Predicting yield of irrigated red clover (*Trifolium pratense* L.) pastures in response to temperature.

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Abstract

Two datasets from red clover monoculture pastures grown in Lincoln, New Zealand, were analysed to generate coefficients to predict red clover yield. The mean annual production of established red clover was 17.0±0.48 t DM/ha, with a maximum mean growth rate of 125±9.36 kg DM/ha/day (spring Year 2). In the establishment year irrigated red clover grew at a constant rate of 7.30±0.14 kg DM/ha/°Cd (T_b = 3 °C) throughout the year. In contrast, there was a split-line linear response in Years 2 and 3, which differed between years and decreased after the second week of January. Specifically, the growth rate in Phase 1 was 7.70±0.38 kg DM/ha/°Cd in Year 2, which was 16% higher than the 6.60±0.28 kg DM/ha/ºCd in Year 3. The difference probably reflected increased competition from weed grasses as red clover content declined from >95% to ~75% of total annual yield. After January, red clover grew at 3.05±0.35 kg DM/ha/°Cd, in both years. This lower rate occurred in the mid-January-July period, and probably reflected a change in partitioning of assimilate to red clover roots in response to a decreasing photoperiod. The coefficients reported here for red clover need to be validated from other datasets. However, they provide easily transferable coefficients that can be used to estimate red clover yield under non-limiting conditions for other locations. These could be integrated into feed budgeting software to assist on-farm decision making.

Keywords: thermal time, *Trifolium pratense*

Introduction

Generalised, climate driven, pasture growth models are useful tools that assist the management of perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) based pastures, particularly on New Zealand dairy farms (Radcliffe and Baars 1987; McCall and Bishop-Hurley 2003; Romera et al. 2010). These models can be used to predict herbage mass between sequential pasture measurements. However, the body of data to support sheep and beef farmers in more extensive areas of New Zealand utilising alternative forage species is limited.

Methods for on-farm prediction of the yield potential of lucerne (alfalfa; *Medicago sativa*) crops in New Zealand have been developed and used to provide guidelines for best management practices (Moot et al. 2022). Cocksfoot (orchardgrass; *Dactylis glomerata* L.) production has also been quantified (Mills et al. 2006) to provide coefficients to estimate yields in response to contrasting levels of water and nitrogen. These data provide a framework for the analysis of yield responses of other forages of economic importance, particularly for New Zealand sheep and beef systems. Environmental variables including temperature, soil moisture and nitrogen affect pasture growth (Mills et al. 2006). Their potential impact on forage performance can be assessed for predictive purposes and used in models designed to examine grazing systems at the farm level to give optimal production responses and reduce risk. For example, Romera et al. (2009) calculated the daily growth rate (N; Equation 1) as:

Equation 1 $N = (a \times I \times gt \times gT \times gW \times c(G) - r(G)) \times 10$

where a is shoot radiation use efficiency (RUE; g DM/MJ), I is total incident solar radiation (MJ/m^2/d), gt is a reproductive function, gT is a temperature function, and gW is a soil water function, c(G) is the fraction of total incident radiation intercepted by the canopy, r(G) is maintenance respiration (g DM/m^2/d) and 10 is the conversion from g/m^2 to kg DM/ha.

Moot et al. (2022) found a simplified relationship between accumulated yield and accumulated thermal time could be used to predict irrigated lucerne production, provided the rate decreased to account for partitioning to the roots in autumn. They reported that after 140 °Cd had accumulated from 1st July (to allow canopy closure), lucerne grew at 11.9 kg DM/ha/ºCd until mid-January, and then declined to 6.7 kg DM/ha/ºCd. Mills et al. (2006) showed a cocksfoot monoculture grew at 7.2 kg DM/ha/ºCd when fully fertilised with nitrogen but at half that when no nitrogen was applied.

In their analysis, Moot et al. (2022) assumed that the lucerne was not limited by nutrient availability, because nitrogen was supplied by fixation. In the current analysis, the same assumption was made for red clover (*Trifolium pratense* L.). Thus, the hypothesis was that under non-limiting conditions the growth of red clover should also respond linearly to thermal time accumulated above a base temperature (T_b).

The factor most likely to cause a deviation from a linear response of growth to temperature is water stress. Mills et al. (2006) showed that their unirrigated N-fertilised and non-fertilised pastures grew at the same rate as their respective irrigated pastures both before and after the period when water limited growth. Thus, ensuring red clover swards are adequately watered is an important component for determining the growth rate response to temperature accumulation (kg DM/ha/ºCd).

Once the growth rate is calculated, the need for other parameters that relate to forage yield, such as partitioning to flower or root tissue, can be determined. Therefore, the aim of this study was to determine whether red clover growth can be accurately predicted from a growth rate response to temperature accumulation, using thermal time accumulation. The objective was to determine if the relationship between accumulated yield of red clover monocultures and temperature was linear, and consistent across years and seasons. The null hypothesis was that the coefficients derived from linear regression equations of growth against thermal time would not differ between the two datasets. If accepted, a single co-efficient could be used to estimate growth rate, and consequently yield, at different locations.

Materials and Methods

This research used published and unpublished datasets to determine whether similar linear relationships of growth against temperature can be developed for red colver monocultures. Specifically, red clover yield is accumulated and related to the accumulation of temperature as thermal time over the same period. This was used to quantify the temporal pattern of red clover production under non-limiting water conditions. For both datasets, red clover was irrigated to create non-limiting soil water conditions. To confirm this, a soil water budget was calculated for each dataset. Specifically, monocultures that experienced moisture stress during each growth season (1 July – 30 June), would be expected to show a reduction in the yield versus thermal time relationship as the soil dried and growth slowed.

Datasets

Dataset 1: ‘Pawera’ red clover was monitored over three years. The experiment was sown on 1/11/1996 and the final observation made on 22/04/1999. Full experimental details were reported by Brown (2004). The experiment was located on flat land in Iversen Field adjacent to the Lincoln University Field Research Center (44º38’S, 172º28’E, 11 m a.s.l.; NZGD2000 (New Zealand Geodetic Datum) in Canterbury, New Zealand. The experiment included irrigated and dryland treatments and had three replicates. The assumption tested was that the dryland crops grew at the same rate as irrigated crops in spring, but with the expectation that subsequent water stress would reduce the growth rate as the soil dried during summer months (Mills et al. 2006).

Dataset 2: Irrigated monocultures of five commercially available red clover cultivars were grown in four replicates, in 5.0 m x 1.5 m plots and monitored over three years at the Kimihia Research Centre (43º61’S, 172º47’E, 24 m a.s.l.; NZGD2000), Lincoln, New Zealand. The experiment was established on 4/12/2015 and the final observation made on the 29/03/2018. At sowing, plots were fertilized with 200 kg/ha of Diammonium Phosphate (DAP) (17.6%N, 20.0%P, 0%K, 1%S), and pre-emergent chemical Treflan™ (480 g/L trifluralin) was applied at 1.2 L/ha on 5/12/2015 to control weeds during establishment. Post sowing (34 days) at two trifoliate leaves, 65 g/ha of Preside™ (800 g/kg flumetsulam) and 1.0 L/ha of Uptake™ oil (582 g/L paraffinic oil, 240 g/L alkoxylated alcohol non-ionic surfactants) was applied to the site for post emergent weed control. The same rate of Preside™ and Uptake™ was used in Year 2 and Year 3 in October following the emergence of spring weeds. Following the establishment period, the experiment was fertilized with 80 kg/ha N-Rich Urea™ (46%N) on 14/04/2016. Maintenance fertiliser was applied each year (28/10/2016, 13/12/2017, 28/08/2018) using 30% Potash Super (5.6%P, 15%K, 14.28%S, 13.83%Ca). The first harvest occurred 117 days after sowing to allow sufficient root development. The first irrigation occurred three days after sowing in early December. Irrigation was applied using a travelling irrigator at a target rate of 20 mm with four applications per year, occurring from November through to March.

Meteorological data

Weather data from the Broadfields Meteorological Station were accessed from NIWA’s Cliflo database (https://cliflo.niwa.co.nz/). Data were from Agent Number 4882 (1/07/1996 to 30/06/1999) and 17603 (1/07/1999 – current) and were extracted as “Combined Daily 0900 Obs (F301)”.

Soil moisture

A soil moisture function (Equation 2) was used to assess potential soil water deficit (PSWD). The process of determining soil moisture status started with understanding plant water extraction patterns to set the lower limit of extraction. Brown (2004) showed that red clover has the potential to extract 330 mm of water down to an extraction depth of 1.9 m on the Wakanui soil (Dataset 1).

Equation 2 $PSWD = PSWD_{i-1}$ + Potential Evapotranspiration – (rainfall + irrigation)

Where $PSWD_{i-1}$ is the PSWD on the previous day, PSWD was set to zero at the start of each season (1st July) and was not allowed to exceed field capacity (i.e: zero), with excess water expected to have drained or run-off.

Mean daily potential evapotranspiration (EP) was calculated for the duration of the experiment from hourly weather data using Penman EP as formulated by. The PSWD is not constrained by soil depth, nor water holding capacity. It provides a potential figure and allows assessment of the severity, and duration, of water stress within a growth season. The actual soil moisture deficit (ASMD) and plant available water (PAW), were estimated for Dataset 2 from readily available data in S-Map (Landcare Research 2022).

Base temperature (T_b)

The calculation of Tt is often based on three cardinal temperatures; a base (T_b) below which no development occurs (Tt = 0), a maximum temperature (T_{max}) above which development stops, and an optimum (T_{opt}) where daily development reaches a maximum (°Cd). For summarizing temperate pasture growth, a T_b of 3 ºC has previously been applied (Mills et al. 2006; Fasi et al. 2008) and, thus, was used for this analysis.

Thermal time

Daily thermal time (Tt) was calculated based on the method of Jones and Kiniry (1986). This uses a two-stage model to interpolate thermal time of eight three-hourly periods using a sinusoidal curve fitted to daily minimum and maximum air temperatures. A T_{opt} of 25 ˚C and a T_{max} of 40 ˚C was used (Moot et al. 2000). In all cases the daily maximum temperatures experienced for these datasets were below T_{max}.

Statistics

The data yield and growth rate data for Dataset 1 have been published previously (Brown and Moot 2004). The yield and growth rate data for Dataset 2 were analysed by a one-way (cultivar; anonymised) analysis of variance (ANOVA, Genstat v22; VSN International Ltd).

Linear and split-line regression analysis was then used to quantify the relationship between accumulated dry matter yield (kg/ha) and accumulated thermal time for each plot in both experiments. All regressions were fitted using a model/loss fitting procedure, which runs iterations with different coefficients, from a specified start point to reach coefficient values that give the best fit of the relationship. A split-line regression was then applied to determine if there was any quantitative change in the rate of accumulated thermal time. This was also done on a plot basis before ANOVA for both datasets. The coefficients analysed were, any breakpoint (x and y values), Slope 1 and Slope 2 and their intercepts. Standard errors were calculated for each dataset. The time of any breakpoint was also analysed to determine whether changes in the response were influenced by water stress. Means are reported with their respective standard error of the mean (SEM).

The start date for each rotation in Dataset 1 was the day after the sheep were removed from plots. If plots were topped after grazing, Day 1 was the day following the topping event. For Dataset 2, the start of each rotation was the day after harvest as the whole experimental area was mown on the same day as the harvest took place.

Results

For Dataset 1, red clover yield in the establishment year was 13,200±1,210 kg DM/ha/year. Second year crops showed the greatest yield, producing a maximum yield of 21,280±1,910 kg DM/ha/year. Third year crop yields decreased by 16% compared with Year 2.

For Dataset 2, annual dry matter yield in Year 1 (establishment) was not different among the five red clover cultivars (P=0.17) and averaged 3,770±400 kg DM/ha over the 7-month period (Figure 1). In Year 2, accumulated DM yields were also not different among cultivars (P=0.24; 20,290±1,940 kg DM/ha) but were 40% lower (P=0.04) in Year 3 (13,110±1,780 kg DM/ha). In Year 3, Cultivar 2 produced 32% more DM (P=0.01) than Cultivars 1 and 5 (11,470±1,780 kg DM/ha/year). However, only Year 2 and Year 3 were included as a factor in the accumulated yield and thermal time analysis due to the late sowing of red clover in the establishment year.

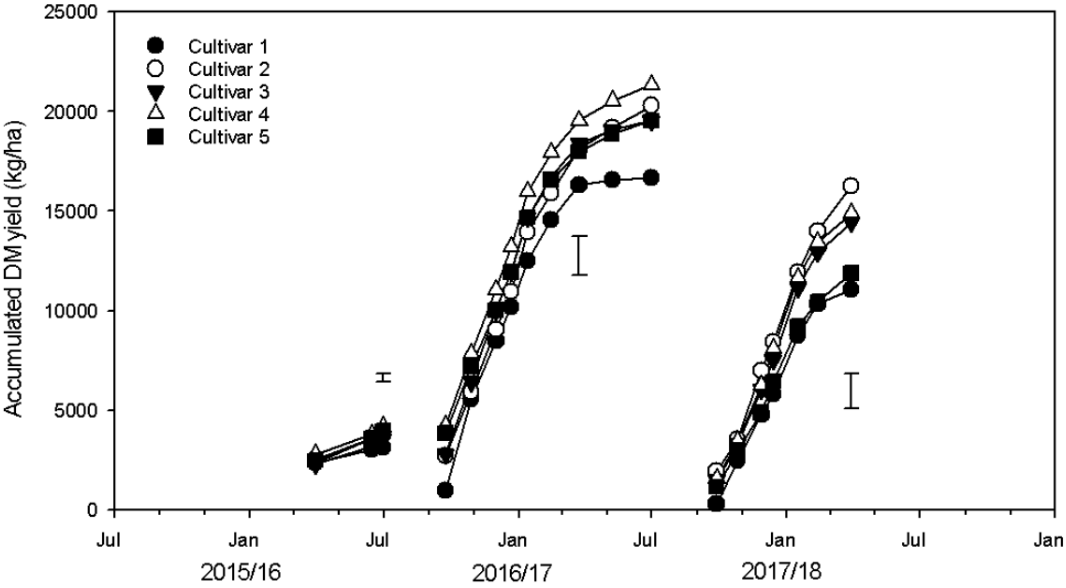

Figure 1 Annual dry matter yield of five red clover cultivars (anonymised) across three growth seasons at Kimihia Research Centre, Lincoln, Canterbury. Error bars are the standard error of the mean for each growth season.

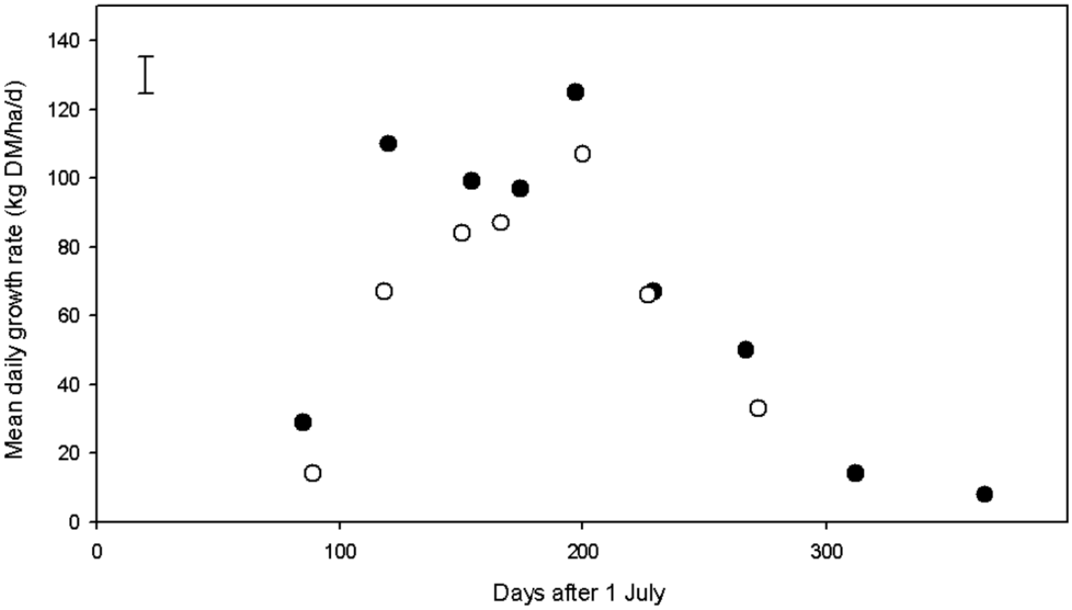

Figure 2 Mean daily growth rate of irrigated red clover monocultures in Year 2 (●) and Year 3 (○) at Kimiha Research Station. Error bar is the maximum standard of error of the mean for the five cultivars over time.

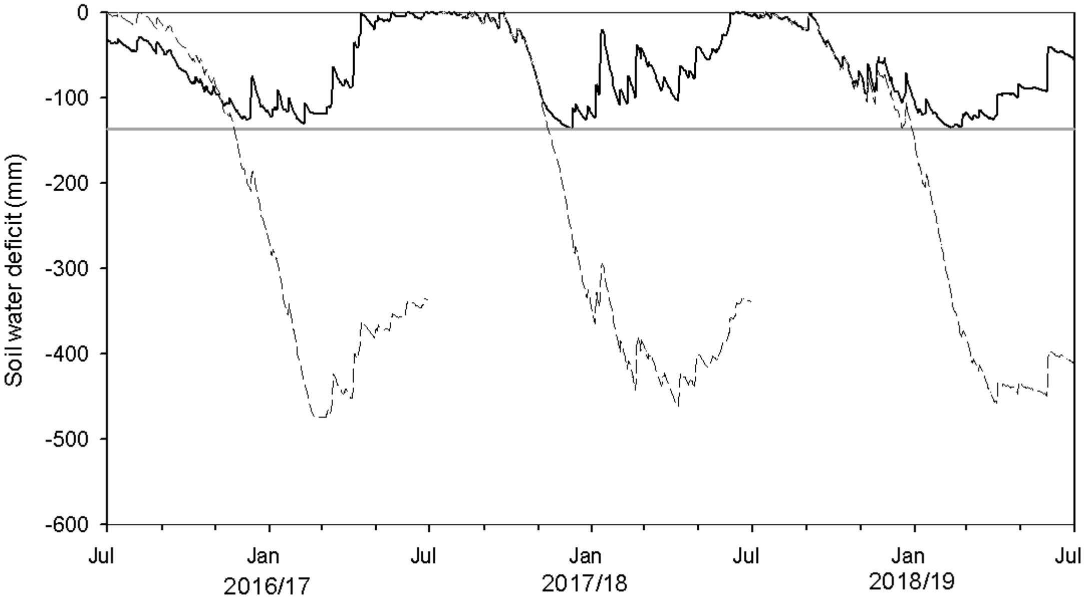

Figure 3 Actual and potential soil moisture deficits at Kimihia Research Station from 1 July 2016 to 30 June 2019 based on meterological data from the Broadfields Meterological Station (3.48 km South). 75% PAW (grey line), ASMD mm (short dash), PSMD mm (long dash).

Mean daily growth rate of the irrigated red clover showed the seasonal differences expected in a temperate climate (Figure 2). Mean daily growth rates for Dataset 1 are presented in Brown (2004) and showed irrigated red clover growth rate peaked at 86.0±3.36 kg DM/ha/d in mid-February and declined to 5.0±0.87 kg DM/ha/d in June.

At Kimihia (Dataset 2), rotation duration ranged from 19 (early summer) to 88 (winter) days. Mean daily growth rates increased from 8.05±1.17 kg DM/ha/d in June to a maximum of 125±5.25 kg DM/ha/d in early January of Year 2. For Year 3 crops, mean daily growth rate increased from 14.0±1.79 kg DM/ha/d in winter to 107±4.68 kg DM/ha/d in January. There was no difference (P=0.82) in the maximum daily growth rate among cultivars in Year 2 but the growth rate of Cultivar 2 (131±5.76 kg DM/ha/d) was 34% faster (P=0.01) than that of Cultivars 1 and 5 in Year 3 (97.9±2.97 kg DM/ha/d).

A soil mositure budget was calculated to determine whether Dataset 2 crops were impacted by soil moisture stress (Figure 3). The crops were considered to be moisture stressed when plant available water dropped below 75%. This did not occur for the experimental period and, thus, the crops were considered non water stressed.

The relationship between accumulated dry matter yield and accumulated thermal time was assessed across the two datasets to determine the response of red clover to temperature and detect any water stress. There were no differences over time (P=0.31) in Dataset 1, nor among cultivars in Dataset 2 (P=0.21). Therefore, split line regressions were fitted to the mean data for each dataset. Both analyses showed a break point in the relationship, which meant separate equations were required before (Slope 1) and after (Slope 2) the breakpoint.

For Dataset 1 (Figure 4) the mean standardised growth rate of Slope 1 was 8.0±0.38 kg DM/ha/°Cd. After the breakpoint, Slope 2 showed the growth rate dropped to 2.57±0.39 kg DM/ha/°Cd for irrigated crops and 2.52±0.35 kg DM/ha/°Cd for dryland crops, a similar value due to non-limiting soil moisture conditions during the growing season (Figure 3). The time of the break point is summarised for each dataset and, as expected, was 12-38 days earlier (P=0.04) for the dryland crops in both years (Table 2).

Figure 5 shows the split line relationship for Dataset 2. The mean standardised growth rate for Slope 1 was 6.40±0.27 kg DM/ha/°Cd and 3.05±0.70 kg DM/ha/°Cd for Slope 2. There was no difference (P=0.14) among cultivars assessed over the three-year period. The time of the breakpoint is summarised for each dataset and was earlier for the Year 2 than Year 3 crops (Table 3).

Analysis of the two datasets indicated a common slope among experiments (Table 1). The estimate

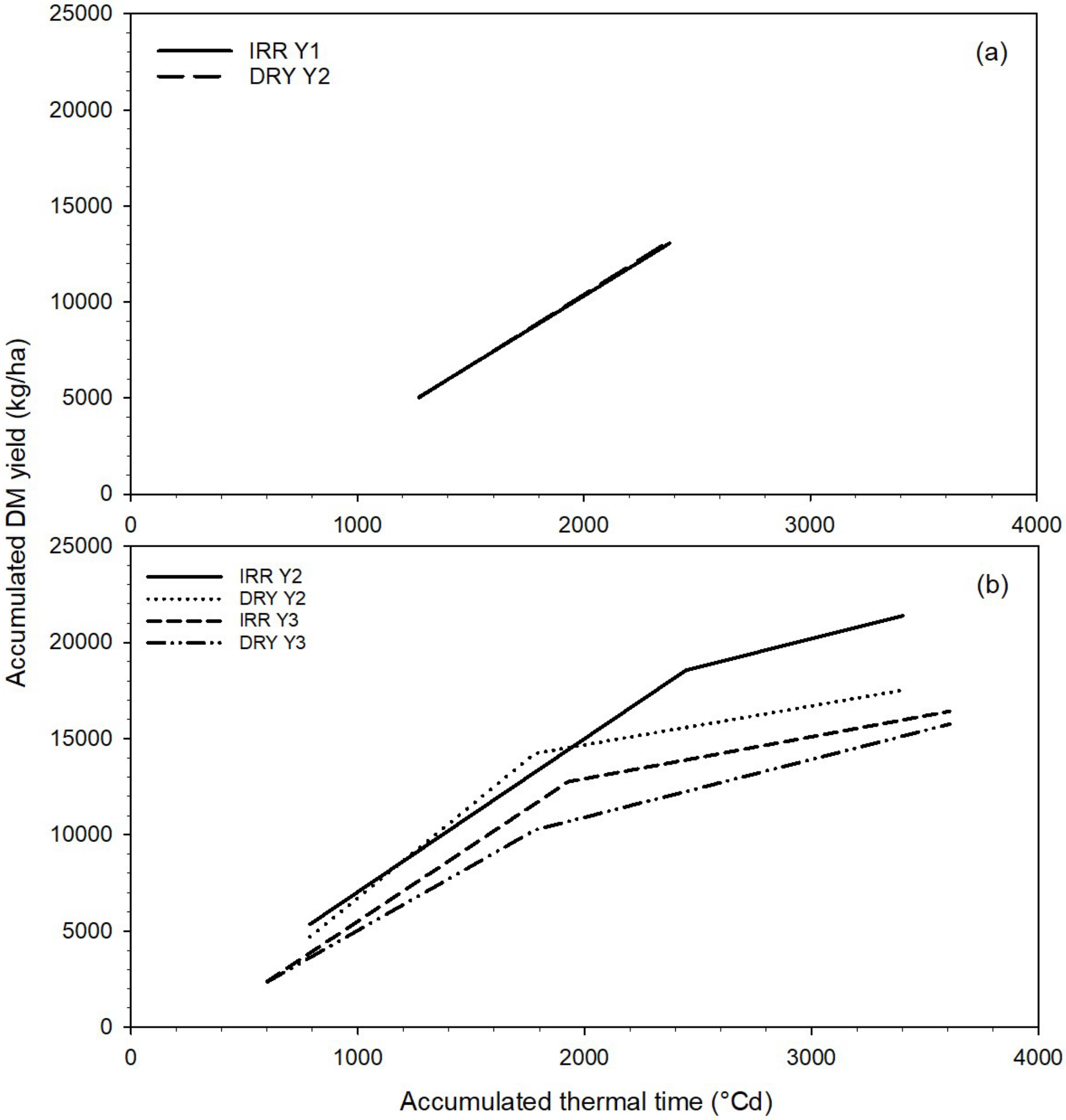

Figure 4 Accumulated yield against accumulated thermal time for establishing (a) and regrowth (b) red clover crops grown under irrigated (IRR) and dryland (DRY) conditions in Years 2 and 3 (Y2 and Y3) at Lincoln University, reanalysed from Brown (2004). Split line regression of the mean of each treatment are shown across two years and their coefficients summarised in Table 1.

Table 1 Parameters of split line regressions fitted to the relationship between accumulated DM yield and accumulated thermal time for two datasets. Standard errors of the slopes and intercepts are reported in parenthesis and coefficients of determination (R2) are shown.

Dataset	Growth year	Equation
1	IRR RC Y1 Slope 1	4200(±510) + 7.27(±0.14)x R^2 = 0.99
1	IRR RC Y2 Slope 1	-940(±310) + 7.97(±0.20)x - 942 R^2 = 0.98
1	IRRRC Y2 Slope 2	11310(±630) + 2.96(±0.45)x R^2 = 0.98
1	IRR RC Y3 Slope 1	-2310(±550) + 7.81(±0.31)x R^2 = 0.98
1	IRR RC Y3 Slope 2	8590(±1470) + 2.17(±0.34)x R^2 = 0.98
1	DRY RC Y1 Slope 1	4420(±1890) +7.40(±0.27)x R^2 = 0.99
1	DRY RC Y2 Slope 1	-2910(±410) + 9.63(±0.56)x R^2 = 0.95
1	DRY RC Y2 Slope 2	10610(±1010) + 2.03(±0.29)x R^2 = 0.95
1	DRY RC Y3 Slope 1	-1660(±350) + 6.69(±0.45)x - 1659± R^2 = 0.96
1	DRY RC Y3 Slope 2	4890(±1650) + 3.01(±0.32)x + 4887± R^2 = 0.96
2	Y2 Slope 1	-1420(±350) + 7.33(±0.30)x R^2 = 0.92
2	Y2 Slope 2	7880(±880) + 3.25(±0.50)x R^2 = 0.92
2	Y3 Slope 1	-2810(±520) + 5.40(±0.25)x R^2 = 0.89
2	Y3 Slope 2	4060(±560) +2.85(±0.90)x R^2 = 0.89

Table 2 Mean breakpoint date for irrigated (IRR) and dryland (DRY) treatments and corresponding date value for Dataset 1 in Year 2 and 3 (Y2 and Y3).

Treatment	Breakpoint (°Cd)	Date
IRR Y2	2440	26/01/1998
DRY Y2	1790	19/12/1997
IRR Y3	1930	29/12/1998
DRY Y3	1740	17/12/1998

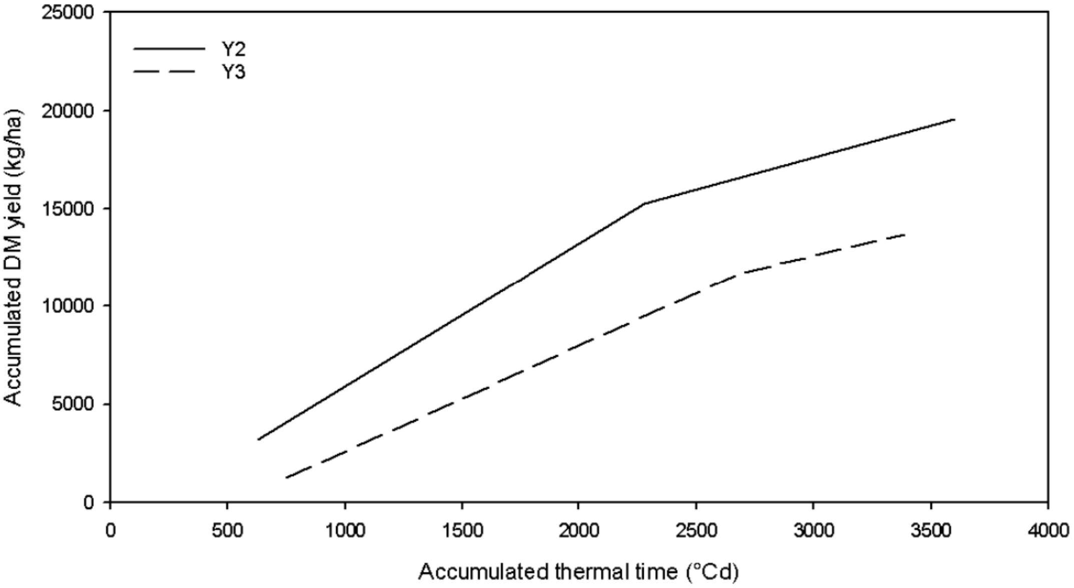

Figure 5 Accumulated dry matter (DM) yield against accumulated thermal time for established red clover crops grown under irrigated conditions at the Kimihia Research Centre, Lincoln, New Zealand. Split line regressions of the mean of five cultivars are shown for Year 2 (Y2) and Year 3 (Y3). Split line regressions coefficients are summarised in Table 1.

Table 3 Mean breakpoint (Tt; °Cd) and corresponding calendar date for irrigated and dryland treatments for irrigated red clover monocultures in Year 2 (Y2) and Year 3 (Y3) at Kimihia Research Centre, Lincoln, Canterbury.

Treatment	Breakpoint Tt (°Cd)	Date
Y2	2280	28/01/2017
Y3	2690	5/03/2018

of red clover growth rate in response to temperature accumulation for Year 1 was from Dataset 1 at 7.27±0.14 kg DM/ha/ºCd for the establishment year. In Year 2 the standardised growth rate was 7.69±0.38 kg DM/ha/ºCd for Slope 1 but then declined to 6.61±.0.28 kg DM/ha/ºCd for Slope 1 in Year 3. The average breakpoint between the slopes occurred 16th January, or day 200 of the growth season. Slope 2, after the break point for Years 2 and 3, was 2.75±0.41 and 2.68±0.52 kg DM/ha/°Cd, respectively (P=0.16).

Discussion

The maximum annual yields attained in these two experiments exceeded 20,000 kg DM/ha/yr when moisture was non-limiting (Figure 1 and Brown 2004) and stands remained productive for three years. Red clover has gained popularity as a specialist finishing crop on sheep and beef farms, and has been used successfully to transform summer safe hill country farms (e.g. Chapman et al. 2022). The advantage of the legume was that it reduced the need for nitrogen fertiliser and provided nitrogen transfer to the subsequent grass-based pasture, which grew in excess of 30,000 kg DM/ha. Thus, the strategic use of legume-based pastures can increase farm productivity by growing more feed, particularly compared with resident species (Smith et al. 2023). The introduction of short-lived perennials is often limited by a lack of knowledge of how much they can grow in a particular location. Therefore, the analyses in this paper provides transferable coefficients for pasture growth in relation to the accumulation of temperature as thermal time.

Red clover mean daily growth rates showed the typical temperate seasonal pattern of pasture production, with highest grown rates in summer, (85±5.25 to 125 kg DM/ha/day) before declining to near zero in winter (Figure 2). This temporal pattern of growth is expected for pastures in New Zealand and has been well documented for irrigated conditions (Radcliffe 1981). However, agronomically, mean daily growth rates are season and location specific, and thus, do not allow growth rates to be predicted outside the location they were determined. The current evaluation aimed to analyse these data to determine if readily transferable coefficients could be calculated for red clover monocultures based on temperature, accumulated as thermal time, to create a standardised growth rate response to temperature accumulation. The emphasis on temperature reflects the fact that the other parameters that affect growth (Equation 1) have been dealt with. Specifically, as a legume, no nitrogen parameter is required, and the pastures were not exposed to growth restrictions due to a lack of soil moisture (Figure 3), which would slow the rate of DM production (Mills et al. 2006). Therefore, the focus was on the growth rate response to temperature accumulation to determine if a single value was appropriate or there was a need for a partitioning coefficient, as previously found for lucerne (Moot et al. 2022).

Analysis of Year 1 (establishment) data from Brown (2004) showed a linear response of yield to thermal time (Figure 4), and the crop grew at 7.27±0.14 kg DM/ha/°Cd. This single value was appropriate for the whole growth season, and was comparable to the irrigated pasture value of 7.2 kg DM/ha/ºCd reported by Mills et al. (2006). Both of these rates are more than double the linear rate of 3.3 kg DM/ha/ºCd reported for a non-N fertilised grass pasture with non-limiting water (Mills et al. 2006). An assumption of the present analysis is that other nutrients (e.g. P, K, S) were adequate for maximal red clover growth. The inclusion of a coefficient for other nutrients may be required if crops are grown in below optimum fertility conditions, but this was not the aim of the current investigation.

For Years 2 and 3 red clover showed strong seasonality of above-ground yield (Figure 4 and Figure 5). This must be accounted for through either a change in radiation use efficiency (Equation 1) or the use of a separate function for the two periods. The simplest estimate of growth rates for fully irrigated red clover stands was 7.65 and 6.61 kg DM/ha/ºCd (Table 3) for irrigated second and third-year crops, respectively, until the break point. Mean growth rates after the breakpoint for second and third-year crops were 3.11 and 2.51 kg DM/ha/ºCd, respectively.

Both datasets identified a breakpoint and results suggested it was independent of water stress. This was confirmed by the results of Dataset 1, which showed the break point occurred 12-38 days, or 188-650 °Cd earlier for the dryland than irrigated crops 26/01/1998 compared with 19/12/1997 (Figure 4). The implication was, for the dryland crops, that the break point was triggered by the combination of a moisture deficit and partitioning, compared with a partitioning requirement alone for the irrigated crops. The level of water stress experienced by the crops in Dataset 1 was low because the soil has 350 mm of available water within the root zone, so this distinction remains to be confirmed in a soil with lower water holding capacity when the reduction in potential growth due to water stress can be expected to be more distinct (Moot et al. 2008).

The decline in yield in Year 3 (Figure 1) of the cultivar evaluation (Dataset 2), was consistent with the decline in botanical composition observed by Brown (2004) for Dataset 1, where by Year 3 red clover plots had only ~80% of the red clover population remaining in the sward (Brown 2004). The 20% reduction in the contribution of red clover to total DM yield was comparable to the 14-20% reductions in the Slope 1 and Slope 2 standardised growth rates between Years 2 and 3. This change in composition was consistent with the need for a lower standardised growth rate for Year 3 compared with Year 2. It probably reflected a reduction in light interception that would be accounted for through Equation 1 but this was not measured in Dataset 2. This is an area for future research to determine if the slope of the growth rate response to temperature accumulation could be estimated from the proportion of red clover present in a monoculture.

The reduction in growth rate response to temperature accumulation after the break point probably reflected a change in partitioning of assimilate to red clover roots in response to a decreasing photoperiod. This physiological trigger has previously been shown to change the partitioning priority from shoot to root in lucerne and was applied after the third week of January (Teixeira et al. 2011; Moot et al. 2022; Yang et al. 2023). For red clover, the mean breakpoint for the irrigated crops also appeared to be about the 3rd week of January. However, with only two datasets available to define this, more work is required to ensure a single date is appropriate for red clover.

The parameters derived from these two experiments provide the basis for yield of irrigated red clover to be estimated based on readily available air temperature data. These need to be further validated with other datasets, however the main features of red clover yield have been accounted for across multiple seasons. Separation of the spring and autumn periods appears necessary for red clover crops, and this analysis provides methods that can be used to assess both periods in different locations across the country. A single coefficient seems appropriate for Year 1 (establishment). For Years 2 and 3, Slope 1 should be used until the third week of January and Slope 2 from that point onwards. The accumulation of thermal time was above a base temperature of 3 °C. These parameters could be used to provide readily accessible yield information for areas where red clover data are not available. They remain to be validated but offer a guide for practitioners to estimate potential yields for the three most productive years of a red clover stand. For example, if a high-altitude site in Taihape accumulates 3200 °Cd annually, with 1680 °Cd accumulated from 1 July to the 1st week of January the results shown here would indicate a second-year red clover stand, grown under non-limiting water and nutrient conditions, has the potential to grow 17,780 kg DM/ha.

Conclusions

- Irrigated red clover growth rates were linearly related to temperature (7.27 kg DM/ha/°Cd above $T_b = 3$) in the first year for both datasets. This coefficient can be used to estimate yields in locations where red clover yield data are unavailable.

- Irrigated red clover growth was linearly related to temperature in Years 2 and 3, but there was strong evidence of a slowing in the rate after the first week of January. The temperature adjusted spring growth rate was 16% higher in Year 2 than Year 3 (7.69 versus 6.61 kg DM/ha/°Cd; $T_b = 3$). The ~20% decline in Year 3 was consistent with the decline in red clover population over time and probably reflects a reduction in total light interception.

- The autumn growth rate in Years 2 and 3 was 3.11 and 2.51 kg DM/ha/°Cd, respectively. The reduction, compared with Slope 1, probably reflects a change in partitioning of assimilate to red clover roots in response to a decreasing photoperiod.

- Based on these data yield predictions can be made for irrigated red clover for other locations based on local temperature data.

- The coefficients remain to be validated by analysis of other datasets from other locations.

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