A comparison of three contrasting farming systems on forage production and soil characteristics over three years

Beverley C. THOMSON*, Noel B. SMITH, Kay R. WARD and Paul D. MUIR

[1]*On-Farm Research, Hastings, New Zealand*
*Corresponding author: bev@on-farm.co.nz

Abstract

There has been considerable interest in regenerative agriculture and the potential impact of diverse forage mixes and grazing to higher residuals on pasture production and soil quality. This study aimed to evaluate the forage productivity, botanical composition, and soil characteristics of three different forage mixtures managed as per best practise for each forage type over three years in a summer-dry environment. The three treatments were A: ryegrass/clover (4 species) rotationally grazed by lambs in winter/spring and yearling cattle in late spring/summer; B: a hyper-diverse mix (23 species) grazed by cattle with daily shifts; and C: plantain/clover/chicory (7 species) rotationally grazed by weaned lambs in winter, and ewes and lambs in spring. Over three years the hyper-diverse mix produced significantly less dry matter than the ryegrass and plantain mixtures (29246, 36709 and 32743 kg DM/ha respectively $P<0.001$). Thirty months after sowing the number of species present had declined to nine, three and four in the hyper-diverse, ryegrass and plantain pastures respectively. There was no effect of farming system on soil carbon, earth worm number or organic matter disappearance. Water infiltration rate was significantly slower on the hyper-diverse treatment, potentially due to the effect of cattle treading. Three years after sowing, the use of a hyper-diverse forage system provided no advantage for forage production or soil health over sowing a plantain or ryegrass mix.

Keywords: diverse forage, earthworms, plantain, ryegrass, soil health, soil carbon

Introduction

Regenerative farming systems are a combination of farming principles and practices (e.g. minimum tillage, diverse pasture species, rotational grazing and reduced synthetic inputs) that aim to increase diversity, enrich soils, accumulate carbon, increase soil moisture and enhance ecosystems (Terra-Genesis 2020; Grelet et al. 2021, Schreefel et al. 2020). However, there is little data on the effects of contrasting management and forage systems on production and soil characteristics in summer dry environments like Hawkes Bay.

There are many theories around what a diverse pasture mix looks like – from adding components to the basic ryegrass and white clover mix to more extreme mixtures from five plant functional groups of grass, legume, herbs/forbs, brassicas and chenopods (Quorum Sense 2025). While there are anecdotal reports of improved soil health (Schon et al. 2021; Khangara et al. 2023) from sowing more complex mixes, there is limited evidence on effects under New Zealand sheep and beef pastoral conditions. Schon et al. (2024) found no effect of sowing a more diverse forage mix on soil health after one year but suggested further monitoring was needed. Similarly, Thomson et al. (2025) found no effect in small plots managed under mowing after two years.

The aim of this study was to examine whether three forage mixes – a ryegrass/clover mix, a plantain/chicory/clover mix and a hyper-diverse mix with a wide range of species, managed using best practice for each mixture would result in differences in herbage dry matter production and soil characteristics in a summer dry sheep and beef farming area.

Materials and Methods

A paddock scale trial was set up at the Poukawa Research Farm (lat. 39.746448 S, long. 176.734201 E) on a Roseberry silt loam (Typic Orthic Melanic, NZ soil taxonomy). The area is typically summer dry with an average annual rainfall of around 730 mm (Mills et al. 2021). The trial area had previously been sown in annual ryegrass (*Lolium multiflorum* cv. Moata) and harvested for silage. Three forage treatments each with 4 paddocks (1.5 ha) were sown on the 4th March 2022 and monitored for 3 years until May 2025. Each mixture was managed using different fertiliser and grazing managements to match current recommended practices.

The hyper-diverse forage (DIV) was based on recommendations from several local regenerative farmers and included 23 species across five plant groups sown at 46 kg/ha (Table 1). A biological fertiliser mix (largely lime, phosphate rock and sulphur, Table 2) was used at 400 kg/ha each year. Only cattle were grazed, to minimise diet selection, with R1 steers used in Year 1 and R2 steers used in Years 2 and 3. Steers were shifted daily and back-fenced with the objective of "eating half and leaving half" of the feed on offer.

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Table 1 Species and sowing rates (kg/ha) of ryegrass, diverse and herb treatments

Species	RYE	DIV	HERB
Perennial grasses			
Brome (Bromus valdivianus)		4	
Cocksfoot (Dactylus glomerata)		2	
Festulolium		2	
Prairie grass (Bromus catharticus)		3	
Ryegrass (Lolium perenne)	20	3	
Timothy (Phleum pratense)		1	
Perennial legumes			
Lucerne (Medicago sativa)		3	
Red clover (Trifolium pratense)	4	1	4
White clover (Trifolium repens)	4	1	4
Perennial herbs			
Chicory (Cichorium intybus)		0.75	2
Plantain (Plantago lanceolata)		1	8
Annual legumes			
Arrowleaf clover (Trifolium vesiculosum)		1	
Balansa clover (Trifolium michelanium)		1	2
Persian clover (Trifolium resupinatum)		1	2
Sub clover (Trifolium subterranean)	4	4	4
Annuals			
Buckwheat (Fagopyrum esculentum)		1	
Daikon radish (Raphanus sativus)		1	
Leafy turnip (Brassica rapa)		1	
Linseed (Linum usitatissimum)		1	
Lotus (Lotus cornicultanus)		0.75	
Oats (Avena sativa)		10	
Phacelia (Phacelia distans)		0.1	
Sunflower (Helianthus annus)		2	
Total (kg/ha)	**32**	**45.6**	**26**

Table 2 Fertiliser added annually to the DIV treatment

Component	Rate (kg/ha)
Lime	147.5
Phosphate rock	100
Potassium chloride	50
Magnesium carbonate	50
Sulphur (SB90)	20
Raw humate	20
Borate	8
Selenium chip	1
Cobalt sulphate	0.3

The ryegrass/clover forage (RYE) consisted of 4 species (Table 1) and was sown at 32 kg/ha. At sowing, 200 kg/ha Cropmaster 15 was applied and thereafter 300 kg/ha of 10% Potassic Super was applied each autumn. Winter trade lambs were rotationally grazed between April and October to residuals of 1400 kg DM/ha. R1 cattle were grazed from October to February to residuals of 1600 kg DM/ha.

The plantain/chicory/clover forage (HERB) consisted of 7 species (Table 1) sown at 26 kg/ha. The fertiliser programme was as used as in the RYE treatment. An insecticide spray for plantain moth (250 ml/ha, Sparta, Corteva) was applied in Year 2 (March 2024). Winter trade lambs were grazed between April and July and, in spring, ewes with twin lambs were grazed to residuals of 1600 kg DM/ha. Post-weaning, lambs were grazed from November until February or for as long as feed was available above 1600 kg DM/ha. Cattle were grazed on the HERB treatment during the late spring of Year 3 as grass invasion was more than could be managed by ewes and lambs.

Herbage accumulation and species composition

Within each replicate two pasture cages (each 2.4 m^2) were positioned about one third and two thirds of the way down each paddock. These cages were mown monthly to 5.5 cm (RYE) and 8 cm for the HERB and DIV pastures. Each month a new site was trimmed and cages shifted.

Herbage dry matter (DM) accumulation was determined by weighing the fresh herbage harvested. A 400 g subsample of the fresh forage harvested was weighed and and dried at 80ºC for 48 hours to calculate the dry matter content (%).

Species composition assessments were carried out on pasture samples cut to ground level using a 0.32 m × 0.32 m quadrat. Dissection samples were taken approximately 3 months after sowing (1/6/22) and, thereafter, each spring (1/10/22, 4/10/23 and 1/11/24). A 200 g subsample was dissected to individual species level. Each individual species sub-sample was dried at 80ºC for 48 hours and weighed and the proportion of each species on a DM basis calculated.

Soil fertility and water infiltration rate

Soil fertility was sampled to 7.5 cm annually in autumn using a GPS transect diagonally across each of the four paddocks in each treatment with 15 cores per paddock. Water infiltration rates were measured twice, in November 2022 (7 months after sowing) and at the end of experiment (May 25). Water infiltration rates were measured by applying 250 ml of water to the soil contained by a metal ring (150 mm in diameter) hammered approximately 25 mm into the ground. The ring was lined with plastic, the measured amount of water added, then the plastic was gently removed and a stopwatch used to record the time for the water to

Table 3 Total DM production (kg/ha) in ryegrass, diverse and herb treatments over 3 years (1 April 2022 - 31 March 2025)

DM production	RYE[2]	DIV	HERB	SE	P
Year 1 (2022/23)[1]	14791[c]	10987[a]	13367[b]	469.2	0.001
Year 2 (2023/24)	13009[b]	10657[a]	11108[ab]	475.8	0.02
Year 3 (2024/25)	8508	7603	8269	628.9	0.59
Total production	36709[b]	29246[a]	32743 [ab]	958.5	0.002

[1] Years are production years from 1st April to 31st March.
[2] Different letters within a row represent significance at p<0.05 between the three treatments

disappear. A total of three applications of 250 ml were applied at each measurement period (Integrity Soils 2022, USDA 2022). Four sets of measurements were done in each paddock.

Soil carbon

Soil total carbon (TC), total nitrogen (TN) and bulk density were measured to a depth of 60 cm using a 50 mm corer in February 2022, prior to sowing. Samples were taken from each of the four paddocks making up each treatment using a diagonal GPS transect. In May 2025, transects were repeated and the same number of cores collected. Each core was analysed for soil total carbon (TC) and total nitrogen (TN) at different depths (0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-60 cm). It was not possible to sample any deeper than 60 cm because of the presence of a hard pan. Each soil sample collected was weighed then dried at room temperature for 48 hours. Samples were then re-weighed, crumbled and any visible root material removed and weighed. There were no stones present. Half the sample was dried at 100ºC to calculate bulk density. The remaining soil was dried at 60°C for 72 hours to avoid loss of carbon and then ground through a 1 mm sieve for laboratory analysis at Analytical Research Laboratories, Hastings. The TC and TN were measured using the 'Dumas' technique; by combusting the soil at a temperature between 1100 and 1200°C, within an inert gas environment and a steady flow of pure oxygen, to create the CO_2 and NO_2 gases for collection. The concentration of these gases was then determined using Non-Dispersive InfraRed detection for 'carbon' and Thermal Conductivity detection for 'nitrogen' using a Skalar Primacs SNC-100.

Bulk density was calculated from the combined oven-dry weights of each sample (i.e., the dry weight % after 48 hours at room temperature and 48 hours in the 100°C oven) and the volume of sample taken.

Soil biological activity measures

At the completion of the trial (May 2025) the earthworms present in a 20 cm × 20 cm × 20 cm turf dug at random from each paddock were identified and counted. Three earthworm species were identified – *Lumbricus rubellus*, *Aporectodea calignosa* and *Aporectodea longa* (Shepherd 2009).

Biological activity was measured by the decomposition method of Correll et al. (1997). Specifically, a known weight of dry cotton cloth was vertically inserted into the ground within each plot. This was done in four random sites in each paddock. After 8 weeks, the cloth was recovered by digging out the remaining material and surrounding dirt. The dirt was removed by washing and the pieces of material remaining were dried at 60°C for 72 hours and then weighed. The amount of cloth that had disappeared was calculated from the difference between the two weights. Measurements were carried out in September 2023, December 2024 and toward the end of the experiment in March 2025.

Statistical analyses

Statistical analyses of herbage accumulation, species proportion, TC, TN, earthworm and decomposition response variables were carried out using a GLM analysis with forage system as a fixed treatment effect (Minitab for Windows, version 14, https://www.minitab.com/en-us/products/minitab/).

Results

Environmental

Year 1 and 2 of the trial were particularly wet years with 1058 and 1015 mm of rainfall, respectively. These higher-than-average annual rainfalls led to very wet ground conditions through late winter and spring in Year 1 and Year 2. In Year 3, annual rainfall was 696 mm with a very dry spring which recorded only 44 mm through September, October and November 2025.

Herbage total production and accumulation rates

Over 3 years, the hyper-diverse, ryegrass and plantain forages produced 29246, 36709 and 32743 kg DM/ha (Table 3), respectively with the hyper-diverse treatment producing less DM than the ryegrass treatment (SEM 1106, P< 0.001).

Forage species composition

Annual clovers had disappeared from all treatments when final measurements were made. There were very high levels of dead material in all swards at the end of the experiment (Table 5). Thirty months after sowing 3/6, 9/23, and 4/7 of the original sown species were present in RYE, DIV, and HERB treatments,

Table 4 Number of species sown and recorded as present at four intervals after sowing in RYE, DIV and HERB treatments

	RYE	DIV	HERB
Number of species sown	6	23	7
Species present 1/6/22 (3 months)	4	12	6
Species present 1/10/22 (6 months)	4	12	6
Species present 1/10/23 (18 months)	3	7	4
Species present 1/11/24 (30 months)	3	9	4

Table 5 Proportion of sown forage species present for the three treatments (RYE, DIV, HERB) at intervals after sowing

	RYE				DIV				HERB			
	17/6/22	28/10/22	4/10/23	1/11/24	17/6/22	28/10/22	4/10/23	1/11/24	17/6/22	17/6/22	17/6/22	1/11/24
Ryegrass	0.62	0.66	0.46	0.58	0.08	0.34	0.24	0.32				
Cocksfoot					0.00	0.03	0.01	0.09				
Brome					0.01	0.04	0.00	0.02				
Timothy					0.00	0.00	0.00	0.01				
Prairie Grass					0.01	0.01	0.00	0.05				
Oats					0.12	0.04	0.00	0.00				
Festulolium					0.00	0.01	0.00	0.01				
Unsown Grass					0.00	0.00	0.00	0.01				
Total Grass	0.62	0.66	0.46	0.58	0.22	0.48	0.26	0.51	0.00	0.00	0.03	0.53
White clover	0.07	0.11	0.35	0.05	0.01	0.03	0.26	0.07	0.03	0.03	0.18	0.05
Red clover	0.04	0.15	0.08	0.05	0.00	0.01	0.04	0.00	0.02	0.03	0.09	0.04
Sub clover	0.01	0.03	0.00	0.00	0.00	0.06	0.01	0.00	0.00	0.02	0.00	0.00
Persian clover					0.02	0.00	0.00	0.00	0.08	0.00	0.00	0.00
Balansa clover					0.01	0.10	0.00	0.00	0.03	0.31	0.00	0.00
Arrowleaf clover					0.00	0.00	0.00	0.00				
Unsown Leg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
Total Legume	0.13	0.29	0.43	0.09	0.04	0.20	0.31	0.07	0.20	0.39	0.27	0.08
Plantain	0.00	0.00	0.00	0.00	0.03	0.11	0.21	0.03	0.39	0.36	0.59	0.08
Chicory	0.00	0.00	0.00	0.00	0.01	0.04	0.15	0.08	0.12	0.15	0.08	0.06
Total Herb	0.00	0.00	0.00	0.00	0.04	0.15	0.36	0.11	0.51	0.51	0.67	0.14
Lucerne					0.00	0.00	0.00	0.00				
Lotus					0.00	0.00	0.00	0.00				
Linseed					0.03	0.00	0.00	0.00				
Phacelia					0.03	0.00	0.00	0.00				
Sunflower					0.00	0.00	0.00	0.00				
Buck wheat					0.00	0.00	0.00	0.00				
Daikon radish					0.24	0.00	0.00	0.00				
Weed	0.06	0.00	0.07	0.03	0.29	0.01	0.02	0.00	0.25	0.01	0.01	0.00
Dead	0.19	0.04	0.04	0.30	0.10	0.16	0.05	0.31	0.05	0.08	0.02	0.24

Table 6 Changes in soil chemistry (7.5 cm) over time across the three treatments

	RYE				DIV				HERB				SE	P_{forage}
	1/3/22	28/2/23	15/2/24	26/5/25	1/3/22	28/2/23	15/2/24	26/5/25	1/3/22	28/2/23	15/2/24	26/5/25		
pH	6.1	5.7	6.0	6.0	6.0	5.8	6.1	6.1	6.0	5.7	6.1	5.9	0.1	0.13
Olsen P	36.8	35.3	32.8	32.8	40.5	39.5	39.8	30.5	34.5	36.5	33.3	32.5	2.1	0.04
Calcium (QTU)	8.3	10.3	10.5	8.8	8.0	10.5	11	9	8.5	10	9.5	9.3	0.5	0.65
Magnesium (QTU)	19.0	21.5	26.3	22.0	19.3	24.0	27.3	22.8	19.3	22.5	24.3	22.0	1.0	0.13
Potassium (QTU)	7.3	7.3	10.3	7.3	7.8	10.5	13.3	9.8	6.3	8.3	10.5	9.8	1.0	0.01
Sodium (QTU)	13.8	10.3	13.2	16.0	13.0	10.3	16.5	16	15.8	13.3	17.5	18.0	1.5	0.03
Sulphate Sulphur ug/g	3.8	3.5	10.7	7.5	2.3	9.8	16	8.8	3.3	7.8	13.3	10.8	1.0	0.001
Ext Org Sulphur ug/g	6.8	4.0	4.3	5.3	7.5	3.8	4.7	5.8	7.5	3.8	5	7.3	0.5	0.16

respectively (Table 4). Six months after sowing the RYE treatments had 62% ryegrass and 20% legume. At the time of the final dissection (30 months after sowing) the RYE still had 58% ryegrass and 9% legume. Of the original 6 sown species, 3 were still present at 30 months. No subterranean or red clover were seen at the 30-month (spring) dissection.

At the 6-month dissection, the DIV treatment had 24% leafy turnip/rape, 12% oats, 8% ryegrass, 4% legume and 4% herb. By final dissection at 30 months the DIV had 32% ryegrass, 9% cocksfoot, 11% herb and 7% legume. Of the original 23 species sown, 9 were present at 30 months and 3 of these 9 species each made up less than 2% of the sward (Table 5).

In the HERB treatment, plantain, chicory and legume made up 39%, 12% and 20% of the sward, respectively, at the 6 month dissection. After 18 months, chicory and plantain combined made up 67% of the sward but by 30 months had declined to 14% with volunteer ryegrass increasing to 53% of the sward. The number of originally sown species declined from 7 to 4, with balansa, subterranean and red clover absent at final dissection (Table 5).

Soil fertility

Across all treatments, pH at the start of the experiment averaged 6.1 and 6.0 at the end. Olsen P levels declined from 38 to 32 over the course of the experiment. The decline in Olsen P levels was greatest in the DIV treatment (11 units) compared to declines of 4 and 3 Olsen P units in the RYE and HERB treatments, respectively (Table 6). The P applied to the DIV treatment was phosphate rock and thus in a much less soluble form. Nevertheless, the P levels across the treatments and paddocks were very high and would have been unlikely to have limited herbage growth.

Water infiltration rates

Water infiltration rates were significantly slower (i.e. it took longer for the water to disappear) in the DIV treatment than in the RYE and HERB treatments however the size of the effect varied with soil moisture (Table 7). Within paddocks, the water infiltration rates were highly variable with no apparent explanation.

Table 7 Soil moisture (%) and water infiltration rates (sec) for each of the three consecutive 25 mm water applications in December 2022 and March 2025 on three forage treatments

Date		RYE[2]	DIV	HERB	SE	P
Dec 2022	Moisture[1]	11.4	13.4	11.4	0.46	0.06
	1	290[b]	158[a]	71[a]	30.4	0.001
	2	731[a]	1444[b]	525[a]	196.9	0.006
	3	1865[a]	4689[b]	1739[a]	521.0	0.001
March 2025	Moisture	21.4	20.8	21.0	0.29	0.37
	1	60	175	40	40.1	0.05
	2	255	1036	316	232.5	0.04
	3	568[a]	1984[b]	753[ab]	388.6	0.03

[1] Initial soil moisture content before infiltration testing
[2]Values within rows with different subscripts are significantly different P<0.05

Soil carbon

There was a wide variation in the soil carbon within a replicate especially in the top 10 cm core. Overall, there was a decrease in soil carbon percentage by the end of the experiment (1.32% vs 1.20% Carbon in 2022 and 2025 respectively SE 0.02 P<0.001). Over the entire soil core the RYE treatment had significantly more carbon than the DIV treatment when the initial carbon from each sampling point was fitted as a covariate (1.21 1.16 and 1.11% carbon for RYE, DIV and HERB respectively, SE 0.03 P< 0.03). However, there were no differences in soil carbon percentage between treatments within a depth band (Table 8). Soil carbon percentages in the top 10 cm increased over the course of the experiment, from 2.67% at the start to 2.82% at the end of the experiment. But the soil carbons at the lower depths decreased over the experiment. The size of the percent decrease increased with depth.

Table 8 Soil carbon percentage in soil cores (0-10,10-20, 20-30, 30-40 and 40-60 cm) measured in three contrasting treatments (RYE, DIV, HERB) at the start (March 2022) and end of the trial period (May 2025) with initial measure fitted as a covariate for each sample

	Start[1]	Final[2]		
Depth (cm)		RYE	DIV	HERB
0-10	2.67^{e}	2.86 ^{e}	2.81^{e}	2.80^{e}
10-20	1.95^{d}	1.60^{d}	1.53^{d}	1.48^{d}
20-30	1.03^{c}	0.88^{c}	0.74^{c}	0.80^{c}
30-40	0.56^{b}	0.61^{bc}	0.44^{bc}	0.43^{bc}
40-60	0.38^{a}	0.36^{b}	0.34^{b}	0.31^{b}
Weighted average		1.21^{a}	1.16^{b}	1.11^{b}
SE	0.03		0.11	
P_{trt}			0.03	
P_{core}	0.001		0.001	

[1]Within a column or between treatments different letters denote significance at P<0.05.
[2] Weighted averages adjusted for the initial soil carbon content before treatment imposition

Earthworm activity

Three earthworm species were identified – *lumbricus rubellus*, a surface dweller in the litter layer, *aporectodea calignosa*, typically a topsoil dweller and *aporectodea longa*, typically a deep burrower. Earthworm numbers tended to be lower and their size smaller in the HERB (Table 9) but it is difficult to see that the pasture species used and management undertaken has made any difference to earthworm activity between the treatments.

Biological activity

There were no treatment effects on cotton decomposition rate but there was a seasonal effect with less breakdown in December 2024 after a very dry spring. The final measurement was carried out after rain in February 2025 and much of the material had disappeared during the eight weeks the samples were buried (Table 10).

Discussion

The use of hyper-diverse sowing mixes was common in the early days of New Zealand agriculture (Harris 1968) but pastures generally regressed to a few dominant species and the use of simpler ryegrass/white clover swards became more prevalent (Levy 1936). Since then, numerous researchers (e.g. Ruz-Jerez 1991; Johnson et al. 1994; Daly et al. 1996; Rollo et al. 1998; Woodward et al. 2013) have re-examined the effect of sowing diverse mixtures with the hypothesis that swards would be more productive or that having species with deeper roots (Terra-Genesis 2020; Quorum Sense 2025) would contribute to production at different times of the year. Generally, these comparisons have seen little or no improvement in total yield but there have been improvements in summer pasture production (Pemberton et al. 2015: Ruz-Jerez et al. 1991; Woodward et al. 2013; Vibart et al. 2016; Thomson et al, 2025). Pasture production declined over the three years in all three treatments (Table 3). Part of this would have been due to the reduced vigour of newly sown pastures but some of the decline would have been due to climatic conditions between years. The first two years of the trial were particularly wet with 1058 and 1015 mm of rainfall, respectively as compared to a long-term average of 730 mm. These

Table 9 Numbers, species and size of earthworms present in four 20 x 20 cm turfs from each of RYE, DIV and HERB treatments three years after sowing

	Initial					Final				
	RYE	DIV	HERB	SE	P	RYE	DIV	HERB	SE	P
Total	30	12	14	7	0.21	22	22	18	4.8	0.79
L	1	5	4	2	0.41	7	5	6	2.6	0.80
AC	27	6	9		0.06	9	12	12	5.2	0.93
AL	2	1	1	1.1	0.90	5	4	1	1.9	0.33

L *lumbricus rubellus,* AC *aporectodea calignosa,* AL *aporectodea longa.*

Table 10 Percentage of a weighed amount of cotton remaining after being buried for eight weeks

Date sample removed	RYE	DIV	HERB	SE	P
Sept 23	60.6	59.6	52.3	3.7	0.25
Dec 24	82.1	90.5	82.5	3.3	0.15
May 25	27.0	38.6	35.1	4.6	0.21

higher-than-average annual rainfalls led to very wet ground conditions through late winter and spring each year. In 2024/25, the annual rainfall was only 696 mm, below the long-term average. Only 44 mm was recorded through September, October and November resulting in very dry soils in spring, while rainfall in early summer resulted in a wetter than average summer. The dry spring in 2024 would have contributed to the difference in pasture production in Year 3 compared to Year's 1 and 2. Summer pasture production on the ryegrass/clover was 6402, 1843 and 973 kg DM/ha in Year 1, 2 and 3 respectively. This variation between years is typical for the area with Mills et al. (2021) reporting summer pasture production on established pastures ranged from 0 to 3700 kg DM/ha.

The monthly cutting technique used to measure pasture production, may have penalised the DIV treatment with its high percentage of vigorous annuals (e.g. brassica and cereals). These species might have benefited from a longer cutting interval in Year 1 as typically we would have not harvested these species until they were more established. On the other hand, the pre-cutting of the pasture cage sites, would have removed the tall reproductive and dead stalks left by the cattle and may have allowed other species to survive.

In grazing studies, sheep especially tend to preferentially select species such as legumes and herbs resulting in heavier grazing of these species relative to other less desirable species (Ruz-Jerez 1991; Grace et al. 2018). To reduce diet selection the DIV treatment was grazed with cattle on daily shifts. Sowing a hyper-diverse sward (23 species) did not lead to a significantly more diverse sward with only 9 species out of 23 remaining after three years and only 6 making a meaningful contributing to pasture production. In addition, the pasture production from the species that remained in the diverse sward was lower than the ryegrass/clover pasture. Whilst the intent of sowing diverse perennial pastures is to assemble plant communities with high functional diversity (i.e. productivity in different seasons and deeper root system) there seems little merit in sowing species that will not compete. It is possible that sowing 5 plant groups in a permanent pasture (e.g. including brassicas and cereals) could actually reduce pasture diversity and production as during establishment, brassicas and cereals may out-compete the smaller and less robust species, thus reducing the number of pasture species that are established. Bare patches of ground, especially in the last year of the experiment, were observed in the diverse pasture. Harris et al. (1972) included rape in a pasture mix and Brougham (1955) included barley and both showed an effect on ryegrass production. Thomson et al (2025) used millet, canary seed, squash and maize in their mix and none of these were seen so they were dropped from this subsequent study. Moreover they used a larger number of annuals including barley, oats, Italian ryegrass and five different brassicas. This resulted in a lot of early growth from fast growing annuals. In the present study, annuals were reduced to oats plus daikon radish which was used for its perceived benefits of its large root. It is possible that the timing of sampling and the use of the quadrat meant that some species that only appeared at certain times of the year, were in small numbers or grew in large clumps (e.g. cocksfoot) are underrepresented in the species data. However, apart from cocksfoot, their scarcity means they are unlikely to make a significant contribution to pasture or soil performance. It is possible that adding a few carefully selected species like plantain and chicory to a more conventional mix could improve productivity.

The RYE treatment had 62% ryegrass and 20% legume after 6 months and after 30 months still had 58% ryegrass with legume reducing to 9%, with the remainder being mainly dead material. Of the original 6 sown species, 3 were still present at 30 months. Subterranean and red clover were not present at the 30-month (spring) assessment. In the case of red clover this may well be due to the timing of sampling as red clover is usually seen in summer.

In the HERB treatment, plantain, chicory and legume made up 71% of the sward at the 6-month assessment. After 18 months chicory and plantain made up 67% of the sward but by 30 months, this had declined to 14% with volunteer ryegrass increasing to 53% of the sward. This rapid decline in plant numbers is in line with what we expect from a plantain sward (Muir et al. 2019) with many plantain pastures needing to be renewed after 2 years. Number of originally sown species declined from 7 to 4, with balansa, subterraneum and red clover absent at final (spring) dissection.

Lax grazing and high residuals are promoted as a key feature of regenerative agriculture (Terra Genesis 2020). The concept of "eat half leave half" originated from work of Sampson (1923) and then Crider (1955) who found that removing more than 60% of forage can reduce root growth by 50%. Savory and Butterfield (1998) extended this concept to claim that this type of grazing could stimulate grass growth and root turnover, allowing carbon to accumulate in soil organic matter through dead roots and litter. There was a lot more trash and tall stalky forage left behind on the DIV treatment as the cattle tended to still eat the shorter leafier plant material first. This was especially noticeable after the pasture plants went reproductive late spring/summer. This stalky reproductive growth appeared to be less palatable and some of it ended up trampled on the ground as trash.

The decline in Olsen P levels was greater in the DIV treatment than the RYE and HERB treatments

(Table 2). These differences may be due to the forms of P supplied.: The P applied to the DIV treatment was phosphate rock and, thus, in a much less soluble form and the available soil P would have been underestimated by the Olsen test (Roberts et al. 1994). Nevertheless, P levels across all treatments were very high at the start of the trial (mean 38 µg/ml) and at the end of the trial the P levels (range 30 to 32 µg/ml) would have been unlikely to limit herbage growth.

Water infiltration rate has been commonly used as a metric to evaluate soil quality and health (Saltiel et al. 2022). The DIV treatment took significantly longer for the water to drain into the soil. This was consistent across all 3 measurements and is probably a result of compaction and treading damage from the cattle grazing as the other treatments had a significant component of sheep grazing.

The DIV treatment was managed with daily shifts of cattle to achieve grazing density and trampling of litter (i.e. eat half of the available feed and trample half) in the belief that these frequent shifts would improve both animal performance by providing a more uniform nutrition and soil health by adding more organic matter in the form of the residual feed left behind. However, the current study found there was no effect on biological activity and earthworm abundance between the contrasting farming treatments. These results are in line with a recent Welsh study (Cooledge et al. 2024) which compared herbal leys and grass-clover under grazing and found no effect on soil porosity, earthworm abundance and microbial communities. These findings conflict with some of the hypotheses raised about plant species composition enriching soil microbial communities (Orwin and Wardle 2005).

A common observation in the soil carbon cores was roots down to 600 mm for all treatments. The presence of a pan meant that sampling deeper than 600 mm was not feasible. Spohn et al. (2023) reported that plant production and plant diversity are positively correlated with soil carbon. They suggested that while plant diversity can increase plant biomass production and thus influence soil carbon stores, plant diversity can also increase soil carbon through the quality of the organic matter input to the soil. In the present study, the RYE treatment had significantly more carbon averaged across the complete full soil core than the HERB treatment and a trend to be higher than the DIV treatment. Increasing the number of species sown, leaving more plant material behind and including deeper rooting species (chicory and radish) as suggested by regenerative practitioners (Terra-Genesis 2020) did not result in any improvement in soil carbon within the three-year time frame of this study.

Conclusions

In spite of very contrasting management systems – a hyper-diverse sward with non-synthetic nutrients and cattle grazing with daily shifts versus more conventional rotational grazing by sheep (e.g. shifts every 3-7 days) and chemical fertilizer inputs, it was not possible to influence soil carbon, biological activity or earthworm numbers within a three-year time frame. Whilst there was no effect of management system on soil biological activity, there were large differences between seasons, presumably reflecting an impact of soil moisture on microbial activity. Moreover, sowing of a hyper-diverse pasture mix of five different plant groups did not lead to increased production or an increase in plant diversity.

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