year 3 of the experiment, the Regenerative system produced 22% more DM than the Conventional system. However, this did not translate into increased liveweight production. This was because the Regenerative system had grass-dominant pastures of lower feed quality than the legume dominant Conventional system. Both the quantity of legume and seasonal timing of the legume availability, combined with increased demand from priority lamb stock, contributed to the reduced liveweight production observed in the Regenerative system. Effects of lower pasture quality were confounded by an increased lambing percentage under the High Regenerative treatment. Measurements will continue to validate these observations at the whole farm system level over an extended period using the same animals and their progeny.

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