Pasture production: a compilation of historical datasets from farms in Bay of Plenty

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† Thomas M. Gee (1935-2016)

Abstract

Bay of Plenty district, and particularly the Rotorua Lakes area, has a diverse terrain and soil types which influence pasture production. Regular measurement of pasture production enables short term decision making on a farm scale and is invaluable for catchment, district and regional long term management strategies. Thomas (Tom) M. Gee, was a retired farmer with more than 18 years of field trial experience with MAF Field Research Division. He collected data from more than 30 farms after he retired. Data from other sites in the district were collected in the early 1970s by MAF technicians stationed in Whakatane and Tauranga and later by AgResearch staff and a farm consultant based in Rotorua. Tom Gee's mission was to use these measurements to provide farmers with rates of growth (ROG) data to inform them about their farm. The Gee farm (Fairbank) of 200 ha was originally leased from Ngati Whakaue Tribal Lands in 1916 and then purchased before much of it was sold back to the Incorporation in 1970. Tom retired in 1989 but kept meticulously recording pasture growth rates on different farms up to ~ 2007. Some field notes were lost, but datasets with gaps are still useful to assist monthly growth rates calculations. His valuable and extensive (almost 25 years) on farm field records have been retrieved, compiled, assembled, and digitised, to be saved electronically, and entered into the AgYields National Database hosted at Lincoln University. Part of this legacy dataset has been summarised and dry matter yields and growth rates calculated, consistent with previous methods, to provide a quantified description of mean monthly pasture growth rates across the Bay of Plenty region, in New Zealand.

Keywords: AgYields database, dry matter yields, legacy datasets, pastoral growth rates.

Introduction

In New Zealand, the Bay of Plenty region, and particularly the Rotorua Lakes area, have a diversity of terrain and soil types which influences the farm type (Tait and Alison 1957) and pasture yield (Baars et al. 1991). Pasture is the dominant feed supply for grazing in the region but measurements of its production over time are rare. Regular pasture measurements can provide valuable data for short term decision making on a farm scale and for catchment, district and regional long term management strategies. Farmers use such data from local monitored farms for feed budgeting and feed planning to identify opportunities on their own properties. Thus, pasture production records provide an invaluable source of information that can be used by multiple entities. Recording such data is time consuming and expensive, and often lost once the immediate use or application has been met. This paper describes the collection and analysis of previously unknown datasets from the Rotorua region that have now been deposited in the AgYields database (Moot et al. 2021). These are therefore publicly available for use by farmers and other stakeholders, whereas historically the paper records would have been lost. The history of the datasets provides an example of the work required to collect it and the risk of data loss that occurs over time.

The aim of this paper is to summarise long term pasture growth rates from previously unpublished on-farm collection in the Bay of Plenty Region. The opportunity to do this was primarily created by Mr Tom Gee (deceased), who was a farmer with more than 18 years of field trial experience with MAF (Ministry of Agriculture and Fisheries) Field Research Division. Data from other sites were collected by MAF technicians in the early 1970's, when New Zealand had a wide geographic distribution of field research staff. The data for this paper came from Whakatane and Tauranga and later sites managed by AgResearch staff and a farm consultant based in Rotorua. The data collected by Tom Gee were given to Martin Hawke by the Gee family. They indicated Tom Gee's mission was to give farmers rates of growth (ROG) data to assist them to be more informed about their farm. The Gee farm (Fairbank) of 200 ha (Tait and Alison 1957) was one of those measured. It was originally leased from NWTL (Ngati Whakaue Tribal Lands) in 1916 then purchased and much of it sold back to the

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Incorporation in 1970. Tom Gee retired in 1989 but continued to meticulously record pasture growth data on ~ 30 different farms up to ~ 2007. His valuable and extensive (almost 25 years) farm field records and knowledge were almost lost due to the challenges of archiving his paper-based field notes. Fortunately the national database initiative in collaboration with former researchers was able to retrieve, assemble, process and load the data into AgYields (Moot et al. 2021). Some of the data have been analysed to provide mean growth rates following methods of analyses suggested by Radcliffe (1974), Radcliffe et al. (1975) and Baars et al. (1991). Additional analysis related these growth rates and yields to temperature following the methods outlined by Mills et al. (2006). In that analysis, thermal time is used to relate mean daily growth rates to temperature which then allows the effects of moisture and nitrogen to be assessed individually (Mills et al. 2021). For example, it was reported that a 10+ year old cocksfoot monoculture, grew between 3.3 kg DM/ha/°Cd (nitrogen deficient) and 7.2 kg DM/ha/°Cd (non-limiting N) above a base air temperature of 3 °C (Mills et al. 2006).

These values set the upper and lower limits of growth rate expectations for pastures. Periods of moisture stress are shown by accumulation of thermal time in periods of no growth which usually result in growth rates of <1.0 kg DM/ha/°Cd. Using abiotic factors as the driver for pasture growth rates allows data to be compared across regions or within districts which is the focus of this analysis.

Material and Methods

Pasture growth was measured on resident pastures in the Bay of Plenty. Paddocks measured within a farm invariably had different pasture species and a range of pasture ages and management practices but these have not been separated. Similarly, the effects of any routine fertilizer application and irrigation are inherent in the data. Gaps in some of the datasets are due to a range of causes (i.e. paddocks closed for hay/silage, moved or broken cages, no pasture growth, records not always available) although the full weather files were available. Pasture data were collected every month, except from June and July when samples were generally cut at the end of July or early August to match the longer on-farm winter rotations due to lower winter growth. At the time, the farmer/manager, farm consultant and other interested parties would have received a copy each of the monthly data and one would have been filed in Toms records. Over the years, some of these records have gone missing, hence the gaps. For the period of January, February and March, it is possible that on one or two occasions over the 17 years of data collection at Wharenui, there may have been no growth, particularly on the sandy flats. Pasture growth is reported to be negligible during dry months, when rainfall is < 20 mm (Moot et al. 2008) and this could be one explanation for no data records. For example, 33% of the missing records during January, February and March months corresponded to a total monthly rainfall < 20mm (mean of 8±2.8 mm). However, potential evapotranspiration (PET) continues to increase from November to March which is likely to have created a soil water deficit that limited pasture growth.

An in depth analysis of the weather parameters (rainfall, Penman Evapotranspiration, air temperature, degree days) (Cliflo 2021) for these particular missing months showed that, of the 98 missing records (months) 17 were from the driest months of January, February and March, which had a soil moisture deficit (SMD, calculated as Total rainfall minus Evapotranspiration (PET)) of 30±14.8 mm. Wharenui was particularly dry, with a moisture deficit for these three months of 128±26.8 mm, 111±40.2 mm and 110±27.4 mm. November and December were also dry months, with an average SMD of 34±14.8 mm across all sites, which may explain the 11 missing records for November and December . Overall, there was a weak positive correlation (r=0.6) between SMD and the frequency of missing records. In contrast 51% of the missing records corresponded to the winter months (June, July, August) when rainfall was > 50mm (overall mean of 67±19.4 mm) and there was no SMD. During these months cool winter temperatures may have been too low to produce measurable pasture growth and stock may have been on a longer winter rotation so paddocks were ungrazed until spring. Tom Gee followed standard MAF techniques which usually involved hand cut samples from 0.5 m^2 cage cuts (2 cages/ paddock). Others were generally taken from large (3 m x 1.5 m) exclosure cages, where two strips were cut with a rotary or reel mower. Tom's samples were all dissected into pasture species (results not included in this paper).

Database

The handwritten notes were organized by location and chronologically. Datasets were compiled, digitalised, electronically saved and further processed to load into the AgYields National database (Moot et al. 2021) template, as per the website: www.agyields.co.nz. Farm types were classified (when notation was available) according to the dominant livestock activity, because some sites were on farms that converted, for example, from dairy to forestry or in paddocks which served multiple purposes over the years (e.g. sheep and then cattle). The site locations were geocoded as x,y coordinates and standardised as decimal degree units using geosearch technique in Google maps through the website www.google.com/maps (Google 2021).When

GPS coordinates or addresses of the farms were not fully provided, the location was estimated by selecting rural areas using map viewer tool.

After data compilation four datasets were selected for analysis and measurement units were standardised as DM yields in kg/ha and monthly growth rates as kg/ha/d. At the time of this publication the process of data entry of this extensive compilation is ongoing. Most of the datasets (~90%) have been entered, revised, submitted and are available online at agyields.co.nz (Moot et al. 2021). The remaining datasets have been entered and are currently in Draft status (~10%) waiting for moderation or at the digitising and typing process. Here analyses of four datasets are presented.

Dataset 1 – Rotorua Districts (1970-1975)

This dataset encompasses measurements from many farms in 14 locations at Bay of Plenty and from one location (Poihipi) in Waikato during five years (1970-1975). Ian McQueen coordinated the projects and the technicians working on those farms.

Dataset 2 – Wharenui (1989-2007)

Wharenui station is located 7 km from Rotorua (-38.110012, 176.32990), it is one of three large stations belonging to Ngati Whakaue Tribal Lands. Originally a beef and sheep farm, it was partly converted to dairy after the purchase from the Gee family in the 1970's (Tait and Alison, 1961). Pastures were monitored in several paddocks with continuous measurements from 1989-2007. The soils around the Wharenui property are classified as Tephric recent and Orthic pumice type (Manaaki Whenua 2021). The terrain is a mix of flat and rolling hill with average altitude of 350 m a.s.l. Pastures were predominantly perennial ryegrass, white clover, with other grasses and weeds such as yarrow (*Achellia millefolium*).

Dataset 3 – Pongakawa (1991-2005)

Pasture and horticulture are common in the Pongakawa stream catchment (LAWA 2021). The dataset was collected from the Scrimgeour family property in Pongakawa, 56 km North from Rotorua (-37.9054, 176.4801). Soils in this area belong to the Orthic pumice and Orthic Allophanic class commonly known as Paengaroa shallow sand and Kaharoa ash soils (Hewitt 2010, Manaaki Whenua 2021). The measurements were taken from flat and slope paddocks across the farm for 14 years.

Dataset 4 – Highland Station (2004-2007)

John Ford's farm is on easy rolling hill country in Rotorua (-38.252468, 176.358796, ~ 450 m a.s.l.). Measured paddocks, during years 2004-2007, had a ryegrass-dominant existing pasture and were rotationally grazed by cattle and sheep. Measurements in one of the paddocks (Kahikatea paddock) were taken only between August 2004 and July 2005 because the site was not representative of the pastoral area and had difficult access. These measurements were part of Tom Fraser's Pasture Plan project (2004-2007) (Hawke, pers. communication, January 2020). The soil in this site is a Paroa silt loam soil (Aquic Dystrochrept) (Hewitt 2010).

Climate

The northern part of the Bay of Plenty region experiences warm winds with mean daily maximum temperatures over 20°C recorded from December to March, and temperatures over 30°C on at least one occasion. Inland areas are subject to cold night-time temperatures during winter, especially when clear skies permit rapid radiational cooling. Air temperatures below 0°C are recorded in most parts of the region each winter, with mean daily minimum temperatures between 1°C and 7°C experienced for most of the region. Annual average temperature in the Bay of Plenty region changes with elevation with~30% of annual rainfall during the winter months (June to August) and ~22% of rain in the summer months, from December to February (Chappel 2013). Highland Station (Rotomahana) is winter-warm and summer-dry with an average rainfall of 1860 mm (Highland Station 2021). The average rainfall during the period of pasture production measurements (from 2004 to 2007, NIWA weather station agent no. 1770) was 1818±218.2. For Wharenui (NIWA weather stations agent no. 1770 and 1819) mean air temperatures ranged from 7.9°C to17.8°C and mean rainfall was 1351±230.2. Pongakawa is characterized by mild summer temperatures ~ 20°C. February is the warmest month, with average temperatures between 15 and 22°C (NIWA weather station agent no. 1673). The average rainfall during the period of pasture production measurements (1991-2005) was 120-9±223.0 (Cliflo 2021).

Irrigation and fertilizer

Notations about any irrigation were not found for these datasets, therefore results are presented as non-irrigated pastures. For Datasets 1 (Rotorua Districts) there was no mention of nitrogen fertilizer applications in the original notes, and its use on farm was negligible in the 1970's ((Moot 2022)). For Dataset 2 (Wharenui) there were notations of +N and -N records. Nitrogen at 30 kg N/ha/year was indicated as being applied on ~10% of the records.

Dataset 3 (Pongakawa) does have some notes about nitrogen application (~14% of the records) within an estimated range of 0 -90 kg N/ha/year. At Highland Station (Dataset 4) there were fertiliser applications over the trial area of the farm. Nitrogen was applied at 45 kg N/ha/year in August (annually from 2003 to 2009). Phosphorus (P) was applied at 35 kg P/ha/year (years 2003, 2004 and 2005); 29 kg P/ha/year in 2006 and 10 kg P/ha/year in 2009. There were also sulphur (S) applications at a mean rate of 56 kg S/ha/year (2003-2007) and then 40 kg S/ha/year (2009). There were no P or S applications in 2008.

Calculations

Growth rates were calculated as: GR (kg DM/ha/d) = DM yield (kg/ha) / No. days, where No.days is the number of days of pasture growth between successive harvests (Radcliffe and Sinclair 1975, Roberts and Thomson 1984, Baars et al. 1991). For each dataset, the value assigned to a particular month considered (i) the exact cut dates when provided in the original datasheets or (ii) when dates were not provided it was considered that samples were cut on the 30 or 31st of each month (except for the February month). To determine if a value was assigned to a particular month (i.e November and not October) we followed the handwritten notation on the sheets made by Tom (i.e. 'November growth rates' written). When dates were given, and no other notation was provided it was considered the month in which most of the growth occurred (i.e. if Start date = 07/04/1997 and End date = 03/05/1997 the month considered was April because the growth happened during 23 days of April and only 3 days of May). When estimated, annual yield mean values (> 10 months measured within a year) considered the calendar year from January to December rather than seasonal means July to June (year starting in winter) following the order in which the BOP datasets were originally organized.

The mean and standard deviation of monthly growth rates were calculated based on the previous procedures (Radcliffe 1974, Radcliffe and Cossens 1974, Mills et al. 2021). Not all datasets have complete year records but there was no systematic pattern or strong relationship established between the missing data and any other variables (e.g. MD; r=0.6 only for summer months and temperature r= 0.35 only for winter months). Therefore these were considered data missing at random (MAR) (Newman 2014) and not considered for analysis (Łopucki et al. 2022). Missing data were not included into the AgYields Database as the system does not recognize empty rows or cells, nor text or symbols (e.g. NAN, NA, *, -). Following the same methodology of Radcliffe (1974), monthly GR is displayed graphically ± 1 average standard deviation to indicate the predicted variability at the site and expected range that growth rates would fall within ~66% of the time (Cumming et al. 2007, Mills et al. 2021). The average standard deviation for unequal sample size was determined and displayed due to the uneven number of monthly records and data gaps (Dunnett 1980) within datasets 1 – 4.

Thermal time was calculated from daily maximum and minimum air temperatures (Cliflo 2021) using the model of Jones and Kiniry (1986). The cardinal air temperatures were set at 3, 25 and 40 °C for base (Tb), optimum (Topt) and maximum temperature (Tmax), respectively as used previously for pastures (Mills et al. 2006). Temperature-adjusted pasture growth rates were estimated using Datasets 2, 3 and 4 due to availability of localised weather data for those locations. Mean daily growth rates (kg DM/ha/°Cd) considered the data from all four seasons of the year (Spring = Sep-Nov; Summer = Dec-Feb.; Autumn = Mar-May; Winter = Jun-Aug) (Radcliffe 1974).

The differences in growth rates (kg DM/ha/°Cd) from Highland station (Dataset 4) were statistically tested for variance using Bartlett's and the non-parametric Kruskal-Wallis test (Witkovský 2020). Accumulated thermal time (°Cd, Dataset 4) started from July and was regressed against accumulated DM yield (kg/ha) using linear equations. A broken stick model was used to determine the critical point when pasture growth rates were expected to be reduced over the seasons (from spring to autumn) (Mills et al. 2006, Andreucci et al. 2016, Moot et al. 2021)numerous models are available to estimate cardinal temperatures but there is uncertainty about whether linear or nonlinear models should be used. Initially a germination experiment was used to describe the rate response of nine forage brassicas to temperature. Three models were compared to estimate cardinal temperatures and the two best models were used for thermal time (Tt. Pairwise comparisons for growth rate means (kg DM/ha/°Cd) and coefficients of slopes (kg DM/ha/ºCd) from spring and summer/ autumn at the α=0.05 level were performed using Wilcox tests with Benjamini–Hochberg adjustment for multiple testing (Benjamini and Hochberg 1995, Shao et al. 2022) with R software (R Core Team 2020).

Results

Historical datasets

Of the farms in the analysis 46% were mainly beef and sheep farms, or a mix of dry stock and dairy and 54% dairy. Figure 1 shows the locations of the datasets collected.

Dry matter yields from selected datasets

Dataset 1 – Rotorua Districts

The datasets used for analyses have some incomplete years as presented in Table 1.

The total herbage dry matter yield measured from the 14 sites in the Bay of Plenty and from 1 location (Poihipi) in the Waikato during five years (1970-1975) are shown in Table 2. The incomplete data means caution must be taken when comparing the summarised

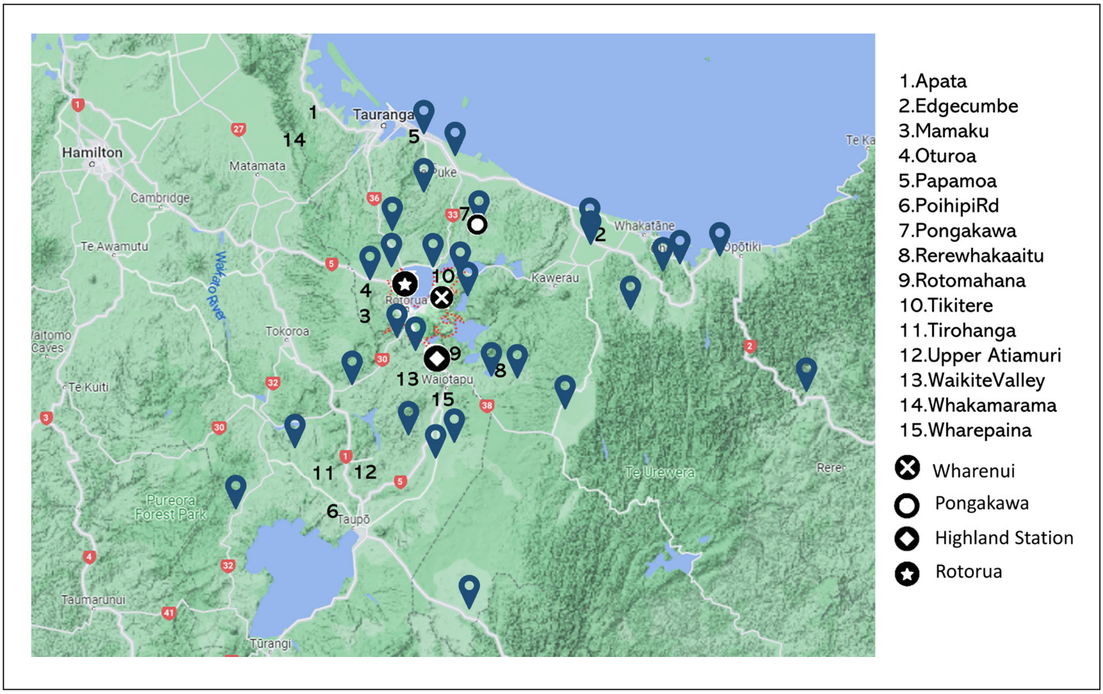

Figure 1 Pasture growth and dry matter yield datasets and their approximate locations in the Bay of Plenty (1970 – 2005). Dataset 1 locations indicated by numbers 1-15 (names on legend); Dataset 2 (Wharenui, black circle and white cross); Dataset 3 (Pongakawa, black and white circle); Dataset 4 (Highland Station, black circle and white diamond). The indicates Rotorua. Blue pinpoint icons ( ) indicate the sites Tom cut after his retirement in 1988 (please refer to AgYields national database for details).

dry matter yields. The lowest total value of 636 kg/ha corresponded to only five measurements in 1973 which occurred in April, May, September, October and November at Poihipi. The highest recorded yields were measured at Edgecumbe in 1970 (13430kg/ha). In this location the values recorded in 1970, 1971 and 1974 reflect annual yields (i.e. more than 9 months in a year were measured). At Papamoa in years 1973 and 1974 yields were 12770 and 11770 kg/ha respectively, and were recorded over more than a 10-month period.

Dataset 2 – Wharenui

Most of the records found at Wharenui were from autumn and spring months (Table 3). The total annual pasture yield (kg DM/ha/year) was 15535 in 1995, when all months were measured Table 3). For years 2002, 2003, 2004 and 2005, yields were 14710 kg/ha when all month's records were found, except for July.

Yield was 17670 kg/ha in 2001 (measurements in Jan, Mar, Apr, May, Sep, Oct, Nov, Dec). During winter months (June, July, August) the lack of measurements was probably due to the low temperatures, and consequently, limited pasture growth. Over the missing months of January and February it was expected that measurements were not taken due to the dry conditions. For example between 1990 and 2000 the evapotranspiration exceed rainfall in January and February by ~ 55 mm ,(Cliflo 2021). Specifically, in Feb 1997 and 1998 the evapotranspiration was ~ 80 mm greater than rainfall. The overall mean pasture yield value for this set of data was 12450 kg/ha. This mean value excluded the dry matter measurements from 1989 and 1992 because full year datasheets were not found.

Dataset 3 – Pongakawa

Dry matter yields recorded at Pongakawa averaged ~3000 kg/ha higher than at Wharenui. The mean yield on this site was 15600 kg DM/ha (collected between 1991 and 2005) ranging from 12130 kg/ha to 17400 kg/ha. Mean yields fluctuated from ~12000 to 16500 kg DM/ha between 1990 and 1996 but were above 15000 kg DM/ha until 2005.

Dataset 4 – Highland Station

The total dry matter yield ranged from 8509 kg/ha (measurements went from August to November 2004) to 16990 in year 2005 when only months of March, June and August were not measured (Table 3) with a mean of 12880 kg/ha.

Table 1 Year and months of pasture growth measurements at Districts at Bay of Plenty and Waikato between 1970-1975.

Location	Year(s)	Months measured
Bay of Plenty		
Apata	1970	Apr May Jun Jul Aug
	1971	Jun Jul Aug
	1972	Jun Jul Aug Sep Oct
	1973	Apr May Jun Aug Sep Oct
Edgecumbe	1970	All months except Jan and Feb
	1971	All months except Jun and Jul
	1972, 1975	Jan Feb Mar Apr May
	1973	Nov Dec
	1974	All months
Mamaku	1971	Sep Oct
	1972	Apr May Aug Sep Oct
	1973	Mar Apr May Aug Sep Oct
	1974	Mar
Oturoa	1971	Sep Oct
Papamoa	1973, 1974	All months except Jul and Aug
	1975	Jan Feb Mar Apr Sep
Pongakawa	1970	Jun Jul Aug Sep
	1971	Jun Jul Aug
	1972	Jun Aug Sep Oct
	1973	Apr Aug Oct
Rerewhakaaitu	1970	Oct
	1971	Sep Oct
	1972	Mar Apr May
Rotomahana	1971	Sep Oct
Tikitere	1973	Nov Dec
	1974	All months except Feb Jul
	1975	Jan Feb Mar Apr May Jul Aug
Tirohanga	1972	Apr May Aug Sep Oct
	1973	May Aug Sep Oct
Upper_Atiamuri	1972	Mar
	1973	Apr
Waikite valley	1972	All months except Jan and Sep
	1973	All months except Mar Apr
	1974	All months
	1975	Jan Feb Mar Apr Sep
Whakamarama	1972	Aug Sep Oct Nov Dec
	1973,1974	All months
	1975	All months except Sep Oct Nov Dec
Wharepaina	1971	Sep Oct
	1972	May Aug Sep Oct
	1973	Mar May Aug Sep Oct Nov
Waikato		
Pohipi Rd (Waikato)	1972, 1973	Apr May Aug Sep Oct

Mean monthly growth rates (kg DM/ha/d)

The mean monthly pasture growth for the Rotorua Districts (Dataset 1) ranged from 11±6.5 kg/ha/d (for July) to 57±16.7 kg/ha/d for November (Figure **2**). At Wharenui (Dataset 2) daily growth rates ranged from 14±5.3 kg/ha/d for June to 67±14.7 kg/ha/d (for November). At Pongakawa (Dataset 3, Figure 4 C) values ranged from 19±4.0 kg/ha/d (for July) to 61±19.4 kg/ha/d (for December). At Highland Station (Dataset 4, D) growth rates ranged from 10±5.1 kg/ha/d for June to 76±26.4 kg/ha/d for November.

Mean temperature adjusted growth rates (kg DM/ha/°Cd)

From 1989 to 2007 the mean daily temperature adjusted growth rates (kg DM/ha/°Cd) were 4.9 ±2.38 kg DM/ha/°Cd for Wharenui (Dataset 2). At Pongakawa (Dataset 3), the mean was 3.7 ±1.65 kg DM/ha/°Cd. At Highland Station (Dataset 4) the mean daily growth rate was 4.1 ±2.05 kg DM/ha/°Cd (Figure 3).

Accumulated DM yield against accumulated Thermal time

Figure 4 shows the relationship between accumulated pasture yield (kg DM/ha) and accumulated thermal time (°Cd) over four growth years (2004-2008) at Highland Station (Dataset 4).

The mean rate of dry matter accumulated per unit of thermal time was 5.8 ±0.89 kg DM/ha/°Cd from September to February which was higher ($P<0.01$) than the mean rate 2.5 ±0.22 for the summer-autumn period (February – May). All coefficients of linear regressions are displayed in Table 4. There was no effect of paddocks ($P=0.46$) or years ($P=0.17$) on the slopes.

Discussion

In this paper long-term pasture growth rates from unpublished on-farm data collected in the Bay of Plenty Region were summarised. Mr Tom Gee extensive work (more than 30 farms,

Figure 1) and mission gave to farmers rates of growth (ROG) data to assist them to be more informed about their farm. These are now stored for future reference due to the recovery of his original notes and the creation of the AgYields central repository of pasture and crops. Mean measured annual pasture yields (> 10 months measured in a year, Tables 2 and 3) were 10890±1118.1 kg DM/ha for Dataset 1, 14910±413.9 kg DM/ha for Dataset 2, 12289±1014.7 kg DM /ha for Dataset 3 and 13147kg DM /ha for Dataset 4.

Over the years, some of the records have gone

Table 2 Location, year and mean total dry matter (kg/ha) measured between 1970 and 1975 from 14 sites across Bay of Plenty and 1 (Poihipi) in Waikato. The number of months of pasture growth measurements is indicated in parentheses superscript (months details shown in Table 1).

Location	Year					
	1970	1971	1972	1973	1974	1975
Apata	$4373^{(5)}$	$2191^{(3)}$	$4458^{(5)}$	$4025^{(6)}$	-	-
Edgecumbe	$13432^{(10)}$	$13095^{(10)}$	$4046^{(5)}$	$3190^{(2)}$	$11676^{(12)}$	$3374^{(5)}$
Mamaku	-	$1612^{(2)}$	$3201^{(5)}$	$3714^{(6)}$	$1036^{(1)}$	-
Oturoa	-	$1876^{(2)}$	-	-	-	-
Papamoa	-	-	-	$12770^{(10)}$	$11771^{(10)}$	$6223^{(5)}$
PoihipiRd	-	-	$1978^{(5)}$	$636^{(5)}$	-	-
Pongakawa	$3531^{(4)}$	$1566^{(3)}$	$2477^{(4)}$	$2325^{(3)}$	-	-
Rerewhakaaitu	$1020^{(1)}$	$2582^{(2)}$	$2406^{(3)}$	-	-	-
Rotomahana	-	$1877^{(2)}$	-	-	-	-
Tikitere	-	-	-	$2122^{(2)}$	$7353^{(10)}$	$5661^{(7)}$
Tirohanga	-	-	$3473^{(5)}$	$3913^{(4)}$	-	-
Upper_Atiamuri	-	-	$992^{(1)}$	$1232^{(1)}$	-	-
Waikite V.	-	-	$6645^{(10)}$	$8868^{(10)}$	$9326^{(12)}$	$5588^{(5)}$
Whakamarama	-	-	$6716^{(5)}$	$11739^{(12)}$	$11115^{(12)}$	$6889^{(8)}$
Wharepaina	-	$1881^{(2)}$	$1813^{(4)}$	$6288^{(6)}$	-	-

Table 3 Years and months of pasture growth measurements between November 1989 and December 2007 at Wharenui property (Rotorua), Pongakawa and Highland Station (Bay of Plenty).

	Wharenui		Pongakawa
Year	Months measured	Year	Months measured
1989	Nov		
1991	Mar Apr May Sep Oct Nov Dec	1991	Sep Oct Nov Dec
1992	Sept Oct Nov	1992	Jan Feb Sept Oct Nov
1993	Jan Mar Sep Oct Dec	1993	All months, except Jan and Jul
1994	All months except May Jun Jul Aug	1994	All months except May Jun Jul Aug
1995	All months	1995, 1996 and 1997	All months except Jun
1996	Jan, Mar Apr Sep Oct Dec	1998	All months except Feb Apr May and Jun
1997	All months except Jun Jul Aug	1999	All months
1998	Mar Apr Sep Oct Nov Dec	2000	All months except May Jun Jul
1999	Jan Mar Apr Sep Oct Nov Dec	2001	All months except Jun Jul Aug
2000	Jan Mar Sep Oct Nov Dec	2002	Jan Feb Sep Oct Nov Dec
2001	Jan Mar Apr May Sep Oct Nov Dec	2003	All months except Aug Sept Dec
2002, 2003, 2004 and 2005	All months except July	2004	All months except Feb Apr Jun July
2006	All months except Jul Nov Dec	2005	Jan Feb Apr
2007	Jan Feb Mar Apr May		

	Highland Station
Year	Months measured
2004	Aug Sep Oct Nov
2005	All months except Mar Jun Aug
2006	All months, except Aug and Nov
2007	All months except Feb Jun Oct Nov Dec

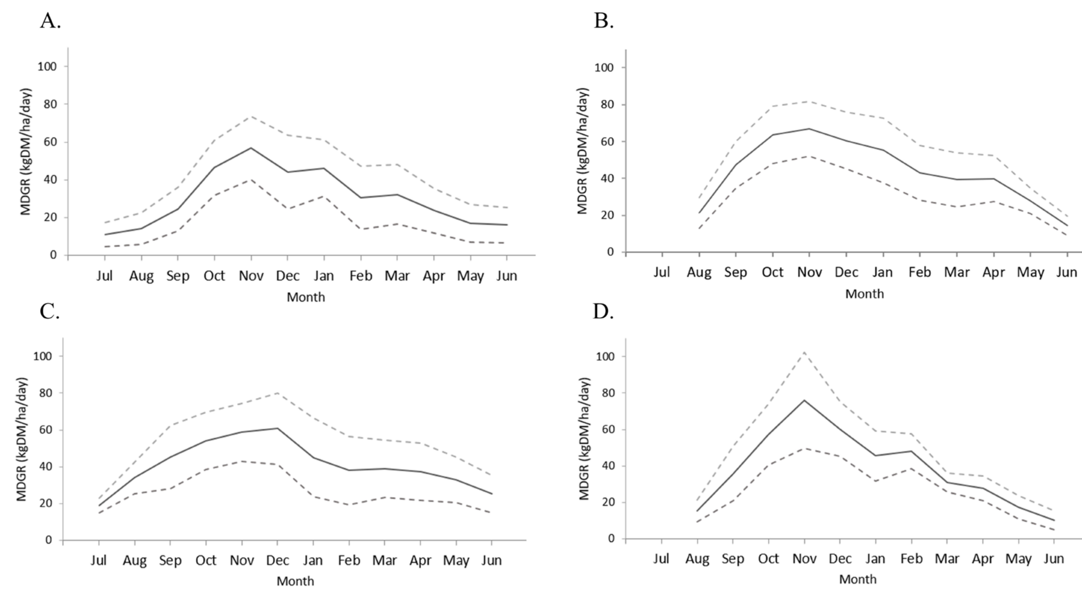

Figure 2 Mean monthly growth rate (kg DM/ha/d) of irrigated and dryland grass-based pastures A) Data collected from 1970-1975 at Districts at Bay of Plenty and Waikato.B) from 1989 to 2007 at Wharenui farm, Bay of Plenty. C) Data collected from 1991-2005 at Pongakawa; D) from 2004 to 2007 at Highland Station, Bay of Plenty. The mean (—) is shown ±1 standard deviation (- -).

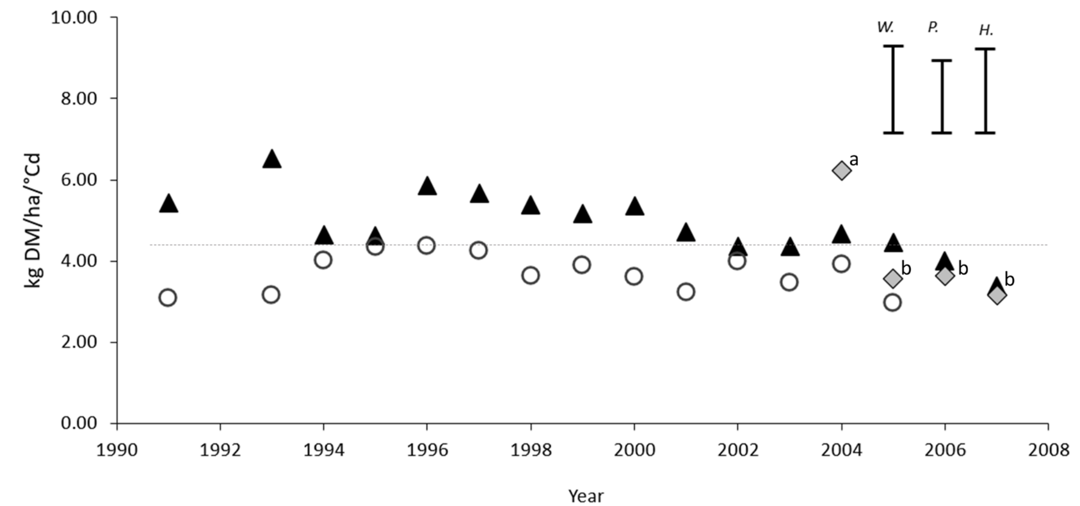

Figure 3 Mean temperature adjusted growth rates (kg DM/ha/°Cd) for pastures at Wharenui property (black triangles ▲), Pongakawa (open circles ○) and at Highland Station (grey diamonds ◆) Bay of Plenty across years. For Highland station, means with different letters indicate statistically significant difference (α<0.05). The error bars are the mean standard deviation for the estimated growth rates for Wharenui property (indicated as *W.*). Pongakawa (*P.*) and Highland Station (*H.*). The dashed line represents the overall mean of 4.3 kg DM/ha/°Cd.

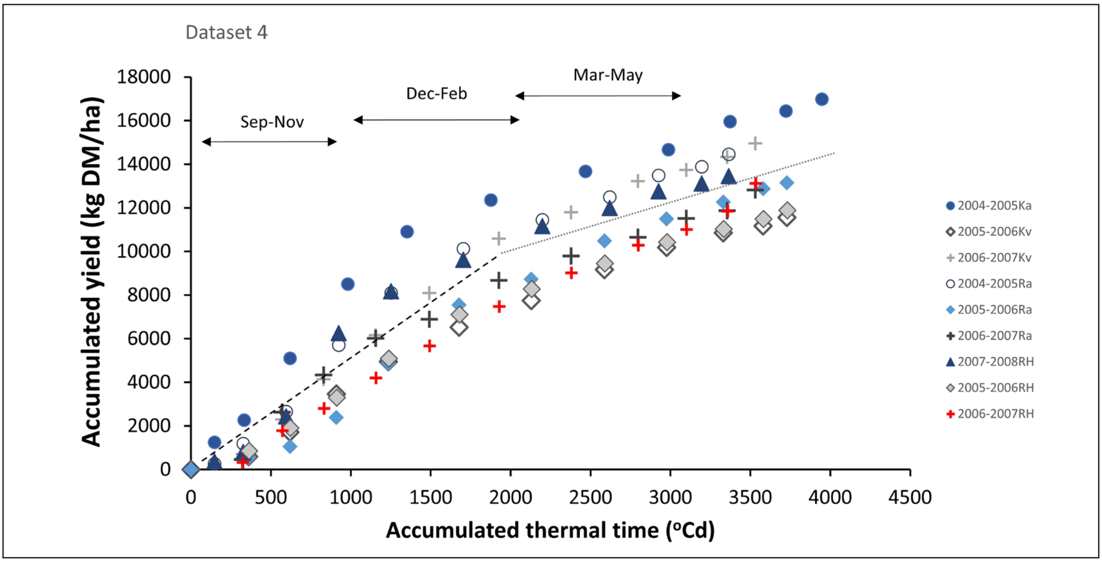

Figure 4 Accumulated dry matter yield (kg DM/ha) against accumulated thermal time (oCd) over four growth years at Highland Station. Circles (○) indicate growth years 2004-2005; Diamonds (◆) 2005-2006; Cross (+) 2006-2007; Triangle (▲) 2006-2008. Detailed colour and symbols are indicated on Table 7. The black dashed line (---) represents the regression derived for the spring -summer period: Yss (kg/ha) = 5.8±0.89x – 790 ±271.6, R^2 = 0.99. The grey dotted line (….) represents the regression for the summer-autumn period Ysa (kg/ha) = 2.5±0.22x + 4600±1264.1 R^2 = 0.98.

Table 4 Regression coefficients from relationships between accumulated pasture yield (kg DM/ha) and accumulated thermal time (ºCd) over four growth years at Highland Station, at Bay of Plenty. Mean coefficients for the spring summer period (Y_{ss}) and for the summer autumn (Y_{sa}). Means with different letters indicate statistically significant difference (α<0.05).

Paddock	Years	Slope	Intercept	R^2	Symbol*
Spring_Summer Regressions					
Ka	2004_2005	8.30	-78.8	0.99	Blue Circle (●)
Kv	2005_2006	3.95	-341	0.98	Diamond (◇)
Kv	2006_2007	5.80	-642	0.98	Grey cross (+)
Ra	2004_2005	6.43	-542	0.98	Empty circle (○)
Ra	2006_2007	4.78	-1418	0.98	Blue diamond (◆)
Ra	2007_2008	7.60	-1323	0.97	Black cross (+)
RH	2005_2006	4.84	-1009	0.99	Black triangle (▲)
RH	2006_2007	4.47	-967	0.99	Grey diamond (◆)
RH	2004_2005	8.30	-78.8	0.99	Red cross (+)
Mean (Y_{ss})		5.7a	-790.3	0.98	
Summer_Autumn Regressions					
Ka	2004_2005	2.32	7890.8	0.99	Blue Circle (●)
Kv	2005_2006	2.31	3050.3	0.98	Diamond (◇)
Kv	2006_2007	2.67	5496.4	0.99	Grey cross (+)
Ra	2004_2005	2.58	5755.5	0.99	Empty circle (○)
Ra	2006_2007	2.34	4470.5	0.99	Blue diamond (◆)
Ra	2007_2008	2.26	5989.0	0.98	Black cross (+)
RH	2005_2006	2.3	3384.1	0.99	Black triangle (▲)
RH	2006_2007	3.39	765.7	0.99	Grey diamond (◆)
RH	2004_2005	2.32	7890.8	0.99	Red cross (+)
Mean (Y_{sa})		2.5b	4600.3	0.99	

*Symbols refer to Figure 4.

missing, hence the data gaps. In these situations, the data have not been included in calculations of annual yields but were used to calculate mean monthly growth rates (Figure 2). Fortunately, most of Tom's field notes were retrieved and now the data are safely stored and available to the public through the AgYields database. The ongoing loss of this legacy knowledge with regard to where and when such data have been collected and the cost and risk of archiving paper-based material is a reality which has been addressed with the creation of a National Database (Moot et al. 2021).

Amies et al. (2021) modelled pasture yields across New Zealand and estimated an average of ~ 9700 kg DM /ha/year on a grassland area of 218000 ha at Bay of Plenty. Their work used satellite imagery and observed data from 16 locations (e.g. Waikato, Canterbury, Taranaki, Wellington, Southland, Otago) but none from Bay of Plenty, therefore their yield forecast was based on a linear model within the range of input pasture data from 4800 kg DM/ha to 17200 kg DM /ha. Amies et al. (2021) pointed out that outside this range the model prediction is less reliable. For instance, for Poihipi (years 1972 and 1973) and Mamaku (Dataset 1, Table 1) yields were recorded for four - five months (years 1973 and 1974) were well below 4000 kg/ha. These low yields could be due to terrain or soil type. The Mamaku plateau soils are strongly leached and have poor fertility (Hewitt 2010). However, it is not possible to attribute the low yields to a particular factor or a combination of factors (i.e. soils, grazing management, terrain, climate etc.) because part of the original records were not found and the retrieved datasheets of Dataset 1 do not contain the full descriptions or notes of all sites monitored. In this present work we kept data manipulation at a minimum and analysis considering an unequal sample size. Another approaches could be used to manipulate the data further and estimate growth rates in the future for Dataset 1 and for other BOP datasets which potentially are incomplete (MAR). These would be single or multiple imputation methods depending on the datasets selection, the inspection of the data and whether statistical techniques needed to be used to handle missing data (Johnson et al. 2021). Amies et al. (2021) emphasised the need for at more field data from sites with very low pasture yield and with accurate georeferencing would be needed to extend their model. This highlights the importance of retrieving on farm records and making them accessible.

Baars et al. (1991) monitored for two years (1990 and 1991) pasture growth rates at three sites in Bay of Plenty (Maketu, Opotiki and Edgecumbe). The authors identified two main peaks of growth occurring in spring (October – November) with rates of ~60 – 70 kg DM/ha/d and in March/April with values ranging from 70-85 kg DM/ha/d. The spring rates reported by these authors aligned with the values for the long-term Datasets 1 (Rotorua Districts) and 2 (Wharenui) displayed in Figure 2. The peak of pasture growth occurred later in December for Pongakawa (Dataset 3) and late November for Highland Station (Dataset 4) (Figure 2). However, no late summer peaks were observed on the four long term datasets. The mid-summer peak in the 1990 and 1991 years reported by Baars et al. (1991) were possibly caused by the contribution of summer grasses from the ingression of subtropical grass species (e.g *Digitarias anguinulis* and *Paspalum dilatatum*) which were not noted in Tom Gee's notes. As expected, for all datasets pasture growth decreased (<20 kg DM/ha/d) from May to August. Goold (1979) demonstrated that between April to August monthly pasture growth rates in Northland (Dargaville) were strongly correlated with temperature, and for every 1°C decline in daily grass minimum temperature, pasture production decreased by ~ 3 kg DM/ha/d. . This relationship was also observed at Bay of Plenty. The decrease in growth rates from March to August at Wharenui (Dataset 2) was 2.6 kg DM/ha/d for every 1°C decline in the daily minimum temperature. For Pongakawa and Highland Station, over the same autumn-winter period the estimated values were 2.3 and 2.8 DM/ha/d for every 1°C decline in the daily air temperature, respectively. At Highland Station strong relationships for the mean accumulated dry matter yield and accumulated thermal time (°Cd) were found (Figure 4.). In 2004, particularly for paddocks in spring, the addition of nitrogen and drilling new grass probably contributed to the higher yield accumulation.

These average temperature adjusted pasture growth rates are lower (4.3 kg DM/°Cd) than previous reports from resident pastures in Hawkes Bay (~5 kg DM/°Cd) (Mills et al. 2021) and for improved pastures in Canterbury. Swards which received nitrogen fertilisation produced 7.0 kg DM/°Cd while non fertilised pastures produced 3.3 kg DM/°Cd (Mills et al. 2006). The pasture yields and growth rates calculated for these long-term datasets (Figure 3) indicate that the effect of water stress was possibly less severe than the lack of nitrogen. This situation is common in "summer safe" regions of New Zealand, where a lack of N either from inorganic N-fertiliser or N-fixation by legumes is the main limitation to pasture growth (Barneze et al. 2020)

For Wharenui the growth rates were higher than at Pongakawa and Highland station, possibly because of pasture renewal reducing yields during establishment between 1990-1994 and 1996-2000. In addition, the range of cultivars and species and paddocks changes overtime (e.g. old grass; drilled grasses; slopes versus flat terrain) which will also influence pasture growth patterns. For Pongakawa dataset for instance, there is no notation about irrigation therefore the assumption was that all paddocks were rainfed. Further work could discriminate the data into subsets to evaluate the effects of terrain, nitrogen application on pastures (Moot et al. 2021).

Farmers' observations indicated that persistence ranked as one of the most important factors to their whole-farm operation, followed by pasture quality and animal performance. Animal performance is the product of pasture quality and quantity, and quality featured as a common descriptor used by farmers in determining which were their 'best' and 'worst' pastures. Soil fertility and fertiliser input featured as prominent management factors in the persistence of pastures (Daly et al. 1999). Sheep and beef farmers want to improve the weight gains of animals in early spring and summer/autumn as well as integrating management of land units that differ in the amount and seasonal pattern of forage production (Bray et al. 2013). The break point at 2000 °Cd (Figure 4) indicate the mean water deficit that affects pasture production, which can be further confirmed using other pasture datasets and local weather and soil data.

Conclusions

Pasture growth rates of 4-5 kg DM/ha/°Cd are consistent with yields from other locations. These add to the growing body of evidence that suggests temperature adjusted growth rates can be used to estimate expected pasture growth. The actual growth rates are lower than the potential yield which indicates a nitrogen deficiency across these grass-based pastures. The break points highlight a reduction in growth rates but whether that was caused by a switch from vegetative to reproductive growth or a soil moisture deficient required further investigation and will be part of the analyses presented.

Practical implications of conclusions

Historical datasets can be used to provide localised information about annual pasture yields (complete datasets) and estimates of pasture growth (partial year datasets) that should represent local, commercial farms. Knowing the forage dry matter yield of a given district or farm is important to determine productivity, to plan feed budgets and to adjust stocking rates. The AgYields database can be used as a repository of on-farm collected pasture data that are valuable well after the time in which it was collected. Retired field technicians never actually retire.

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No potential conflict of interest was reported by the authors.

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