

Growth rates and persistence of annual and perennial clovers

Sonya T. OLYKAN^{1*}, Richard J. LUCAS¹, Stuart R. HUNTER¹ and Derrick J. MOOT¹

¹*Dryland Pastures Research, Field Research Centre, Faculty of Agriculture and Life Sciences, PO Box 85084, Lincoln University, Lincoln 7647, New Zealand*

*Corresponding author: sonya.olykan@lincoln.ac.nz

Abstract

The temporal productivity of monocultures of four annual and two perennial clover species was quantified in a summer dry environment at Lincoln University, Canterbury. In 2019, cultivar affected ($P < 0.001$) yield in early spring with ‘Viper’ balansa producing 5.0 t DM/ha compared ($P < 0.05$) with 3.5 t for ‘Arrotas’ arrowleaf, 3.2 t for ‘Antas’ and ‘Woogenellup’ sub clovers, 1.6 t for ‘Kopu II’ white clover and 1.2 t for ‘Relish’ red clover. After a dry autumn in 2020, white and red clovers regrew, but only ‘Napier’ and ‘Woogenellup’ sub clovers re-established from seed. By September 2020, ‘Woogenellup’ sub (4.3) and ‘Relish’ red (3.7) clovers had higher dry matter (t/ha) yields than ‘Kopu II’ white (2.8) and ‘Napier’ sub (2.2). In contrast, autumn 2020 re-establishment of arrowleaf, balansa and Persian clovers was poor, and each yielded < 0.5 t DM/ha by September and were dominated by weeds. These results confirm poor re-establishment of these top flowering clovers in their second year, and recommendations for their use as specialist one-year crops. The earlier growth profiles of the annual compared with perennial clovers highlighted their potential to increase early spring feed supply to meet requirements of sheep in dry regions.

Keywords: Balansa, top flowering, winter yield

Introduction

In dryland systems, plants that produce high quality feed in spring, when soil moisture is non-limiting, enable maximum animal production in lactating stock and their offspring (Macfarlane *et al.* 2014). Animal live weight gain averages 40% more with clover than ryegrass, due to more efficient utilisation of metabolisable energy (ME) for growth (Nicol and Edwards 2011). In addition, pastures with high legume content in early spring have higher water-use efficiency, (Moot 2012) due to their ability to fix ~30 kg N/t of clover dry matter (Lucas *et al.* 2010). In contrast, grass dominant pastures are frequently N deficient at this time, which restricts growth and reduces water efficiency (Mills *et al.* 2006). Perennial legumes can be productive in dryland environments. Peak white clover growth rates of 50 kg DM/ha/d have been measured in mid-October (Black *et al.* 2003). Similarly, red clover (*T. pratense*) in a dryland monoculture accumulated

~16 t DM/ha/yr in the first two years, with growth rates peaking in mid-November at ~70 kg DM/ha/d (Brown *et al.* 2003). However these perennial red and white clovers are suited to environments with > 750 mm annual rainfall with at least 150 mm in summer (Brock *et al.* 2003). Low soil moisture in summer decreases the rate of taproot carbohydrate replenishment in red clover, which slows regrowth and stands frequently only persist for 2 to 3 years (Brock *et al.* 2003). White clover plants are vulnerable to summer dry conditions after 1 to 2 years, because their taproot dies and they become small stoloniferous clonal plants (Brock and Hay 2001) with shallow root systems. In contrast, winter active annual legumes can accumulate high quality biomass over the winter and early spring period (Hyslop *et al.* 2003) and can be more productive during late winter and spring (Evans and Mills 2008; Teixeira *et al.* 2017).

Long-term persistence and resilience are important considerations for annual clovers, because they need to re-establish viable plant populations from a seed bank. Therefore first year seed set and level of hardseededness, are important considerations. Macfarlane *et al.* (2015) reported that grazing the top-flowering arrowleaf (*T. vesiculosum*) and Persian (*T. resupinatum*) clovers after mid to late October greatly reduced their seed set. However, allowing them to set seed means the paddock is closed at peak animal demand and results in a large amount of lignified and unpalatable above-ground dry matter. In contrast, to maximise first year subterranean (sub) clover (*T. subterranean*) seed set, Olykan *et al.* (2019) recommended a six week cessation from grazing, followed by light cattle grazing to produce a seed bank. This allowed clover to be controlled through grazing management (Monks *et al.* 2008; Olykan *et al.* 2019) and the level of hardseededness (Teixeira *et al.* 2021).

In New Zealand, with its cool climate, sub clovers (Lucas *et al.* 2015; Olykan *et al.* 2018) and balansa (*T. michelianum*) (Monks *et al.* 2008) with low ratings of hardseededness are most successful in re-establishing populations from the seed bank. In contrast, re-establishment can be poor for Persian, even though it is soft-seeded (Macfarlane *et al.* 2015; Nori *et al.* 2019), and for arrowleaf, which has a high level of hardseededness (Nori *et al.* 2019).

This study compared growth rates of monocultures of annual and perennial clovers at Lincoln, Canterbury over two years.

Methodology and analysis

An experiment was established in March 2019 at Lincoln University, Canterbury, New Zealand (GPS coordinates -43.6493, 172.4659, elevation 10 m a.s.l.). The site is ~21 m (west-east) by 100 m long (north-south) and located in a flat paddock in Iversen Field 4. The soil is Wakanui silty loam (NZ: Mottled Immature Pallic Soils, USDA: Aeris Epiaquept) that is > 100 cm deep and imperfectly drained (Manaaki Whenua 2021). Bulk soil samples (20 cores from the 0–75 mm depth) were taken on 22 February 2019 and 17 June 2020 and analysed by Hill Laboratories Ltd. Results indicated adequate soil fertility in both years (Table 1).

Site preparation

After a summer fallow in 2019, the area was conventionally cultivated and rolled. A pre-sowing spray of Weedmaster 540 (540 g glyphosate/L) at 2 l/ha in 200 l water was applied on 20 March 2019 to kill emerging weeds. A germination test used two replicates of 50 seeds of each cultivar, incubated for seven days at 18°C to determine sowing rates. Five replicates of 10

clovers were direct drilled on 22 March 2019, using a Flexiseeder® drill into 10 x 4.2 m plots in a randomised, split-block design, with the blocks split by growth habit (Table 2). The site was heavy rolled post-sowing.

Post-emergence, on the 10 May 2019, the area was sprayed with Preside (800 g flumetsulam/kg) at a low rate of 30 g/ha in 200 l of water to target spurrey (*Spergula arvensis*). On 13 May 2019, clover plant population density was visually scored using a scale from 1 (poor) to 10 (excellent). The area was sprayed on 27 June 2019 with 330 ml/ha Centurion Xtra (360 g clethodim /l) with 2 l uptake oil/ha in 200 l water to target the Poa grass (*Poa annua*). For Year 1, herbage was harvested on 14 August, 28 August (three replicates), 24 September, 9 October, 19 November, 19 December 2019 and 7 January 2020 (four replicates). A change in sampling occurred because Replicates 1 and 2 were slow to establish. However, they recovered and Replicate 5 was subsequently dropped due to poor growth. ‘Napier’ and ‘Lusa’ Persian did not establish adequate populations for harvest. ‘Cefalu’ arrowleaf showed visual symptoms of herbicide damage, so was

Table 1 Soil chemical analyses of bulk samples (0-75 mm depth) from Iversen Field 4W, Lincoln University, Canterbury, taken on 22 February 2019 and 17 June 2020. MAF Quick Test units are shown in brackets for the cations.

Date	pH	Olsen P (mg/L)	Potassium	Calcium (me/100 g)	Magnesium	SO ₄ -sulphur (mg/kg)
Feb-19	6.3	21	1.2 (27)	8 (11)	1.1 (26)	11
Jun-20	6.0	16	0.8 (17)	7 (8)	1.0 (21)	7

Table 2 Agronomic and experimental details for the clover species and cultivars sown at Lincoln University, Canterbury in March 2019.

Clover species	Cultivar	Growth habit ³	TSW (g) ⁴	Sowing rate kg/ha ⁵
Arrowleaf	Arrotas	Tall	1.55	20
	Cefalu	Tall	1.83	10
Balansa	Taipan C ¹	Tall	0.97	20
	Viper	Tall	1.15	10
Persian	Lusa	Tall	1.06	10
Subterranean	Antas (B) ²	Short	7.81	20
	Napier C (Y)	Short	12.2	40
	Woogenellup (S)	Short	8.22	20
Red	Relish C	Short	1.96	12
White	Grasslands Kopu II	Short	0.60	6

¹ C - sown as coated seed;

² Subterranean subspecies: B = *brachycalycinum*, S = *subterraneum*, Y = *yanninicum*;

³ Growth habit = tall (erect top flowering stems or long scrambling stems), short (prostrate);

⁴ TSW: Thousand Seed Weight of bare seed. Coated TSW: ‘Taipan’ 1.70 g, ‘Napier’ 25.0 g, and ‘Relish’ 4.80 g;

⁵ Coated seed sown at double the rate of bare seed.

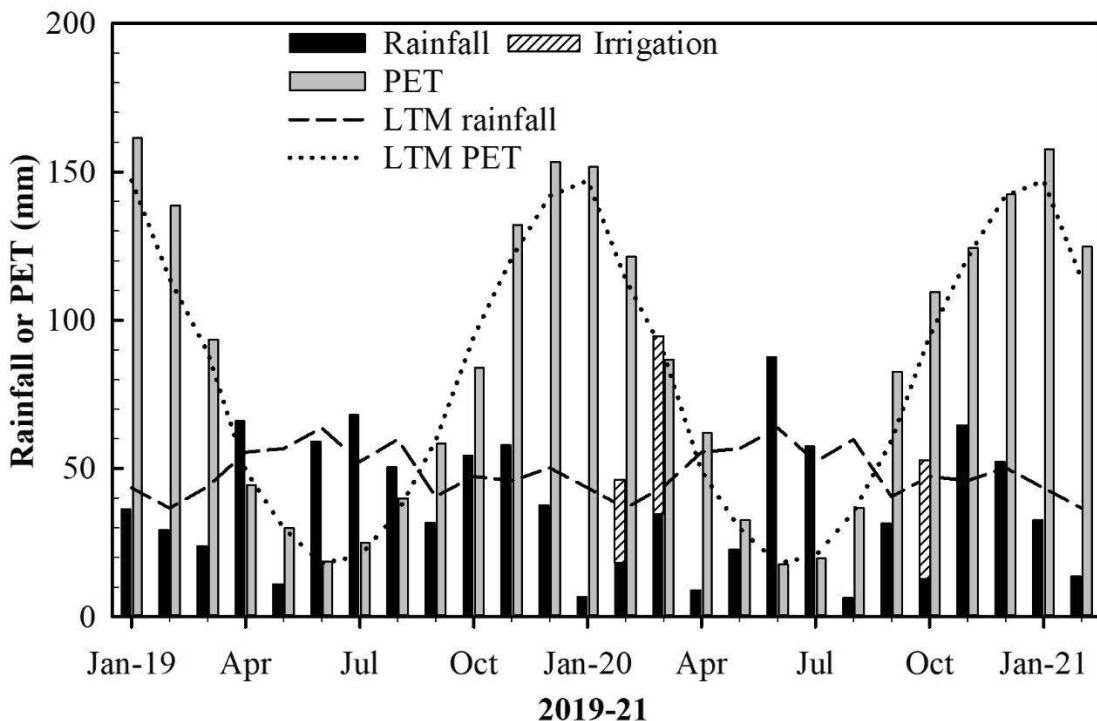


Figure 1 Total monthly rainfall, evapotranspiration (PET) and irrigation from January 2019 to February 2021 at Lincoln (Canterbury). Data, including 30 year (1990-2019) long term mean (LTM), from Lincoln-Broadfield station (CliFlo 2020).

not sampled until 7 January 2020.

From 20 to 23 January 2020 the site was grazed by 140 dry ewes and residual stems removed by mowing to a height of 60 mm on 4 February. This left bare ground with minimal litter or herbage cover. Year 2 started with below average rainfall (Figure 1), so irrigation was applied with 28 mm on 25-27 February 2020, 30 mm on 9-10 March and a final 30 mm on 18 March 2020, in anticipation of the Covid-19 lockdown on 25 March 2020. Annual clover emergence was not observed due to the Covid-19 lockdown, but estimated to be ~20 March, two days after the third irrigation event. On 14 October 2020, 40 mm irrigation was applied because the was 42 mm rainfall since 1 August 2020 was well below the long term mean (Figure 1). On 19 October 2020, 80 kg/ha superphosphate (P 9, S 11, Ca 20) and 180 kg/ha sulphur super 30 (P 7, S 30, Ca 16) were applied.

Germination tests of the seeds set in Year 1, were carried out in July 2020 on seed from fully mature plants of 'Taipan' (harvested 29 November 2019) and 'Viper' balansa (17 December 2019), and 'Arrotas' (28 January 2020) and 'Cefalu' (14 January 2020) arrowleaf that had been air dried and stored in paper bags. Seeds were taken from the dried flower heads. Seeds of 'Antas' sub clover were taken from burrs collected on site.

In 2020 (Year 2), harvests occurred when there

was sufficient (2 to 3 t DM/ha) clover herbage that farmers would utilise if on-farm. This occurred on 26 May (white, red, and 'Woogenellup' sub), 20 August (white, red, 'Woogenellup' and 'Napier' subs, Persian); 17 September, 2 November and 9 December 2020 (all clovers). On 26 January 2021 only red clover and white clover were sampled. After each harvest, the site was grazed for 1 to 2 days by 145 mixed-age dry ewes and then mown to 30 mm with the residual herbage removed. Exceptions were after 20 August harvest, site was ungrazed or mown because the plants were small, and after 17 September harvest only the red, white and 'Napier' and 'Woogenellup' sub clover plots were mown, as the other annual clover plants were too small.

Herbage mass was cut using motorised shears to a stubble height of 20 mm from one 0.2 m² quadrat/plot to indicate productive potential. Samples were separated into clover, weed and dead components, dried at 65°C for 48 hours, and weighed. On 26 January and 5 March 2021, visual groundcover assessments were made of the red and white clover plots.

Near-infrared (NIR) spectroscopy (FOSS NIRSystems 5000) of the clover component of the 2020 harvests determined metabolisable energy (ME) and crude protein. Accumulated thermal time was calculated from 1 July 2019 using a two-stage model. To enable comparisons among species (Moot *et al.*

2000) a common set of cardinal temperatures was used with a base of 0°C, optimum of 26°C and maximum of 37°C. In 2020 thermal time was accumulated from the day after mowing.

Climate

Climate data were from the Lincoln-Broadfield meteorological station located 2.6 km north of the site (CliFlo 2020). Annual mean maximum and minimum air temperatures were 17.7 and 7.4°C in 2019, respectively, and 17.6 and 7.3°C in 2020. Both years were warmer than the 30-year long-term mean (LTM, 1990-2019) of 16.7 and 6.6°C. Annual rainfall (January to December) was 525 mm in 2019 and 403 mm in 2020. In 2019, germination started in early April after 30 mm rain. May had only 11 mm of rain (Figure 1) but winter/spring monthly rainfall was close to the LTM. In 2020, January and February were drier than average (7 and 18 mm) as were April and May (9 and 23 mm). After a total of 145 mm rainfall in June/July, there was only 6 mm in August and 12 mm in October.

In 2019 and 2020 the annual PET was 980 and 990 mm, respectively, which indicated a maximum potential soil moisture deficit of 587 mm in 2020.

Statistical analyses

Genstat statistical software (18th edition) was used for all statistical analyses.

In 2019, clover growth rates were calculated from individual plot data, except for the 24 September to 9 October period, when the means were used due to the change in replicates sampled. In 2020, all growth rates were calculated using the individual plot data. Clover yield, accumulated yield, total DM, growth rates at each harvest, ME and protein values were analysed by one-way ANOVA with growth habit (Table 2) as a covariate and clover cultivar as the factor. The orthogonal contrasts were annual versus perennial (2019 only), sub clover versus perennial or top flowering annuals, and top flowering annuals versus perennial. Cultivar means separation used LSD $\alpha=0.05$. The relationship between accumulated DM and thermal time was analysed using least squares linear regression with groups based on clover cultivar and then clover groupings using cultivars when slopes were not different. In 2019, the clover groupings were 1) 'Taipan' and 'Viper' balansa, 2) 'Antas' and 'Woogenellup' subs and 'Arrotas' arrowleaf, and 3) perennials 'Relish' red and 'Kopu II' white. In 2020, groups were 1) 'Napier' and 'Woogenellup' subs with 'Relish' red and 'Kopu II' white, and 2) the remaining annuals.

Results

Germination tests

Pre-sowing germination was >90% for all seeds

compared with the Year 1 (2020) field results at 3 and 8% for 'Arrotas' and 'Cefalu' arrowleaf seeds, 29 and 25% for 'Taipan' and 'Viper' balansa and 8% for 'Antas' sub.

Establishment – Year 1 (2019)

Clover cultivar affected ($P<0.001$) seedling population scores on 13 May 2019. 'Arrotas' arrowleaf was 9.4 ± 0.31 , higher ($P<0.05$) than 'Cefalu' (7.4), 'Taipan' and 'Viper' balansa (7.0). 'Antas' and 'Woogenellup' sub and perennial clovers scored 4.0 and 'Lusa' Persian (0.6) and 'Napier' (1.2) sub scores were the lowest ($P<0.05$).

Accumulated clover dry matter yield - 2019

In Year 1 'Arrotas' arrowleaf accumulated yield peaked at 12,900 kg DM/ha on 19 December 2019, which was higher ($P<0.05$) than 'Woogenellup' sub (10,000 kg DM/ha), 'Relish' red (7,950 kg DM/ha), and 'Antas' sub (7,670 kg DM/ha) clovers, which were higher than 'Kopu II' white (4,600) clover (Figure 2). The accumulated clover DM yields at each harvest were affected ($P<0.001$) by cultivar. From 28 August until 9 October the annual clovers had higher ($P<0.05$) DM yields than the perennial clovers (Figure 2).

In late winter and early spring, the balansa cultivars 'Taipan' and 'Viper' produced ~1500 kg DM/ha, and 'Antas' and 'Woogenellup' sub clovers had ~800 kg DM/ha by the 14 August (Figure 2). Six weeks later, on the 24 September, 'Viper' had accumulated 5,010 kg DM/ha, which was not different from 'Taipan' (3,890 kg DM/ha) but higher ($P<0.05$) than 'Antas' and 'Woogenellup' sub clovers (~3,200 kg DM/ha) and the 'Arrotas' arrowleaf (3,500 kg DM/ha). By 28 August 2019, the accumulated yields of the perennial 'Kopu II' white and 'Relish' red clovers were ~230 kg DM/ha and less ($P<0.05$) than the annuals. By the 19 November, the 6,300 kg DM/ha from 'Relish' was not different from the highest annual clover yields and higher ($P<0.05$) than 'Kopu II' (4140 kg DM/ha). Year 1 sown clover as a percent of the total DM differed ($P<0.05$), increased from 61% and 48% for annuals and perennials, respectively, on 14 August to 96% and 88% by 19 November.

Accumulated clover dry matter yield – Year 2 (2020)

Yield in Year 2 was accumulated from 4 February for the perennials and 20 March for the annuals. On 26 May, 'Kopu II' white, 'Relish' red and 'Woogenellup' sub yields of ~1,400 kg DM/ha (Figure 2) were not different. There was insufficient herbage to sample the other clovers. By 20 August, 'Relish' had a higher ($P<0.05$) accumulated yield (2,890 kg/ha) than 'Napier' (1,340 kg/ha) while 'Woogenellup' and 'Kopu II' accumulated 2,340 and 2,010 kg DM/ha, respectively.

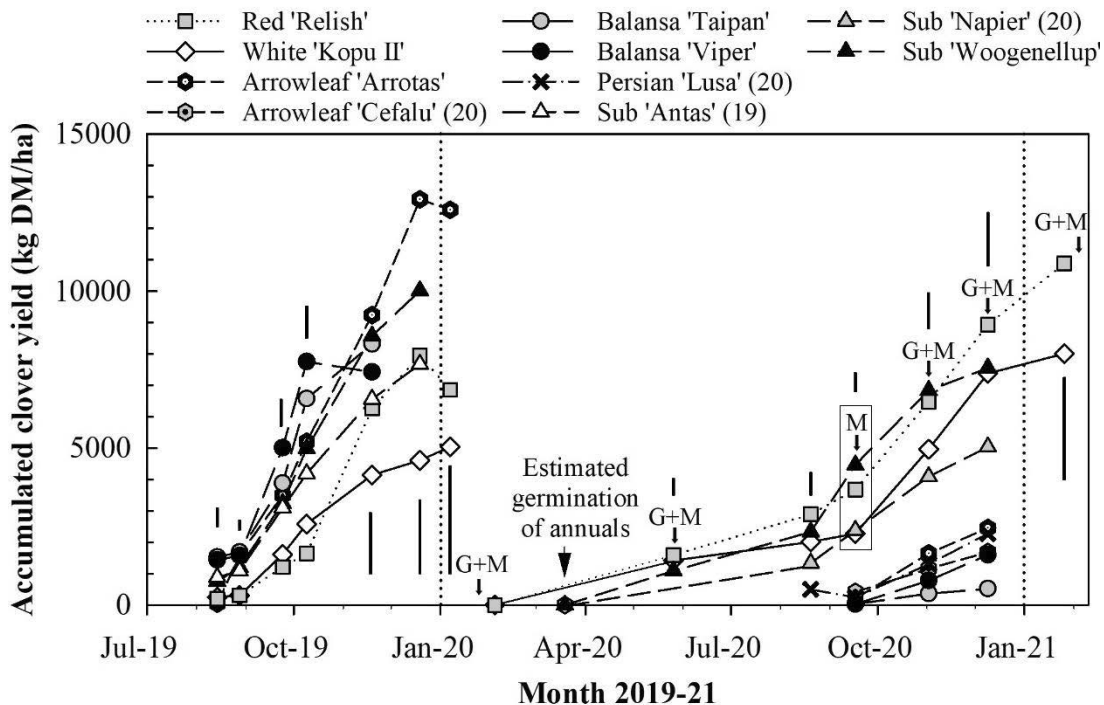


Figure 2 Accumulated clover dry matter yield of non-grazed (2019-20) and grazed (2020-21) monocultures of annual and perennial clovers grown at Lincoln University, Canterbury. If a clover was not sampled in both years, the year of sampling was noted. 1 January = dotted vertical line (·). In 2020, ↓ = grazing (G) and/or mowing (M) after harvest. Bars at each harvest are LSD 5%.

'Woogenellup' and 'Relish' had the highest ($P < 0.05$) accumulated yields of 4,460 and 3,680 kg/ha by 17 September, and both accumulated ~6,700 kg/ha by 2 November.

After the December harvest, the sub clover cultivars senesced, while red and white clovers continued to grow. By 26 January 2021, 'Relish' had accumulated 10,900 kg DM/ha and the 1,950 kg/ha grown since 19 December 2020 was higher ($P < 0.05$) than the 630 kg/ha from 'Kopu II'.

In Year 2, the first harvest of 'Lusa' Persian on 20 August only yielded 500 kg DM/ha which was lower ($P < 0.05$) than the other clovers. The arrowleaf and balansa cultivars were first harvested on 17 September and their clover yield, with 'Lusa', averaged 190 kg DM/ha (range of 34 to 420 kg), or 12% of the total DM harvested.

Daily growth rates – Year 1 (2019)

In Year 1, daily clover growth rates from August to November differed ($P < 0.05$) among cultivars. 'Arrotas' grew 111 kg DM/ha/d from 14 to 28 August, which was higher ($P < 0.05$) than the other clovers (Figure 3A). From the 28 August, 'Viper' and 'Taipan' balansa grew 123 and 106 kg DM/ha/d, respectively, and had

the highest growth rates (~180 kg DM/ha/d) from 24 September to 9 October. 'Kopu II' growth rate peaked at 65 kg DM/ha/d on 24 September, and 'Relish' at 113 kg DM/d on 19 November (Figure 3A). Apart from 'Arrotas', annual clover growth rates declined after 9 October, particularly for the balansa cultivars.

Daily growth rates – Year 2 (2020)

From 26 May to 20 August, the growth rate of the harvested clovers was ~13 kg DM/ha/d (Figure 3B). On 17 September, 'Woogenellup' sub had a growth rate of 75 kg DM/ha/d which was double ($P < 0.05$) that of 'Napier' sub. On 9 December 2020, the perennial clovers averaged 74 kg DM/ha/d, which was higher ($P < 0.05$) than the 21 kg DM/ha/day of the annuals (Figure 3B).

Accumulated DM yield versus accumulated thermal time

To enable species comparisons, growth rates were calculated per unit of temperature accumulated per day ($^{\circ}\text{Cd}$) (Mills et al. 2006; Mills et al. 2021). From 14 August to 9 October 2019, balansa clovers grew 11 kg DM/ha/ $^{\circ}\text{Cd}$, sub and arrowleaf clovers 8 kg DM/ha/ $^{\circ}\text{Cd}$ and red and white at 4.0 kg DM/ha/ $^{\circ}\text{Cd}$ (Figure 4A). In

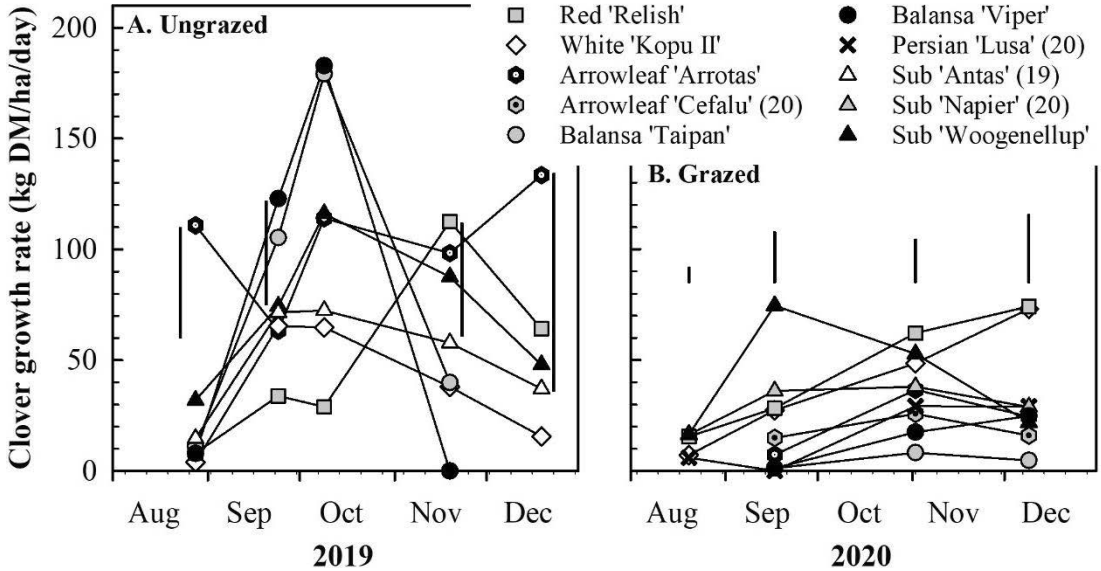


Figure 3 Annual and perennial clover cultivar monoculture growth rates of A. 2019 non-grazed and B. 2020 grazed from August to December at Lincoln University, Canterbury. If clover was not sampled both years, year of sampling (19 or 20) noted. Bars are LSD_{0.05} for each harvest, except for 9 October 2019, when growth rates calculated from mean DM values

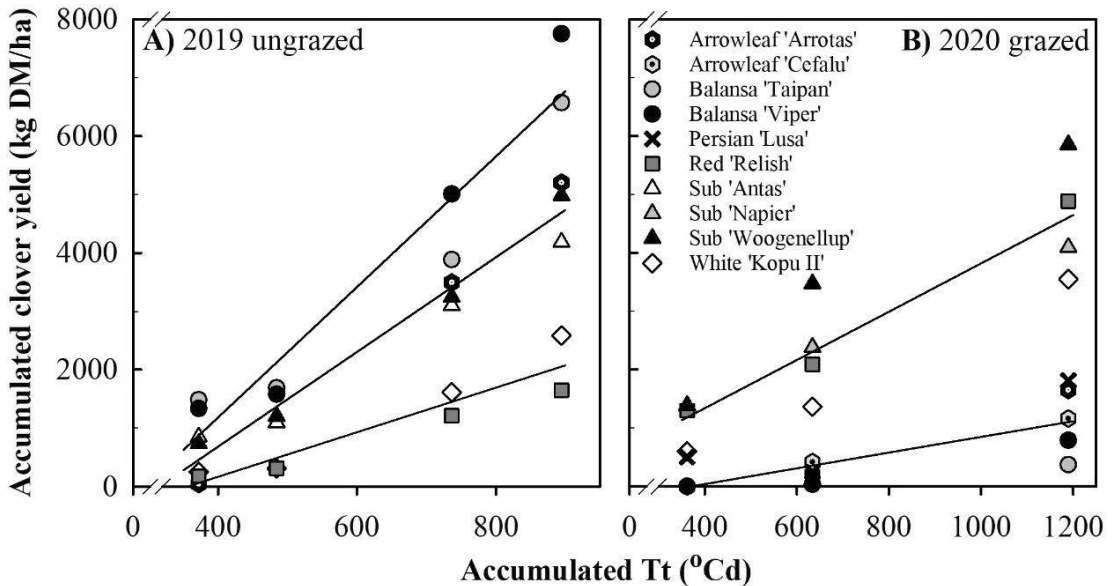


Figure 4 Accumulated dry matter (DM) against accumulated thermal time (Tt) for clover monocultures harvested from A) 2019 non-grazed plots (14 August to 9 October), groupings were 1) balansas, 2) arrowleaf + sub clovers, 3) perennial red + white clovers, and B) 2020 grazed plots (20 August to 2 November) groupings 1) sub + red + white clovers, 2) other annuals (balansa + arrowleaves + Persian), at Lincoln University, Canterbury. (T_b = 0°).

2020, from 20 August to 2 November, 'Woogenellup' sub clover grew 5.2 kg DM/ha/°Cd, which was not different to 'Relish' red (4.4 kg DM/ha/°Cd), but higher ($P < 0.05$) than 'Kopu II' white and 'Napier' sub clover at 3.6 and 3.2 kg DM/ha/°Cd respectively. These clovers grouped together had a higher ($P < 0.05$) mean growth rate of 4.1 kg DM/ha/°Cd compared with

the top flowering annual clovers at 1.3 kg DM/ha/°Cd (Figure 4B; $R^2 = 87.2$).

Feed quality

In 2020, clover herbage ME values peaked on 17 September and ranged from 11.0 in 'Relish' red to 12.5 MJ/kg DM in 'Kopu II' white clover. Protein peaked

at 33.3% for 'Kopu II' in August, and then declined. 'Woogenellup' sub clover had the highest accumulated total ME and protein on 17 September due to its higher ($P < 0.05$) herbage production.

Groundcover assessment 2021

'Relish' red and 'Kopu II' white clover groundcover declined during the dry summer in 2021 from 70 and 36%, respectively on 26 January, to 27 and 6% by 5 March.

Discussion

Establishment Year 1 - 2019

The annual arrowleaf, balansa and sub clovers established high plant populations. Given the aim was to optimise winter production of annual clovers in dryland systems, early sowing of seed can be recommended (Moot *et al.* 2003a) to take advantage of any late summer rainfall. Weed competition occurred during the autumn, requiring herbicide to support establishment. The success of this strategy was apparent in mid-November, when sown clover represented 95% of the total DM. However, 'Cefalu' arrowleaf appeared to be more sensitive to herbicide, so additional work for this species is needed.

In Year 1, the annual clovers were all more productive than white clover, which supports previous reports (Evans and Mills 2008; Teixeira *et al.* 2017) and was most apparent in the critical spring period of August to October.

The accumulated yield profiles of the top flowering balansa and arrowleaf clovers matched feed requirements of ewes and lambs in dryland areas. Mean lambing date was ~20 August at Lincoln, so high quality pastures are required in early August. 'Arrotas' arrowleaf grew the fastest in August (111 kg DM/ha/d) while 'Viper' balansa grew at 123 kg/ha/d during September and then at 183 kg DM/ha/d into early October. However, these impressive growth rates resulted from stands left to seed. Allowing full seed set meant the two top flowering species were unavailable for grazing and feed quality declined (Hackney *et al.* 2021) before it could be used. The consequent residual herbage was difficult to 'clean-up' over summer (Macfarlane *et al.* 2015). In practice, sub clover provided opportunity for both grazing and seed set in the establishment year. For top-flowering clovers, an early spring graze may be possible but can compromise the level of seed set. However, given the lack of re-emergence for some cultivars in Year 2, farmers may opt to use this early season feed and resow each year. Neither of the perennial legumes produced useful amounts of feed in early spring from a mid-autumn sowing.

In Year 1, the annual clovers, particularly the balansa cultivars, grew more DM per unit of thermal time than

the perennial clovers, highlighting their superior late winter-early spring growth. Sub clovers grew at twice the rate of the perennial clovers. 'Arrotas' arrowleaf continued growing into the summer and accumulated 12,900 kg DM/ha, which emphasised its ability to extend the growing season when ungrazed (Evans and Mills 2008).

In Year 1 the red clover growth rates of 113 kg DM/ha/d were the highest from early October until mid-November as the annual clovers, except arrowleaf, were in decline. Ideally perennials would have been sown in spring or late summer (Moot *et al.* 2000) but, in practice, the LTM rainfall suggests this is not feasible in dryland areas.

Year 2 - 2020

In Year 2 'Antas' sub clover, balansa, arrowleaf, and Persian clovers had zero to low populations of seeds re-establish so were dominated by weeds. A germination test of seed harvested in January 2020 showed that <10% of the arrowleaf 'Arrotas' and 'Cefalu' and <30% of the 'Taipan' and 'Viper' balansa seeds germinated. The hardseededness of arrowleaf has previously been noted as an issue in re-establishing plants in from the initial seed bank (Evans and Mills 2008; Macfarlane *et al.* 2015), while the Persian cultivar 'Lusa' was moderately hardseeded (Evans 2006). Production from top flowering annuals in year two and beyond was unpredictable and ongoing contribution in summer dry environments was less reliable than sub clover (Taylor *et al.* 2021)). These results supported the premise that arrowleaf and Persian and, to a lesser extent, balansa monocultures may be grown as one-season specialised legume feed for grazing from late winter to early summer or for forage production (Hyslop *et al.* 2003; Zhang *et al.* 2004).

'Napier' and 'Woogenellup' sub clover along with the two perennials produced sufficient feed for grazing. As expected, growth rates were lower under grazing than in the non-grazed establishment year. 'Woogenellup' growth rates were highest ($P < 0.05$) from mid-August to mid-September and provided the most ME and protein/ha in late winter/early spring. 'Relish' red clover was as productive as 'Woogenellup' from mid-September, presumably due to mobilising root reserves. 'Kopu II' white clover suffered from dry conditions more than red clover, probably due to the short-lived nature of its tap roots (Widdup and Barrett 2011). White and red clovers accumulated more DM and had the highest growth rates from November onwards, when the annual sub clover was dying.

The Year 2 yields highlighted the potential 'complementarity' of sub and perennial clovers in rainfed environments, provided there is sufficient summer rainfall for perennials to survive. In this

experiment, red and white clover groundcover declined during summer 2021, after low rainfall of 54 mm from January to March. Being an annual, sub clover avoids the summer dry conditions as a hard seed and relies on the late summer autumn rains to re-establish each year. Despite growing in a deep, fertile soil, there was insufficient summer rainfall to sustain these perennials into year three.

Conclusions

These results highlighted the difficulties of dryland farming. An increasingly variable climate (Salinger 2003) means a range of strategies are required to manage legumes to provide effective high quality feed. The mass of unpalatable herbage and unreliable seed germination in Year 2 from top flowering annuals suggests an opportunity to use them as single season sources of forage in their vegetative state in earlier spring and to fix nitrogen. In contrast, sub clover is the most likely winter annual to fit dryland pastoral systems, due to earlier spring production than perennial legumes. Maintaining its seed bank is required to maximise the contribution to the farm system over time. White and red clover provided the opportunity for summer growth responses to rainfall, as seen in 2019/20, but lucerne could provide the greatest production and persistence in these environments (Moot et al. 2003b).

ACKNOWLEDGEMENTS

Lincoln University technical staff (David Jack, Dan Dash, Malcolm Smith) for pasture establishment and management, and Dr Keith Pollock (climate data). Funding was provided by Beef + Lamb New Zealand, MBIE, Seed Force New Zealand and PGG Wrightson Seeds under the "Hill Country Futures" research programme (BLNZT1701).

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