Agronomic performance of summer forage crops on a Waikato dry-stock farm

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Abstract

Forage crops options are required by dry-stock farmers to fill summer feed gaps. This trial compared a brassica monoculture with simple and hyper-diverse mixtures containing up to 21 forage species sown in October on a Waikato dry-stock farm. Two of the twelve treatments were established at paddock scale. Species included rape, oats, plantain and red clover. Seedling emergence was assessed four weeks after sowing and herbage production, metabolisable energy and botanical composition in mid-January. Rape was common in all mixtures for the provision of high-quality forage. Oats suppressed rape production, even at low sowing rates (<13 kg/ha), and reduced weed ingress. Plantain, sown at <2 kg/ha, contributed negligible dry matter in mid-January but provided ground cover and additional forage by late February. Red clover failed to establish. Most diverse treatments provided a similar energy yield (MJ ME/ha) to rape. Simple mixtures and hyper-diverse mixtures were similar for most metrics. Results at plot and paddock scale were consistent for the energy yield effects. When these data were combined with production costs, the energy costs were similar for most treatments. The most promising was a rape dominant mixture, with high energy yield, low weed abundance and low energy costs.

Keywords: crop mixtures, livestock maintenance, summer feed

Introduction

With increasing climatic variability and droughts in the upper North Island, pasture growth in mid to late summer is often insufficient to meet livestock requirements on hill country farms. Current practices used to fill this feed gap include the use of supplements (*e.g.,* palm kernel extract; PKE), deferred grazing, and single-graze brassica crops. However, all these come with associated financial and environmental costs. Deferred grazing can provide feed during drought, but the nutritive value of deferred pasture is low, particularly in dry years when the deferred pasture has a high content of senescent vegetation (Tozer et al.*,* 2020).

Brassica monocultures provide high energy feed and are a summer-safe option to finish stock when pasture quality is low (de Ruiter et al.*,* 2009; Barry 2013). They are intensive to manage, require chemical inputs to control pests and weeds, and have high fertiliser requirements for optimal production (de Ruiter et al.*,* 2009; Morton et al.*,* 2020). Summer brassica crops provide less ground cover than pasture, which can increase the risk of phosphorus, nitrogen and sediment losses to water bodies through leaching and runoff (Morton et al.*,* 2020).

Recently, there has been interest in hyper-diverse multi-species forage crops (*e.g*., 12-spp., Alemu et al.*,* 2019; Rowarth et al.*,* 2020). Benefits of botanical diversity include greater yield, stability of yield in years of climatic extremes and reduced weed ingress (Sanderson et al.*,* 2007; Pembleton et al.*,* 2015). Including a wide range of species can act as an 'insurance policy' ensuring that at least some of the species in the mix will grow well regardless of the environmental conditions, 'taking the place of species that fail from stress or mismanagement' (Sanderson et al.*,* 2007). In the late 1800s, hyper-diverse mixtures containing at least 20 species were popular and known as 'shotgun' mixtures (Charlton 1991). A weakness of this approach is that many of the species in a hyper-diverse mix may be outcompeted or not well suited to an upper North Island environment, and will fail to establish. These mixtures may be costly as many of the species are niche-produced and not readily available.

Another approach is to use mixtures with fewer species carefully selected to provide key functional agro-ecological attributes suitable for their environment (Charlton 1991). Pembleton et al. (2015) showed that the benefits of multi-species mixtures come from species selection and proportions within the mix and not through the species number *per se*. This diversity effect was demonstrated by Ryan-Salter and Black (2012) and Black et al. (2017), who demonstrated that it is the proportions of the species in the mix, not just the identity, which affect the overall yield. However, it is unknown how the production of diverse forage crops, containing mixtures of grasses, legumes and herbs, compare with a conventional summer brassica monoculture.

The approach of the following trial was to apply these principles in designing diverse mixtures for a single-graze summer crop for a Waikato dry stock farm.

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(Anderson 1973; Eagles et al., 1979; Barry 2013). It was hypothesised that: (i) diverse crop mixtures would be as productive as a brassica monoculture, and (ii) simple crop mixtures, where species have been chosen for a few key traits, would be as productive as hyper-diverse mixtures.

To test these hypotheses, a range of simple four-species mixtures and more complex multi-species mixtures with up to 21 species were compared with a brassica monoculture on a Waikato dry-stock farm. Key performance indicators were herbage production, metabolisable energy (ME), weed incursion and energy yield costs.

Materials and Method

Site establishment

A 0.07 ha plot study and two case study paddocks, averaging 1.3 ha, were established in September 2021 on a 240 ha dry stock finishing property at Te Pahu, Waikato, New Zealand (37º 55’ 9.12” S, 175º 8” 6” E, 100 m a.s.l.). The site had a typic orthic allophanic soil with 0-75 mm values of pH = 6.0, Olsen P = 23 mg/kg, potassium = 7 MAF Quick Test, calcium = 10 MAF QT, magnesium = 12 MAF QT, and sulphate sulphur = 32 mg/kg. Spring rainfall (September-November) measured at the site was 480 mm. In early December, 30 mm was recorded, after which there was no rainfall for 40 d, until after the site was harvested. Spring rainfall was higher than the long-term average of 384 mm but the rainfall in December and January was much lower than the long-term average of 106 mm and 92 mm, respectively (NIWA virtual climate station data 2010-2020, 10-year average rainfall).

Plot study establishment and management: A mixture of Crucial™ (non-selective) herbicide and Dew600™ insecticide (Table 1) was applied with 150 l water/ha in September 2021. Fertiliser was applied one week later at a rate of 500 kg/ha, comprising a mix of PastureMag 12N, Muriate of Potash and NutriMax Boron15% (N: 51.8, P: 23.0, K:25, S: 28.4; Mg: 17.1, Ca: 56; Ballance Agri-Nutrients). The site was disced, power harrowed and rolled prior to sowing.

A small plot precision drill with a width of 1.5 m and

Table 1 Chemicals used in the small plot study and case study paddocks a.i.: active ingredient.

Trade Name	Chemical	Chemical type	Application rate	
			Product (ml/ha)	a.i. (g/ha)
Crucial™	600 g/l Glyphosate	Herbicide	2400	1440
Dew600™	600 g/l Diazinon	Insecticide	400	240
T-Max™	30 g/l Aminopyralid as a triisopropylamine salt	Herbicide	1000	30
Ampligo™	50 g/l Lambda-Cyhalothrin + 100 g/l Chlorantraniliprole	Insecticide	100	150
SeQuence™	100 g/l Clethodim	Herbicide	350	250
Prestige™	150 g/l Picloram + 225 g/l Clopyralid	Herbicide	300	113
Exirel™	100 g/l Cyantraniliprole in the form of a suspo-emulsion	Insecticide	150	150
Bonza oil™	471 g/l Petroleum-based wetting agent	Wetting agent	1000	471
Slugout™	18 g/kg Metaldehyde	Slug bait	8*	144

* Slugout applied as kg/ha.

Table 2 Species and sowing rates (kg/ha) for ten of the twelve mixtures established in a small plot study. Plan: plantain, RC: red clover, CF: cocksfoot.

Species	Mono-				Dom-					Equal-spp
	Rape	Oats	Plan	RC	Rape	Oats	Plan	RC	CF	
Rape	4				2.4	0.5	0.5	0.5	0.5	1.0
Oats		100			13	61	13	13		25
Plantain			12		1.6	1.6	7.3	1.6	1.6	3.0
Red clover				9	1.2	1.2	1.2	5.5	1.2	2.3
Cocksfoot									9	
Total	4	100	12	9	18.2	64.3	22.0	20.6	12.3	31.3

row spacing of 15 cm was used to sow all seed mixtures (Table 2) at a depth of 1 cm on 16 October. The site was not rolled after, as there was risk of burying some species too deeply and reducing emergence. After sowing, diammonium phosphate (DAP, Ballance Agri-Nutrients) was hand-broadcast at 200 kg/ha, followed by application of Slugout™ (Table 1). No further chemical applications were made for the study duration.

Case study paddock establishment and management: The seed bed was prepared in the same way as the plot study. Paddocks were sown between 9-23 October 2021 with a Kuhn Triple disc drill. To control broadleaf weeds and insects, a mixture of T-Max™ and Bonza oil with 200 l water/ha was applied to the four-species mixtures, and a mixture of Ampligo™, Sequence™, Prestige™ and Bonza oil™ with 200 l water/ha was applied to the rape monoculture, one month after sowing (Table 1). Exirel™ was applied with 200 l water/ha in early January to control white butterfly (*Pieris rapae*) on rape.

Treatments

Plot study: Twelve treatments were arranged in a randomised complete block design, with three replicates of each treatment. Plot size was 3 m x 6.5 m. Treatments comprised four monocultures, six four-species mixtures, and two hyper-diverse 11- and 21-species mixtures (Table 2). Rape (*Brassica napus*), oats (*Avena sativa*), plantain (*Plantago lanceolata*), and red clover (*Trifolium pratense*) were sown as monocultures (-mono). Rape, oats, plantain and red clover were combined in equal proportions by weight, and in mixtures where each of the species was dominant in turn. In the dominant treatments (-dom), the dominant species was sown at 61% of the monoculture sowing rate and the other three species were sown at 13% of the monoculture sowing rate. For the equal-species treatment (equal-spp), each of the species were sown at 25% of the monoculture sowing rate (Table 2). There was an additional treatment in which cocksfoot (*Dactylis glomerata*) was substituted for oats to create a cocksfoot-dom treatment.

Two hyper-diverse mixtures were designed by the seed suppliers to provide a high yielding and high energy mix. The 11-species mixture (11-spp), sown at a rate of 27 kg/ha included: rape (1 kg/ha), plantain (1 kg/ha), red clover (2 kg/ha), chicory *(Cichorium intybus* 1 kg/ha), buckwheat (*Fagopyrum esculentum,* 2 kg/ha), phacelia (*Phacelia tanacetifolia,* 1 kg/ha), pea (*Pisum sativum,* 8 kg/ha), crimson clover (*Trifolium incarnatum* 2 kg/ha), white clover (*Trifolium repens,* 1 kg/ha), vetch (*Vicia sativa,* 3 kg/ha) and triticale *cv.* Kudos *(xTriticosecale)* (5 kg/ha).

The 21-species mixture (21-spp), sown at 66 kg/ha included: rape (0.3 kg/ha), oats (8 kg/ha), plantain (2 kg/ha), red clover (4 kg/ha), cocksfoot (*Dactylis glomerata,* 2 kg/ha), prairie grass *(Bromus wildenowii* 4 kg/ha), chicory (1 kg/ha), tall fescue (*Festuca arundinacea,* 4 kg/ha), meadow fescue *(Festuca pratensis,* 6 kg/ha), sulla *(Hedysarum coronarium,* 3 kg/ha), sunflower (*Helianthus annus,* 3 kg/ha), perennial ryegrass (*Lolium perenne,* 4 kg/ha), hybrid ryegrass (*Lolium hybridum,* 4 kg/ha), lupin (*Lupinus angustifolius,* 5 kg/ha), lucerne (*Medicago sativa,* 4 kg/ha), timothy (*Phleum pratense,* 1 kg/ha), strawberry clover (*Trifolium fragiferum,* 2 kg/ha), crimson clover (2 kg/ha), balansa clover (*Trifolium michelianum,* 2 kg/ha), white clover (3 kg/ha) and vetch (2 kg/ha).

Case study paddocks: There were two paddock-scale case studies, which comprised a rape dominant mixture and an 11-species mixture. The rape-dominant mix (rape-dom-pdk), sown at a rate of 19 kg/ha included: rape (3 kg/ha), oats (13 kg/ha), plantain (1.5 kg/ha) and red clover (1.5 kg/ha). The 11-species mix (11-spp-pdk) was the same species and sowing rates used for the plot study 11-spp mixture.

Seedling emergence

Glasshouse seedling emergence: This was conducted to ensure that the seed for the plot study was viable. In mid-October 2021, 100 seeds each of rape, oats, plantain, red clover and cocksfoot were sown at a depth of 1 cm into seed trays (30 cm x 41 cm, 5 cm depth) filled with Premium Seed Mix (Daltons Ltd, Matamata). The trays were placed in a glasshouse at AgResearch, Hamilton, with average day/ night temperatures of 21.9^{o}C and 15.7^{o}C, respectively, watered daily and emerged seedlings counted one month after sowing. Covid19 prevented this being done prior to sowing the trial.

Trial site seedling emergence: One month after sowing, all seedlings of sown species were counted in four randomly selected, 1 m lengths of drill row in each plot and paddock.

Herbage measurements

Between 18-21 January 2022, herbage was cut to ground level in two randomly positioned 1 m^2 quadrats per plot (four per paddock). A mid-January harvest date was chosen by the farmer, as that is when there was a pasture supply shortage. Herbage was weighed, shredded to obtain pieces <5 cm in length, sub-sampled (*ca*. 500 g) and oven-dried at 65^{o}C for 48 h or until a constant weight. Sub-samples were bulked and ground using a UDY Mill with a 1 mm sieve for a feed profile analyses by Hill Laboratories, Hamilton. All samples were analysed for ME and crude protein (CP) using near Near-infrared spectroscopy (NIRS; Corson et al*.*, 1999).

A second sub-sample of the shredded herbage was dissected into individual sown species, weeds and dead material, and oven-dried at 65°C for at least 48 h to a constant weight. To determine dry matter production of a rape plant and the ratio of leaf to stem, twelve plants were randomly selected and cut to ground level from rape-mono, rape-dom, equal-spp., and oat-dom treatments. The leaves and stems were separated and oven-dried at 65°C for at least 48 h to a constant weight.

Plantain population density

It was observed in February that plantain growth was prolific. Therefore, density counts were conducted to obtain some quantitative data on its performance. Plantain plants were counted in four, 0.1 m^2 quadrats in each plot on 22 February for the plan-mono, plan-dom, equal-spp and rape-dom treatments. Quadrats were positioned in areas which had been harvested for yield assessments in January.

Statistical Analysis

All analysis was performed in R version 4.1.1. ANOVA was used to assess the treatment effect where row and column position of the plot was included as blocking structure. Pairwise difference used 'predictmeans' whereby pairs of means that share the same letter were not significantly different at 95% confidence limits ($P<0.05$). Statistical analysis was preformed using all 11 treatments, with SED, pairwise significant difference (letter) and P-values presented from this analysis. Treatment 12, the red clover monoculture, was not analysed as red clover did not establish. Herbage production, nutritive value and botanical composition data for the RC-mono, RC-dom, plan-mono, plan-dom and CF-dom were not presented due to establishment failure of the red clover.

For botanical composition and dry matter (kg/ha), a natural logs transformation was required to normalise the variance. Where logs were used, the raw means are presented with the P-values and lettering performed on the log scale. For ME and CP, 25% of the samples were subjected to wet chemistry analyses (Clarke et al., 1982), with ME calculated as 0.16 * DOMD (digestible organic matter in DM) (Alderman and Cottrill 1993). Results obtained by wet chemistry were plotted against values from NIR and a regression analysis undertaken. The relationship between the NIR and wet chemistry results were:

(1) Wet Chemistry ME = 1.47 + 0.86 * ME, $R^2 = 0.99$ ($P<0.001$)

(2) Wet Chemistry CP = -2.53 + 1.16 * CP, $R^2 = 0.85$ ($P=0.002$)

Therefore, NIR was a good predictor of wet chemistry results for ME and crude protein. NIR data were statistically analysed and reported.

The three mixtures sown at paddock scale were not replicated and therefore were not statistically analysed.

Because sunflower stems may be avoided by grazing livestock when they have the choice, the 21-spp treatment in the small plot study was adjusted by removing the sunflower herbage contribution to total DM (21-spp-adj). Estimates for herbage production, energy yield and energy costs for the 21-spp-adj treatment are presented. The adjusted data were not included in the statistical analyses.

Results

Seedling emergence

Seedling emergence in the glasshouse was greater than 70% for the five species tested, except for red clover which had 24% emergence (Table 3). All the sown species emerged in the field for each of the 12 treatments in the plot study (Table 3). Emergence for rape, oats, plantain and red clover increased as its sowing rate increased, with the lowest seedling densities observed when a species was sown as 13% of its monoculture rate and highest when it was sown as a monoculture (Table 3).

Herbage production, energy yield and crude protein content

There was an effect of species mix on herbage production, whereby herbage production of rape-dom and equal-spp was greater than rape-mono ($P<0.05$) while herbage production for 11-spp and 21-spp were similar to rape-mono (Table 4). The ME content was highest for rape-mono, and lowest for equal-spp, with the other treatments being intermediate ($P<0.05$). The energy yield for rape-dom and 21-spp was similar to rape-mono; and energy yield for equal-spp and 11-spp was lower than rape-mono ($P<0.05$). For the case study paddocks, herbage production and energy yield were highest for the rape-dom-pdk and lowest for the 11-spp-pdk.

There were no differences between treatments in the crude protein content, which averaged 8.8±0.6% (±SED) ($P>0.05$).

Botanical composition

Weed content in the case study paddocks ranged from 36-40% of the total DM. Rape-dom, equal-spp, 21-spp, oat-dom and oat-mono had a significantly lower weed content than rape-mono ($P<0.05$, Figure 1). Weed content for 11-spp was similar to rape-mono.

The oats had senesced at the time of harvest but for the purpose of this study were not placed in the 'dead' component. The oat content in equal-spp and oat-dom were similar to oat-mono ($P<0.05$, Figure 1). The oat content in rape-dom and 21-spp was significantly less than oat-mono ($P<0.05$), but oats were the dominant

Table 3 Glasshouse emergence of rape, oats, plantain and red clover; and field emergence of rape, oats, plantain, red clover, cocksfoot, sown grasses, legumes and herbs one month after sowing for the small plot study and two case study paddocks. Species were aggregated into sown grasses, legumes or herbs for the hyper-diverse mixtures (11 spp. and 21 spp. mixtures).

Treatment	Rape	oats	Plantain	Red clover	Cocksfoot	Sown grasses	Sown legume	Sown herbs
Glasshouse emergence (% of total number of seeds sown)								
Glasshouse	74%	97%	83%	24%	83%			
Field emergence (plants per m^2) *Small plot study*								
Rape-mono	80							
Oat-mono		240						
Plan-mono			366					
RC-mono				26				
Rape-dom	33	33	73	7				
Oat-dom	7	120	47	7				
Plan-dom			173					
RC-dom	7	27	47	7				
Equal-spp	20	80	87	13				
CF-dom	7		60	0	133			
11-spp	20		33	13			40	60
21-spp	7	33	20			273	140	27
Case study paddocks								
Rape-dom-pdk	40	13	53	3				
11-spp-pdk	15		40			30	106	65

Table 4 Herbage production, metabolisable energy values and energy yield for seven treatments in the small plot study, the 21-spp-adj treatment, and the two case study paddocks. Rounded values for herbage production and energy yield have been presented.

Treatment	Herbage production kg DM/ha	Metabolisable energy MJ/kg DM	Energy yield MJ ME/ha
Small plot study			
Rape-mono	10860 ^{ab}	11.0 ^{f}	119780 ^{d}
Rape-dom	13350 ^{c}	8.0 ^{ad}	106720 ^{cd}
Equal-spp	13670 ^{c}	6.8 ^{ce}	93280 ^{bc}
11-spp	9470 ^{a}	8.3 ^{a}	78200 ^{ab}
21-spp	12610 ^{bc}	7.9 ^{ad}	100270 ^{cd}
Oat-dom	13040 ^{c}	6.9 ^{ce}	90770 ^{bce}
Oat-mono	11430 ^{bc}	6.6 ^{e}	76050 ^{abe}
SED	999	0.27	10820
Significance level	**	**	*
21-spp-adj	7570	7.9	59770
Case study paddocks			
Rape-dom-pdk	13250	10.8	143070
11-spp-pdk	8530	8.4	71660

Within each column, means with different letters are significantly different for the small plot study ($P<0.05$). Letters refer to the logged transformed data. The standard error of the difference (SED) and means refer to the untransformed data. Case study results are arithmetic means and statistically analysed.

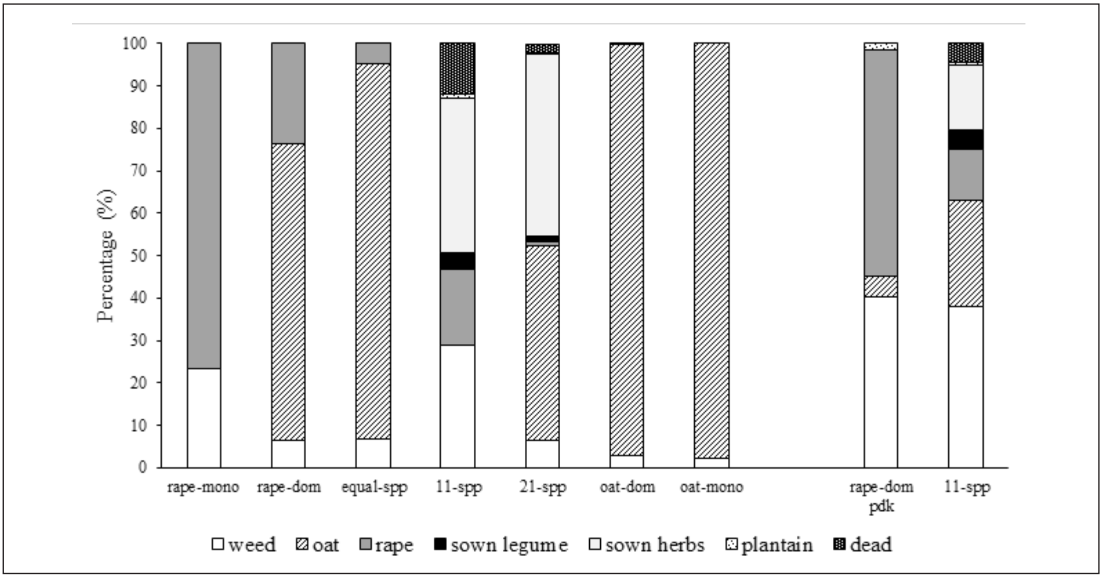

Figure 1 Contribution of weed, oat, rape, sown legumes, sown grasses, sown herbs, plantain and dead vegetation to total DM in the small plot study and two case study paddocks.

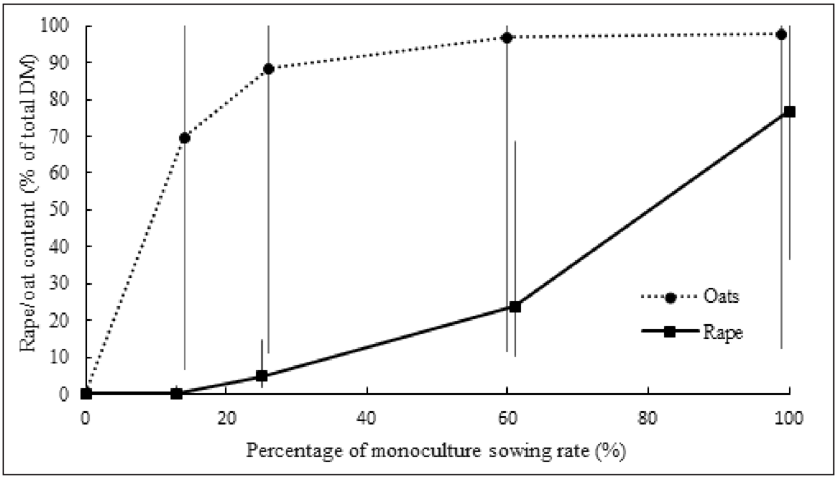

Figure 2 The effect of sowing rate on the contribution of rape and oats to total dry matter (%). The vertical lines show the 95% confidence intervals for means. Sowing rates included 13%, 25% (equal-spp), 61% (-dom) and 100% of their monoculture sowing rate (Table 1).

species in both mixes *i.e.*, 70% and 46% total DM, respectively.

The dominant sown species in 11-spp were rape (18%), triticale (17%), phacelia (15%) and provider pea (4%) (data not presented). For the 21-spp mix, sunflowers contributed approximately 40% of the total DM (86% of the sown herbs) and no sown grasses were present. For plan-dom and plan-mono, the plantain content was less than 10% of the total DM and weeds comprised 90% of total DM (not presented). The content of cocksfoot in cf-dom was less than 0.5% (data not presented).

Effect of rape/oat sowing rates on rape DM and weed suppression

As the sowing rate of rape declined it contributed less to total dry matter, but there was little decline in the contribution of oats to total dry matter until oats comprised 13% or less of their monoculture sowing rate (Figure 2).

When oats comprised 13% or more of their monoculture sowing rate, there was a low content of weeds (<7%, Figure 3), but when oats comprised less than 13% of their monoculture sowing rate, the content of weeds in the total DM rapidly increased. The weed content reached 23% of total DM with no oats were included in the mix.

The effect of the rape sowing rate on the yield of rape plants and the ratio of leaf to stem

Yield per rape plant was highest in rape-mono and rape-dom, intermediate in equal-spp, and lowest in the oat-dom (P<0.05, Table 5). There were no significant differences between the treatments in the ratio of leaf to stem (P>0.05).

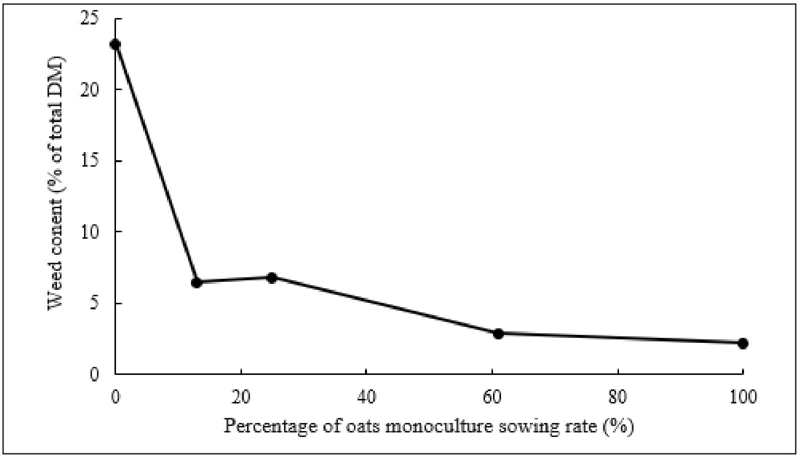

Figure 3 Effect of oat sowing rate on weed content (% of total DM) – oats were sown at 13% (rape-dom), 25% (equal-spp) and 61% (oat-dom) of the oat monoculture sowing rate (100%).

Plantain cover

The content of plantain in total DM was negligible in mid-January in both the plot study and case study paddocks (Figure 1). However, in late February, there were plantain densities of 158, 182, 40, 24 plants per m^2 in the plan-mono, plan-dom, rape-dom and equal-spp treatments respectively.

Economic analysis

All treatments had a similar energy cost in the small plot study (P>0.05, Table 6, Figure 4). The energy cost was 2-fold greater in 21-spp-adj than rape-mono, similar for the 11-spp mixture at plot scale and paddock scale, but lower at paddock scale than plot scale for the rape-dom mixture.

Discussion

Productivity

The results supported the hypothesis that a diverse crop mixture could provide a similar energy yield to a brassica monoculture in mid-summer for this Waikato dry-stock farm. Several of the crop mixtures had a greater herbage production than the rape monoculture, but the lower herbage production of the rape monoculture was compensated by rape having the highest ME. Therefore, considering herbage production and ME combined,

Table 5 Effect of the sowing rate of rape (expressed as a percentage of its monoculture sowing rate) on dry matter production per plant, and the ratio of leaf to stem.

Treatment	Sowing rate (%)	Stem (% of rape DM)	Leaf (% of rape DM)	Yield (g/rape plant)
Rape-mono	100	46_{a}	54_{a}	27_{d}
Rape-dom	61	52_{a}	48_{a}	24_{cd}
Equal-sp	25	51_{a}	49_{a}	15_{ac}
Oat-dom	13	63_{a}	37_{a}	2_{b}
SED		9.53	9.53	3.64
Significance level				**

Within each column, means with the same letter are not significantly different (P>0.05).

Table 6 Production costs, energy yield and energy cost for the treatments in the small plot study, the 21-spp-adj treatment, and case study paddocks. All figures are GST exclusive.

Item ($/ha)	Rape-mono	Rape-dom	Oat-mono	Oat-dom	Equal-spp	11-spp	21-spp	21-spp-adj	Rape-dom-pdk	11-sp-pdk
Seed	86.69	122.89	182.79	81.28	161.53	243.09	467.50 [1]	467.50 [1]	122.89	243.09
Sowing costs [2]	784.84	784.84	784.84	784.84	784.84	784.84	784.84	784.84	784.84	784.84
Post-emergent weed/pest control [3]	319.78	329.26	0.00	329.26	329.26	0.00	0.00	0.00	329.26	0.00
Total production cost ($/ha)	*1191.31*	*1236.99*	*967.63*	*1195.38*	*1275.63*	*1027.93*	*1252.34*	*1252.34*	*1236.99*	*1027.93*
Energy yield (MJ ME/ha)	*119780*	*106720*	*76050*	*90770*	*93280*	*78200*	*100270*	*59770*	*143070*	*71663*
Energy cost ($/100 MJ ME)	*0.99*	*1.16*	*1.27*	*1.32*	*1.37*	*1.31*	*1.25*	*2.10*	*0.86*	*1.43*

[1] The cost based on summing each of the components was $771.20/ha but its retail price of $467.50/ha has been used here.

[2] Sowing costs ($/ha) comprise: Crucial™ (72.42), Dew600™ (13.58), fertiliser (343.22), Slugout™ (84.07), and labour for cultivation, drilling and chemical application (271.55). Chemical application rates are provided in Table 1.

[3] It was assumed that a mix of Ampligo™, Sequence™, Prestige™ and Bonza oil™ (49.30, 36.48, 36.48 + 13.77 $/ha) was applied to the rape monoculture and T-MAX™ and Bonza oil™ (107.43 + 13.77 $/ha) to the 4-species mixtures in September 2021, as would occur given standard farm practice. It was also assumed that a second chemical application comprising Exirel™ + Bonza oil™ (58.76 + 13.77 $/ha) was applied to the rape monoculture and 4-species mixtures in January 2022. Labour was costed at $50/ha for each of the two applications.

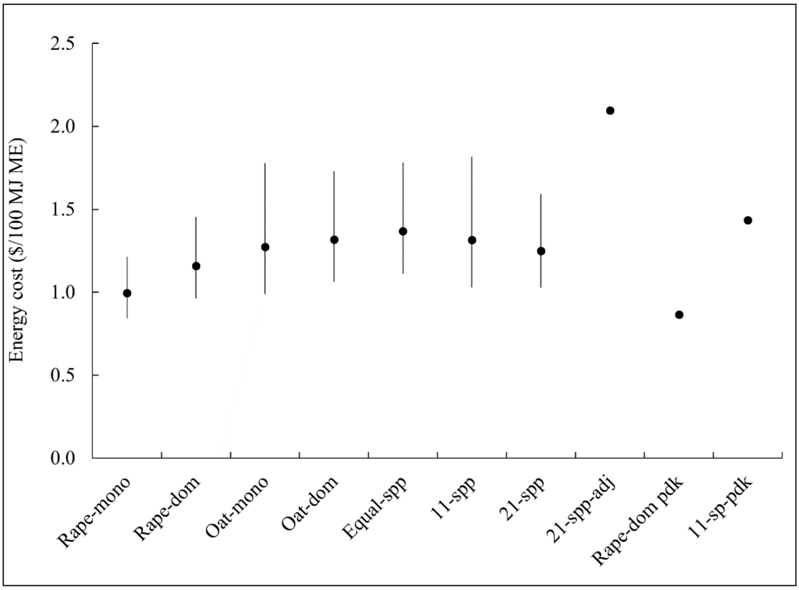

Figure 4 Energy cost ($/100 MJ ME) for treatments in the small plot study, the 21-spp-adj treatment, and the two case study paddocks. Confidence intervals are provided for the treatments in the small plot study. The energy cost confidence intervals were calculated as: ((cost of production)/(energy yield ± 2*SED)). SED: standard error of difference. ME: metabolisable energy.

energy yields for the rape monoculture and the diverse crop mixtures were similar in this one growing season. In a review by Florence and McGuire (2020), the best monocultures and best mixtures performed similarly for a range of metrics, including yield, yield stability and weed suppression.

The energy yields for the simple crop mixtures were comparable to the two hyper-diverse mixtures, supporting our hypothesis that a few carefully chosen species can enable a simple mixture to be as productive as a hyper-diverse mixture. In a meta-analysis review of perennial ryegrass and herbal ley mixtures in regenerative grazing practices, Jordon et al. (2022) did not detect a significant increase in herbage production with higher sward species richness. Due to the clover failing to germinate and plantain failing to produce measurable dry matter, the four-species mixtures were effectively mixtures comprised of rape and oats in different proportions. Rape was a critical component of the mixtures for the provision of high yielding and high-energy forage for stock.

The higher energy yield of the 21-species mixture when compared to the 11-species mixture may reflect the large contribution of sunflowers to the total dry matter. Anecdotal evidence suggested that stock sometimes avoid sunflower stalks in hyper-diverse pastures. If sunflowers were excluded from the dataset, the herbage production and energy yield of the 21-species mixture would have been much lower and similar to the rape-dom and 11-species mixture. Even if the sunflowers were consumed, their high neutral detergent fibre (NDF) content (*e.g.*, 61% for the whole plant, Gholami-Yangije et al*.,* 2019) may have reduced palatability and intake, as their NDF content was far in excess of the recommended maximum of 50%, for sheep and cattle (Roche et al*.,* 2015; Anon 2019). A high content of sunflowers in the mixture and the diet is therefore likely to limit stock performance.

The crude protein was similar for all treatments and equivalent to that of low protein whole crop maize silage (Wilkinson and Waldron 2017). Further research is required to quantify the amino acid balance of low protein diverse forage crop mixtures such as these, to ensure that they provide adequate ruminant nutrition (Anon 2021).

Over the trial period, several disadvantages of the diverse crop mixtures were identified. All sown pasture grasses and many of the sown legume species failed to emerge or establish so did not contribute to herbage production in any of the mixtures. The 21-species mixture was not specifically designed for the Waikato region and sub-optimal climatic conditions and competitive interactions may explain why some of the species failed to establish. Another explanation was that planting all the seeds at a single depth may have compromised the ability of slow-germinating, smaller-seeded species to establish and compete with faster-growing, larger-seeded species (Murrell et al*.,* 2017).

Oats were very competitive and dominated all mixtures where present. For example, when sown at 8% of the recommended sowing rate in the 21-species mixture, oats comprised approximately 40% of the total dry matter production. Caballero et al. (1996) found that oats were competitive in a vetch-oat hay mixture when oats comprised greater than 20% of the seed sown. An increasing oat content was associated with lower weed abundance in the absence of post-emergent herbicide application in the plot study. Even when oats were included at their lowest sowing rate, summer grass and broad leaf weed content was lower by 20% when compared to the rape monoculture. Using cover crops to control weeds is not a new concept, but this trial showed that a small amount of oats in a forage mixture can have a positive impact on weed suppression. This was supported by Baraibar et al. (2018) who suggested that cover crop mixtures require only low seedling rates of aggressive species, such as oats, to provide weed suppression.

The oats had senesced and begun to lodge by mid-January when the farmer needed the summer crop, and had a very low ME (6.6 ME MJ/kg DM in the oats monoculture), lowering their contribution to total energy yield at the time of harvest. An alternative to oats could be triticale, and this species was included in the 11-species mixture at rate of 5 kg/ha. It reached maturation at a similar time to the rape, but did not dominate the mixture and contributed 17% of the total dry matter. Given that triticale maintains it's quality for longer, it would contribute to higher energy yield, but research is required on a rape-dominant mixture containing triticale. Dhima and Eleftherohorinos (2001) found that triticale was less competitive than oats. This may have advantages for rape production but may reduce the ability of triticale to suppress weeds.

Rape was susceptible to competition in diverse mixtures, especially from oats. Its contribution to total dry matter rapidly declined as its sowing rate was reduced, in contrast to oats. For example, in the rape-dom treatment, rape contributed only 30% to total dry matter, while in the oat-dom treatment, oats comprised 97% of the total dry matter.

The size of individual rape plants was affected by the proportion of oats in the mixture. As the sowing rate of rape declined and oats increased, rape plants became much smaller, although there was no significant change in their ratio of leaf to stem. For example, the mass of a single rape plant in the oat-dom mixture was approximately 10% of that measured in the rape-dom mixture. These results were consistent with Murrell et al. (2017), who found that brassicas underperformed in cover crop mixtures compared to their growth in monoculture.

At the time of the mid-January harvest, plantain had been outcompeted by other sown species and weeds. Plantain can be sensitive to sowing depth and competition from other plants in the first few months (Anon 2013). Plantain regrowth occurred when such competition was removed, and plantain was available for a second graze approximately six weeks after the initial grazing. Similarly, the farm manager noted that the chicory in the 11-species mixture dominated the paddock after the January grazing and early February rainfall and provided valuable feed in autumn. Chicory and plantain provided ground cover, which could help to reduce soil and nutrient loss (Sanjari et al., 2009).

Economic analysis

Based on the estimated costs of energy production, all the treatments in the small plot study were similar. The hyper-diverse mixtures had high seed costs but negligible chemical costs, while the rape monoculture and rape containing mixtures had higher chemical costs but lower seed costs. If sunflowers in the 21-species mix were not included, its energy cost was much greater than for all other treatments, making it the least cost-effective option.

The similar costs of energy production for the 11-spp mixture at plot and paddock scale give us confidence that results for this treatment are scalable. However, results at plot and paddock scale were not consistent for the rape-dom mixture. There was greater emergence of rape and lower emergence of oats at paddock scale than at plot scale. The lower cost of energy production at paddock scale was consistent with the greater content of rape and higher energy yield.

Forage crops must produce more energy than pasture alone to provide a viable option, especially if it is assumed that pasture has none of the production costs itemised in Table 6. Deferred grazing is a tool that can be used to accumulate pasture for livestock in mid-summer. It has negligible production costs, but the energy yield is likely to be low due to the low nutritive value of the deferred pasture (Tozer et al., 2021).

Using the analyses provided by Tozer et al. (2021), it has been estimated that deferred grazing could provide approximately 57700 MJ ME/ha, which was similar to that provided by the 21-spp-adj mix in this study, but much lower than that provided by the rape monoculture and simple mixtures containing rape. Assumptions were that (i) there were no costs associated with energy production of deferred pasture; (ii) 2400 kg DM/ha were produced between 21 September (when the field site was sprayed out) and 31 October with a ME value of 10.7 MJ/ha and growth rate of 60 kg DM/ha/day, which was typical for mid-spring growth for this farm, and (iii) pasture deferred from 13 October until 26 January (when crops in this study were harvested) accumulated 4000 kg DM/ha with a ME value of 8.0 MJ ME/ha. These assumptions were based on interpolated data from Tozer et al. (2021) from a replicated field study in Lower Kaimai. The Kaimai site had a similar longitude, pasture-base and rainfall to the farm in the current study. Production values vary between years, within farms and between farms and replicated field studies that include deferred grazing as a treatment are required to substantiate these estimates.

Limitations of this study

While the results were from replicated field research, they are preliminary and obtained from one farm in one year. These need to be validated by further research on different farms in different years in different regions to account for interactions with soils, climate, and livestock and pasture management. Forage utilisation varies between treatments, depending on factors such as stocking rate (Francis and Smetham 1985), neutral detergent fibre content and digestibility (Dixon and Stockdale 1999) and grazing damage. For example, Greenall (1958) found that only 65% of a rape crop, grazed by wethers, was utilised, with 18% comprising dirty or damaged prostrate or dropped leaves which were not consumed. Livestock performance data are therefore critical. This trial focused primarily on metabolisable energy yield and energy cost, but there are other important factors to consider, such as a range of nutritive values and the mineral content of the diverse crops, impacts on livestock health and welfare, plant-soil interactions and impacts on farm system resilience.

Conclusion

Diverse mixtures provided a viable alternative to a brassica monoculture, based on energy yield and energy costs, for this Waikato case study farm. At the time of sowing a summer forage crop, it is not possible to predict if and when a summer feed shortage will occur and how this corresponds to the optimal harvest date. Optimising the harvest date may be even more difficult for diverse mixtures than monocultures, when the mixtures contain species with different maturity dates. Hyper-diverse mixtures did not provide energy yield or cost advantages when compared to a simple mixture. Rape was a critical component of the diverse mixtures for providing high yielding and energy forage. It was susceptible to competition and plants became smaller, but there was no significant effect of treatment on the proportion of leaf to stem, as the level of competition increased. Oats were highly competitive and suppressed rape, although oats had senesced and were of low nutritive value by mid-summer. However, when included in the mixtures at low sowing rates (<13 kg/ha), oats reduced weed ingress. The data suggested that, for this region, an alternative cereal, such as triticale, may provide higher quality forage, increase the energy yield and reduce weed ingress in a rape-dom mixture harvested in mid-summer. Plantain growth was initially suppressed and contributed little to total dry matter in mid-summer. After the crop was harvested, it grew well and provided herbage at the end of February for a second grazing, even when sown at 13% of its monoculture sowing rate (*i.e.*, <2 kg/ha). The same occurred for chicory in the 11-species mixture at paddock scale. Red clover did not establish due to low seed viability so no conclusions can be drawn regarding its contribution to energy yield. A diverse mix may require fewer chemicals for weed control, but will limit herbicide options. Further research is required to validate these preliminary findings by comparing crop mixture performance at a range of sites for several years and which include both crop and livestock performance data.

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