DEVELOPMENT OF A SIMULATION MODEL FOR PASTURE GROWTH

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ABSTRACT

A simulation model for pasture growth was developed in 1975 as part of a project with Massey University to model beef production from grazed perennial ryegrass/white clover pastures. Subsequent model development as a result of field studies on pasture regrowth and analyses of climate/pasture yield relationships is described. In the present models the likely shape of potential regrowth curves for total sward production for a region is calculated from radiation and/or regrowth data. Actual production is then calculated using temperature response data for different seasons of the year and a water balance model.

The specific objective of present modelling activity is to construct a model which can simulate various harvesting managements from standard meteorological observations. Model output is compared with published data for irrigated sites in Otago and Canterbury.

INTRODUCTION

Recent New Zealand work (Baars and Waller, 1979 and unpublished; Radcliffe, 1980) suggests that a large percentage of year to year variations in pasture production can be explained by climatic factors. Quantitative information on those climate parameters which have most influence on pasture production can be incorporated into pasture models to predict the variation in grassland production in time and space.

Wright and Baars (1976) developed a pasture model which was specifically designed to study management systems in the Waikato. Many of its equations and constants were based on guess estimates and the structure of the model was rather empirical. Subsequent studies have been directed at developing a model, which is based on general ecophysiological principles so that it may have widespread applicability. The main objective has been to formulate a model for perennial ryegrass/white clover pastures in New Zealand from which pasture growth rates can be predicted using weather data from standard meteorological stations.

The potential use of such a model is great. One of the problems facing farmers and advisers is that of extrapolating from the results of local pasture growth rate trials (Radcliffe, 1974) to the variety of management systems being used on farms. If acceptable models can be developed they could be of considerable benefit for that purpose. A further use might be to simulate growth rates for areas which are not covered by field trials.

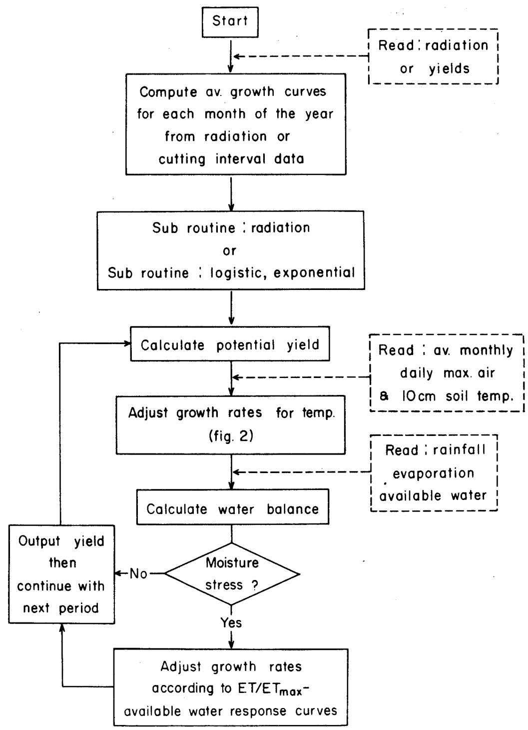

Figure 1: Flowchart of a pasture simulation model to calculate expected total sward yields.

MODEL DESCRIPTION

A simplified flowchart of the model is presented in Figure 1 and the input parameters required are listed in Table 1. The timestep size used is one day. It is possible however to let calculations proceed on a cutting or grazing interval basis with appropriate climatic input data over the corresponding periods. A detailed description will be published elsewhere.

Monthly average potential growth curves

The seasonal trends of day length, solar radiation and atmospheric temperature for a particular location are major determinants of the potential rate of pasture growth. It logically follows that a reasonably consistent pattern of average potential production may be specified for any defined pasture type and location when moisture and fertiliser are non-limiting. Differences between years in pasture productivity would then be largely attributed to fluctuations in temperature, the amount of rainfall and to the effect of grazing intensity on the amount of foliage in the sward. An assessment of average potential production is possible where preferably long term trials have been conducted with irrigation and where fertiliser was non-limiting. Brougham (1955) has shown that logistical curves can be fitted to pasture regrowth data. Work in the Waikato under grazing has confirmed Brougham's earlier assumptions (Baars and Douglas, unpublished). If it is accepted that families of average potential monthly logistical (or simpler exponential) curves do exist for sites and regions,

TABLE 1: Input parameters required.

RAD - Mean daily insolation (langleys/day)

or

YLD - Yields for different cutting intervals (kg dry matter/ha)

T_1 - Average monthly daily maximum air temperatures at screen height (°C)

T_2 - Average monthly daily soil temperatures at 10cm (°C)

T_3 - Average daily maximum air temperature (°C)

T_4 - Average daily maximum 10cm soil temperature (°C)

A - Available water in the assumed rooting depth at field capacity (mm)

S - Critical point of available soil water below which growth rates drop

R - Daily rainfall (mm)

ET - Daily pan evapotranspiration (mm)

the problem is how to calculate the relevant coefficients for these curves. In the present models exponential growth curves have been chosen for simplicity. This approach is based upon findings by Brougham (1959) that growth is exponential up to 4 weeks after low cutting. Exponential coefficients can be calculated either from yields measured at two different regular cutting intervals or from radiation data.

The use of radiation to calculate exponential coefficients is based on work by Brougham (1959), Noble (1972) and Baars and Waller (unpublished). Brougham (1959) found that 96% of the variation in pasture production rate between 3 and 4 weeks after defoliation was explained by radiation. The correlation coefficient was significantly higher between radiation and pasture growth rate than between growth rate and temperature. In the Waikato, Noble (1972) found that the conversion of energy of irrigated pasture is virtually constant at 0.55% between November and April which indicates direct correlation with solar radiation. The latter finding related to a management where pasture was defoliated to 11-1200 kg DM/ha (about critical LAI) and then spelled for 3-4 weeks. The seasonal influence of temperature on pasture yield for this trial has been discussed by Baars and Waller (1979). For the same trial Baars and Waller (unpublished) found that pasture production was strongly correlated with the natural logarithm of the radiation input. As Brougham (1959) found, the correlation coefficient between pasture production and radiation was significantly greater than between pasture production and temperature (Table 2). The above findings are consistent with conclusions by Alberda (1962), who stated that for pastures receiving an optimal supply of water and mineral nutrients the rate of DM production is principally determined by radiation after a closed canopy is reached. Thus it can be inferred that reasonable estimates of exponential coefficients can be made from regression relationships between pasture growth rates and radiation.

Using results from the above studies a subroutine was written to calculate exponential coefficients from radiation data.

The initial potential yield estimates, obtained by linear interpolation, are then corrected by dimensionless multipliers for temperature and moisture.

Temperature

The structure of the temperature module is depicted in Figure 2.

TABLE 2: Correlation coefficients between pasture production and climatic factors in an irrigated Waikato trial.

Factor	r
Radiation ($\log_e$)	+ 0.91**
Accumulated heat units 10cm soil temperature > 5.5°C	+ 0.71**
Daily maximum air temperature	+ 0.60**
Daily minimum air temperature	+ 0.48**
Grass minimum	+ 0.46**

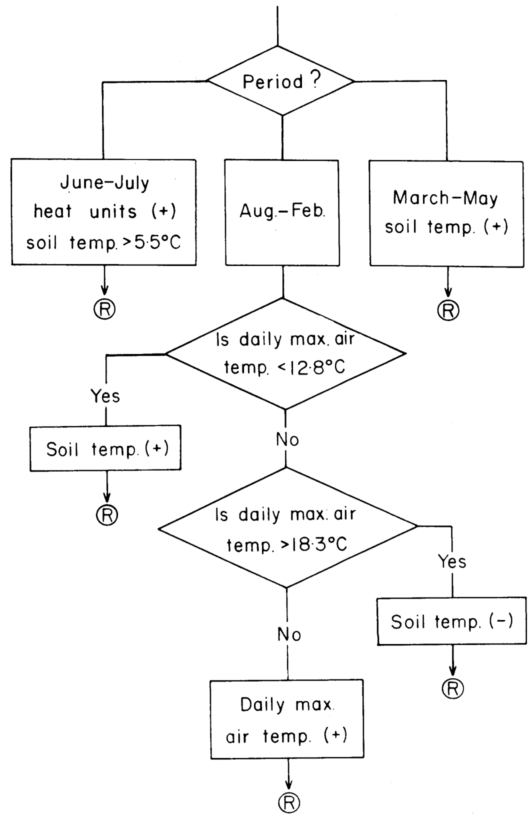

Figure 2: General structure of the temperature module. (+ = positive correlation, – = negative correlation, R = return to main line).

In earlier work (Wright and Baars, 1976) growth rates were positively correlated with minimum temperature from mid-July to mid-December, negatively correlated with maximum temperature from mid-December to mid-April and positively correlated with maximum temperature from mid-April to mid-July. This approach was based on data for short swards by Brougham (1969). Since Brougham's early work the increased ability to handle complex field data has made it possible to quantify the influence of individual climatic factors on long term trial data (Baars and Waller, 1979; Radcliffe, 1980). Baars and Waller (1979) have shown that the influence of the air and soil temperature, changes according to the time of the year and physiological stage of pasture development. Consequently the year has now been divided into three periods.

The periods used are (Figure 2):

1. Winter (June-July). Over this period growth is positively correlated with accumulated day degrees above a threshold value of 5.5°C soil temperature.
2. Spring-summer (August-February). Spring growth is determined by soil temperature and daily maximum air temperature. Maximum air temperature threshold values of 12.8°C and 18.3°C found in regression analyses of growth against temperature are in agreement with controlled climate cabinet data (Mitchell, 1956; Scott, 1970). The latter authors found that ryegrass growth rates dropped above 18°C which is in agreement with the negative effect of high daily maximum air temperatures on pasture production in the Waikato found by Baars and Waller (1979).
3. Autumn (March-May). Over this period growth is positively correlated with soil temperature.

Linear response curves have been used. Essentially it is assumed that a single temperature variable at a given simulation time expresses the greatest limitation. The effect on the initial potential yield estimates is represented as a dimensionless multiplier, which is calculated as a function of the differences between actual and mean temperature.

Moisture

In the earlier model of Wright and Baars (1976) a simple waterbalance model was used. Soil moisture affected growth rates through a soil moisture factor (P), defined as the ratio of actual (ET) to potential avapotranspiration (ET_{MAX}. P) was a function of atmospheric demand (ET) and available soil moisture (ASM). This approach was based on a soil depth from O to 30cm and gave satisfactory results (Baars *et al.,* 1976). A similar approach was used in the present model, but the waterbalance is calculated for the rooting depth and only one relationship between P and ASM is used. Not many New Zealand data to formulate a relationship between ASM and the soil moisture factor ($P = ET/ET_{MAX}$), over rooting depth are available. Recently Scotter *et al.* (1979) published data for a Tokomaru silt loam and, in a trial to validate parts of this model, Dr J. McAneney has determined a curve for a Horotiu sandy loam in the Waikato (Figure 3).

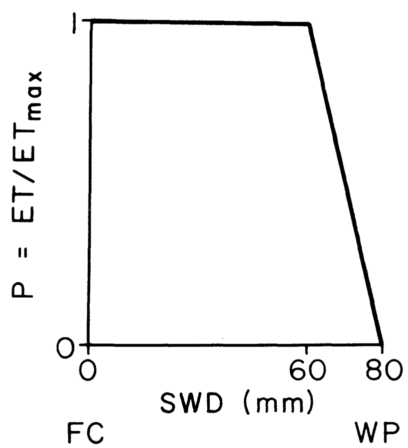

Figure 3: Relationship between soil water deficit (SWD) and the soil moisture factor (P). (FC = field capacity, WP = wilting point).

TESTING

The models were tested by simulating actual trials for which pasture production data were available, using meteorological data given in Table 1. Results are shown in Figures 4 and 5 for irrigated trials in Otago and Canterbury.

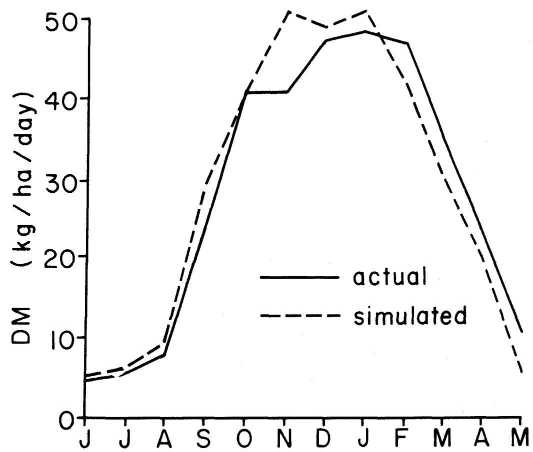

Figure 4: Model prediction and field observations of harvested dry matter yield at Winchmore (Canterbury) with irrigation.

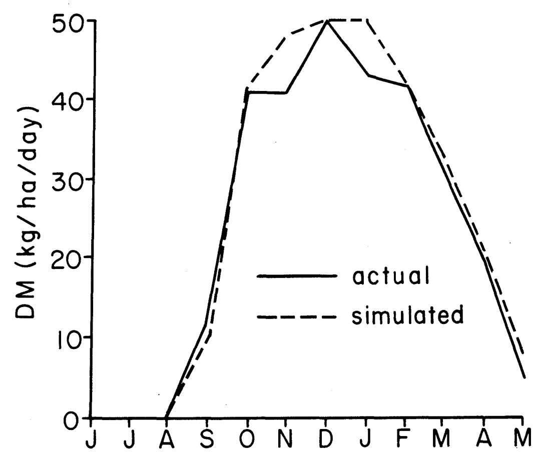

Figure 5: Model prediction and field observation of harvested dry matter yield at Poolburn (Otago) with irrigation.

DISCUSSION

The simulation runs to date have shown that the present model originally developed for the Waikato has enough accuracy and versatility to be extrapolated to other areas of New Zealand. However, testing and validation has been restricted to irrigated sites and a simplified approach to the waterbalance will be necessary initially for many sites (see below).

Essentially it is assumed that a single temperature variable at a given simulation timestep expresses the greatest limitation. This method of using single dominant controlling factors is simple and convenient and is used in combination with "on-off" threshold values. However, in some 'atypical' individual years, pasture production was over estimated when temperature was high but radiation levels well below normal. This suggests that it is necessary to determine the effect of temperature and radiation individually and then multiply these effects by each other to yield a total combined control.

Fick (1978; 1980) has formulated a pasture simulation model for Canterbury. The coefficients for exponential growth curves and temperature responses, are calculated from mean daily air temperatures response curves. The use of the latter methods might lead to serious discrepancies between simulated growth rates and actual growth rates. Although mean daily air temperature is highly correlated with radiation, radiation is of more importance in determining potential production levels and coefficients for growth curves. In addition Baars and Waller (1979) have shown that other temperature variables are more highly correlated with yield than daily mean air temperatures.

The present model has been specifically developed for a grass dominant ryegrass/white clover pasture, well fertilised and without nitrogen deficiencies. In further development towards a more general model it will be necessary to extend the 'average potential' growth curve approach and consider the effects of different proportions of ryegrass and white clover and nitrogen on the shape and ceiling yields of these curves. This also implies a requirement for separate ryegrass and white clover temperature modules.

Through development and use of this model attention has been focused on the importance of data sets and research areas to explain the dynamics of pasture production in more detail. Field experiments have and should be designed to describe and quantify certain processes and measure missing data sets. Data are required:

1. on stubble yield (and dead/green ratio's) and regrowth after defoliation.
2. on the relationship between available soil moisture in the rooting zone on various soil types and pasture production. Relevant data only seem to be available for two soil types in New Zealand, in spite of its importance for irrigation scheduling, modelling and economic assessments of water stress.
3. on growth curves for pasture species and pasture mixtures to supplement the grazing and cutting interval data, routinely collected at present. Brougham (1959) stated many years ago that it was fundamental to grassland research to collect these data in a variety of environments and regions.

In summary, it can be said that a set of experiments with and without irrigation, where balanced data sets on moisture status of the soil, climate and pasture growth had been collected, would have overcome many of the deficiencies still apparent in this model.

CONCLUSION

The present model based on relatively simple relationships between pasture production and climate seems to have enough flexibility to use the established climatological network to assess irrigated grassland productivity.

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