Forage yield, botanical composition and soil characteristics of a species diversity by harvest height experiment in Hawke's Bay

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Abstract

There has been considerable pastoral sector interest in regenerative agriculture practises and the potential impact of diverse forage mixes and grazing to higher residuals on pasture production and soil quality. This small plot study aimed to evaluate the productivity, botanical composition, and soil characteristics of four different forage mixtures under two mowing regimes over two years at a summer-dry site. The mixtures were: ryegrass/clover (4 species), plantain/clover (6 species) and two 'hyper-diverse' (31 species sown at 45 or 180 kg/ha). The two mowing heights were 8 cm and 20 cm to replicate lax and very lax grazing management systems. The diverse mixtures produced more feed in the first six months due to the presence of cereals and brassicas. In fact, these vigorous annuals may have reduced the success of other species as only a small number of species in the diverse plots were present after 2 years. The 8 cm cutting height produced a mean of 26 185 kg DM/ha and the 20 cm cutting height produced a mean of 15 951 kg DM/ha across the four forage mixtures. Within the 20 cm mowing height the two diverse mixes produced the most herbage while within the 8 cm mowing height the plantain/clover mix and hyper-diverse mix at a high sowing rate produced the most herbage. There was no effect of forage mix or mowing height on soil carbon, soil nitrogen, water infiltration rates, earthworm abundance or decomposition activity over the two year period.

Keywords: diverse pasture, mowing height, plantain, ryegrass, soil characteristics

Introduction

Whilst ryegrass/clover pastures and more intensive management systems have dominated the New Zealand farming landscape for many years, there has been increasing debate around the role of regenerative farming practices. Regenerative farming systems are a combination of farming principles and practices (e.g., minimum tillage, diverse pasture species, compost, rotational grazing and reduced synthetic inputs) that aim to increase diversity, enrich soils, accumulate carbon, soil moisture and enhance ecosystems (Terra-Genesis 2020; Grelet et al 2021, Schreefel et al. 2020).

There are a range of ideas around what constitutes a diverse pasture mix – from adding components to the basic ryegrass and white clover mix to more extreme mixtures with a wider range of plants from five plant functional groups: 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.

The aim of this study was to examine whether four forage mixes – a ryegrass/clover mix, a plantain/clover mix and a 'hyper-diverse' mix with a wide range of species at two sowing rates, under different mowing heights 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 small plot 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, USDA soil taxonomy). The area is typically summer dry with an average annual rainfall of around 750 mm (P. Muir, unpubl. data).

Establishment

Following a squash crop and subsequent full cultivation, eight treatments (four forage seed mixes with two mowing heights - 8 cm and 20 cm) were hand sown on the 11th May 2021 in a randomised block plot trial with 4 replicate blocks per treatment. Plots were 3 m × 5 m. Compost was applied at sowing at the equivalent of 10 m^3/ha, and based on laboratory analysis would have delivered 80, 43 and 86 kg of N, P and K per hectare, respectively. No other fertiliser was applied. Compost is not a typical fertiliser under more traditional New Zealand pastoral systems but is used in regenerative type systems and this allowed all plots to have the same fertility background. Plots were covered with bird netting until seedlings were established.

The hyper-diverse mix was as used by a local regenerative farmer (Glenlands Farm 2021) and included 31 species (5 different plant functional groups)

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Table 1 Seed mixtures at sowing (May 2021) and species present (% of harvested DM) after two years (May 2023) in plots cut at 8 or 20 cm height using a mower.

A . Ryegrass/clover mixes (RYE)

Species and cultivar	Seed weight kg/ha	8	20
Perennial ryegrass - Governor	20	36.8	14.2
White clover – Weka	4	17.1	13.5
Red clover – Morrow	4	19.4	35.1
Sub clover – Coolamon	4	0	0
Unknown clover		0.3	0.9
Total	**32**		

B. Plantain/clover mixes (PLANT)

Species and cultivar	Seed weight kg/ha	8	20
White clover – Weka	4	12.4	12.1
Persian clover – Laser	2	0	0
Red clover – Morrow	2	9.0	7.8
Sub clover – Coolamon	4	0	0
Balansa – Vista	2	0	0
Plantain – Captain	8	55.7	35.1
Grass		8.0	14.2
Total	**22**		

C. Diverse species mixtures (DIV)

	Seed weight kg/ha	DIV180[1]		DIV45[1]	
Species and cultivar		**8**	**20**	**8**	**20**
Italian ryegrass	8	0.9	7.6	0.5	3.9
Tall fescue	1	0	0	0	1.5
Perennial ryegrass - Matrix SE	0.5	3.4	0	2.2	0
Cocksfoot - Kainui	1	14.4	19.4	23.8	13.9
Prairie grass - Atom	1.5	0.4	5.4	8.7	0
Grazing brome - Bareno	3.5	9.9	1.8	4.4	3.6
Other grass		2.8	12.5	4.7	0
Japanese millet	5	0	0	0	0
Canary seed	2	0	0	0	0
Oats	35	0	0	0	0
Barley	35	0	0	0	0
Maize	10	0	0	0	0
Peas	55	0	0	0	0
White clover – Weka	0.5	5.8	3.3	14.7	1.1
Persian clover – Laser	0.25	0	0	0	0
Arrowleaf – Zulu 11	0.5	0	0	0	0
Crimson clover	1	0	0	0	0
Lucerne	1	0	0	0	0
Red clover	1.5	9.9	7.7	5.7	8.7
Lotus	0.25	0	0	0	0
Rape - Kingsford	1	0	0	0	0
Rape - Bouncer	0.5	0	0	0	0
Pasja – Pasja II	1	0	0	0	0
Turnip - Dynamo	0.25	0	0	0	0
Oil seed rape	1	0	0	0	0

Plantain - Captain	1.5	18.9	7.8	9.6	19.7
Chicory	1	15.0	7.5	0	4.9
Sunflower	6	0	0	0	0
Squash	0.25	0	0	0	0
Buckwheat	2	0	0	0	0
Linseed	2.5	0	0	0	0
Phacelia	0.5	0	0	0	0

[1]DIV180 (180 kg seed/ha) and DIV45 (45 kg seed/ha) diverse mixes have the same species-cultivar proportions.

Species identifications (ref): Italian ryegrass *Lolium multiflorum*, Tall fescue *Festuca arundinacea*, Perennial ryegrass *Lolium perenne*, Cocksfoot *Dactylus glomerata*, Prairie grass *Bromus catharticus*, Grazing brome *Bromus stamineus*, Japanese millet *Echinchloa esculenta*, Canary seed *Phalaris canariensis*, Oats *Avena sativa*, Barley *Hordeum vulgare*, Maize *Zea mays*, Peas *Pisum sativum*, White clover *Trifolium repens*, Persian clover *Trifolium resupinatum*, Arrowleaf clover *Trifolium vesiculosum*, Crimson clover *Trifolium incarnatum*, Lucerne *Medicago sativa*, Red clover *Trifolium pratense*, Lotus *Nelumbo nucifera*, Rape *Brassica napus*, Pasja *Brassica rapa* × *Brassica napus*, Turnip *Brassica rapa*, Plantain *Plantago lanceolata*, Chicory *Cichorium intybus*, Sunflower *Helianthus annus*, Squash *Cucurbita spp.*, Buckwheat *Fagopyrum esculentum*, Linseed *Linum usitatissimum*, Phacelia *Phacelia distans*, Sub clover *Trifolium subterraneum*, Balansa clover *Trifolium michelanium*,.

and a sowing rate of 180 kg/ha. As the suggested sowing rate was considered very high relative to conventional New Zealand pastoral re-grassing practise, we included an additional treatment with the same diverse mix sown at 45 kg seed/ha with the same seed proportions. In both the hyper-diverse mixes, peas, oats and barley made up 66% of the total seed weight sown but only made up 12.7% of the total number of seeds sown. The ryegrass/clover and plantain/clover mixtures were as normally sown at the research farm. Treatment mixtures were as follows (detailed in Table 1):

- Ryegrass/clover. Sown at 32 kg/ha (four spp; (RYE)
- Plantain/clover. Sown at 22 kg/ha (six spp; PLANT)
- Diverse species mix. Sown at 45 kg/ha (31 spp; DIV45)
- Diverse species mix. Sown at 180 kg/ha (31 spp; DIV180)

Additional plots were sown for the 20 cm harvest height treatments to allow destructive measures (i.e., for pasture species composition and water infiltration) to be undertaken without compromising the forage growth rates within the trial period.

Herbage accumulation and species composition

All plots were mown to either 20 or 8 cm when the DIV180 plots cut to 20 cm reached approximately 30 cm in height. This resulted in 15 harvest dates over the two-year trial period.

Herbage dry matter (DM) yield was determined by weighing the fresh herbage harvested down to 8 or 20 cm with a modified lawn mower. A 400 g subsample of the fresh forage harvested was weighed and and dried at 100ºC for 48 hours to calculate the dry matter content (%). The dry matter yield was then calculated from the fresh weight and the dry matter percentage. Species composition assessments on the additional plots were carried out on pasture samples cut to ground level using a 0.32 m × 0.32 m quadrat 6 months after sowing (November 2021). Species composition assessments on the main herbage accumulation plots were carried out on pasture samples cut to ground level using a 0.32 m × 0.32 m quadrat at the end of the experiment (May 2023). The samples were dissected to individual species level (cultivars of the same species could not be distinguished reliably). The species present were identified and recorded. Each individual species sub-sample was weighed moist, then dried at 100ºC for 48 hours and reweighed. The proportion of each species on a DM basis was then calculated.

Soil measurements

Water infiltration rates were measured three times – November 2021, December 2022 and May 2023 on the RYE and DIV180 and DIV45 plots cut to 20 cm, and in May 2023 in all plots. Water infiltration rates were measured by applying 250 ml of water to the soil contained by a metal ring (150 mm in diameter, one per plot) 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 disappear. Two further applications of 250 ml were applied at each measurement period (Integrity Soils 2022, USDA 2022).

Soil total carbon (TC), total nitrogen (TN) and bulk density were measured to 30 cm using a 50 mm corer. Prior to the plots being laid out and any treatment or compost applied, sixteen core samples were taken in a grid across the experimental area. At the end of the experiment, two core samples within each plot were collected. 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 100°C to calculate bulk density. The remaining soil was dried at 60°C 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 'Dumas combustion'; 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 TC and Thermal Conductivity detection for TN 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.

Biological activity measures

At the completion of the trial (June 2023) earthworms present in a 20 cm × 20 cm × 20 cm turf dug at random from each plot were identified and counted. Three earthworm species were identified – *Lumbricus rubellus*, *Aporectodea calignosa* and *Aporectodea longa* (Shepherd, 2009).

Biological decomposition activity was measured by the method of Correll et al. (1997). Specifically, a known weight of dry cotton cloth was vertically inserted into the ground within each plot. After 8 weeks, the cloth was recovered by digging out the remaining material and the surrounding dirt. The dirt was removed by washing and the pieces of material remaining 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.

Statistical analyses

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

Results

Herbage total production and accumulation rates

Plots harvested at 8 cm produced significantly more total DM over two years (P_{height} < 0.001, Table 2). Within the 8 cm harvest height treatment, the PLANT and DIV180 mixes produced the greatest total herbage DM, and the RYE and the DIV45 mixes the least (P_{forage} <0.001). Within the 20 cm harvest height treatments, the two diverse mixes grew the most herbage DM although this was only significant for the DIV180 treatment, hence the harvest height × forage mix interaction was also significant (P <0.01).

The DIV45 and DIV180 grew more DM over the first six months after sowing than the RYE and PLANT at 20 cm cutting height and the DIV180 was also significantly higher at the 8 cm cutting height (Table 2). All forage treatments grew more DM at 8 cm than at 20 cm. There was a seasonal pattern of mean daily DM accumulation measures (Fig. 1) but there was no

Table 2 Dry matter production (kg DM/ha) from different forage mixtures, mowed at 8 cm and 20 cm above ground at each harvest, from sowing (May 2021) until the end of the study (May 2023).

Cutting height	Sowing mix	6 month DM production	6 to 12 month DM production	Year 2 DM production	Total DM production
8	RYE	3377^{c}	8035^{c}	13786^{c}	25198^{d}
8	PLANT	3371^{c}	9461^{d}	14818^{d}	27651^{e}
8	DIV45	4094^{cd}	7537^{c}	13415^{c}	24867^{d}
8	DIV180	4705^{d}	8131^{c}	14190^{cd}	27026^{e}
20	RYE	1635^{a}	4500^{a}	6697^{a}	12851^{a}
20	PLANT	1714^{a}	5103^{ab}	8586^{b}	15383^{b}
20	DIV45	2554^{b}	5008^{ab}	8881^{b}	16782^{bc}
20	DIV180	3343^{b}	6010^{b}	9434^{b}	18787^{c}
SEM		173	251	289	464
P_{forage}		0.001	0.001	0.001	0.001
P_{height}		0.001	0.001	0.001	0.001
$P_{interaction}$		0.38	0.001	0.007	0.001

RYE, ryegrass/clover mix, PLANT, plantain/clover mix DIV45, diverse mix sowed at 45kg/ha; DIV180, diverse mix sowed at 180 kg/ha. SEM = average standard error of the means.

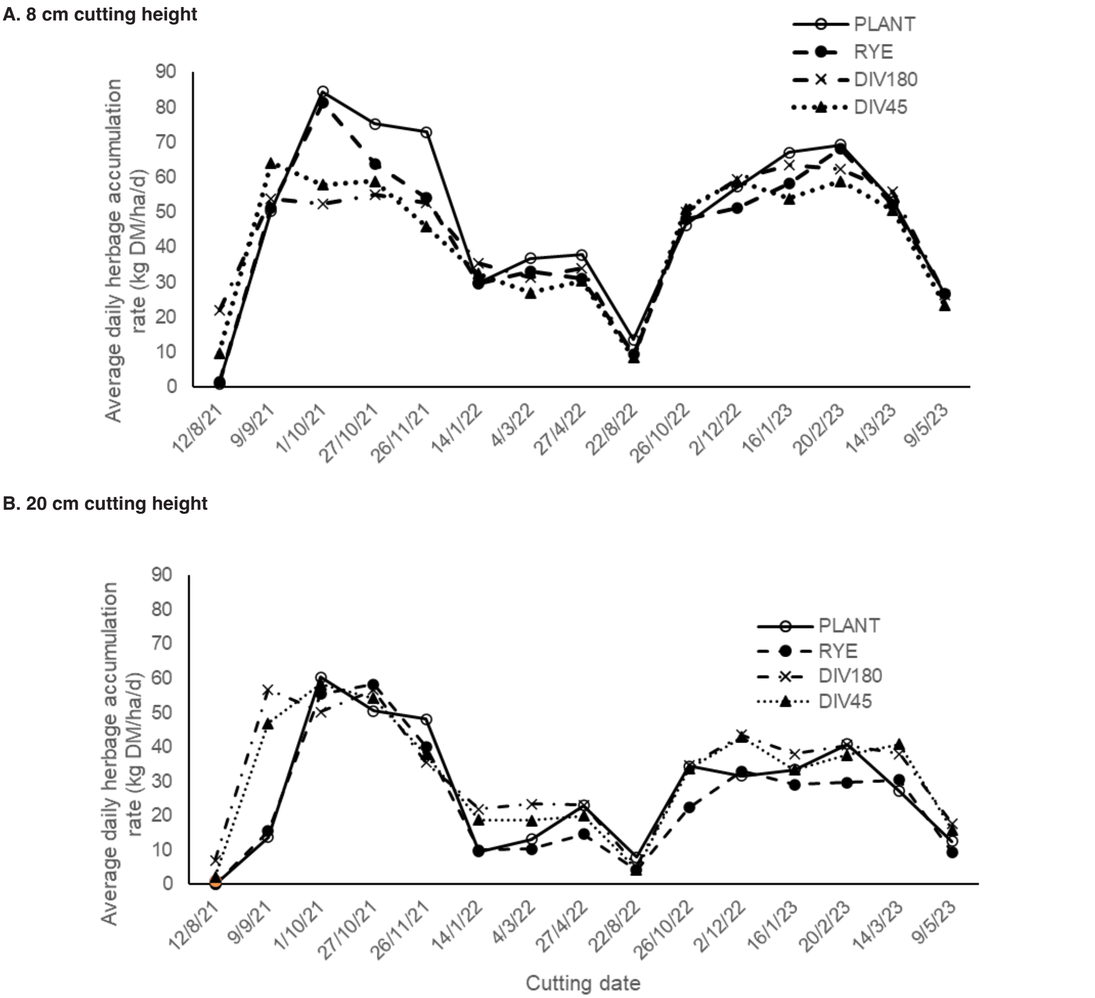

Figure 1 Daily herbage accumulation rates (kg DM/ha/d) of the 4 forage treatments mown at two different heights, a) 8 cm and b) 20 cm, over a two-year period from sowing in May 2021. DIV45, diverse mix sowed at 45 kg/ha; DIV180, diverse mix sowed at 180 kg/ha; PLANT, plantain/clover mix; RYE ryegrass/clover mix.

evidence that the daily DM accumulation was greater on the DIV mixes than the PLANT mix.

Forage species composition

In the RYE forage mixture cut at 20 cm, ryegrass made up only 14% while red clover made up 35% of the total herbage DM at the end of the study (Table 1a). However, at the 6-month spring dissection on the additional plots, the ryegrass component made up almost 90% of the species present in the 20 cm cutting height (Table 3a).

In the PLANT forage mixture, plantain made up 56.6% of total DM six months after sowing and 35% in plots cut at 20 cm at the end of the study (Table 3a,b) while in the plots cut at 8 cm, plantain remained at 55.7% at the end of the study (Table 3b).

Cereals (barley/oats) and brassicas made up 50% and 69% of total herbage DM produced in the first six months in the DIV45 and DIV180 treatments cut at 20 cm respectively (Table 3a) but were absent at the end of the trial (Table 1c, 3b). Nine of the species sown in the DIV mixes were not seen at all in any plot and two were only seen shortly after germination. Cocksfoot was the most dominant sown grass (17%) present across all four DIV treatment combinations at the end of the two-year study (Table 1c). There were no significant differences in pasture composition between the DIV45 and the DIV180 at 6 months after sowing or at the end of the study (Table 3a,b).

Annual clovers had disappeared from all treatments when final measurements were made in May 2023. There were very high levels of dead material in all swards (15-41%) at the end of the experiment (Table 3a,b). The PLANT cut at 8cm had the lowest level of dead material but it was only significantly different to

Table 3 Herbage dry matter proportions of different plant groups across four forage treatments 6 months after sowing (November 2021) and at the end of the study (May 2023).

A. Plant group composition six months after sowing in the additional plots cut at 20 cm.

Forage treatment	Grass	Clover	Other legume	Brassica	Herb	Cereal	Other	Weed	Dead
RYE	89.8[c]	2.9 [b]	0 [a]	0 [a]	0 [a]	0 [a]	0	7.3	0 [a]
PLANT	16.3 [a]	20.2 [c]	0 [a]	0 [a]	56.6 [b]	0 [a]	0	6.7	0 [a]
DIV45	37.1 [b]	0.9 [b]	3.4 [b]	37.4 [b]	0.2 [a]	12.8 [a]	1.5	6.4	0.5 [ab]
DIV180	20.5 [ab]	0.1 [b]	2.5 [b]	42.1 [b]	0.5 [a]	26.7 [b]	5.5	0.6	1.5 [b]
SEM	5.7	3.1	1.2	5.8	3.9	4.3	2.0	3.1	0.3
P	0.001	0.002	0.16	0.001	0.001	0.002	0.21	0.46	0.01

B. Species group composition at the end of the study in the main plots, cut at 8 or 20 cm

Cutting height	Forage treatment	Grass	Clover	Other legume	Brassica	Herb	Cereal	Other	Weed	Dead
8	RYE	38.6[ab]	36.7 [bc]	0	0	0 [a]	0	0	0	24.7 [abc]
	PLANT	7.9 [a]	21.4 [ab]	0	0	56.7 [b]	0	0	0.5	14.5 [a]
	DIV45	47.3 [b]	22.0 [ab]	0	0	9.6 [a]	0	0	2.9	18.2 [abc]
	DIV180	33.1 [ab]	15.9 [ab]	0	0	33.8 [ab]	0	0	0.9	16.3 [abc]
20	RYE	14.2 [a]	48.6 [c]	0	0	0 [a]	0	0	0	37.2 [bc]
	PLANT	14.3 [a]	20.0 [ab]	0	0	35.1 [ab]	0	0	0.1	30.6 [abc]
	DIV45	22.8 [ab]	9.8 [a]	0	0	24.6 [ab]	0	0	1.7	41.1 [c]
	DIV180	34.7 [ab]	10.9 [a]	0	0	15.3 [a]	0	0	0	39.1 [bc]
	SEM	7.0	5.3			8.1			0.74	5.23
	P_{forage}	0.009	0.001			0.001			0.02	0.4
	P_{height}	0.5	0.7			0.3			0.2	0.001
	$P_{interaction}$	0.07	0.2			0.12			0.9	0.7

RYE, ryegrass/clover mix, PLANT, plantain/clover mix DIV45, diverse mix sowed at 45kg/ha; DIV180, diverse mix sowed at 180 kg/ha. Grass includes Italian ryegrass, tall fescue, perennial ryegrass, cocksfoot, grazing brome, Japanese millet, canary seed; Clover includes white, red, persian, arrowleaf, crimson, sub, balansa clovers; Other legume includes peas, lucerne, lotus; Brassica includes rape, pasja, turnip, oil seed rape; Herb includes plantain and chicory; Cereal includes oats, barley; Other includes maize, sunflower, squash, buckwheat, linseed, phacelia. SEM = average standard error of the means. P_{forage} P value for differences between the four forage treatments P_{height} statistical differences between the two cutting heights. $P_{interaction}$ statistical interaction between the two main treatments

Table 4 Effect of four forage mixture treatments and two cutting heights (8 cm vs 20 cm) on infiltration rates (seconds to water disappearance) following three consecutive 250 ml water applications at the end of the study (May 2023)

	Cutting height and water application					
	8 cm			20 cm		
Forage mixture	**1**	**2**	**3**	**1**	**2**	**3**
RYE	36.6	215.0	544.1	35.3	122.2	290.3
PLANT	36.6	319.7	616.0	18.6	76.3	135.3
DIV45	15.8	115.7	306.9	21.5	70.4	141.5
DIV180	22.5	74.1	154.7	28.4	190.1	321.0
SEM	9.3	67.1	159.1			
P_{forage}	0.31	0.44	0.52			
P_{height}	0.77	0.17	0.11			

RYE, ryegrass/clover mix, PLANT, plantain/clover mix DIV45, diverse mix sowed at 45kg/ha; DIV180, diverse mix sowed at 180 kg/ha. SEM = average standard error of the means.

Table 5 Effect of four forage mixture treatments and two mowing heights (8 and 20 cm) on soil bulk density (BD), total nitrogen (TN) and total carbon (TC) levels in the top 30 cm of soil in May 2023, two years after sowing.

Mowing height (cm)	Forage mixture	BD (mg/m^3)	TN (%)	TC (%)	C:N Ratio
8	RYE	1.02	0.21	2.48	11.7
	PLANT	1.01	0.22	2.55	11.9
	DIV45	1.05	0.23	2.67	11.4
	DIV180	0.98	0.22	2.43	10.9
20	RYE	1.00	0.19	2.42	16.2
	PLANT	1.05	0.22	2.33	11.8
	DIV45	1.06	0.19	2.34	14.0
	DIV180	1.02	0.22	2.34	12.0
SEM		0.03	0.02	0.21	1.77
P_{forage}		0.22	0.66	0.95	0.42
P_{height}		0.26	0.15	0.20	0.09

RYE, ryegrass/clover mix; PLANT, plantain/clover mix ; DIV45, diverse mix sowed at 45kg/ha; DIV180, diverse mix sowed at 180 kg/ha. SEM =average standard error of the means.

the two diverse swards and the RYE sward cut at 20 cm (Table 3b).

Soil characteristics

Water infiltration rates were variable across replicates and when the DIV180 and RYE cut at 20 cm were compared at three different dates there was no effect of application date or forage treatment. There were no differences in water infiltration rates due to forage treatments or mowing height at the end of the study (Table 4).

At the end of the two-year study, there was no significant difference in bulk density, soil TC or TN between forage mixture type or mowing height ($P>0.05$, Table 5).

The initial site measures enabled a test of overall site changes in bulk density, TC and TN over time. Soil bulk density decreased from 1.14 g/cm^3 prior to sowing to an average of 1.03 g/cm^3 at the end of the trial. Soil carbon increased over the course of the trial, from 2.1% (71.8 t C/ha to 30 cm depth) in the newly cultivated soil prior to sowing to an average of 2.5% (77.2 t C/ha to 30 cm depth) across all the sampled plots two years after sowing. Soil nitrogen stayed much the same at 0.22% (7.4 t N/ha to 30 cm depth) prior to sowing and 0.21% (6.5 t N/ha to 30 cm depth) at the end.

Biological activity measures

Earthworm numbers were variable across replicates and there was no effect of forage or mowing height on population numbers at the completion of the trial (June 2023, Table 6). Most of the earthworms were

Table 6 Earthworm species and numbers measured two years after sowing four forage mixture treatments under two different cutting regimes (8 cm and 20 cm cutting heights).

	Lumbricus rubellus		*Aporectodea calignosa*		*Aporectodea longa*		All species	
Forage mixture	**8 cm**	**20 cm**	**8 cm**	**20 cm**	**8 cm**	**20 cm**	**8 cm**	**20 cm**
RYE	6	3	27	28	6	13	39	42
PLANT	6	7	33	44	9	7	48	58
DIV45	3	6	27	38	3	9	33	53
DIV180	9	5	23	30	7	5	39	40
Mean	6.3	5.4	27.6	34.6	7.3	8.4	41.9	55.3
SEM	2.3		8.8		1.9		7	
P_{forage}	0.60		0.50		0.30		0.50	
P_{height}	0.60		0.30		0.14		0.02	

RYE, ryegrass/clover mix; PLANT, plantain/clover mix; DIV45, diverse mix sowed at 45kg/ha; DIV180, diverse mix sowed at 180 kg/ha. SE M = average standard error of the mean.

Aporectodea calignosa (70%) with smaller numbers of *Lumbricus rubellus* (13%) and *Aporectodea longa* (17%).

On average, half of the buried cotton material was broken down over 8 weeks (46.6% under the 8 cm mowing height treatments and 53.1% under the 20 cm mowing height treatments; Table 7). However, neither the mowing height treatment effect nor the forage mixture treatment effects were statistically significant (P>0.05).

Table 7 Decomposition rates (percent disappearance of buried cotton over eight weeks) when measured at the end of the trial period (May 2023) in four forage mixture treatments and two cutting height treatments.

Forage mixture	Cutting height	
	8 cm	20 cm
RYE	57.3	78.8
PLANT	37.1	42.9
DIV45	44.6	33.4
DIV180	47.7	57.1
SEM	16.8	
P_{forage}	0.59	
P_{height}	0.15	

RYE ryegrass/clover mix.; PLANT, plantain/clover mix; DIV45, diverse mix sowed at 45kg/ha; DIV180, diverse mix sowed at 180 kg/ha. SEM average standard error of mean.
SEM = average standard error of the means.

Discussion

The use of up to 20 species in a sowing mix was common in the early days of New Zealand agriculture when there was little knowledge on the productivity of different species (Harris 1968). Pasture ecologists noted that these complex seed mixtures led to a few dominant species and this led to the development of ryegrass/white clover swards (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 different 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 benefit in terms of total yield but there have been increases in summer production (Pemberton et al 2015: Ruz-Jerez et al. 1991; Woodward et al. 2013: Vibart et al. 2016). It was hoped that this increase in summer production would be beneficial in increasing pasture production under the summer-dry conditions that occur in the Hawke's Bay. Plantain-based pastures have shown previous advantages by producing a bulk of high-quality feed in spring and enabling destocking before summer (Muir et al. 2019).

Whilst the studies above focused on moderate levels of species diversity, the present study aimed to replicate a hyper-diverse mixture which had been promoted locally and included 5 plant functional groups (grasses, legumes, forbs, brassicas, chenopods). The need to include these 5 plant groups in a sowing mix is a recent trend which has been popularised by some proponents of regenerative agriculture (Quorum Sense 2025) and by some of the seed companies selling mixes to meet this market (e.g., 20 Way perennial mix, Pastoral Improvements).

In the present study, sowing of annuals contributed to early DM production (cereals and brassicas made up 68.8% of total DM 8 months after sowing in the high sowing rate) then they disappeared. At the end of the study, only around 7 of the original 31 sown species were present with 7 species never seen in any of the plots and with a further two species only seen around germination. Tracy and Sanderson (2004) saw a similar effect with no improvements in dry matter production when more than two species were sown i.e. in going from a moderate diverse mix through to a hyper-diverse mix, and with only around 30% of the original species sown present in the more complex mixes (up to 15 species) after three years. The remaining species after three years were dominated by perennial grasses.

In grazing studies, the preferred species such as legumes and herbs are likely to be heavily grazed by sheep (Ruz-Jerez 1991, Grace et al. 2018) and this means that some of the red clover present at the end of this mowing study may have disappeared in a grazing situation. In the present study, cocksfoot in the diverse swards became the dominant species presenting as large clumps by the end of the study. It is worth noting that whilst most New Zealand pastures appear to be similar when viewed from a distance and are generally referred to as ryegrass/white clover dominant, the reality is that they are often far from homogeneous. As an example, 30-year-old pastures at the current site contained 7 pasture species with ryegrass making up 32% of the sward (Mills et al. 2021). Chapman et al. (2024) found while in lowland areas of NZ, pastures are mostly ryegrass and white clover, hill country pastures which are subject to less intense management, typically contained 6–10 perennial grasses and broadleaved species (including legumes). Tozer et al. (2014) found a wide variety of species including sown grasses, unsown grasses, clovers, herbs and a range of broadleaved weed, in pasture samples collected from dairy farms with differences between regions and seasons. Dodd et al. (2003) reported that hill country pasture in the North Island of New Zealand typically consists of 15 to 25 species/m^2 with up to 40 species found. Clearly many current New Zealand pastures already contain substantial species and functional diversity and many sheep and beef farmers sow more than two species into their permanent pasture mixes.

Lax grazing and high residuals are promoted as a key feature of regenerative agriculture (Terra Genesis 2020). Both cutting heights (8 and 20 cm) resulted in high amounts of dead material (20-30%) at the end of the experiment. The 8 cm cutting height produced an average of 10 tonnes more herbage DM over two years than the 20 cm cutting height when averaged across the forage mixes (26185 vs 15950 kg DM/ha, Table 2). This difference in yield is more than can be explained by the difference in cutting height. At the 8 cm cutting height, there were no significant differences in herbage DM yield between PLANT and DIV180 mixtures but the DIV45 and RYE mixtures produced less total herbage DM. At the 20 cm cutting height the DIV180 and DIV 45 mixtures grew more herbage DM than PLANT mixture and all grew significantly more herbage DM than the RYE mixture. Whilst the mowing height of 8 cm was well suited to the PLANT mixture, the 20 cm mowing height was poorly suited to the PLANT mixture and particularly to the RYE mixture.

The current study found no treatment effects of pasture mixtures or mowing height on water infiltration rates, decomposition activity and earthworm abundance. A recent Welsh study (Cooledge et al. 2024) compared herbal leys and grass-clover under grazing and also found no effect on soil porosity, earthworm abundance and microbial communities. These results conflict with some of the hypotheses raised about plant species composition enriching soil microbial communities (Orwin and Wardle 2005).

There were no treatment effects on soil carbon, so increasing the number of species sown and including deeper rooting species did not result in any differences in soil carbon within the two year timeframe of this study. This time period is short but we aimed to determine whether trends would occur due to the use of the high sowing rates and hyper-diversity of the diverse mix. However, soil carbon (0-30 cm) increased from 2.1% in the recently cultivated paddock prior to sowing to an average 2.5% carbon across the sown swards two years later. The area had been fully cultivated prior to sowing and cultivation and exposure of the soil increases the loss of carbon and once re-pastured the carbon could be expected to re-accumulate (Schon et al. 2024) as it did here.

Conclusions

A mowing height of 8 cm generated significantly more dry matter than the 20 cm mowing height across all forage mixtures, but the different forage mixes responded differently to mowing height. There was evidence that sowing a plantain/clover mix or a ‘hyper-diverse’ mix (which included the five plant functional groups at a high sowing rate) produced more dry matter production over two years compared to a ‘conventional’ ryegrass/clover sward, when cut at a high residual (20 cm) to represent very lax grazing. However, with only approx. one third of the species remaining after 2 years in the DIV180 treatment, the high cost of the seed mix and the value of the extra sown species is questionable. It is possible a smaller number of carefully selected species would be beneficial and could be achieved at a lower cost. Sowing cereals or brassicas in a hyper-diverse mixture appeared to compromise the survival of other species. At the lower cutting height, the plantain/clover mix represented the highest dry matter production. In this mowing study, sowing mixture and mowing height had no effect on earthworm numbers, decomposition activity, water infiltration rates, soil nitrogen or soil carbon over the two-year measurement period.

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