

# Diversified pastures at the front line of climate change in Northland: farmers experiences, new directions and wider implications for other parts of the country

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## Abstract

The persistence of both perennial ryegrass and white clover is challenged under summer-dry conditions. Future climate change projections indicate greater incidence and severity of summer moisture stress for many regions in New Zealand, and therefore, greater pressure on our traditional pasture base. The 'Northland Diversified Forages Project' aimed to identify alternative pasture species that provide an advantage in terms of dry matter yield, quality and/or timing of growth within a summer-dry environment, with a particular focus on legumes. A series of mown-plot trial and paddock demonstrations were established across a range of soil types to assess the potential of a wide variety of forage species. Perennial ryegrass and white clover both failed to persist, comprising less than 25% of the sward within 3 years of establishment. Cocksfoot demonstrated potential as a more persistent alternative to perennial ryegrass. However, whilst a range of legumes were successful at increasing the proportion of legume in the sward and total yield in the first year, significant challenges were identified in maintaining functional legumes across multiple years. This raises questions around whether we currently have the right species in New Zealand to adapt to a changing climate.

**Keywords:** annual clovers, *Dactylis glomerata*, *Lolium perenne*, pasture persistence, summer-dry

## Background

Increasing experimental and anecdotal evidence indicates challenges in maintaining perennial ryegrass swards in some dryland environments, particularly within the upper North Island (e.g., Kelly et al. 2011; Lee et al. 2017). In addition, while perennial ryegrass is often the focus of the 'poor persistence conversation', legumes are a fundamental component of a productive and persistent pasture. However, the limitations of white clover in summer-dry environments are well established (Brock & Caradus 1996). The persistence of both major components of perennial pasture swards is challenged under summer moisture and/or temperature stress. This has stimulated

interest in the role of alternative species to increase pasture production when conditions are favourable and/or better tolerate and persist through hot, dry, summer conditions. In addition, legislation limiting the use of artificial nitrogen (N) further highlights the role that a productive N-fixing legume base plays in maintaining New Zealand's international competitiveness.

Abiotic and biotic factors such as climate, soil type, insect pest pressure and grazing management interact to influence the persistence of dry matter (DM) yield in stressful environments (Chapman et al. 2011). Farmers in the upper North Island are already challenged by increased variability of summer rainfall (Glassey 2011). In addition, future climate change projections indicate greater incidence and severity of summer moisture stress for many regions in New Zealand, over the coming decades (Ministry for the Environment 2018). Because of its latitude, Northland provides a pointer to the effects on pasture productivity of the warmer and drier conditions that are predicted for other regions of New Zealand. Thus, the current 'Northland experience' may hold relevant lessons to inform future mitigation strategies for other parts of the country.

This paper describes the key findings and conclusions from the 'Northland Diversified Forages Project', a 4-year Sustainable Farming Fund project. The outcome sought from this project was to reduce risk to feed supply and improve farm system resilience by identifying forage solutions that provide advantages in DM yield, feed quality and/or seasonal yield relative to demand.

## The Diversified Forages Project

Our motivation for undertaking this project stemmed from dissatisfaction with the ryegrass/white clover/kikuyu status quo and a view that alternative species could offer opportunities to help address some of the challenges within our systems.

In our experience, over the last decade, white clover has contributed <10% of annual herbage yield in most Northland dairy, and sheep and beef pastures. This presents a major opportunity to improve sward productivity and quality. This view is supported by

historic research indicating the potential of some annual clover species in the Northland region (Taylor et al. 1979). It seemed appropriate to revisit some of these comparisons alongside different species and cultivars now commercially available.

Secondary to legume potential was the recognition that forage systems in Northland are reliant on ryegrass (perennial and annual) and kikuyu, each with their own respective seasonal benefits and challenges. Dry summers favour kikuyu dominance. Poor persistence of perennial ryegrass accentuates this with kikuyu filling the gaps in the sward. Successful pasture management requires the transition of kikuyu-dominant swards into a winter-active state, generally achieved by mulching the kikuyu and undersowing annual ryegrass during the autumn (Jagger 2009). From our experience, if poorly managed, the effects on early lactation feed supply of carrying high quantities of kikuyu into winter, in combination with a frost, can be worse than a drought.

The resulting annual regrassing cycle is labour-intensive and adds costs to the system. It also accentuates a reliance on imported supplementary feed as pastures transition between spring-to-summer, and summer-to-winter active states. Even if a sward was no more productive than the status quo, but could persist for longer, this would reduce the regrassing burden and be classed as a considerable advantage.

The Diversified Forages Project therefore explored two main directions toward future forage systems for the region: 1) consider alternative perennial species that can better withstand the challenging climatic conditions; or 2) exploit species which can execute a growth advantage when conditions are more consistently favourable.

In regard to persistence, the perennial grass species tall fescue (*Festuca arundinacea*) and cocksfoot (*Dactylis glomerata*) are well known for their greater tolerance of seasonal moisture deficits compared to perennial ryegrass (*Lolium perenne*, e.g., Nie et al. 2008; Nie & Norton 2009). However, despite historic comparisons (e.g., Lambert 1967), the authors could not find any study to report the relative yields of all three of these species in the upper North Island within recent decades. Meanwhile, considerable effort has been invested in breeding tall fescue and cocksfoot cultivars for improved palatability and seasonal DM production (Reed et al. 2008). Whilst comparisons between species have been made within similar climates overseas, e.g., in Australia (Reed et al. 2008), the implications of these improvements for the performance of these species compared with perennial ryegrass in the upper North Island have not been reported.

In regard to DM yield, for Northland, and arguably, an increasingly wider area of the upper North Island, the period of most consistent growth is winter and spring.

Annual (and Italian) ryegrasses are well recognised for their greater winter/early spring production compared to their perennial counterparts. Yet, despite previous research indicating their potential (Taylor et al. 1979; Macfarlane et al. 2015; Nori et al. 2015), farmer recognition and adoption of annual clovers for similar purposes is considerably more limited.

Hence, the Diversified Forages Project pursued two main objectives:

- 1) To compare the production and persistence of the temperate perennial grass species, perennial ryegrass, tall fescue and cocksfoot, in two Northland environments.
- 2) To screen a wide range of annual, biennial, and perennial legumes for their suitability to Northland environments.

## Materials and Methods

A series of mown-plot trials (Table 1) and paddock demonstrations were established across a range of soil types in Northland between 2016 and 2020. In addition to seasonal herbage yield, field establishment, flowering dates, feed quality and any insect pest and/or soil-borne pathogen problems were observed over the course of the project.

### Legume screenings

In Year 1 of the project (2016/17), we aimed to assess the establishment of a wide range of legume species (Table 2), sown as pure swards, to inform the selection of the most suitable species to include in subsequent comparisons. Seed was sown at recommended sowing rates. The viability of these seed lines was assessed retrospectively to help inform differences in establishment. Seed was not inoculated other than where already included in the seed coating.

### Perennial grass trials

These were established at sites near Awanui and Te Kopuru in autumn 2017 to compare the relative performance of perennial ryegrass, tall fescue and cocksfoot, sown with white clover. Measurements of these plots continued for 3 years after establishment. At the Awanui site, treatments were established directly after existing pasture while at Te Kopuru, treatments were established following a summer brassica crop.

At each site, the experimental design comprised plots (2 m × 3 m) of each grass species replicated three times in a randomised complete block. Each treatment consisted of a single grass species sown with white clover. The grass species used were perennial ryegrass (cv. Prospect) with AR37 endophyte, tall fescue (cv. Hummer) with MaxP® endophyte, and cocksfoot (cv. SF Greenly II). Treatment plots were sown at a rate of 20, 25 and 12 kg seed/ha for the perennial ryegrass, tall

fescue, and cocksfoot treatments, respectively, plus 5 kg seed/ha of white clover (cv. Mainstay).

Nitrogen fertiliser use was low due to the project's focus on legumes. Nitrogen management differed slightly between the two sites. No N fertiliser was applied in Year 1 at Awanui, with 30 kg N/ha and 60 kg N/ha applied during spring in Years 2 and 3, respectively. At Te Kopuru, no N fertiliser was applied in Years 1 and 2 of the experiment with 35 kg N/ha applied during spring in Year 3.

Pasture yield was measured by mowing an area from each plot (0.91 m × 3 m; 2.73 m<sup>2</sup>) to a residual stubble height of 7 cm. Harvested material was weighed and a 100 g subsample oven dried at 98°C for 36 hrs to determine DM yield. Herbage quality was measured infrequently with a second subsample dried at 62°C for 12 hrs, ground to pass through a 1.0 mm sieve and analysed for contents of crude protein and metabolisable energy (ME) by near-infrared spectroscopy (Corson et al. 1999). Harvests occurred when herbage biomass reached a target of 2500–3500 kg DM/ha. Over the 3 years, each site was harvested between seven and nine times each year, resulting in a total of 24 harvests at each site.

Botanical composition was measured at every harvest

at Te Kopuru and from the second autumn onward at Awanui. Botanical composition was measured by taking random snip cuts with hand shears along the edge of the mown strip to a height of 7 cm. Approximately 400 g of herbage was harvested and pooled across replicates. Herbage was well mixed, and a 200 g subsample dissected into botanical components (i.e., sown grass species, volunteer grass species, clover and weed) and oven-dried at 98°C for 36 hrs. The relative proportion of botanical components was then expressed on a dry weight basis.

### Mixed species trials

Further plot-scale work sought to assess the yield, quality, and complementarity of companion species by successively adding additional species to a mixed pasture sward. Experimental design and measurement protocols were the same as those outlined for the perennial grass trials. In Year 3 (2018/19), plot trials were established to compare the performance of the annual clovers balansa (cv. Taipan), Persian (cv. Resal) and berseem (cv. Elite II), sown in a mixed sward with white clover (cv. Legacy), red clover (cv. Ceibo) and either perennial ryegrass, tall fescue or cocksfoot.

**Table 1** Soil type and fertility of experimental sites.

Plot trial	Years	Sites	Soil type	Soil fertility		
				pH (pH units)	Olsen P (mg/l)	Potassium GTK <sup>1</sup> (MAF QT units)
Legume screening	2016/17	Awanui	Whakapara molted clay loam	5.8	18	8
		Te Kopuru	Red Hill sandy loam	6.9	56	12
		Dargaville (Northland Agricultural Research Farm)	Kaipara clay loam	7.0	98	17
Perennial grass trials	2017/18 - 2019/20	Awanui	Whakapara molted clay loam	5.8	18	6
		Te Kopuru	Red Hill sandy loam	6.5	33	8
Annual clover mixes	2018/19 & 2019/20	Awanui	Whakapara molted clay loam	6.3	48	16
		Te Kopuru	Red Hill sandy loam	7.1	27	10
		Dargaville (Northland Agricultural Research Farm)	Kaipara clay loam	7.0	98	17
		Ruakaka	Ruakaka peat	5.6	50	4
Herb comparison	2018/19 & 2019/20	Te Kopuru (High fertility)	Red Hill sandy loam	6.9	83	9
		Te Kopuru (Low fertility)	Red Hill sandy loam	6.2	12	5

<sup>1</sup>Quick test potassium (K)

Treatment plots were sown at a rate of 4, 6 or 10 kg seed/ha for balansa, Persian, and berseem clover, respectively, plus 3 and 4 kg seed/ha of white and red clover, respectively. The grass species used were perennial ryegrass (cv. Rely) with AR37 endophyte, tall fescue (cv. Hummer) with MaxP® endophyte, or cocksfoot (cv. Savvy), sown at a rate of 10, 15 and 5 kg seed/ha, respectively. Monoculture plots of the annual and perennial clovers were also sown to indicate differences in the timing of growth and feed quality.

### Herb trials

Additional comparisons were included at Te Kopuru, at either high or low soil fertility (Table 1), to determine the effect of adding the herbs plantain (cv. Ecotain) and chicory (cv. Choice), at 1 kg seed/ha each, to a diverse sward. This comprised tall fescue (cv. Hummer; 12 kg seed/ha), cocksfoot (cv. Savvy; 1.5 kg seed/ha), white clover (cv. Mainstay; 3.5 kg seed/ha), red clover (cv. Ceibo; 4 kg seed/ha) and Persian clover (cv. Lusa; 3 kg seed/ha).

Paddock-scale demonstrations were also sown throughout the duration of the project to identify factors affecting the successful establishment of a range of mixed swards and integration into a farm system.

## Results and Discussion

### Climate variability

Monthly rainfall data at two of the sites used throughout the project (Figure 1) were obtained from the National Institute of Water and Atmospheric Research virtual climate database (Tait et al. 2006). Total annual rainfall was 1570, 1460, 1030 and 910 mm in Years 1 to 4 at Awanui, and 1200, 1180, 970 and 760 mm at Te Kopuru. This compares to a 15-year average of 1330 mm at Awanui and 1100 mm at Te Kopuru.

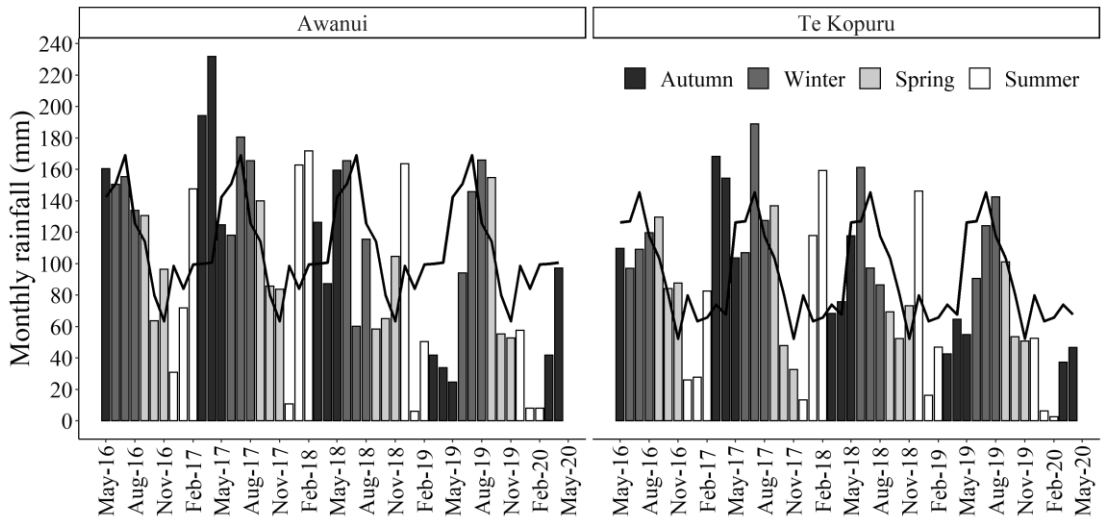
### Perennial grass trials

Across both sites, perennial ryegrass failed to persist beyond 3 years after establishment, supporting farmer experience and galvanising our view of a need for change. By the end of the third year, the contribution of the sown grass species in the perennial ryegrass treatment had declined to 25% and <10% of herbage yield at Awanui and Te Kopuru, respectively (Figure 2). In addition, despite the low use of N fertiliser (0-60 kg N/ha/yr) across both sites, the herbage contribution of clover to DM yield beyond the first year was less than 3% (except in tall fescue swards at Te Kopuru). With the low rates of N fertiliser applied, the poor persistence of clover may have influenced the relative yields of the

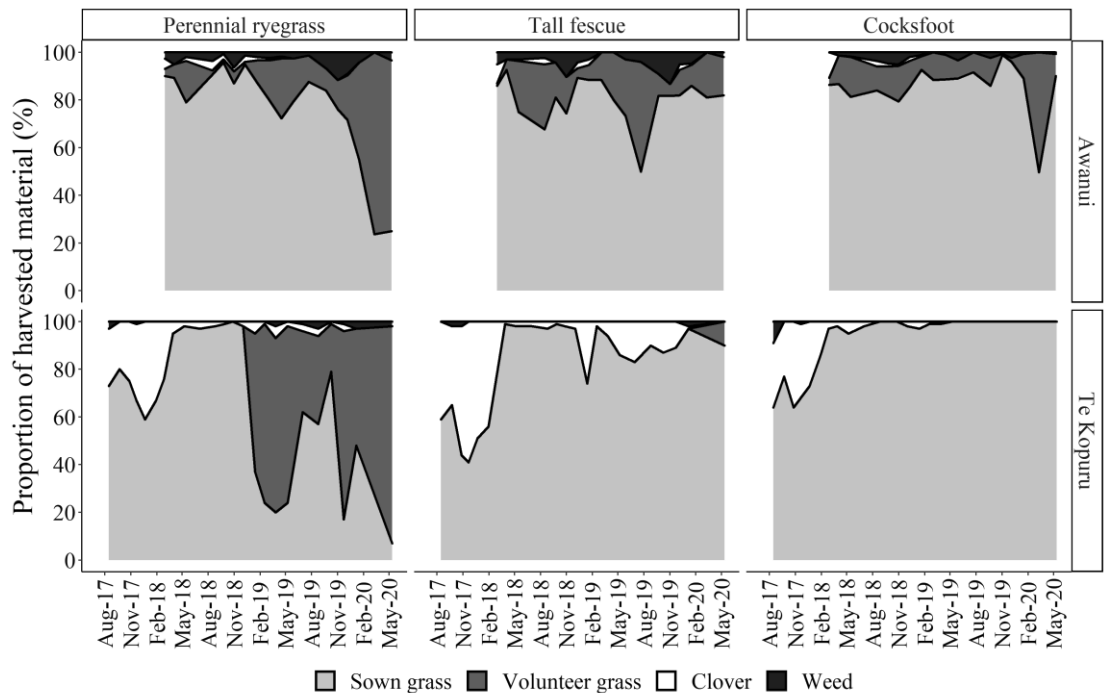
**Table 2** Legume species evaluated for field establishment.

	Common name	Species	Cultivar
Annual	Arrowleaf clover	<i>Trifolium vesiculosum</i>	Apache, Arrotas
	Balansa clover	<i>Trifolium michelianum</i>	Viper
	Berseem clover	<i>Trifolium alexandrinum</i>	Attila, Axi, Meteor, Tabor
	Burr medic	<i>Medicago polymorpha</i> var. <i>brevispina</i>	Spineless
	Crimson clover	<i>Trifolium incarnatum</i>	AU Sunrise
	Faba bean	<i>Vicia faba</i>	KT2
	Persian clover	<i>Trifolium resupinatum</i>	Lusa
	Rose clover	<i>Trifolium hirtum</i>	Overton R18
	Subterranean clover	<i>Trifolium subterraneum</i>	Antas, Coolamon, Woogenellup
	White sweetclover*	<i>Melilotus albus</i>	NPMC2701
	Yellow serradella	<i>Ornithopus compressus</i>	Madeira
Biennial	Sulla	<i>Hedysarum coronarium</i>	Grasslands Aokau, Wilpena
Perennial	Caucasian × white clover hybrid	<i>Trifolium ambiguum</i> × <i>repens</i>	AberLasting
	Birdsfoot trefoil	<i>Lotus corniculatus</i>	Grasslands Goldie
	Lotus major	<i>Lotus pedunculatus</i>	Grasslands Trojan
	Lucerne	<i>Medicago sativa</i>	SF7
	Red clover	<i>Trifolium pratense</i>	Relish
	Strawberry clover	<i>Trifolium fragiferum</i>	Grasslands Upward
	Talish clover	<i>Trifolium tumens</i>	Permatas
	White clover	<i>Trifolium repens</i>	Kakariki, Mainstay

\*annual or biennial species



**Figure 1** Monthly rainfall (vertical bars) relative to 15-year average (black line) at Awanui and Te Kopuru sites.



**Figure 2** Botanical composition of swards of perennial ryegrass, tall fescue and cocksfoot at Te Kopuru (August 2017 to May 2020) and Awanui (March 2018 to May 2020).

grass species, with cocksfoot generally regarded as being more tolerant of lower soil fertility (Reed 1996).

At Awanui, the average annual herbage yield of cocksfoot and tall fescue was greater ( $P < 0.02$ ) than that of perennial ryegrass (Table 3). In contrast, at Te Kopuru, there was no significant effect of pasture species on annual herbage yield. However, volunteer grass species, primarily cocksfoot, made a dominant

contribution to the yield of the perennial ryegrass treatment beyond the second summer, masking the effect of species on herbage yield at this site. The ingress of cocksfoot, rather than kikuyu, likely reflected the history of the paddock, with control of kikuyu achieved through a summer crop prior to planting and the existence of cocksfoot seed in the soil from a previous pasture with cocksfoot.

At both sites, for two consecutive summers, soil moisture content was near estimated permanent wilting point for a period of at least 3 months. This presented a significant and dominant abiotic stress which likely interacted with other factors such as soil type and fertility, insect pest pressure, and competition from volunteer species. Whilst the question is often raised around the practical relevance of mown-plot trials in a grazing system, the results demonstrate a failure of perennial ryegrass even without the added influence of the grazing animal and associated treading damage, overgrazing and re-introduction of weed seed/material.

Perennial ryegrass failed to persist (Figure 2) despite being sown with AR37 endophyte. This supports the view that, while the appropriate selection of endophyte has an important influence on persistence (Ussher & Hume 2015), in some environments, even with an appropriate endophyte, the compounding effects of stressors (drought, high temperatures, insect pests etc.) may be too severe for perennial ryegrass to persist, and more persistent species should be evaluated.

Regardless of the effect on yield, differences between species in persistence alone could provide an economic incentive to question the status quo. At both sites, the proportion of sown grass species was maintained in the tall fescue and cocksfoot treatments, in stark contrast to the perennial ryegrass treatment, where the proportion of perennial ryegrass decreased dramatically. This would likely result in a less frequent requirement for renewal of cocksfoot and tall fescue swards compared to perennial ryegrass (estimated 5 vs. 3 years). When the cost of establishment (including differences in the cost of seed) is annualised over the sward's potential productive lifetime, this has the potential to provide an additional \$100 and \$130/ha/yr for tall fescue and cocksfoot respectively, compared to perennial ryegrass. This presents an annual advantage without even considering the effect of species on yield.

The potential economic value of differences in seasonal DM yield can be estimated by applying the economic values of the DairyNZ Forage Valuation Index (FVI; Chapman et al. 2017). At Awanui, compared to perennial ryegrass, differences in seasonal DM yield could have been worth approximately \$470 and \$690/ha for tall fescue and cocksfoot, respectively. Both tall fescue and cocksfoot are generally accepted to have lower quality than perennial ryegrass (e.g., Martin et al. 2017) which could diminish the value of this potential yield advantage. Griffiths et al. (2020) reported a 12.3 kg MS/ha increase in production from an increase in ME of 0.1 MJ/kg DM. At an assumed milk price of \$6.30/kg MS, potential differences in ME between species across the season (assumed 0.5 MJ ME/kg DM) could reduce this potential to \$80 and \$300/ha for tall fescue and cocksfoot, respectively. It should be noted that such an effect may be overstated as, during summer, the quality of cocksfoot was often greater than perennial ryegrass partially due to the influence of rust.

When considering the effects of yield and persistence the results suggest a combined annual advantage of \$180 and \$430/ha/yr for tall fescue and cocksfoot, respectively. This figure is in line with previous estimates of the value of increasing pasture persistence (Brazendale et al. 2011). However, across both sites, the persistence of white clover beyond the establishment year was poor, which likely presented a significant constraint to productivity. This suggests that an equally large opportunity exists from considering the role of alternative legumes and companion species to support continued productivity within a more persistent sward.

### Legume screening trials

Of the initial seed lines obtained, there was considerable variation in seed viability (measured as the sum of direct germination and hardseededness through

**Table 3** Mean annual herbage yield<sup>1</sup> (kg DM/ha/yr) of swards of perennial ryegrass, tall fescue and cocksfoot over 3 years at two sites.

Site	Year	Perennial ryegrass	Tall fescue	Cocksfoot	SED	P-value
Awanui	2017/18	9810 b <sup>2</sup>	11760 a	10320 ab	722	<0.05
	2018/19	8035 b	10225 ab	11050 a	926	0.02
	2019/20	7970 b	8860 ab	11455 a	1063	0.02
	Mean	8605 b	10280 a	10940 a	528	0.01
Te Kopuru	2017/18	14000	15080	14200	2025	0.87
	2018/19	12115	12010	14025	991	0.11
	2019/20	6925	5815	7160	768	0.26
	Mean	11015	10965	11795	794	0.52

<sup>1</sup> total herbage yield including unsown species

<sup>2</sup> within rows, different letters indicate differences at P<0.05

scarification). For example, seed of white sweetclover and crimson clover had viability of less than 5% and seed of berseem (uncertified), subterranean clover and birdsfoot trefoil had viability of <70%. These results reflect the difficulty of obtaining viable seed for species with a limited commercial market. This also presents a conundrum where there is limited ability to demonstrate the potential of novel species necessary to establish a market. These challenges with seed viability were confined to the initial legume screening as trials in subsequent years were conducted on species where adequately viable seed (>70%) could be sourced with sowing rates set to achieve similar numbers of viable seed/plot.

Hardseededness was also an important characteristic influencing the ability to establish swards for some species. Species with noteworthy hardseededness were yellow serradella (97% for seed line used), arrowleaf clover (71%), strawberry clover (38%) and balansa clover (20%). Hardseededness may provide useful benefits in carrying seed over into future years, allowing natural re-establishment following drought. However, where a very high proportion of seed is 'hard', such as for yellow serradella, this is likely to present a practical challenge to its potential agronomic usefulness.

Not all species were inoculated with rhizobium. This may have been a factor influencing the failure of some species within the legume screening trials. However, at least in the case of white, red, Persian, berseem and balansa clovers, there was no indication that this presented a significant constraint to growth as indicated by visual inspection of nodulation and herbage crude protein tests.

White clover and red clover were the most productive perennial legume species with yields of 13 and 14 t DM/ha/yr, respectively. Both species maintained a relatively pure sward across the year, contributing 70-98% of harvested DM across sites. The most consistently successful annual clover species across sites were Persian and berseem clovers, and to a lesser extent balansa clover. Average yields from an April/May sowing date through to December/January were 6.2, 9.7 and 9.8 t DM/ha for balansa, Persian and berseem clovers, respectively. At the Dargaville site, yields of up to 13 t DM/ha were achieved from both Persian and berseem clovers over the same period. Other successful species included faba bean and *Lotus* species. Additionally, despite continued attempts with alternative seed lines and cultivars over the course of the project, and successful establishment, productive swards of subterranean clover were not achieved, in part due to susceptibility to soil pathogens and the wet nature of the environment during winter and spring.

There were also important differences in the

seasonal distribution of growth between species. Growth of white and red clovers was greatest during the summer and, therefore, reliant on early summer rainfall. In contrast, annual clover growth was greatest in late spring (associated with flowering date) when conditions for growth are more reliable. Furthermore, there were differences in the seasonal growth profiles between the annual clover species with balansa having a shorter growing period compared with Persian and berseem. Balansa consistently ceased growth by mid-October whereas Persian and berseem clovers continued to produce forage through to December/January, increasing their relative yield potential.

Differences in herbage quality (ME and crude protein) between species varied across the season (Table 4). Herbage quality was similar across clovers in a vegetative state, however, the quality of balansa declined earlier in the season compared to Persian and berseem clovers due to earlier onset of flowering and high proportion of stem.

#### Annual clover mixes

The inclusion of annual clovers in mixtures, in general, increased clover content in winter/early spring in the establishment year (Figures 3, 4) and enhanced feed quality. However, the effects on total yield were variable, depending on the companion species sown and a wide range of site-related factors such as drainage.

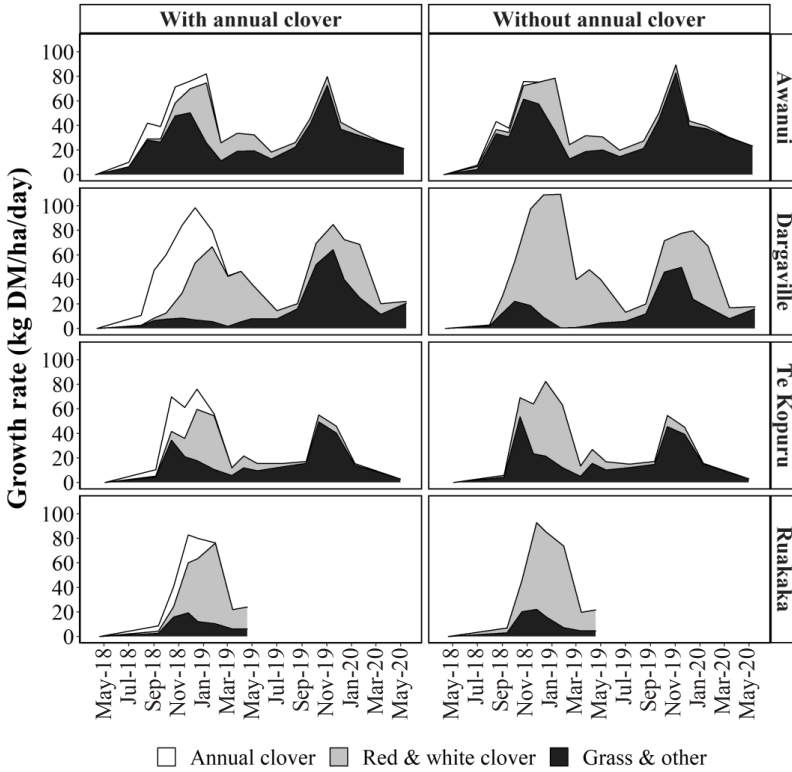
Within ryegrass swards, successful establishment of annual clovers was reliant on reducing traditional ryegrass sowing rates due to high competition (particularly with annual/Italian ryegrasses). For example, ryegrass sowing rates of 5-10 kg/ha were required to prevent clovers from being 'swamped' by ryegrass. Consequently, there is likely a temporary trade-off between quantity and quality of forage produced (e.g., Lee et al. 2018).

With the variability of summer pasture production and Fonterra's introduction of the Fat Evaluation Index grading system (to limit the use of palm kernel), there has been renewed recognition of the role of home-grown pasture silage in providing a low-cost alternative to imported, high-protein supplementary feeds. The addition of annual clovers within a short-term sward is

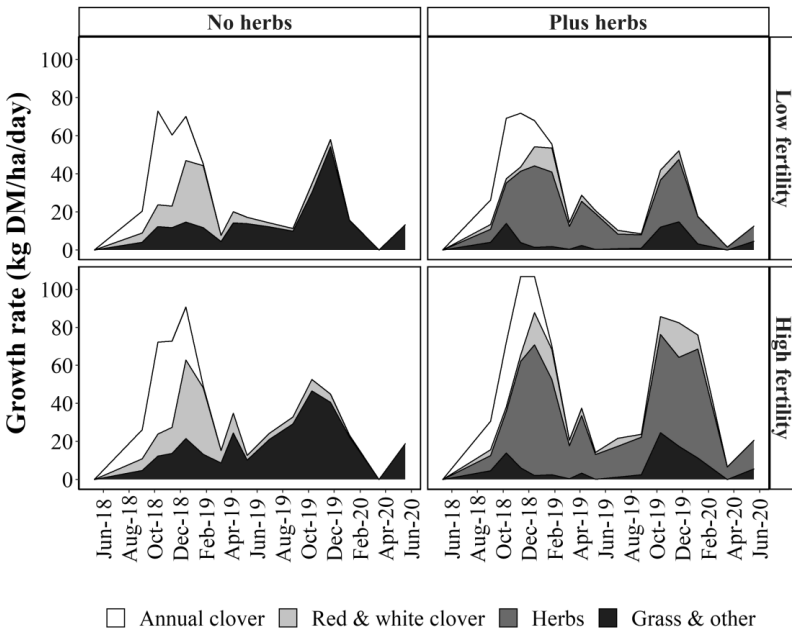
**Table 4** Mean seasonal metabolisable energy (MJ ME/kg DM) and crude protein (% of DM) contents of annual clovers at Awanui, Te Kopuru, Dargaville and Ruakaka sites in 2019.

Species	October/November	December
Balansa	9.8 (15.2) <sup>1</sup>	
Berseem	10.6 (16.0)	10.5 (20.5)
Persian	11.3 (20.8)	10.6 (20.2)

<sup>1</sup> crude protein in parentheses



**Figure 3** Effect of the inclusion of annual clovers on growth and botanical composition of swards at four Northland sites near Awanui, Dargaville, Te Kopuru and Ruakaka.



**Figure 4** Effect of adding herbs (plantain and chicory) on growth and botanical composition of swards on a sandy loam soil at high and low soil fertility (Olsen P of 83 and 12 mg/l, respectively).

highly complementary to a silage production strategy. Both berseem and Persian clovers continued to flower after perennial ryegrass, often extending the period of active growth. Consequently, the addition of annual clovers had dual benefits of increasing the quality of early cuts and often providing an additional late cut of high-protein feed.

Tall fescue and cocksfoot are generally recognised as being slower establishing than perennial ryegrass (e.g., Nie et al. 2004). In these slower-establishing perennial swards, the addition of annual clover can increase clover content and early season pasture growth (predominantly during September to December) and suppress weeds.

Despite the potential early season advantages, the net effect on annual yield from adding annual clovers is heavily dependent on the relative productivity of perennial clover species and, therefore, summer rainfall. For example, within the plot trials, averaged across sites, the addition of annual clovers to the sward provided a growth advantage at the first cut of approximately 400, 500 and 600 kg DM/ha for balansa, Persian and berseem clovers, respectively. However, this early growth advantage was subsequently lost during late spring and summer. Above-average rainfall during November and December resulted in exceptional growth from red clover during this period. The strong growth of annual clovers in early spring reduced the proportion of red clover in the sward, ul-

timately depressing growth in late spring/summer as the annual clovers died.

Consequently, there was no net growth advantage from including annual clovers in a wet year when perennial species could take advantage of a longer growing season. However, in a dry year, an advantage could be expected from having 'brought feed forward' before dry conditions restrict growth. Therefore, a diverse sward containing both annual and perennial clovers may offer a valuable 'insurance policy' in areas subject to inconsistent summer rainfall.

### Perennial species mixes

Throughout the project, across a range of soil types, red clover substantially out-yielded white clover in mixed swards. For example, within the plot trials, the yield of red clover in Year 1 was 4-14 t DM/ha/yr across sites (25-70% of total DM) compared to white clover at 1-2 t DM/ha/yr (5-15% of total DM).

Herbs (plantain and chicory) also displayed significant potential across soil types. However, soil fertility was an important factor affecting the ability of herbs, especially chicory, to express this advantage. Adding herbs to the sward resulted in an additional 2 and 3.5 t DM/ha in Year 1 at low and high fertility, respectively (Figure 4). However, in Year 2, there was no advantage from including herbs at low fertility but a 5.5 t DM/ha advantage at high soil fertility. This effect indicates the considerable influence of soil fertility on the persistence of some species.

This, and further paddock-scale work also indicated the potential of chicory in its second year to contribute DM within a mixed sward. It was worthwhile allowing pre-established root systems of the species to be carried into the second year, reducing the need to re-establish these (a resource hungry process), ultimately providing earlier growth. Currently, this practice is generally avoided, due in part to lower winter growth rates and 'bolting' in the subsequent spring. However, we see potential to offset these challenges through management. For example, hard grazing and light chemical control in autumn can allow for the successful introduction of annual clovers and plantain to improve winter growth. In addition, mechanical 'topping' can be used to control bolting in the following season. Such a practice would only be suitable on well-drained sandy soils where plant loss through winter from soil pathogens is low.

### Paddock demonstrations

There were two main causes of failure of annual clovers in the field: 1) low germination resulting from poor seed bed preparation; and 2) soil-borne pathogens.

Poor establishment occurred where existing pastures were not sprayed or, if sprayed, where residual dead

plant material was not removed well. Mulching of non-sprayed kikuyu-dominant pastures, as is commonly practised with annual/Italian ryegrass, did not ensure establishment of annual clovers, even when using very high sowing rates (e.g., 15 kg/ha Persian clover). The use of slug bait is also highly recommended.

Another major problem for annual clovers during the establishment phase (from germination in May to September) was the presence of soil-borne pathogens (fungi and oomycetes). In the worst cases the presence of soil-borne pathogens killed 80-90% of annual clover seedlings. Important pathogens were *Rhizoctonia solani*, *Phytophthium* and a *Pythium* species – pathogens that favour wet or fluctuating wet and dry soil conditions. Annual clovers appeared to be more susceptible to these pathogens than the perennial clovers with balansa and subterranean being the most susceptible.

Lucerne showed potential within the project's paddock-scale demonstrations on well-drained soils both as a pure sward and as a component of a mixed sward. Mixed swards are likely best established by sowing into an established pure stand, with challenges in establishment encountered when sowing lucerne as a component of a pasture sward in its first year. Once established, lucerne has demonstrated a strong ability to vary as a seasonal component of a mixed pasture sward, dominating the sward in summer then reducing as a sward component through winter. However, whilst lucerne can 'hold on for longer', it too was inevitably affected by drought with growth rates decreasing to less than 10 kg DM/ha/day in early March 2019. In addition, even on what was almost effectively a pure sand soil, in some instances, lucerne was challenged by soil pathogens during winter.

### General conclusions and wider implications

From our experiences during the project across a range of soil types, we would advocate for the use of a modern cocksfoot as the basis of 'longer-term' pasture in summer-dry areas, supported by small-seed species (chicory, plantain, Persian, red and white clovers). However, a consistent theme of the project has been the major lack of growth from white clover beyond the establishment year. Whilst red clover showed great potential to increase yield in the establishment year, it too was challenged with persistence. In addition, the suitability of more persistent legumes, such as lucerne, is limited to particular soil types.

Similarly, whilst annual clovers have the potential to boost clover content in the establishment year, there has been limited success in carrying this advantage across years through natural re-establishment from a seed bank. Long spells from grazing (i.e., deferred grazing) are required in spring to allow for viable seed set, requiring change to grazing management. However, even when

left to grow to maturity, only balansa has displayed a moderate ability to re-establish from self-set seed, in agreement with the conclusions of Macfarlane et al. (2015) on the East Coast. In areas with kikuyu (which are likely to expand), vigorous autumn growth is likely to further challenge this natural re-establishment.

With poor persistence of perennial legumes and challenges with natural re-establishment of annual clovers, summer-dry areas with kikuyu are likely to remain reliant on an annual regrassing cycle involving chemical and mechanical control to re-establish clover populations. Further work is required to integrate the key lessons from this project into current kikuyu management to refine a medium-term alternative to annual/Italian ryegrass management.

We advocate for the expansion of the FVI to include non-ryegrass species to give farmers confidence in the value of considering alternative pastures within more challenging environments. In addition, there is also a case for reviewing the economic values for DM yield in the FVI for the spring seasons to recognise management strategies and forage types that generate additional conserved supplement for summer feed. It is our view that the current economic values within the FVI undervalue late-spring pasture production for systems where summer dryness is a consistent constraint to pasture production. This reduces the implied value of additional feed grown by tall fescue and cocksfoot grown in late spring.

Our experiences within this project have raised questions of whether we have the right species in New Zealand for a changing climate and has sparked our interest in investigating the potential role of subtropical legumes. We must learn from our counterparts overseas within homologous climate zones (particularly Australia) to identify potentially useful pasture species/germplasm that will thrive in our current and future climate. It is untenable to advocate a climate change emergency without developing mitigation and adaptation solutions for the agriculture sector. We believe that consideration should be given to the introduction of new species that have desirable traits that provide for mitigation and adaptation to climate change.

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