EFFECTS OF TEMPERATURE ON PASTURE PRODUCTION

J.A. Baars and J.E. Waller
Ruakura Soil and Plant Research Station and
Biometrics Section, Ruakura Agricultural Research Centre
Ministry of Agriculture and Fisheries,
Private Bag, Hamilton.

ABSTRACT

Quantitative relationships between pasture growth and climate (temperature, heat sums, radiation, rainfall, soil moisture) were studied for three sites. The influence of air and soil temperature and interactions with other weather factors and pasture management on total yield over the year is discussed.

Regrowth of temperate ryegrass dominant swards following defoliation shows a marked dependence on soil temperature at 10cm. depth and daily maximum air temperature. It appears that both autoregressive terms and actual temperature data are necessary to get the best fit with growth data.

It is concluded that multiple regression analyses will provide a basis for constructing simple models of pasture growth.

INTRODUCTION

Understanding the response pattern of pastures to climatic variables and the predictive value of that knowledge is fundamental to technological advancement (e.g. Waggoner 1975, Kerr 1977). Within New Zealand, considerable variation in temperature, light and rainfall occurs between districts and seasons and this is reflected in different patterns of pasture growth throughout the country (e.g. Radcliffe 1974b, Baars 1975).

However, little research has been done on the relative importance of the climatic factors causing this variation. The examination of individual factors by means of simple regressions has often proved disappointing (Hughes 1965). Past attempts may have failed for a variety of reasons:

a) weather factors do not operate independently
b) often cut by cut data and corresponding daily meteorological data have not been available
c) growth periods have not been well defined
d) responses of crop and pasture yield components are not necessarily linear.

Little or insufficient use seems to have been made of multiple regression analysis to quantify the relative importance of climatic factors throughout the year. Regression coefficients and associated equations, although sometimes difficult to interpret should be useful in elucidating the most important climatic factors influencing pasture growth within a particular environment.

A programme has been undertaken to study multiple regression methods using data from a network of national pasture growth rate trials. Interim results are presented for two sites in the Waikato and one in the Hawkes Bay, and for the purpose of this symposium most of the discussion will center on temperature effects throughout the year.

METHOD

Climatic data were summarized over the period between total yield cuts and stepwise linear regressions performed on these data with yield being the dependent or response variable. Predictor variables (e.g. temperature, rainfall) are entered into the regression on the basis of the partial correlation coefficients. The relative importance of each predictor is indicated by the order of inclusion of the variable into the regression equation. The following 5 seasonal periods were examined:

1. Early to mid-spring (August-October), during which growth rate is increasing with time.
2. Late-spring to early summer (November-December), a period of irregular fluctuations in growth rates following defoliation of reproductive tillers.
3. Summer (January-February).
4. Autumn (March-May), during which growth rate is decreasing with time.
5. Mid-winter (June-July).

DATA

Climate measurements

Local weather records were used. They were daily rainfall (mm); fortnightly soil moisture percentages (Hawkes Bay only); daily radiation in Langleys (Waikato only); heatsums (accumulated temperature above 5.6°C for soil temperature); daily maximum, minimum and mean air temperature in °C at screen height (1.2m); daily soil temperature in °C at 10cm depth and daily grass minimum.

Pasture yield measurements

1. Waikato

Dry matter production data (DM kg/ha) were collected from 2 beef cattle grazing trials:

a. Trial 1 (under irrigation from 1955-1960) Yields were collected from the following treatments:

i) grazed at 10-11 days interval to a height of 3cm
ii) grazed at 10-11 days interval to a height of 7cm
iii) grazed at 21 days interval to a height of 3cm
iv) grazed at 21 days interval to a height of 7cm

Proceedings Agronomy Society of New Zealand 9; 1979

TABLE 1: The influence of some climatic factors on pasture production in the Waikato and Hawkes Bay.

	AUGUST-OCTOBER				JANUARY-FEBRUARY				MARCH-MAY				JUNE-JULY			
	df	R^2	F	SI order	df	R^2	F	SI order	df	R^2	F	SI order	df	R^2	F	SI order
Waikato (Trial 1)																
10-11 days (3cm)	35	.68	***	*MAX*,RAD	27	.24	**	*10 Soil*	35	.44	***	*10 Soil*	13	.56	**	*10 Soil*
10-11 days (5cm)	34	.74	***	*MAX*,RAD,*10 Soil*	26	.29	***	*10 Soil*	35	.43	***	*10 Soil*	13	.52	**	*MAX*
21 days (3cm)	18	.70	***	*MAX*	11	.48	**	RAD, *10 Soil*	19	.73	***	*10 Soil*	NS			
21 days (5cm)	18	.66	***	*MAX*	12	.51	**	RAD	19	.68	***	*10 Soil*				
Waikato (Trial 2)																
Irrigated	28	.83	***	*LACCS*,LRAD	16	.74	***	RAD,*MAX*,*ACCS*	28	.74	***	*LACCS*,LRAD				
Non Irrigated	28	.76	***	*MAX*	16	.70	***	*MAX*,(*LACCS* X LRAD), RAIN	22	.22	**	*MIN*,*MAX*,RAD				
Hawkes Bay																
2 weekly	23	.83	***	*10 Soil*	13	.72	***	(*10 Soil* X SM 0-10), RAIN, *10 Soil*	25	.50	***	*10 Soil*, SM 0-10	13	.83	***	(*10 Soil* X SM 0-10), (*MIN*^{2}), (*ACCS*), (*MAX*^{2})
4 weekly	09	.82	***	*10 Soil*, SM 0-10	07	.64	**	SM 10-20	13	.64	***	RAIN	06	.96	***	*10 Soil*, SM 10-20, *ACCS*

R^2 – percentage variation explained by the regression
df – degrees of freedom
SI order – order of stepwise inclusion
MAX – daily maximum air temperature (°C)
LRAD – natural log radiation (langleys)
10 Soil – soil temperature at 10cm depth
LACCS – natural log accumulated day degrees above 5.6°C
MIN – daily minimum air temperature
SM – soil moisture percentage at 0-10cm or 10-20cm depth

b. Trial 2 (with and without irrigation from 1953-1964)
Yields from paddocks which were grazed to a height of 5-8cm every 3-4 weeks.
Both trials used a yield measurement technique whereby mowing dates corresponded with grazing dates (Weeda 1965).

2. Hawkes Bay
Yields from a rate of growth trial (Radcliffe 1974a) with fortnightly and monthly trimming and mowing of pasture cages, under sheep grazing from 1971-1977. On each site, pastures consisted mainly of ryegrass (Lolium perenne L.) and white clover (Trifolium repens L.).

RESULTS AND DISCUSSION

A condensed summary of results is presented in Table 1. The relative importance of temperature variables is of immediate interest and they have been put in italics in Table 1.

Early to mid-spring (August-October)

In Hawkes Bay daily minimum air temperature was correlated with yield (r = 0.72***), confirming a similar finding by Brougham (1959) for pasture growth rates near Palmerston North, but the effect of soil temperature at 10cm was significantly greater than both daily minimum and maximum air temperature. The results are also in agreement with observations by Alcock *et al* (1968) in Wales who found that spring growth had a strong correlation with 10cm soil temperature and accumulated day degrees above a threshold value of 5.6°C, below which growth stopped.

In the Waikato, daily maximum air temperature, accumulated heat units, soil temperature at 10cm and radiation were all of similar importance with a long rotation. Daily maximum air temperature rather than accumulated heat units, soil temperature at 10cm and radiation, however, accounted for most of the variation in yield of regularly (10-11 days) defoliated swards. The magnitude of fluctuations in growth rate attributable to weather factors is of interest. In the Waikato a change of 1°C in daily maximum air temperature was associated with a change in growth rate of 7-12 kg DM/ha/day respectively for a 10-11 day rotation interval.

These results suggest that it should be possible to forecast growth rates in spring. Using only meteorological data it was found that 60-83% of current growth in the Waikato could be explained by the previous mean daily maximum air temperatures indicating the importance of immediate past climate on present pasture yield over the spring months.

Late spring to early summer (November-December)

Over this period, climate seemed to be of little importance at either location although soil temperature had a significant negative correlation with yield. These negative correlations, also found by Brougham (1969), have been related to a change from the vegetative to the reproductive stage. In Britain, Anslow (1965) related the lack of a relationship between yield and temperature and radiation over the late spring-mid summer period on irrigated pure grass swards to the physiological growth rhythm of grasses as manifested in the development of flowering tillers and the regeneration of vegetative tillers.

Summer (January- February)

Daily maximum air temperature had the highest (negative) correlation with yield in Hawkes Bay, although the multiple regression analyses pointed to soil moisture and soil temperature at the 10cm level, as being the more influential variables. Mitchell (1956) noted that in summer the temperature of the surface layer of the soil may rise for a considerable period each day to 27^{0}C or higher. At 9am., summer soil temperatures at the Hawkes Bay site were about 17^{0}C, therefore rising rapidly throughout the day.

Since rapid decline in ryegrass shoot production rates occurs at temperatures above 18^{0}C (Mitchell 1956) the effect of this variable is obvious, even if secondary to the effect of soil moisture.

The negative effect of high soil temperature levels on pasture production was confirmed on irrigated Waikato pastures and the effect was strongest when pastures were frequently grazed. In this area, the average soil temperature at 9am. is almost 20^{0}C over summer and daily maximum air temperatures are well above 20^{0}C. The effect of soil temperature and daily maximum air temperature were of similar importance with a 10-11 day rotation. Allowing pasture to become reasonably long in combination with a lax defoliation assists in reducing the detrimental effect of high soil temperatures on pasture production as shown by very low correlations with yield. But not with-standing this effect, daily maximum air temperature decreased irrigated pasture yield with long lax defoliation by about 200kg DM/ha for each unit increase in temperature. The results confirm controlled climate extrapolations for the northern part of New Zealand by Mitchell (1963) and emphasize the problem of high summer temperatures on temperate plant growth.

Consideration of previous temperature regimes in addition to current temperatures over the same cutting periods, resulted in predictive equations which explained 85-93% of the variation in yield under the longer rotations with irrigation. There was however, no improvement for the short rotation treatments and plant factors or its functional periodicity appeared to override meteorological variables.

Autumn (March-May)

On the dryland site in Hawkes Bay most of the autumn pasture yield variation was explained by soil moisture levels (0-10cm) and 10cm soil temperatures. These two factors had a considerably higher positive correlation with growth rates than the other temperature factors (for which correlations were well below 0.50). Rainfall was a more significant factor under 4 weekly than 2 weekly cutting, although its correlation coefficient with yield was only slightly larger (0.80*** vs 0.70***). This effect can be related to a greater response of the longer swards to moisture. Overall, moisture stress was clearly the overriding influence in determining the size of the autumn flush at the Hawkes Bay site.

At Hamilton, under irrigation, soil temperature was of greater importance than daily maximum air temperature. The reverse situation applied in the spring. The best predictive equation using the log ACCS x log Radiation factor was found for the long, lax defoliation treatment as occurred in the spring at this site. In autumn, actual soil temperature levels were important, while in spring, both the previous daily maximum temperature the soil temperature levels combined to explain most of the variation in growth rates.

Mid winter (June-July)

In Hawkes Bay, growth rates were strongly correlated with soil temperature (0.77***) and heat units (0.63***) when swards were cut every 4 weeks, with other temperature variables being of less importance. Under fortnightly cutting, daily maximum air temperature showed the highest correlation with yield (0.55**), followed by soil temperature (0.44**) and accumulated heat units (0.40**). Daily air minimum and grass minimum had low correlations with yield (0.35 NS). Predictive equations were of a rather more complex nature than at other periods of the year. At Palmerston North, Brougham (1969) also found that the only significant positive correlation obtained with weather factors in mid-winter was day-time temperature during early stages of regrowth which is in agreement with our results for fortnightly cutting.

At Hamilton, daily maximum air and soil temperatures explained about 50% of the variation in yield under short rotations. There was however, little difference in the size of the correlation coefficients between temperature variables and yield. The lack of more pronounced weather effects on pasture production over this period might be due to the rather crude yield measurement techniques, or the failure to include appropriate climatic factors in the model. For example, yearly analyses for the Waikato trials indicated the importance of the number of frosts over this period.

Although mean air temperature has often been used to examine temperature growth relationships and even in modelling of pasture growth (Fick 1978), this variable appeared to be of little relevance in the present studies. Peacock (1975), using heat cables in the soil, found that temperature was effective at the level of the stem apex rather than being a general effect of soil and air temperature on leaf growth. While daily maximum temperature strongly relates to canopy temperatures (Coulter 1964), soil temperature at 10cm has a strong correlation with air temperature close to the soil surface (Alcock *et al.* 1968). This explains the importance of both daily maximum air temperature and soil temperature at 10cm in the analyses.

CONCLUSIONS

Regrowth of temperate ryegrass dominant swards following defoliation shows a marked temperature dependence, which is influenced by the temperature environment prior to defoliation and management, confirming controlled environment findings for single plants (McWilliam 1976). While it is virtually impossible to define the exact influence of each temperature variable, the magnitude and relative importance of temperature can be quantified from these analyses. Our aim is to fit the best possible empirical relationship. The regression coefficients must be examined to see if they do not violate common sense. The more climatic factors are put in the regression as independent variables the more strongly will the climatic features of that particular area be emphasized, and as a result, the better will the model fit that area. However, on the other hand, by doing so, the widespread applicability of that model is likely to be lost. Because factors of statistical significance might not always be causal, it will be necessary to combine data from groups of sites to identify the causal climatic factors. In spite of the limitations, it is considered that the techniques employed are of considerable value in assessing the relative importance of temperature (and other weather factors), on growth of pasture swards and species. These methods deserve far more attention, as they will provide a basis for constructing simple models of pasture growth.

ACKNOWLEDGEMENT

To J. G. Manson for processing of the data.

REFERENCES

Alcock, M. B., Lovett, J. V., Machin, D. 1968. Analysis of environmental influence on productivity. In proceedings of Symposium on Hill land Productivity. European Grassland Federation.

Anslow, R. C. 1965. Grass growth in mid-summer. *Journal of the British Grassland Society 20:* 19-26

Baars, J. A. 1975. Seasonal distribution of pasture production in New Zealand IX. Hamilton. *N.Z. Journal of Experimental Agriculture 4:* 157-161

Brougham, R. W. 1959. The effects of season and weather on the growth rate of a ryegrass and clover pasture. *N.Z. Journal of Agricultural Research 2:* 283-296

1969. Weather fluctuations and the daily rate of growth of pure stands of three grass species. *Ibid. 12:* 125-136

Coulter, J. D. 1964. The climate of New Zealand in relation to agriculture. *Proceedings N.Z. Institute of Agricultural Sciences 9:* 41-60

Fick, G. W. 1978. Computer simulation models of pasture production in Canterbury: Description and Users Manual. Agricultural Economics Research Unit. Research Report No. 89.

Hughes, R. 1965. Climatic factors in relation to growth and survival of pasture plants. *Journal of the British Grassland Society* 20: 263-272.

Kerr, J. P. 1977. Climate and crop production. *Proceedings Agronomy Society of N.Z. 7:* 1-3

McWilliam, J. R. 1976. Response of pasture plants to temperature. In "Plant Relations in Pastures." CSIRO, Melbourne 1976.

Mitchell, K. J. 1956. Growth of pasture species under controlled environment. I. Growth at various levels of constant temperature. *N.Z. Journal of Science and Technology A 38:* 203-216.

Mitchell, K. J. 1963. Production potential of New Zealand pasture land. *Proceedings N.Z. Institute of Agricultural Sciences 9:* 80-94.

Peacock, J. M. 1975. Temperature and leaf growth in Lolium perenne. II. The site of temperature perception. *Journal of Applied Ecology 12:* 115-23

Radcliffe, J. E. 1974a. Seasonal distribution of pasture production in New Zealand. I. Methods of measurements. *N.Z. Journal of Experimental Agriculture 2:* 337-340

——— 1974b II Southland Plains *Ibid* 2: 341-348.

Waggoner, P. E. 1975. What to do? *Agricultural Meterorology 15:* 161-164

Weeda, W. C. 1965. The effects of frequency and severity of grazing by cattle on the yield of irrigated pasture. *N.Z Journal of Agricultural Research 8:* 1060-1069.