Accumulated yield of clovers grown in a summer dry environment after three years

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Abstract

A 2019 experiment quantified the productivity of clover monocultures in a summer dry environment. 'Taipan' and 'Viper' balansa clovers were the most productive in their first early spring (see Olykan et al. 2021). They set seed at the end of Year 1 but there was poor establishment in Year 2. The unexpected reestablishment of high balansa populations in Year 3 prompted the experiment's continuation to study balansa growth alongside 'Woogenellup' sub and 'Relish' red clovers that were still persistent and productive.

Over three years, the total yield during the annual clover growing season (~late winter to early summer) was ~20.0 t DM/ha for sub and red clover, which was higher than the ~13.3 t for the balansa cultivars due to its re-establishment failure. In Year 3, the final accumulated yield from the best plot areas of all clovers, including balansa, was ~3.6 t DM/ha.

Supported by sufficient early summer rainfall (i.e., 50+ mm), red clover provided an additional summer yield of 1.7 t in Year 2 and 7.2 t DM/ha in Year 3. The results confirmed that the growth rate and yield patterns of sub clover (late winter to late spring) and red clover (Late spring to mid-summer) are complementary.

The possible reasons for the failure of balansa clover to re-establish in Year 2 relate to hot and dry conditions in 2020. Under these conditions, management options for balansa may require the inclusion of other pasture species.

Keywords: Balansa clover, monocultures, red clover, sub clover

Introduction

Legumes provide high-quality feed for a range of grazing animals and fix nitrogen (N) that can be utilised by companion pasture plants or is available for subsequent crops.

In summer dry regions, accumulated yields from legume monocultures can exceed 20 t dry matter (DM)/ha/yr for lucerne (*Medicago sativa* L., Brown et al. 2003; Jones et al. 2025), 16 t for red clover (*Trifolium pratense* L., Brown et al. 2003), 16 t for balansa clover (*T. michelianum* Savi, Nori et al. 2015), 10 t for sub clover (*T. subterraneum* L., Olykan et al. 2021) and 7 t for white clover (*T. repens* L., Black et al. 2003) when grown in deep, well drained fertile soils. In this situation, lucerne and red clover are the most productive because they are deep tap-rooting perennials able to access soil water to a depth of 1.9+ m (Brown et al. 2003) compared with the shallower rooted sub clover (~95% root DM located in top 30 cm of 60 cm deep pots, Cullen et al. 1972) and white clover (~95% in top 60 cm of 130 cm deep glass-fronted cases, Caradus 1981). Furthermore, if summer rainfall occurs these perennial legumes continue growing.

Winter annual clover plants are not present during the "dry" season and survive as a seed on the soil surface (e.g., balansa clover) or buried in the soil (e.g., sub clover). Their cool season growth starts with late summer/autumn rainfall events, which initiate germination and promote continued vegetative growth through the cool winter/spring, and finishes after seed set before the next summer dry begins. Therefore, winter annual clovers have a shorter growing season than perennial legumes. Monoculture growth rates of winter annuals peak in early spring with over 100 kg DM/ha/d measured for both balansa clover in late September (Hyslop et al. 2003; Olykan et al. 2021) and sub clover in early October (Olykan et al. 2021). Peak growth rates for perennial clovers occur later, being 50 to 65 kg DM/ha/d for white clover in mid-October (Black et al. 2003; Olykan et al. 2021), and 70 to 110 kg DM/ha/d in mid-November for red clover (Brown et al. 2003; Olykan et al. 2021). This temporal difference in the availability of high-quality legume-rich pasture provides an opportunity to meet feed requirements for lactating ewes from late winter/to late spring using annual clovers and then weaned lambs from late spring/to early summer using perennial clovers before the summer dry commences.

An experiment at Lincoln University investigated the annual productivity and growth rates of monocultures of four species of annual clover (two cultivars of arrowleaf, two of balansa, one of Persian, and three of sub clover) and two perennials (one red and one white clover) in a dryland environment to compare late winter and early spring production. Olykan et al. (2021) reported the results for the first two years, 2019 and 2020, and noted that the Year 2 re-establishment

and subsequent yields of 'Taipan' and 'Viper' balansa clover were low and therefore recommended it should only be considered as a one-year crop.

However, in summer dry regions of New Zealand, balansa clover has been successfully grown as a legume component in pasture mixtures (Monks et al. 2008; Macfarlane et al. 2014) and as a monoculture to graze or harvest in spring (Hyslop et al. 2003; Nori et al. 2015). The poor re-establishment of balansa clover in 2020 coincided with extremely hot, dry summer conditions. Olykan et al. (2021) noted that by early February 2020, after grazing and mowing to remove residual clover dry matter, the site was mostly bare ground and there was no obvious germination response to the application of irrigation in late February and early March.

The unexpected re-establishment of high populations of balansa clover in Year 3 (2021) prompted the continuation of the experiment for a third year to study the growth of balansa clover alongside the 'Woogenellup' sub and 'Relish' red clovers that were still productive.

This paper compares the productivity of the three clover species – balansa, sub and red – in Years 1 to 3 (2019 to 2021) and growth rates of the annual clovers in Year 3. The discussion also covers options for the effective management of balansa clover when there is poor germination in the second year due to hot and dry conditions.

Materials and methods

Full experimental details were described in Olykan et al. (2021). In brief, the experiment was conducted at Lincoln University, Canterbury, New Zealand (GPS coordinates -43.6493, 172.4659, elevation 10 m a.s.l.). It was established on a deep (> 100 cm) and imperfectly drained Wakanui silt loam soil (Mottled Immature Pallic, Manaaki Whenua 2021) with adequate soil fertility (i.e., pH 6.0 and Olsen P 16 mg/L in July 2020). Five replicates of 10 clovers: the annuals were 'Arrotas' and 'Cefalu' arrowleaf, 'Taipan' and 'Viper' balansa clover, 'Lusa' Persian, 'Antas' ssp. brachycalycinum, 'Napier' ssp. yanninicum, and 'Woogenellup' ssp. subterraneum sub clover; and the perennials were 'Relish' red and 'Kopu II' white clover. They were direct drilled on 22 March 2019 into 10 × 4.2 m plots in a randomised, split-block design, with the blocks split by growth habit: 'tall' (i.e., erect top flowering or long scrambling stems) represented by arrowleaf, Persian, and balansa clovers; or 'short' (i.e., prostrate) by sub, red, and white clovers. In Year 1, replicate 5 was dropped from the experiment due to poor growth.

By Year 3 (2021), four clovers remained dominant in their plots, namely balansa cultivars 'Taipan' and 'Viper', 'Woogenellup' sub clover, and the perennial 'Relish' red clover. Weeds and volunteer white and/or red clover had invaded the 'Arrotas' and 'Cefalu' arrowleaf, 'Lusa' Persian, 'Antas' and 'Napier' sub clover treatments, and they were considered commercially unacceptable so discarded from further measurement. The following methods were used during 2021 (Year 3).

Annual clover seedling populations

Annual clover seedlings at the cotyledon stage were observed on 30 April 2021. Seedling populations were scored on 28 May 2021 by placing a circular 0.1 m^2 quadrat randomly five times within the central area of the plot, staying at least 1 m away from the northern/southern boundaries, and estimating the seedlings in the quadrat using the 0-5 scoring system described by Olykan et al. (2024), i.e., 0 = no seedlings, 1 = 1 to 10 seedlings (average is 5.5 i.e., equivalent to 55 seedlings/m^2), 2 = 11 to 50 seedlings (30.5), 3 = 51 to 100 seedlings (75.5), 4 = 101 to 150 seedlings (125.5), and 5 > 150 seedlings per quadrat. The relationship between seedling population score and average seedlings/m^2 was described by a second order polynomial (order 2) equation $y = 77.9x^2 + 9.6x - 12.3$ ($r = 0.99$, Olykan et al. 2024).

Accumulated DM yield

The experiment was not grazed in 2021 so that the winter and spring yield potential of the balansa cultivars could be followed until the end of the annual clover growing season. Five harvests of 'Taipan' and Viper balansa and 'Woogenellup' sub clover occurred at ~fortnightly intervals on 16 August, 6 and 21 September, and 8 and 27 October from plots in replicates 1 to 4. Several challenges led to data gaps. From the 16 August harvest, only four samples were salvageable after the Level 4 Covid-19 lockdown (17-31 August 2021), therefore no statistical analysis was possible for this date. The 'Woogenellup' samples taken on 8 October were spoiled and therefore unusable. By the end of October, the balansa cultivars were in full flower and had lodged after rain and were past their best as a grazeable legume.

Herbage was harvested from the 'Relish' red clover and 'Kopu II' white clover plots on 27 October 2021. The site was grazed with sheep on 30-31 October and then mown at a height of 30 mm on 8 November, with all cut herbage removed from the site. The 'Relish' red clover plots were harvested on 17 January 2022. At this point the 'Kopu II' white clover plots were dominated by weeds so were not sampled.

At all harvests, herbage biomass was cut using electric shears to a stubble height of 20 mm from one 0.2 m^2 quadrat/plot from the best area in the plot to indicate productive potential. The plot samples were separated into sown clover, volunteer white clover,

Table 1 Harvest dates in Years 1 to 3 used for calculating accumulated yield for the four clovers at Lincoln University, Canterbury. These dates represented the point of highest accumulated yield each year.

		Harvest date		
Clover	**Yield period**	**Year 1 (2019)**	**Year 2 (2020)**	**Year 3 (2021)**
'Taipan' balansa	Peak spring	19/11	9/12	27/10
'Viper' balansa	Peak spring	9/10	9/12	8/10
'Woogenellup' sub and 'Relish' red	Final spring	19/12	9/12	27/10
Grazed/mown #		No	Yes	No
'Relish' red	Summer	7/01/2020	16/12/2020 to 26/01/2021*	9/11/2021 to 17/01/2022*

During annual clover growing season * Summer growth period.

weeds (grass and broadleaves), and dead components. Samples were dried at 65°C for 48 hours and weighed.

Accumulated yields in Years 1 to 3

Yield data from Years 1 and 2 were included with the Year 3 data to calculate the accumulated yield that occurred during the annual clover growing season, from mid-August to peak (balansa) or final (red clover and sub clover) harvest (see Table 1), for each of the three years. In addition, dates are included for the summer yield of red clover.

Ground cover assessment

A visual whole-plot ground cover assessment of the balansa clovers, 'Woogenellup' sub clover and 'Relish' red clover was carried out on 28 October 2021, as this was the last annual clover harvest. Red clover and white clover ground covers were also assessed on 17 January 2022.

Climate

Climate data were accessed from the Lincoln-Broadfield meteorological station located 2.6 km north of the site at an altitude 18 m a.s.l.

Temperature, rainfall and PET (potential evapotranspiration) data for 2019 and 2020 were reported by Olykan et al. (2021). In summary, both years had warmer air temperatures than the long-term mean (LTM) for 1991-2020 (CliFlo 2022) and were also drier than the LTM of 595 mm, with annual rainfalls of 525 mm in 2019 and 403 mm in 2020.

2021 climate data

In 2021, the annual mean maximum and minimum air temperatures were 17.4 and 7.9°C, respectively, and warmer than the LTM of 16.7 and 6.6°C. Annual rainfall was 616 mm. Monthly rainfall in the summer and early autumn was below the LTM with 33 mm in January (LTM = 43 mm), 14 mm in February (37 mm), 7 mm in March (44 mm) and 37 mm in April (54 mm), for a total of 91 mm over four months. During this time, PET was 439 mm and above the LTM of 400 mm.

On 17 April there was 16 mm rainfall and a further 11 mm on 25 April that initiated the first full germination of annual clovers. Monthly rainfall in 2021 was above the LTM in May (108 mm) and June (99 mm). After this monthly rainfall fluctuated in the winter/spring months but was >20 mm/month. Rainfall was 112 mm in December.

The potential soil moisture deficit (PSMD), calculated using rainfall, irrigation and PET, was based on the soil storing 158 mm of plant available water in the 0 to 100 cm depth (Figure 1). The 10-year LTM for PSMD was based on data from 1/7/2011 to 30/6/2021. The summer PSMD in 2021, when plant available water (PAW) was <50%, extended into May. The high rainfall in December 2021 reduced the PSMD below the LTM value for four weeks.

Statistical analyses

Genstat statistical software (Version 24, VSN International Ltd 2024) was used for all statistical analyses.

The experiment was sown as a split-block design with blocks split by growth habit, but by Year 3 only two measurable clovers remained in each sub-block, too few to estimate a separate sub-block error term. All analyses were therefore conducted as randomised complete blocks with replicate as the blocking factor.

Year 1 to 3 yields

Total annual clover growing season yield for the three years (2019 to 2021) was analysed by two-way ANOVA (clover cultivar × year main effects and interaction), including orthogonal contrasts of Annual vs Perennial species groups (A vs. P) and Balansa vs Sub clover groups (B vs. S).

Year 3 data

Annual clover seedling population scores were analysed by one-way ANOVA (clover cultivar, orthogonal contrast of B vs. S). Microsoft Excel was used to convert the mean population scores to seedling numbers/m^2 using the equation noted above.

Three of the 2021 individual harvest yields of the annual clovers, i.e., two balansa cultivars and sub

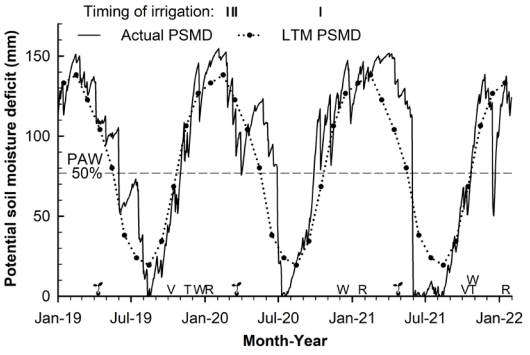


Figure 1 Potential soil moisture deficit (PSMD), germination dates (), irrigation event dates (I), annual peak yield dates for 'Viper' (V) and 'Taipan' (T) balansa, and final yield dates for 'Woogenellup' (W) sub clover and 'Relish' (R) red clover from January 2019 to January 2022 at Lincoln, Canterbury. Data, including calculated 10 year (1/7/2011 to 30/6/2021) long term mean (LTM), was from the Lincoln-Broadfield station (CliFlo 2022) 2.6 km from the experimental site. The horizontal line (..) represents 50% plant available water (PAW).

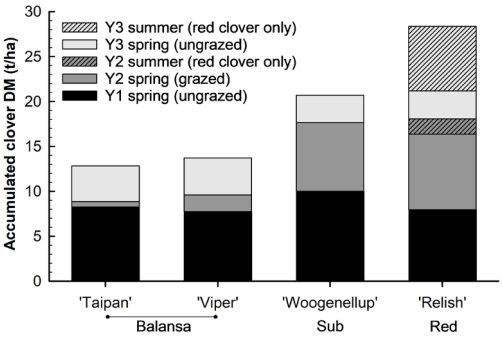


Figure 2 Three-year accumulated DM yield of four clovers at Lincoln University, Canterbury. Data based on peak yields each year for 'Viper' and 'Taipan' balansa, final yield for 'Woogenellup' sub and 'Relish' red clover, and additional summer yield for 'Relish' red clover. Y1 = 2019, Y2 = 2020, and Y3 =2021.

clover, were analysed by one-way ANOVA (clover cultivar and orthogonal contrast of B vs. S).

A one-way ANOVA (clover cultivar, orthogonal contrasts B vs. S and A vs. P) was used to analyse the 2021 accumulated harvest data from 27 October (total DM, clover DM, clover% of total DM) and the % ground cover of the four clovers (two balansa, sub, and red clovers).

A one-way ANOVA (clover type) analysed the 2021 ground cover % and DM harvests of the perennial red and white clovers.

When main effects were significant in the ANOVA ($p<0.05$), means were separated by Tukey's HSD test at the $\alpha=0.05$ level. Standard errors of the means were calculated and presented alongside the means, i.e. mean ± SEM in the results.

Results

Year 1 to 3 annual clover growing season

There was an interaction ($P<0.001$) between clover cultivar and year on yield during the annual clover growing season. In Year 1 production ranged from 7.8 to 10.0 ± 0.4 t DM/ha with no differences between the clovers (Figure 2). In Year 2, the balansa clover yield of 0.6 to 1.8 t DM/ha was less than ($P<0.05$) the ~8.0 t for 'Woogenellup' sub clover and 'Relish' red clover. In Year 3, the average yield was 3.6 t DM/ha and there were no differences between the clovers.

The Year 3 final accumulated yield was the lowest yield ($P<0.05$) of the three years for 'Woogenellup' sub clover, at 3.0 t DM/ha, and 'Relish' red clover at 3.1 t DM/ha (Figure 2). The 'Taipan' balansa yields in Years 2 and 3 were less ($P<0.05$) than in Year 1. The 'Viper' yield in Year 3 was not different from Year 1 or 2.

Summer yield of red clover

At the end of Year 1, red clover yield measured on 7/01/2020 had declined in the 19 days since the previous harvest (-1.1 t DM/ha, Olykan et al. 2021), the Year 2 harvest on 26/01/2021 provided an additional 1.7 t DM/ha in 41 days, and in Year 3 on 17/01/2022 an additional 7.2 t in 69 days (Figure 2) at a growth rate of 104 ± 13 kg DM/ha/d.

Year 3 results (2021)

Annual clover seedling populations

Seedling population scores in May 2021 were affected ($P<0.001$) by clover cultivar. The balansa cultivars had higher ($P<0.05$) mean population scores than 'Woogenellup' sub clover: 4.2±0.17 *vs*. 2.0. This equated to ~1370 *vs*. ~320 seedlings/m^2 respectively, based on the Olykan et al. (2024) scaling equation, acknowledging that a non-linear relationship was used and no uncertainty could be carried through to the seedling numbers.

Clover yields, growth rates, and ground cover %

For the 2021 individual harvests where the three annual clovers could be compared, there were no differences in accumulated yields (Figure 3). 'Viper' balansa yield peaked on 8 October (4.2 ± 0.5 t DM/ha) after growth rates of 83 ± 22 kg DM/ha/d from 21 September to 8 October. 'Taipan' balansa growth rates during this time were 67 kg DM/ha/d but yield peaked later at 4.0 t ± 0.6 t DM/ha on 27 October.

When red clover was included in the final harvest on 27 October 2021, there was no clover effect ($P=0.529$) on accumulated total (~4.8 t DM/ha) or clover yield (~3.6 t DM/ha). There were differences in the percent clover in the total DM, with the balansa cultivars averaging 89 ± 7%, higher ($P<0.05$) than 'Relish' red clover with 58%, but not different from 'Woogenellup'

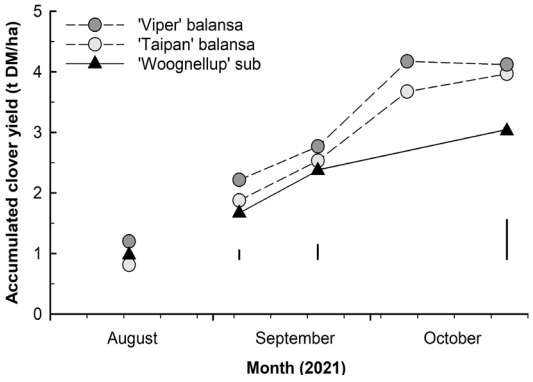


Figure 3 Accumulated dry matter (DM) yield of ungrazed monocultures of 'Taipan' and 'Viper' balansa clover cultivars and 'Woogenellup' sub clover grown at Lincoln University, Canterbury. 16 August values were unreplicated. Bars are SEM for each harvest.

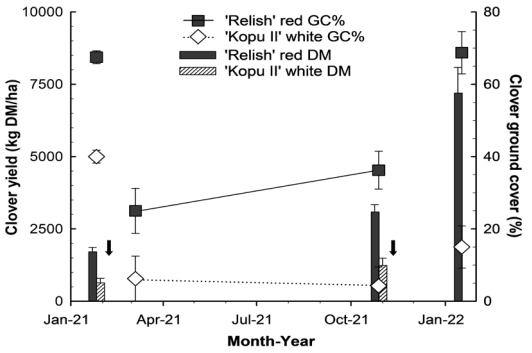


Figure 4 Yield and ground cover % (GC%) of 'Relish' red clover and 'Kopu II' white clover in Year 3 (2021) at Lincoln University, Canterbury. ↓ = Mowing of site after grazing. Bars are SE of the mean.

sub clover at 66%.

The visual assessment of ground cover on 28 October 2021 found a clover effect ($P<0.001$). Ground cover in the balansa plots was ~94 ± 3%, higher ($P<0.05$) than 'Woogenellup' sub clover at 56%, which was higher than 36% for 'Relish' red clover.

Perennial clovers

Clover type affected ($P<0.05$) ground cover % (except for 5/03/2021) and DM yields with 'Relish' red clover having higher values than 'Kopu II' white clover (Figure 4).

During 2021, the 'Relish' red clover ground cover declined from 68% in January 2021 to 25% in early March (post grazing and mowing) before recovering to 69% by January 2022 (Figure 4). In contrast, 'Kopu II' white clover ground cover did not recover during this time reaching 15% by January 2022. 'Kopu II' yields were low in 2021 with the 1.2 t DM/ha in October 2021 representing 37±12% of total DM highlighting plot variability and weed dominance.

Discussion

Accumulated yield over three years

'Relish' red clover was as productive as 'Woogenellup' sub clover across the three years (Figure 2) yielding ~20 t DM/ha based on the annual clover growing season which typically finished from late October to mid-December each year (Figure 1). When summer conditions were favourable, red clover grew additional DM that was harvested in January before the summer clean-up grazing and mowing of the site to remove poor quality annual clover residual herbage.

Previous legume research at this Lincoln site by Brown et al. (2003) found that a grazed monoculture of 'Kaituna' lucerne averaged ~20 t DM/ha/yr (Years 1 to 5) and 'Pawera' red clover averaged 16 t DM/ha/yr (Years 1 and 2). They reported that the deep-rooting lucerne accessed soil moisture to a depth of at least 2.3 m and red clover to a depth of 1.9 m. These results highlight the relative productivity of perennial legume monocultures; particularly a well-managed lucerne pasture that maintains a botanical composition >90% for 5+ years.

Balansa clover

Balansa was most productive in Year 1, with the highest early spring yields of the clovers studied, but re-establishment and yields were low in Year 2 (Olykan et al. 2021). In Year 3 balansa re-established high plant populations from its Year 1 seed bank, with spring yields comparable to 'Woogenellup' sub clover and 'Relish' red clover (Figure 2). Macfarlane et al. (2015) notes that if balansa is allowed to set seed at the end of Year 1 then the seed bank should carry over for at least three years. This potential variation in the presence and productivity of balansa across the three years presents management challenges.

In Canterbury, the Year 2 re-establishment of balansa monocultures from the soil seed bank has been successful (Monks et al. 2008; Nori et al. 2019) when the summer (i.e., December to February) rainfall was close to or above the LTM of 130 mm. In response to early summer rainfall of 50+ mm, Monks et al. (2008) observed that 'Bolta' and 'Frontier' balansa germination could be initiated in late December with subsequent germinations occurring until April/May with additional rainfall events. Likewise Nori et al. (2019) reported 'Bolta' balansa germination in mid-January in response to 28 mm of rain in late December.

In our experiment, the 37 mm rainfall on 17-18 December 2019 did not initiate a balansa germination. This was followed by 7 and 18 mm of rain in January and February 2020. The summer/autumn temperatures were hotter than usual and, with a predominance of bare

ground after 4 January, the soil surface temperatures exceeded 40°C. Olykan et al. (2021) reported that irrigation was applied in late February and twice more in early and mid-March 2020 (Figure 1) with the latter event initiating a sub clover germination but there was little response from the balansa cultivars.

To investigate the effects of temperature and moisture on the germination of 'Taipan' and 'Viper' balansa, a series of hydrothermal incubations were carried out with 'Woogenellup' sub clover included for comparison (Olykan et al. 2026). The results indicated that the reestablishment of the balansa clover cultivars after seed set will be more difficult than for 'Woogenellup' sub clover in autumn when soils are warm and dry.

Leading into Year 3, the January plus February rainfall was 47 mm, while March had only 7 mm, so annual clover germination was delayed until 25 April. The reestablishment of 'Taipan' and 'Viper' balansa resulted in high populations of seedlings that allowed the balansa cultivars to dominate their plots - being 89% of the total DM yield and 94% of the ground covers in late October 2021. As noted by Dear et al. (2006), legume species such as balansa that have small seeds, relatively high growth rates and dense canopies, can outcompete other species. In this experiment the balansa cultivars were able to outcompete the grass and broadleaf weeds. Management of the experiment in Year 3 excluded grazing and this favoured balansa, which is not as productive as sub clover under rotational grazing (Taylor et al. 2021). However, the peak balansa yields in Year 3 (Figure 2) were half those reported by Olykan et al. (2021) for Year 1: 4 vs. 8 t DM/ha. The growing season in Year 3 started two weeks later than in Year 1. While yields peaked at the same time for Viper in Years 1 and 3 (early October), in Year 3 'Taipan' finished three weeks earlier than Year 1, possibly due to the low rainfall in September (28 mm).

From a farm systems perspective, there are several potential options for managing balansa either as a monoculture or a component of pastures:

a) Single-year monoculture

As a monoculture, Olykan et al. (2021) concluded that balansa was best grown as a one-season specialised legume feed for grazing from late winter to early summer or for forage production, as previously suggested by Hyslop et al. (2003) and Macfarlane et al. (2015). In this scenario, balansa is not given the opportunity to reseed.

Additional reasons for the single-season approach include the need to shut balansa paddocks mid-October to ensure seed set at a time when feed may be required for stock (Macfarlane et al. 2015), and then the difficulty of removing the large amounts of unpalatable balansa dry matter in the summer. The hard 'clean-up' graze of balansa, by cattle or weaned ewes, is needed to ensure its re-establishment the following autumn (Craig and Ballard 2000) by providing bare space for balansa emergence and leaf production (Monks and Moot 2010). There is also the risk of a hot dry summer supressing balansa reestablishment from the seed bank.

b) Incorporating non-competitive species

Nori et al. (2015) suggested sowing balansa with a non-competitive companion species such as plantain or chicory to reduce weed invasion and provide forage production during wet summers. However, there are no published data for balansa-herb mixed pasture yields in New Zealand, so this option should be trialled first.

c) Over drilling in Year 2

Another approach is to keep the Year 1 balansa monoculture weed-free after seed set and then over drill with a grass in the Year 2 autumn (Nori et al. 2019). For example, the balansa paddock could be oversown with a cereal or Italian ryegrass, if balansa has failed to germinate by late April, followed by a summer brassica with the expectation that balansa will return in Year 3 if conditions are suitable. If the balansa did germinate in Year 2, then the developing clover-grass pasture could be highly productive in the subsequent spring.

d) Oversowing hill country pastures

Balansa has been oversown to reliably 'refresh' legume populations in the dry, mid-altitude hill country pastures at Omarama Station (Olykan et al. 2018). They reported that the farmer (Richard Subtil) had a 5-ha paddock of balansa yielding ~900 kg seed/ha that was sown at 8 to 10 kg/ha in March/April along with 150 kg/ha sulphur super.

Sub clover

Of the three sub clover cultivars originally included in the experiment - 'Antas', 'Napier', and 'Woogenellup' - the subterraneum subspecies 'Woogenellup' was the most productive and persistent: re-establishing in dry summer conditions, providing autumn feed, having the highest spring growth, and withstanding grazing (see Olykan et al. 2021). In a one year field evaluation of 15 sub clover cultivars by Teixeira et al. (2017), 'Woogenellup' and 'Antas' were the most productive cultivars with yields of 8 t DM/ha. However, in this experiment 'Antas' failed to re-establish in Year 2. 'Napier' sub clover did not establish harvestable populations in Year 1 but was present in Year 2, although not as productive as 'Woogenellup' (Olykan et al. 2021).

A comparison of 'Woogenellup' sub clover yields in Years 2 and 3 highlights two factors – the length of the growing season and the importance of grazing. In Year 2, the growing season was ~8.5 months from late March to early December (Figure 1) resulting in 7.7 t DM/ha. In Year 3 the growing season started in late April and was finished in late October (~6 months) when the

balansa season was complete and the site subsequently grazed and mown. Based on the summer regrowth of red clover (Figure 2) and the ability of 'Woogenellup' sub clover to continue growing until mid-December, as it did in Years 1 and 2 (Olykan et al. 2021), it could be assumed that growth would have continued for another seven weeks into December of Year 3. However, sub clover growth was slowing down by 27 October (Figure 3) and in the six weeks from mid-October until late November there was only 20 mm rainfall suggesting that the sub clover would have senesced early.

The length of the sub clover growing season is governed by sufficient rainfall initiating establishment in summer/autumn and supporting continued growth into early summer (Olykan et al. 2018). Moot et al. (2003) reported that 'Denmark' and 'Woogenellup' sub clover plants that germinated on 7 March produced ~7 t DM/ha by mid-September compared with ~1.8 t from plants that germinated on 7 May. In Year 2 of this experiment, 'Woogenellup' sub clover was 88% of the total DM in the final harvest when grazed, compared with 66% in Year 3 when ungrazed. Grazing minimised grass and broadleaf weed ingress, thereby reducing competition for resources, resulting in improved sub clover production. A similar result was identified by Teixeira et al. (2017) with 'Woogenellup' sub clover being 81% of the total DM on 28 September, after which the site was mechanically cut and carried to simulate grazing, and in the final harvest on 17 November the 'Woogenellup' was 94%.

Sub clover is the most common annual clover in New Zealand dryland pastures (Stewart et al. 2022) and provides high quality livestock feed in the late winter/early spring. It thrives on drier sites such as sunny hill faces and stony soils. Typically, it is studied as the legume component of a dryland pasture (e.g., Mills et al. 2015; Olykan et al. 2024).

Sub clover is not normally sown as a monoculture in New Zealand but continues to be the most productive annual clover for grazed dryland pastures, particularly in hill and high-country terrains. In these environments, sub clover productivity and persistence relies on pasture management strategies that minimise the effects of competing grasses such as herbicide suppression (e.g., Olykan et al. 2024) and/or timely grazing (e.g., Dodd and Sheath 2003; Olykan et al. 2019).

Red clover

The perennial 'Relish' red clover had the opportunity to continue growing from the end of the annual clover season (late October to mid-December) until the site clean-up (graze and/or mow) in January. The additional mid-summer red clover DM yield ranged from a loss in Year 1, when red clover was not grazed at the end of the annual clover growing season, to a high level of production in Year 3 after the site was grazed in spring (Figure 2).

Perennial clovers, such as red and white clover, often struggle in dryland environments and are therefore recommended for sites with >750 mm annual rainfall with at least 150 mm in summer (Brock et al. 2003). In this experiment, the December rainfall events were 38, 52 and 112 mm, in Years 1 to 3 respectively, showing that when red clover is under minimal soil moisture stress it can be extremely productive, as previously reported (e.g., Brown et al. 2003).

The 'complementarity' of annual sub clover and perennial (red and white) clovers in rainfed environments, provided there was enough summer rainfall for the perennial clovers to survive, was highlighted by Olykan et al. (2021). This was in reference to the higher growth rates and yields of sub clover in early spring, which were superseded by the red and white clovers late spring to mid-summer based on Year 1 and 2 results. Within a dryland system, sub clover would be sown with cocksfoot (*Dactylis glomerata*) (Mills et al. 2015) and the red clover may be grown as a monoculture (Brown et al. 2003).

If summer soil moisture is low, the rate of red clover taproot carbohydrate replenishment decreases, which slows regrowth and therefore stands frequently only persist for 2 to 3 years (Brock et al. 2003). Based on observations in early 2021, Olykan et al. (2021) concluded there had been insufficient summer rainfall in 2020/21 to sustain the perennial clovers into a third year despite growing in a deep, fertile soil. There was a decline in 'Relish' red clover groundcover going into the Year 3 autumn (Figure 4) and the soil moisture deficit remained high until late April 2021 (Figure 1). However, this was followed by a relatively wet winter that allowed red clover to recover and the high rainfall in December supported exceptional red clover growth into early 2022. In contrast, 'Kopu II' white clover did not recover during 2021.

Conclusions

'Woogenellup' sub clover and 'Relish' red clover were the most productive and persistent clovers over three years in the Lincoln dryland system, particularly when regularly grazed. Red clover monocultures can be productive during summer when supported by sufficient early summer rainfall (i.e., 50+ mm in December). The growth rate and yield patterns of sub clover (late winter to late spring) and red clover (early to mid-summer) are complementary. It is recommended that sub clover is sown with cocksfoot and red clover grown as a monoculture in dryland environments.

While a monoculture of balansa clover can be a highly productive in its first year, subsequent reestablishment from the seed bank may be low if hot dry summer/

autumn conditions prevail. Options for managing balansa in this situation may require the introduction of other pasture species, which needs further investigation.

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