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Growth rates and relationships between weather and growth rates for lucerne *(Medicago sativa* L.) in Canterbury and the Rotorua-Taupo region

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Abstract

Two experiments were conducted to study the weekly and seasonal growth rates of lucerne in Canterbury (Winchmore) and the Rotorua-Taupo area (Wairakei). One of the main objectives was to measure more accurately the weekly growth rates of lucerne, rather than the rates measured from final yields under a hay-type regime, and relate them to weather factors over time. Weekly growth rates of lucerne were assessed from sequential cutting over S-week periods, followed by rapid grazing. After defoliation with sheep, the sequential cutting was repeated at a new site to avoid any interaction from repeat samplings of the previously measured areas. 'Wairau' lucerne was used but after the second year of the irrigated experiment at Winchmore 'Saranac' was used. Lucerne growth curves with and without irrigation in Canterbury and without irrigation in the Rotorua-Taupo area were constructed. During periods of rapid production lucerne growth rates were linear for up to 5 weeks. Daily growth rates of up to 185 kg DM/ha were recorded on both sites. These trials suggested that ceiling yields can reach 8500 kg DM/harvest. The main determinants of the amount of lucerne available at a particular time were the time of the year and length of regrowth period. Lucerne yields can be predicted from evaporation data and age of regrowth.

Keywords lucerne, growth curves, seasonal growth rates, weather, regressions

Introduction

Few detailed measurements of lucerne's growth rate have been taken in New Zealand. Data on seasonal growth patterns and growth rates of lucerne have been presented by Baars *et al.* (1975) and McQueen & Baars (1980) for the Rotorua-Taupo region, Hayman & McBride (1984) for Canterbury and annual yield data for both areas by Douglas (1986).

Most published growth rates are mean rates calculated over the period(s) between the dates of defoliation for grazing or cutting, usually based on a hay-type cutting regime or grazing at 10% flowering. Occasionally, graphs of growth rates have been produced, but mostly these have been derived simply from harvests under a standard hay-cutting type regime. While derived graphs of this type give the general shape of the growth pattern, they are at best an approximation and could be grossly inaccurate for any one limited period. The seasonal growth pattern and rates of growth need to be defined more closely. Such basic data will be useful for improving management decisions in intensive grazing systems and for more detailed analyses of the relationships between weather and growth rates of lucerne.

The main objectives of the two trials were to determine lucerne growth rates throughout the year and to supply-data for analyses--on weather=growth rate relationships. This paper presents initial analyses of the data.

Methods

Rotorua-Taupo (Wairakei)

A uniform area of lucerne (cultivar Wairau) was divided into 4 paddocks, each at least about 0.1 ha. Each paddock was quickly defoliated every 8 weeks with large mobs of sheep. The starting date and hence the subsequent grazing dates for each paddock were staggered at 2-weekly intervals. From each paddock the growth curve of lucerne was plotted from weekly harvests of strips of the standing crop of lucerne. Each cut of 6 x 0.6 m was replicated 3 times. The paddock sizes allowed a full season's cutting without having to recut previous plots. The trial was laid down on 6 September 1977 and ran for 2 consecutive years. The programme began in early September each year and finished in May.

Lucerne production over winter was assessed, although the grazing at the end of 8 weeks was dispensed with so as not to weaken the lucerne (McLeod & Douglas 1976).

Canterbury (Winchmore)

An unirrigated and an irrigated area of established lucerne (cultivar Wairau), each of 0.4 ha, was subdivided into 4 equal-sized paddocks. After 1974-75 the irrigated site was shifted to a l-year-old stand of cultivar Saranac.

From each of the 4 unirrigated and irrigated paddocks weekly dry matter (DM) measurements were taken by harvesting 4 1 m^2 quadrats per paddock. New quadrat positions were randomly selected each week but were not returned to within 12 months. Frames were placed in each paddock just before each grazing to provide information on spelling periods longer than 7 weeks. Four quadrats were harvested 11 weeks after grazing and 4 15 weeks after its last grazing. Frames were relocated to new positions at each grazing. Grazing was completed in 1 week and a grazing technique similar to Wairakei was followed.

Statistical analyses

Growth curves

A Bayesian smoothing technique was applied so that the data could determine the form of the curve rather than having to pre-specify it. The smoothness of the curve was described by a doubly integrated Gaussian covariance function (Upsdell 1985). The yield and its standard error and resulting rate of growth and its standard error were determined at a fine grid of points. The maximum of these was taken as the estimate of the maximum rate of growth and the corresponding position as the time of maximum rate of growth (Wahba 1977).

Weather-growth rates

Simple linear and quadratic regressions, correlating monthly maximal growth rates and ceiling yields with monthly weather, were carried out for the two sites. Weather data were monthly averages for radiation, soil and air temperatures, total monthly rainfall, total monthy evapotranspiration and the monthly deficits calculated from a monthly water balance.

Results

Shape of growth curves

Measurements of the herbage mass after defoliation showed that regrowth followed 2 or 3 phases which were related to the amount of herbage present (Figure 1). The basic shape of the regrowth curves showed an exponential phase, a linear phase, and a gradual decline in herbage mass after a ceiling yield was reached. Table 1 presents fitted average monthly maximal growth rates and ceiling yields over the trial periods.

Specific points for each phase are:

Exponential phase A short exponential phase lasted from September to November. There was no marked exponential phase after November.

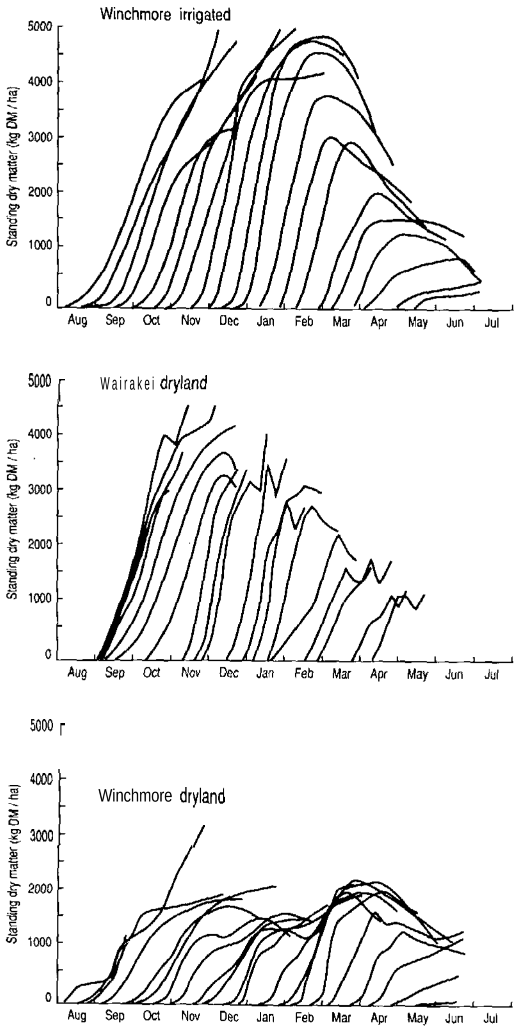

Figure 1 Regrowth curves for total forage yield (kg DM/ha) for different dates of spelling for Canterbury (with and without irrigation, 1973/74) and for Rotorua-Taupo (1978/79).

Linear phase Each of the growth curves, with or without exponential phase, had a linear phase of growth which was maintained until herbage mass accumulated at ceiling yield. In times of rapid growth the linear phase was constant for up to 7 weeks. In this linear phase growth rates were relatively constant from October to January with irrigation in Canterbury and without moisture stress in the Rotorua-Taupo region. Daily growth rates were up to 185 and 136 kg DM/ha at Wairakei and Winchmore respectively.

Ceiling yield There was a distinct trend in ceiling yields in irrigated treatments over the growing season, with the highest ceiling yields in October-November, which then progressively decreased to

Table 1 Average monthly maximal growth rates (kg DM/ha/day) and ceiling yields (kg DM/ha) over 1973-76 (Canterbury) and 1977-79 (Rotorua-Taupo).

	Canterbury				Rotorua-Taupo	
	Dryland		Irrigated		Dryland	
	max	cy	max	cy	max	cy
September	66	3500	76		69	3450
October	59	2560	87	4420	55	4600
November	49	2450	112	5660	58	4600
December	49	2340	100	5977	85	4150
January	41	1560	77	5178	70	3950
February	77	2140	105	3868	35	3400
March	76	2100	65	2890	31	2600
April	60	1850	66	1640	27	2025
May	23	1760	19	553	20	1150

max = maximum growth rate
cy = ceiling yield

approximately 1500 kg DM/ha in April-May and 800 kg DM/ha in June. Maximum ceiling yields reached 8500-10000 kg DM/harvest at Wairakei and 7000 kg DM/ha at Winchmore. The standing crop of DM decreased rapidly after ceiling yields were reached.

Weather-growth rates

The regression equations with the highest squared correlation coefficients are given in Table 2.

Rotorua-Taupo area There were no significant relationships between growth parameters and average monthly mean, daily maximum and daily minimum temperatures, rainfall, radiation and water deficits.

Growth rates after November were significantly correlated with accumulated evapotranspiration and monthly evapotranspiration levels. Ceiling yields were significantly correlated with accumulated evapotranspiration and radiation. All relationships were best fitted by quadratic regressions except the relationship between maximal growth rates and monthly evapotranspiration, which was best described by an exponential curve.

Canterbury dryland Growth rates over the active growing season and after November were significantly correlated with monthly evapotranspiration, calculated by the Penman formula. Correlations with Thornthwaite estimates of evapotranspiration and sunken pan evaporation were lower and less significant.

Canterbury irrigated Growth rates were significantly correlated with evapotranspiration (Penman) and radiation. They were also correlated with 10 cm soil temperature and mean air temperature but less strong than with evapotranspiration and radiation. The correlation with 10 cm soil temperature was stronger than with mean air temperature.

Ceiling yields were highly correlated with daily maximum air temperature, Penman evapotranspiration and radiation. The correlations with evapotranspiration and radiation were much stronger than with daily maximum air temperature. The relationship between ceiling yields and radiation could be described by a simple linear regression. All other relationships were quadratic.

Discussion

Shape of growth curves

The typical regrowth curve of pastures has been described as sigmoidal, with exponential growth up to a critical leaf area index, followed by a period of linear growth until a maximum plant mass, depending on solar light receipt, is reached (Brougham 1955). Lucerne exhibited a less typical sigmoid growth because of the lack of an exponential

Table 2 Regressions for growth parameters on Rad (radiation, langleys/day), Evap (evapotranspiration, mm/month) and Ac_Ev (accumulated evapotranspiration).

Area	Regression	r^2
Rotorua-Taupo		
maximum growth rate after November	$78.6 \quad 0.31 * Ac\_Ev + 0.00004 * Ac\_Ev^2$	0.59
	$117.9 * 10^{(-5.8 * e\text{-}3 * Evap)}$	0.55
ceiling yield	$3150 + 7.9 * Ac\_Ev \quad 0.00135 * Ac\_Ev^2$	0.78
	$-3466 + 26.3 * Rad \quad 0.0026 * Rad^2$	0.53
Canterbury		
Dryland:		
maximum growth rate after November	$-39.3 + 2.82 * Evap - 0.753 * Evap^2$	0.64
Irrigated:		
maximum growth rate	$-54.5 + 21 * ST10 - 0.011 * ST10^2$	0.54
	$-28.34 + 2.4 * Evap - 0.011 * Evap^2$	0.69
	$-48.9 + 0.566 * Rad - 0.000054 * Rad^2$	0.73
ceiling yield	$-1566 + 86.02 * Evap - 0.20 * Evap^2$	0.92
	$-1385 + 13.2 * Rad$	0.94

r^2 — percentage variation explained by the regression
Ac_Ev — accumulated evapotranspiration since November (mm)
Evap — total monthly evapotranspiration (mm)
Rad — total monthly radiation (langleys/day)
ST10 — soil temperature at 10 cm depth

phase after November and the sudden decline in standing DM yield after ceiling yield is reached, which is not obvious with pasture (Brougham 1955, 1959). This rapid decline, after ceiling yields were reached, was undoubtedly due to high senescence and decay rates which exceeded net growth.

Maximal growth rates (linear phase)

The results show the high production potential of lucerne. Daily growth rates reached 100 kg DM/ha in the Rotorua-Taupo area and 120 kg DM/ha in Canterbury. The higher growth rates of Lucerne (up to 150 kg DM/ha/day) recorded by Hoglund *et al.* (1974) in Canterbury may be related to the higher density of the stand and the use of nitrogen. Daily rates during the growth cycle can regularly exceed 70 kg DM/ha over the November to February period, lower than the 186 to 200 kg DM/ha recorded by McFarlane et *al.* (1974) in New South Wales.

Ceiling yields

Ceiling yields reached up to 5000 kg DM/ha in the Rotorua-Taupo area (Figure 1). Ceiling yields in Canterbury were higher than in the Rotorua-Taupo area, possibly because daily maximum air temperatures in the Rotorua-Taupo area in summer are higher than in Canterbury. Ceiling yields were lower than the 8500-10000 kg DM/ha measured by McFarlane *et* al. (1974) in New South Wales.

The clear decline in ceiling yields in mid and late summer has been related to high night temperatures leading to low carbohydrate levels in root and crown. It is well-known that the cycle of lucerne growth is also closely correlated with the total amount of available carbohydrates stored in the root system (Nelson & Smith 1968).

Weather-growth parameter relationships

Lucerne is an inefficient user of water since it has low stomata1 resistance to water transpiration (Kerr *et al.* 1973). This may well explain why the values for growth curve parameters and finally lucerne yields under irrigation can be simply predicted from evapotranspiration and radiation. These findings are in agreement with studies by McFarlane *et al.* (1974).

The results show that while irrigated lucerne yields without moisture stress are well related to environmental factors, there are problems in defining the effects of rainfall and water deficits on dryland lucerne yields. More detailed analyses, using daily weather data and the weekly cutting data, are required. Also, the lack of correlation between weather variables and dryland growth rates indicates that growth is not related simply to environmental factors over the season. As discussed for ceiling yields, the cycle of lucerne growth is also closely correlated with the total amount of available carbohydrates stored in the root system. The interaction with management determines the available quantities of carbohydrates available for regrowth, Additional interactions will eventuate when water deficits occur and this will make less clear the role environmental factors play in determining growth rates.

Growth rates and ceiling yields are still well below those recorded in California and New South Wales (Leach 1978), where radiation and summer temperatures are higher. Both regions in this study have daily maximum temperatures and radiation levels well below the maxima for lucerne reported by Leach (1978). Growth rates appear to be highest when daylight temperatures are 20 to 25°C. In Canterbury long-term average daily maximum air temperatures reach 21.8 °C in January and 21.6 °C in February, and, in the Rotorua-Taupo area, 23.4 °C and 23.6 °C.

This is also confirmed by the strong linear relationship between radiation and maximal growth rates under irrigation found for Canterbury.

Effect of management

The experiments did not consider the effects of cutting interval on lucerne yield, which can be significant. Generally, the lucerne crop should be spelled until the one-tenth bloom stage is reached. Spelling intervals will vary, as flowering is affected by seasonal temperature and moisture conditions.

The regrowth curves suggest that lucerne paddocks should be grazed or cut before ceiling yield is reached, as senescence, decay and leaf fall is marked.

Lucerne growth rates compared with pasture

In order to maximise yields, lucerne has to be managed on a rather inflexible basis compared with pasture, but growth rates are impressive. Growth rates under good lucerne management exceed by a large margin the growth rates of pasture with and without irrigation. For example in Canterbury pasture growth rates with irrigation do not exceed 75 kg DM/ha/day on most soil types. Similarly in the Rotorua-Taupo area rates of pasture growth do not exceed 85 kg DM/ha/day.

These rates compare with maximum growth rates for pasture in New Zealand of up to 160 kg DM/ha/day in mid-spring with a similar cutting technique as used in these trials (Brougham 1959; Piggott *et al.* 1986). Also in comparison with pasture maximum lucerne growth rates can be maintained from October to February without any noticeable slump as is normal with pasture.

Conclusions

The main determinants of the amount of lucerne available at a particular time are evaporation levels as determined by the time of the year and length of regrowth period, although the importance of spelling interval for carbohydrate build up for maximum regrowth should not be overlooked. Areas of lucerne have decreased considerably since the 1970s because of diseases, such as verticillium wilt (*Verticillium albo-atrum*) and insect pests like blue-green aphid

(*Acyrthosiphon kondoi*), which have resulted in reduced life expectancy (Douglas 1986). Plantings in the Rotorua-Taupo area have declined greatly. The results show the potential high growth rates of lucerne on low-moisture retentive soils and in summer dry areas. This may justify a re-evaluation of the place of lucerne in specialised farming systems under these conditions.

The availability of new wilt- and aphid-resistant cultivars warrants a resurgence of interest in lucerne.

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