

# Resident hill country pasture production in response to temperature and soil moisture over 20 years in Central Hawke's Bay

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## Abstract

The production of resident pastures on rolling hill country was measured in three paddocks over 20 years at Poukawa in Central Hawke's Bay. The pastures had been routinely fertilised with 250 kg/ha/yr of superphosphate but no pasture renovation, nor nitrogen fertiliser application, occurred during the measurement period. Total annual dry matter (DM) yield ranged from 4.5 to 12.8 t/ha/yr, which shows the level of variability to be expected in this summer-dry environment. The greatest proportion (60-90%) of growth occurred in winter/spring with consistent mean growth rates of 50-62 kg DM/ha/d in September and October. These rates were calculated to be  $5.49 \pm 0.55$  kg DM/ha/°Cd when spring moisture was non-limiting. The pastures had a mean water use efficiency of  $16.9 \pm 0.34$  kg DM/ha/mm of water available ( $R^2 = 0.93$ ). The amount of water available was calculated from a soil water budget based on a plant available water holding capacity of 124 mm (0-1.0 m depth). The results provide coefficients that can be combined with readily available climate data to predict pasture growth rates for feed budgeting purposes. Rainfall data collected on-site was highly correlated ( $r=0.94$ ) with that predicted from the NIWA virtual climate station network.

**Keywords:** soil moisture deficit, thermal time, VCSN, water use efficiency

## Introduction

Pasture production underpins New Zealand's agricultural sector. For dryland (rainfed) sheep and beef systems on hill country, pasture supply is predominantly from unimproved resident pastures. The practical challenges and costs associated with hill country development means these pastures are not commonly renovated and superphosphate is the main fertiliser input. Accurate assessment of growth rates from these pastures is difficult because of the spatial and temporal variability in pasture production (Tozer et al. 2014). However, long-term datasets can be used to assess the impact of abiotic factors on pasture growth and to determine how these have changed over time.

Historically, Radcliffe (1974) created a template for collecting and collating monthly pasture growth rates.

Her methodology was subsequently adopted and used in the 1970s and 1980s to characterise pasture production across different regions of New Zealand (e.g., Radcliffe 1975; Baars 1976; Rickard & Radcliffe 1976; Round-Turner et al. 1976; Roberts & Thomson 1984; Baars et al. 1991). The variable topography, edaphic and climatic influences across the country means these localised datasets are invaluable in understanding the variability in pasture supply. These datasets have been utilised by students (Fleming 2003), consultants (Pasture Growth Forecaster, FARMAX®) and scientists to investigate and adapt farm systems across the changing pastoral landscape. Additionally, variability in climate expected from global climate change, and changes in government policy that affect land use, are likely to increase the need for accurate localised pasture production data. Data from resident pastures provide the baseline or control situation, to which comparisons of pasture improvement, new species introductions and the impact of fertilisers can be assessed.

Since the 1980s, dryland farming systems in Hawke's Bay have become more flexible, with less reliance on breeding ewes and cows and more trading stock such as winter lambs and bulls. The increased threat and occurrence of prolonged summer-dry conditions (Salinger 2003) has expedited the move towards these flexible farming systems. For many, this means using trading stock to harvest feed when moisture is not limiting. However, as summer feed deficits approach there is a need to sell trading stock, or lambs at weaning, to reduce feed demand. To make effective and timely decisions, it is useful to be able to predict pasture growth rates in relation to readily available local weather data. Temperature and moisture are key drivers of pasture growth, particularly where there is limited use of nitrogen (N) fertiliser (Mills et al. 2006). Thermal time (Tt; Jones & Kiniry 1986) can be used to standardise pasture growth rates in relation to daily temperatures under non-limiting soil moisture conditions. This removes the temporal variation typically seen when mean daily growth rates are reported from different locations. Previously, Mills et al. (2006) reported that a 10+ year-old cocksfoot monoculture grew between 3.3 (N deficient) and 7.2 kg DM/ha/°Cd (non-limiting N) above a base air temperature of 3 °C. Soil water budgets

have also shown that, for grass-based pastures, growth rates generally decline when >50% of plant available soil moisture has been depleted (Penman 1971; Mills et al. 2006; Murdoch 2012).

Here we describe a long-term (20-year) pasture growth dataset recorded by On-Farm Research Ltd at Poukawa in Central Hawke's Bay. The aim is to provide an indication of the impact and importance of abiotic factors on pasture growth in this environment. It is anticipated that this information could be used by farmers in the region, in association with their own on-farm rainfall and temperature records, to estimate current and future pasture growth rates. This can aid tactical and strategic farm management decisions to reduce any adverse effects of climate change and create resilient farm systems.

## Materials and Methods

Data collection was conducted at the Poukawa Research Farm in Central Hawke's Bay on a Roseberry silt loam soil (Typic Orthic Melanic, USDA soil taxonomy). The area is winter-warm and summer-dry with a 30-year (1990-2019) annual average rainfall of 730±26.5 mm (NIWA 2020).

### Baseline situation

Pasture growth was measured on resident pastures in three rolling (8-15° slope) hill country paddocks from 1999 to 2019. Pastures were at least 10 years old when measurements commenced and were deemed representative of the resident vegetation in the environment. No data are available on when pastures were sown or what sowing mixtures or rates were used. Pastures had an annual application of 250 kg superphosphate/ha and lime was applied in 2005 and 2013 at 2.0 t/ha. Soil fertility was measured on 22 September 2020 (Table 1) and shows that routine fertiliser has maintained high fertility conditions for pH, P and S, with no obvious nutrient deficiencies.

### Environmental conditions

Rainfall was recorded from an on-site manual rain gauge and compared with the National Institute of Water and Atmospheric Research (NIWA)'s Virtual Climate Station Network (VCSN) data (39.725°S, 176.725°E; NIWA 2020). The relationship between monthly on-site rainfall records and VCSN data had a Pearson's correlation coefficient (*r*) of 0.94 (Figure 1) which confirmed VCSN data adequately estimated on-site conditions.

Figure 2 shows that annual rainfall for a growth season (GS; 1 Jul-30 Jun) ranged from 424 mm (2014/15; GS 17) to 1003 mm (2003/04; GS 6). For the 20 growth seasons reported, annual rainfall averaged 721±40.1 mm. Over the same period, annual potential evapotranspiration (PET; mm) averaged 997±21.5 mm and ranged from 946 (1999/00; GS 1) to 1045 mm (2002/03; GS 4). In 2003/04 (GS 5) rainfall exceeded PET, but in every other year PET exceeded rainfall by an average of 293±8.80 mm (range 34 to 598 mm).

The potential soil moisture deficit (PSMD; Figure 3) was accumulated daily as the difference between Penman potential evapotranspiration (PET) and rainfall (*R*) (French & Legg 1979) (Equation 1).

$$PSMD = \int PET - R \quad \text{Equation 1}$$

The accumulated PSMD was reset to zero at the start of each growth season (1 July) to reflect soil moisture recharge and was not allowed to exceed zero which indicates field capacity. In this analysis the PSMD represents the cumulative difference between daily rainfall and daily PET. The maximum PSMD reached in each growth season ranged from 414 (2010/11; GS 13) to 813 mm (2013/14; GS 16). Annually, the linear regression of maximum PSMD and total annual DM yield accounted for 64% of the observed variation (not shown). Total DM production decreased from a maximum of 12 t DM/ha/yr at a rate of 16 kg DM/ha/mm as the maximum annual PSMD increased from 417 to 812 mm.

**Table 1** Soil test results (0-75 mm) taken in Paddocks 9, 10 and 12 at the Poukawa Research Farm, Central Hawke's Bay on 22 September 2020.

Parameter	Paddock			Recommended range <sup>1</sup>
	9	10	12	
pH (H <sub>2</sub> O)	6.0	6.1	6.1	5.8-6.0
Olsen P (µg/ml)	39	20	43	20-30
Potassium (QTU)	19	8	18	5-8
Sulphate S (µg/g)	9	8	10	10-12
Organic S (µg/g)	8	7	8	15-20

<sup>1</sup> Recommended range for near maximum pasture production sourced from Morton & Roberts (2018). QTU is a Quick Test Unit.

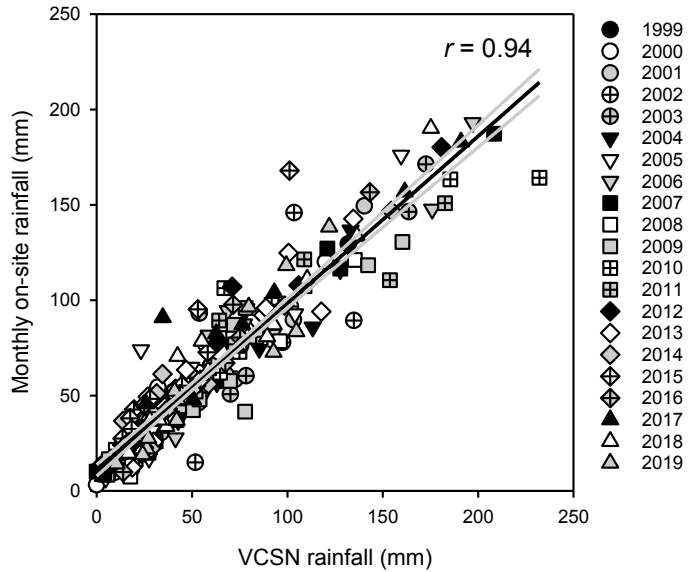
A soil water budget was also calculated to reflect seasonal growing conditions. To do this the soil moisture deficit (SMD) was calculated which accounts for the plant available water holding capacity (PAWC) of the soil. It reflects the fact that soil moisture becomes more difficult to extract as the soil dries (Passioura 2002). Equation 2 decreases the PET component of Equation 1 (NIWA 2019) when the PSMD on a given day exceeds half the PAWC (wilting point). The SMD cannot exceed PAWC.

$$PET = (PAWC - PSMD_{today}) / (0.5 \times PAWC)$$

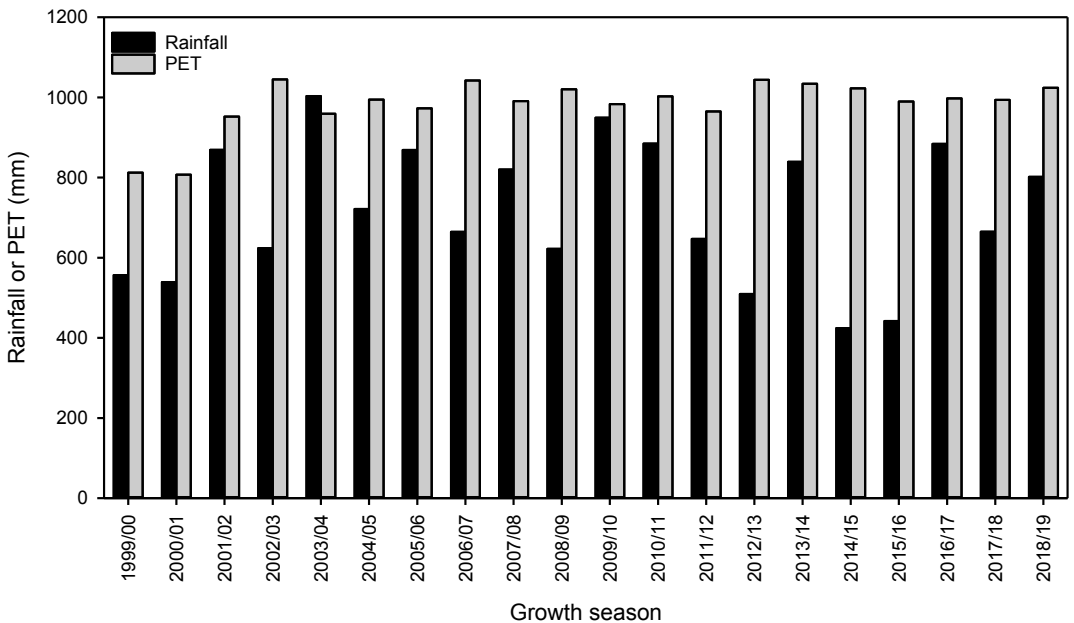
Equation 2

This analysis used data from S-Map (Manaaki Whenua - Landcare Research 2019), which quantified the PAWC for the top 0-1.0 m of a Roseberry soil as 124 mm. For this soil water budget the SMD was not re-zeroed at the start of a new growth season because it represents the actual soil water available. Rainfall in excess of field capacity was allocated as runoff/drainage and did not contribute to pasture water use. The budget was restricted to a maximum PAWC of 124 mm, the maximum SMD reached in each growth season averaged  $120 \pm 0.76$  mm. However, the duration of the period when the

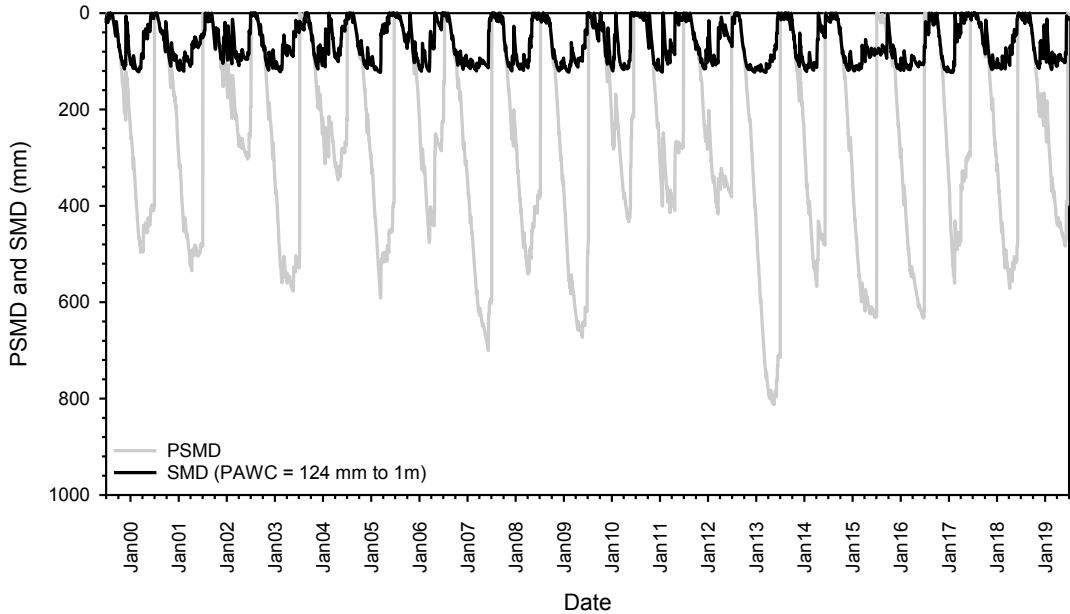
SMD had <50% of PAWC remaining ranged from 118 days (2016/17; GS 18) to 340 days (2015/16; GS 17). This maximum represents insufficient winter rainfall to recharge the soil profile with the SMD still at 82 mm on 1 July 2015 (Figure 3). However, later winter/early spring rainfall meant the SMD was zero and fully recharged by 29 September 2015.



**Figure 1** Correlation between rainfall measured on-site and VCSN predicted rainfall, using monthly data over a 20-year period at the Poukawa Research Farm in Hawke's Bay.



**Figure 2** Total annual rainfall and potential evapotranspiration (PET, mm) from 1999/00 to 2018/19 at Poukawa Research Farm in Hawke's Bay.



**Figure 3** Potential soil moisture deficit (PSMD; grey line) and actual soil moisture deficit (SMD, black line) calculated based on plant available water holding capacity (PAWC) of 124 mm (0–1.0 m depth) at the Poukawa Research Farm in Hawke’s Bay from 1 July 1999 to 30 June 2019.

The average mean monthly air temperature (MAT; °C) for the period 1999 to 2019 ranged from 8.8 °C in July to 18.7 °C in January. Over time, the lowest MAT was 7.2 °C in July 2003 and the highest was 21.5 °C in January 2018.

### Measurements

Pasture growth rates were measured using randomly placed exclusion cages (3.0 m × 1.5 m) placed on both NE- and SE-facing slopes in each of the three paddocks. A 2.77 m<sup>2</sup> area in each cage was mown at 4–6 week intervals using a rotary mower set at 5 cm height. Cages were then shifted to a new nearby area that had been pre-trimmed to 5 cm. The pasture collected was weighed fresh and a 200 g subsample was dried at 80 °C for 48 hours to enable dry matter (DM) yields to be calculated. Regrowth periods were extended during periods of negligible growth, usually due to dry summer conditions. Of the 180 harvest dates, the minimum regrowth period was 17 d (summer 2004 and spring 2019) and the maximum was 120 d in summer 2016.

On 20 July 2020, two additional exclusion cages were placed in each paddock in areas adjacent to pasture measurement cages. On 20 October 2020, these cages were cut to ground level (pasture mass was an average of 5000 kg DM/ha and pasture height was an average of 410 mm). Botanical composition was determined from herbage subsampled and dissected by hand into component species and then dried at 80 °C for 48 hours.

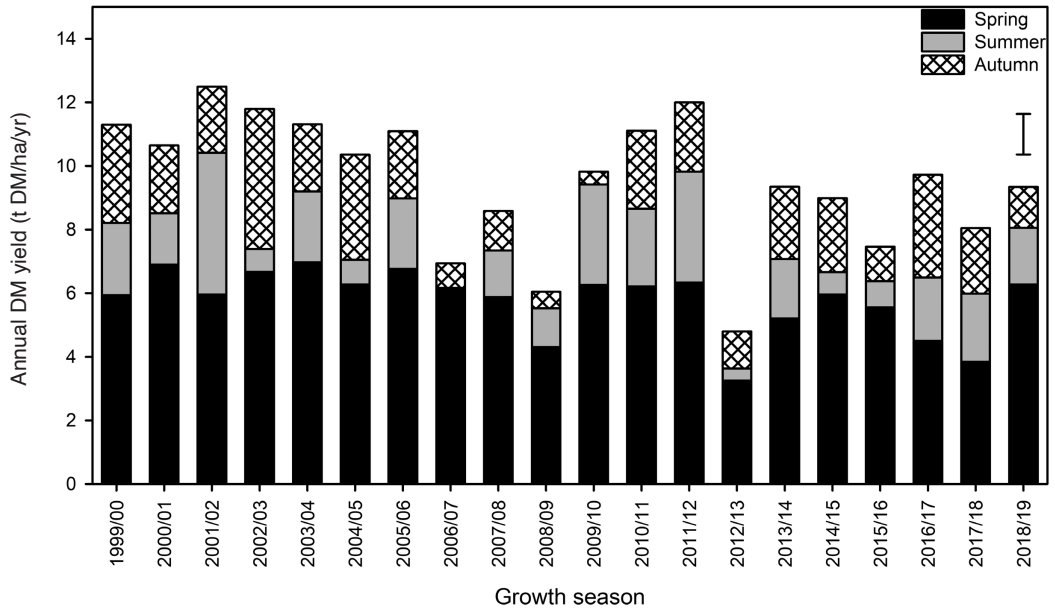
Thermal time was calculated from VCSN-derived

daily maximum and minimum air temperatures (NIWA 2020) using the model of Jones & Kiniry (1986). The cardinal air temperatures were set at 3, 25 and 40 °C for base ( $T_b$ ), optimum ( $T_{opt}$ ) and maximum temperature ( $T_{max}$ ), respectively, as used previously for pastures (Mills et al. 2006). To align with previous analyses, where pastures are often destocked over winter months, standardised seasons include spring (DM produced in the period July–Nov), summer (DM produced from Dec–Mar) and autumn (DM produced from Apr–Jun) (Mills et al. 2014, 2015; Moot et al. 2020).

### Statistical analyses

The data were initially summarised and monthly growth rates calculated in a similar manner to the previously summarised historic datasets (Radcliffe 1974). Additional analyses were then used to relate pasture growth rates to readily available meteorological data.

Analysis of variance (ANOVA) and grouped linear regression were conducted in Genstat v.20 (VSN International Ltd). Repeated measures analysis was conducted on annual DM yield (kg DM/ha) and monthly mean daily growth rate (MDGR: kg DM/ha/d) data to evaluate if differences existed among the three paddocks over time. Unless otherwise indicated by zero values, the MDGR for the period was assumed to be constant throughout regrowth and assigned to each month when rotation length was extended due to low growth. Occasionally, cages were moved by grazing stock before harvest. Of 1121 individual cage cuts



**Figure 4** Mean annual dry matter yield (t DM/ha/yr) of three dryland hill country pastures at the Poukawa Research Farm, Hawke's Bay from 1999/00 to 2018/19, separated into spring (Jul-Nov), summer (Dec-Feb) and autumn (Mar-Jun) periods. The error bar is the SEM for the effect of time on total annual yield ( $P < 0.05$ ).

taken between 1999 and 2019 a total of 30 records, or 2.7%, were missing values.

The slopes and y-intercepts, allowing calculation of x-intercept values, for thermal time standardised spring growth rates and annual water use efficiency (WUE) over time, were fitted by grouped linear regression. The parameters generated were then analysed by repeated measures analysis. When Paddock was found to be non-significant, data were recoded and analysed by one-way ANOVA with Growth Season as the treatment with six replicates. Where deemed important to interpreting results, trends ( $P < 0.10$ ) are reported. Unless otherwise stated, means are reported with their associated standard error of the mean (SEM). Following the methodology of Radcliffe (1974), monthly MDGR data are presented graphically  $\pm 1$  standard deviation. This gives an indication of the expected variability at the site and the range expected growth rates would fall within 66% of the time. When significant, means were separated by Tukey's HSD test at the  $\alpha = 0.05$  level.

## Results and Discussion

### Total annual yield

Total annual DM production differed ( $P < 0.05$ ) over time (Figure 4). Yields ranged from 4.8 (2012/13; GS 14) to 12.5 t DM/ha (2001/02; GS 2). The  $10.3 \pm 0.64$  t DM/ha produced in 13 of the 20 growth seasons (GS 1, 2, 4-8, 11-13, 15, 16, 18 and 20) was not different to the maximum, observed in GS 3. Annual total yields did not differ among paddocks ( $P = 0.118$ ) and subsequent

analysis showed aspect did not have an effect on the total yield produced ( $P = 0.732$ ). This is consistent with both aspects having the same amount of soil moisture and suggests the soil water holding capacity was not different between the NE- and SE-facing slopes in this rolling hill country.

### Spring (Jul-Nov)

Dry matter grown in spring was generally consistent over time with  $6.00 \pm 0.52$  t DM/ha produced in 18 of the 20 growth seasons (Figure 4). However, a trend ( $P < 0.10$ ) showed the  $3.55 \pm 0.52$  t DM/ha produced in spring 2012/13 and 2017/18 (GS 14 and 19) was about half the  $6.88 \pm 0.52$  t DM/ha produced in spring 2000/01, 2003/04 and 2005/06 (GS 2, 5 and 7). Aspect had no effect ( $P < 0.76$ ) on spring production.

The percentage of total annual DM yield produced in the spring period ranged ( $P < 0.05$ ) from  $52.0 \pm 2.85\%$  (1999/00, 2001/02, 2002/03, 2010/11, 2011/12, 2013/14, 2016/17 and 2017/18) to  $89\%$  (2006/07; GS 8). Means separation was complex but the 89% of total annual DM produced in spring of GS 8 was greater ( $P < 0.01$ ) than in any other year.

For dryland farming systems, spring is the crucial production period associated with the lowest amount of risk (Avery et al. 2008) because generally soil moisture has recharged over winter to be non-limiting to growth. These results confirm a generally consistent amount of spring feed was produced in 18 of the 20 growth seasons but also indicates that one year in ten experienced lower

than expected production at a time when stock demand is at its highest.

### Summer (Dec-Feb)

Summer DM production ranged ( $P<0.01$ ) from 0 (2006/07) to  $3.70\pm 0.26$  t DM/ha (2001/02; 2009/10; 2011/12) and accounted for 0 (2006/07) to 36% (2001/02) of total annual production ( $P<0.05$ ). In practice this variability is dealt with on-farm by the buying or delaying the sale of trade cattle to deal with the large fluctuations in summer feed supply. For resident pastures this feed is often dominated by grass with seed head development from November onwards meaning pasture quality declines (Waghorn & Clark 2004).

### Autumn (Mar-Jun)

In autumn the 2.27 t DM/ha produced by Paddock 9 was 21% more ( $P<0.05$ ) than the  $1.88\pm 0.17$  t DM/ha produced by Paddocks 10 and 12 over time. This may reflect differences in botanical composition. Autumn production also varied over time and ranged ( $P<0.001$ ) from 0.93 t DM/ha (2006/07-2009/10; 2012/13 and 2015/16) to 4.40 t DM/ha (2002/03). Subsequent analysis showed that aspect was not responsible ( $P=0.25$ ) for the observed yield difference.

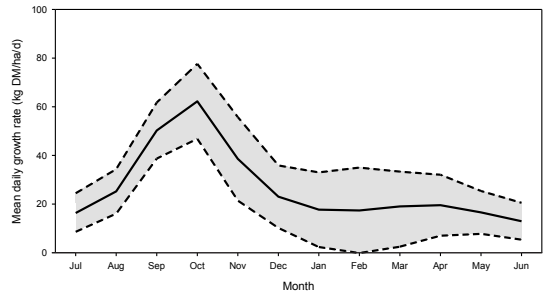
### Current botanical composition

Botanical composition was quantified once, on 20 October 2020 (Table 2). Given the age of the pastures, coefficients of variation were high for the minor pasture components (not shown). Regardless, analysis indicated that the three paddocks monitored had similar composition at this time. Together, perennial ryegrass ( $32.2\pm 10.3\%$ ) and annual brome ( $36.3\pm 6.05\%$ ) accounted for ~70% of the total composition. Subterranean clover content was low (7.2%) on both aspects and no white clover was present in the herbage samples.

**Table 2** Botanical composition (%) of three dryland hill country pastures on 20 October 2020 at Poukawa Research Farm in Central Hawke's Bay. At the time of sampling pastures were >30 years old and had been monitored for yield since 1999.

Pasture component	Latin name	Lifecycle	Composition (% of DM $\pm$ SEM) <sup>1</sup>
Perennial ryegrass	<i>Lolium perenne</i>	Perennial	32.2 $\pm$ 10
Brome	<i>Bromus mollis</i>	Annual/biennial	36.3 $\pm$ 4.1
Subterranean clover	<i>Trifolium subterranneum</i>	Annual	7.2 $\pm$ 4.4
Browntop	<i>Agrostis tenuis</i>	Perennial	4.3 $\pm$ 4.3
Poa (Kentucky bluegrass)	<i>Poa pratensis</i>	Perennial	2.2 $\pm$ 0.7
Vulpia	<i>Vulpia bromoides</i>	Annual	5.7 $\pm$ 3.9
Yorkshire fog	<i>Holcus lanatus</i>	Perennial	7.9 $\pm$ 5.2
Californian thistle	<i>Cirsium arvense</i>	Perennial	4.2 $\pm$ 2.4

<sup>1</sup> SEM is the standard error of the mean



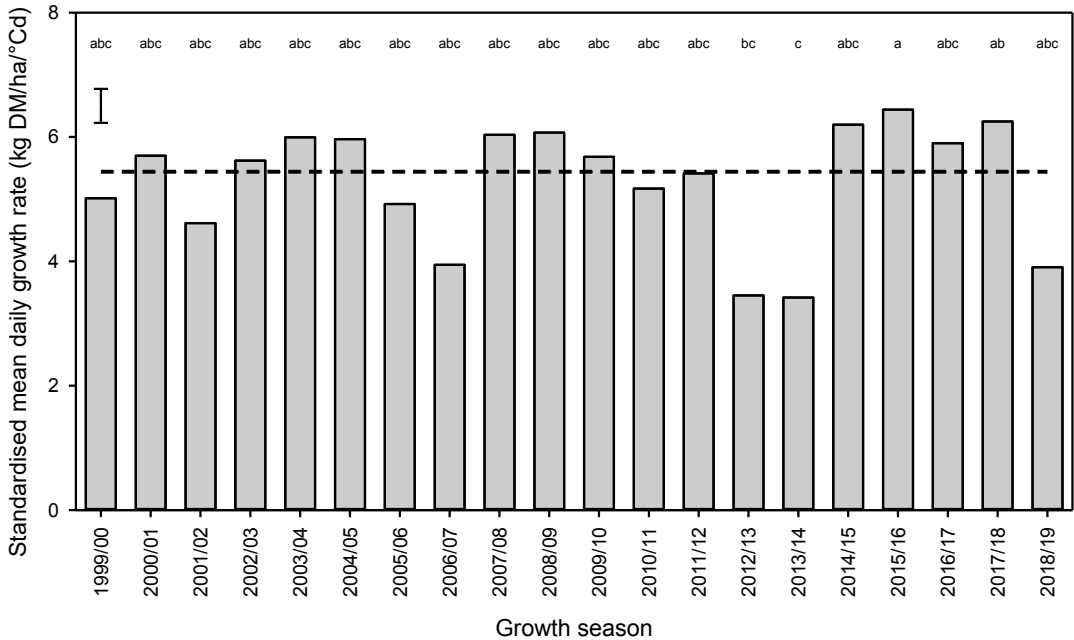
**Figure 5** Monthly mean daily growth rate (kg DM/ha/d) of three dryland grass-based hill country pastures from 1999/00 to 2018/19 at Poukawa Research Farm, Hawke's Bay. The mean (solid line) is shown  $\pm 1$  standard deviation (dashed line).

### Mean daily growth rate (MDGR; kg DM/ha/d)

Over time MDGR ranged from 0 kg DM/ha/d in February 2000 and January/February 2005 to 84.7 kg DM/ha/d (October 2015). The MDGR was most consistent in September ( $50.2\pm 4.92$  kg DM/ha/d) and October ( $62.3\pm 6.73$  kg DM/ha/d), which reflects reliable spring pasture production. Figure 5 shows the mean monthly MDGR (Additional online file: Table A1).

### Standardised MDGR (SMDGR)

Grouped linear regression showed the inclusion of growth season increased the  $R^2$  from 0.74 to 0.96 ( $P<0.001$ ). Pastures grew at a rate of  $5.49\pm 0.55$  kg DM/ha/ $^{\circ}$ Cd in 18 of the 20 spring periods (Figure 6). The lowest ( $P<0.001$ ) SMDGR was  $3.42\pm 0.55$  kg DM/ha/ $^{\circ}$ Cd in GS 15 (2013/14) which was about half ( $P<0.001$ ) that in GS 17 and 19 ( $6.34\pm 0.55$  kg DM/ha/ $^{\circ}$ Cd). Of the 126 regressions fitted, y-intercepts encompassed the origin 87 times, or ~70% of cases (not shown), indicating pasture growth commenced at the start of the growth season. This contrasts with results from the South Island where a lag phase of about



**Figure 6** Standardised mean daily growth rates (kg DM/ha/°Cd) for the spring (Jul-Nov) period for three dryland grass-based hill country pastures at the Poukawa Research Farm in Hawke's Bay over 20 growth seasons. Dashed horizontal line is the mean ( $5.49 \pm 0.55$  kg DM/ha/°Cd) for 18 of 20 similar growth seasons based on means separation. The error bar is the SEM. Letters are the Tukey HSD means separation.

350 °Cd is apparent (Fasi et al. 2008). Further work is required to determine the cause and validity of the discrepancy but it may reflect the base temperature used was too low, with thermal time accumulating when there is no growth. This would be more likely to affect data from the South Island which experiences cooler winters.

Mills et al. (2006) reported SMDGRs of 3.3 to 7.2 kg DM/ha/°Cd for a cocksfoot monoculture under cut and carry management. The  $5.49 \pm 0.55$  kg DM/ha/°Cd reported here for mixed species hill country pastures with low legume content is about halfway between these rates which suggests some nitrogen (N) transfer through urine return to these pastures under grazing (Saggar et al. 1990; Ledgard 2001). The implication is that the use of N fertiliser or greater legume content offers potential to increase these spring growth rates when moisture is available.

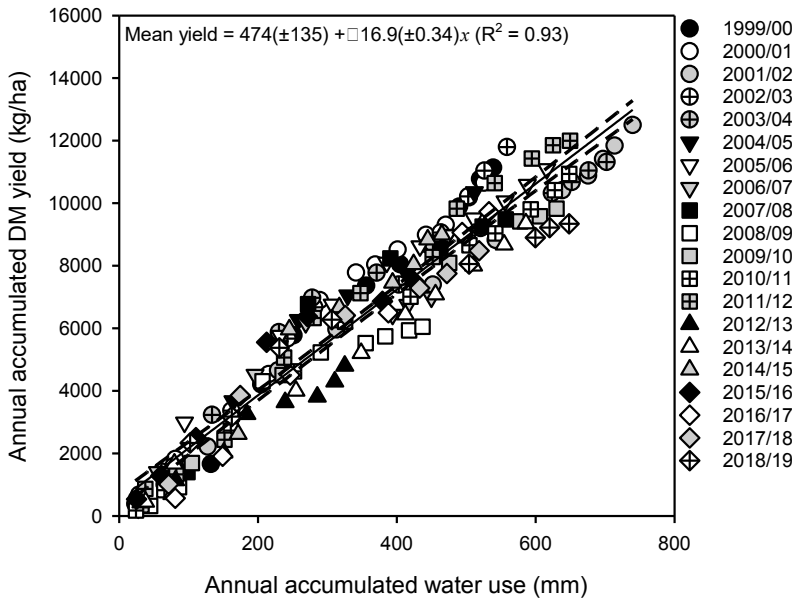
#### Effect of water availability on annual DM production

The calculated x-intercepts ranged ( $P < 0.001$ ) from  $29.7 \pm 10.8$  mm, in 16 of 20 growth seasons, to  $133 \pm 10.8$  mm in 2005/06, 2007/08 and 2018/19. In about 70% of cases, the intercept encompassed the origin, which indicates full soil moisture recharge at the start of the growing season.

Slopes showed WUE was more variable and ranged ( $P < 0.001$ ) from 12.2 kg DM/ha/mm (2018/19) to 21.5

kg DM/ha/mm (1999/00). Results indicated WUE was  $17.2 \pm 1.38$  kg DM/ha/mm in 16 out of 20 growth seasons and this did not differ from the maximum WUE (1999/00). The consistency of these results over time allowed a single regression to be fitted that explained 93% of the observed variation in mean annual DM production. Pastures grew at a rate of  $16.9 \pm 0.34$  kg DM/ha/mm from an x-intercept value of 28 mm (Figure 7). This value is lower than the 20 kg DM/ha/mm estimated for ryegrass/clover (Martin et al. 2006) and suggests potential exists to grow more feed from the limited rainfall available. It remains to be determined whether the use of other species such as lucerne, subterranean or red clover could improve the feed quality, quantity and WUE of these paddocks.

The consistency of these results indicate that these two relationships are sufficient to predict DM production from grazed, dryland, resident grass-based hill country pastures. In spring, pastures will grow at  $5.49 \pm 0.55$  kg DM/ha/°Cd until water becomes limiting. Thus, given weekly weather forecasts that include daily maximum and minimum temperatures, pasture production can be estimated on-farm. Equally, a simple soil moisture spreadsheet using on-farm rainfall, PET from the local NIWA VCSN site and an estimated PAWC readily available from S-Map, can be used to predict how many more days of growth could be expected if no rain falls during spring. For example, if a soil has a PAWC of 150



**Figure 7** Relationship between mean annual accumulated DM yield (kg DM/ha) and accumulated water use (mm) over 20 growth seasons at Poukawa Research Farm, Hawke's Bay.

mm it would have potential growth of 2540 kg DM/ha (150 mm × 16.9 kg DM/ha/mm). If 2 weeks later only 60 mm remains, potential feed production is 1015 kg DM/ha (80 × 16.9). If no rain occurs and the SMD falls to zero, growth stops. Forecasted rainfall or long-term rainfall averages could be used to predict future pasture growth as the season progresses. This could then be integrated into a feed budget to help short- and mid-term decision making to match feed supply and animal demand. These results provide a quantitative assessment of pasture growth rates based on readily available weather and soil factors. The accuracy of predictions remains to be validated but the data provide a simple approach that could be used on-farm in similar environments to predict expected pasture growth rates for feed budgeting.

### Conclusions/Practical implications/Relevance

In spring, when soil water was generally non-limiting to growth, pastures grew at 5.49±0.55 kg DM/ha/°Cd in 18 of the 20 growth seasons.

Annually, 93% of the variation in mean annual yield was explained solely by estimated water use. Assuming a conservative WUE of 16.9±0.34 kg DM/ha/mm after 28 mm of water had been used, DM production could be estimated with a soil water budget spreadsheet. Required data would be rainfall, PET and estimated PAWC in the top 1.0 m of the soil profile, which can be accessed easily from S-Map.

It would be expected that pastures with higher levels

of N fertility, through legume or fertiliser, would grow at faster rates and use water more efficiently. However, for the majority of resident grass-dominant hill country pastures these rates provide an estimate of production and could be used to aid on-farm decision making. Further work to quantify the relationships for different species and regions is required to provide more accurate data for feed budgeting.

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### SUPPLEMENTARY MATERIAL

Additional Online File 1: Table A1-Mean daily growth rates for each calendar month. <https://www.nzgajournal.org.nz/index.php/rps/article/view/3451>

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